COMECAPEC 2014

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Maria Kanakidou
Nikolaos Mihalopoulos
Panagiotis Nastos Editors

12 International Conference of Meteorology, Climatology and Physics of the Atmosphere
Heraklion 28 – 31 May 2014

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12th INTERNATIONAL CONFERENCE
of Meteorology, Climatology and Physics of the Atmosphere
Heraklion 28 – 31 May 2014

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Preface

The Conference on Meteorology, Climatology and Atmospheric Physics (COMECA) has been co-organized by the Hellenic Meteorological Society on a biennial basis since 1992. The previous conferences took place in Thessaloniki (May 1992, September 1994, September 2000 and May 2008), Athens (September 1996, September 1998, May 2006 and May 2012), Ioannina (September 2002), Nicosia (September 2004), and Patra (May 2010). All the conferences have been organized by the members of the Hellenic Meteorological Society and their national and international collaborators from disciplines associated with the study of atmospheric environment. This year COMECAP takes place in Heraklion (May 28-31, 2014) and is co-organized by the University of Crete (Department of Chemistry, Division of Environmental Chemistry, Environmental Chemical Processes Laboratory), the Hellenic Meteorological Society and the Mariolopoulos-Kanaginis Foundation for Environmental Sciences.

COMECA Conferences provide a great opportunity for the dissemination of new knowledge in the fields of Meteorology, Climatology, Atmospheric Chemistry and Physics and Climate Change, hosting experts, scientists and young researchers to present their latest research studies and share innovative ideas. COMECAP 2014 covers various research topics related to Meteorology, Climatology and the Atmospheric Environment that requires interdisciplinary studies. A total of more than 270 papers have been submitted from which approximately 255 are published in the Proceedings of the Conference by the Crete University Press after being peer reviewed. The published scientific contributions in the e-book are provided in alphabetic order and include 76 papers in Meteorology, Agrometeorology and Extreme Events, 86 papers in Climatology and Remote Sensing and 93 papers in Atmospheric Chemistry and Physics and Environmental Pollution. The registered participants (more than 180) come from 19 countries. More than 25% of the participants are from countries other than Greece and more than 40% of the participants are Master and PhD students in relevant disciplines. These statistics indicate the continuously increasing international and educative character of the Conference.

We acknowledge the contributions of the authors, the careful reading by the appointed reviewers, the Scientific Committee and especially the Organizing Committee for their valuable efforts for the success of the Conference and the production of the e-book of the proceedings, as well as our Sponsors. This work could not have been fulfilled without the help of Dionysia Daskalou of Crete University Press, to whom we also offer our thanks.

We wish you all a fruitful Conference and a pleasant stay in the beautiful city of Heraklion,

The Chair of the Organizing Committee

Maria Kanakidou, Professor (University of Crete)

The President of the Hellenic Meteorological Society

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Mapping variability and trends of near surface NO\textsubscript{x} rural concentrations over Europe during 2004-2011

Aggelis D.E., Zanis P., Zerefos C.S.

Nitrogen oxides (NO\textsubscript{x} = NO + NO\textsubscript{2}) play a central role for controlling tropospheric ozone levels and a number of measures aimed at reducing NO\textsubscript{x} emissions have been effective in reducing peak ozone levels in Europe. The aim of this work is to investigate the seasonal variations as well as the annual and seasonal trends of NO\textsubscript{x} using near surface measurements from the European Monitoring and Evaluation Programme (EMEP) network, including only rural stations throughout Europe over the recent period 2004-2011. Additionally, applying the Kriging interpolation technique to the observational data, a geographical depiction of the spatial distribution over Europe has been constructed, concerning amplitude, maximum values and trends of mixing ratio of these compounds related to ozone, during 2004-2011, which may contribute to a better evaluation of NO\textsubscript{x} emissions abatement strategies.

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1 Introduction

Nitrogen oxides (NO\textsubscript{x} = NO + NO\textsubscript{2}) are emitted primarily by anthropogenic activities including fossil fuel combustion by road transport, power plants, industry, off-road transport and domestic sources but also naturally by lightning, soil emissions and forest fires. NO\textsubscript{x} contribute to ozone formation in a non-linear way and their reduction affect peak ozone levels. Since reduced domestic NO\textsubscript{x} emissions may lead to increased ozone in winter and reduced ozone in summer at background sites on a European scale, while changes in North American and Asian NO\textsubscript{x} levels influence tropospheric ozone over Europe in spring and late autumn (Logan et al. 2012), the mapping of NO\textsubscript{x} seasonal behaviour across Europe, based on ground measurements in rural monitoring sites, would reveal their spatial and temporal variability and recent trends.

2 Data and Methodology

The primary surface NO\textsubscript{2} and NO data, used in this study, originated from unified monthly mean density measurements (μg m\textsuperscript{-3}) of the EMEP ground-based rural stations (European Monitoring and Evaluation Programme, www.emep.int/ccc/), during the recent period 2004-2011, considered as reliable when continuous observations are more than 75% in each year, after converted to mixing ratio by volume (ppbv), with the approximation of the ideal gas equation (Fjaeraa et al. 2013). Measurements overestimate real NO\textsubscript{2} concentrations since measured NO\textsubscript{2} in rural and remote locations, as well as in substantially aged air masses, is often an upper limit of the mixture of all nitrogen species such as NO\textsubscript{2plus}=HNO\textsubscript{3}+NO\textsubscript{3}+N\textsubscript{2}O\textsubscript{5}+NO\textsubscript{3}- +PAN+PAN\textsubscript{like} + other organic nitrogen-containing compounds (Steinbacher et al. 2007).

The seasonal cycle, based on averaged monthly mean values, and the annual linear trends, obtained by the ANOVA technique on the deseasonalised monthly mean mixing ratio time series, were also investigated, concerning 70 NO\textsubscript{2} and 29 NO measurement stations, spread in the greatest part of the continent. Focusing on rural sites, the mapping of spatial and temporal seasonality was constructed through Gaussian Kriging Interpolation and Generalised Cross Validation implementation to observations, (www.r-project.org), evaluated as successful when correlation coefficient R between individual and estimated - modelled values was greater than 0.70, in the aspect of Kethireddy et al. study (2014).

3 Results

Surface NO\textsubscript{2} seasonal cycle amplitude, calculated from 70 measurement stations (Fig. 1), ranges from 0.04 (Tustervatn, Norway) to 2.47 ppbv (Tänikon, Switzerland), adequately depicted by interpolated estimates between 0.40 and 1.45 ppbv, with higher values in The Netherlands, southeastern UK and Montelibretti (Italy). Similarly the lowest and highest observed values, 0.08 (Jungfraujoch, JFJ) – 4.17 ppbv (Vredepeel, The Netherlands), are successfully reproduced by interpolation in the interval 0.80 – 2.80 ppbv despite the underestimation of the highest values.

Seasonal cycle shows maximum usually in winter or generally in the cold season, followed by minimum in summer or generally in the warm season, even in sites like elevated JFJ (3,578m, asl), remote northern Tustervatn, Kårøtøn in Norway and Bredkålen in Sweden, where variability is relatively small (<0.2 ppbv) in all seasons compared to other EMEP stations.

Ground-level NO seasonal behaviour, at 29 sites in western and southern Europe, exhibits amplitude and peak values from observations between 0.01 (JFJ) – 2.38 ppbv (De Zilk) and
0.02 (JFJ) – 2.68 ppbv (De Zilk) respectively, successfully mapped by kriging (0.00 – 2.20 ppbv and 0.00 – 2.40 ppbv), enhanced in The Netherlands with a gradient from west-southwest to east-northeast.

Curves indicate a) maximum usually in winter or generally in the cold season followed by minimum in summer or generally in the warm season and b) quite small variability in all seasons (JFJ, Iberian Peninsula).

Surface NO\textsubscript{x} amplitude lies between 0.06 (JFJ) and 4.35 ppbv (De Zilk) for observations, 0.40 – 4.00 ppbv (The Netherlands and southeastern UK) for the interpolation field. Similarly, peak values between 0.10 (JFJ) – 6.74 ppbv (Vredepeel) and 0.80 – 6.30 ppbv respectively, appear higher in The Netherlands. Maximum usually emerges in winter or generally in the cold season followed by minimum in summer or generally in the warm season, except for small variability in all seasons at the high altitude alpine station JFJ due to the low NO\textsubscript{x} levels (Fig. 1, 2).

Linear regression combined with least square fit to deseasonalised monthly mean observations time series, taken by subtracting the overall monthly mean values from the monthly mean concentrations, at 70 stations placed west of 30° E longitude, results in annual NO\textsubscript{2} trends ranging from -0.19 (Lazaropole, FYROM) to +0.19 ppbv yr\textsuperscript{-1} (Vilsandi, Estonia)
with higher values in Estonia (small positive, statistically significant, \( p=10^{-13} \)), close to zero and slightly downward values mainly in Central and Southern Europe. Interpolation field, successfully represents \( \text{NO}_2 \) trends' geographical distribution, giving estimations between -0.12 and +0.12 ppbv yr\(^{-1}\) and statistically significant (\( p<0.1 \)) annual positive trends in Estonia and Western France towards the Atlantic Ocean, close to zero in Scandinavia - Hungary - Slovakia and negative in the rest of the study area (Fig. 3). We should note that in the French sites \( \text{NO}_2 \) levels during 2008 are respectively higher than in other years and also relatively high values during 2005 first months in Lazaropole.

Winter trends, 0.00 - (+0.10) ppbv yr\(^{-1}\), unsuccessfully reproduced by interpolation, reveal dominant close to zero values except for The Netherlands – Belgium (slight positive). Trends in spring are close to zero except for downward in The Netherlands coast (Kollumerwaard, -0.49 ppbv yr\(^{-1}\)), in summer appear positive in Kollumerwaard (+0.71 ppbv yr\(^{-1}\)) and Belgium and close to zero in the rest of the study area, while \( \text{NO}_2 \) levels seem to be constant in autumn except for The Netherlands. Interpolation field confirms these findings in these three seasons. Trends in all seasons are not statistically significant. Elevated locations (altitude>1,000m) show slight negative close to zero trends and the alpine JFJ, usually in free tropospheric conditions, exhibits very small \( \text{NO}_2 \) seasonal variation (0.05 ppbv) and peak at 0.08 ppbv. The spatial patterns of peak rural \( \text{NO}_2 \) values in The Netherlands, Belgium, southeastern UK, western Germany, Mediterranean, low levels in Spain and prevailing negative/close to zero \( \text{NO}_2 \) trends with isolated positive values in Estonia, Hungary-Slovakia and western France in our study are similar (Table 1) to satellite – derived values, EMEP model estimates and country – level \( \text{NO}_2 \) patterns from background stations during the periods August 2002 – August 2011, 1999 - 2008 and 2002 – 2009 respectively (Schneider and van der A 2012).

\( \text{NO}_2 \) annual trends, at 29 measurement sites in western and southern Europe, vary from -0.12 (Peyrusse Vieille) to (+0.09) ppbv yr\(^{-1}\), (St Osyth), developed successfully by interpolation (-0.11 – (+0.07) ppbv yr\(^{-1}\)), with close to zero values prevailing, positive in eastern UK and downward in the borders of Spain-France.

Table 1. Country-Level averages of percentage \( \text{NO}_2 \) trends from SCIAMACHY - satellite data and station observations (Schneider and van der A 2012) and from EMEP rural sites in our study.

<table>
<thead>
<tr>
<th>Country</th>
<th>Number of months</th>
<th>Satellite (at Stations) (% / yr(^{-1})) (2002-2009)</th>
<th>Stations (your(^{-1})) (2002-2009)</th>
<th>Number of EMEP stations</th>
<th>Average trend (% / yr(^{-1})) (2004-2011)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>71</td>
<td>-1.7±2.6</td>
<td>-1.1±0.7</td>
<td>2</td>
<td>0.73±1.76</td>
</tr>
<tr>
<td>Belgium</td>
<td>19</td>
<td>-4.0±1.9</td>
<td>-2.1±0.6</td>
<td>3</td>
<td>-1.94±1.73</td>
</tr>
<tr>
<td>Switzerland</td>
<td>22</td>
<td>-3.2±2.5</td>
<td>-1.4±0.7</td>
<td>5</td>
<td>-1.24±1.79</td>
</tr>
<tr>
<td>Czech Rep.</td>
<td>35</td>
<td>-3.8±3.0</td>
<td>-2.0±0.7</td>
<td>2</td>
<td>-2.07±1.79</td>
</tr>
<tr>
<td>Germany</td>
<td>183</td>
<td>-4.0±2.2</td>
<td>-1.7±0.6</td>
<td>6</td>
<td>-0.01±1.78</td>
</tr>
<tr>
<td>Spain</td>
<td>58</td>
<td>-2.1±2.6</td>
<td>-1.2±0.7</td>
<td>9</td>
<td>-2.06±1.79</td>
</tr>
<tr>
<td>France</td>
<td>255</td>
<td>-3.0±2.4</td>
<td>-1.9±0.7</td>
<td>2</td>
<td>2.53±2.20</td>
</tr>
<tr>
<td>UK</td>
<td>22</td>
<td>-4.5±2.3</td>
<td>-0.6±0.7</td>
<td>13</td>
<td>-1.40±1.77</td>
</tr>
<tr>
<td>Italy</td>
<td>33</td>
<td>-2.1±2.2</td>
<td>-0.6±0.6</td>
<td>1</td>
<td>-2.05±1.78</td>
</tr>
<tr>
<td>Netherlands</td>
<td>26</td>
<td>-3.8±1.9</td>
<td>-2.1±0.8</td>
<td>3</td>
<td>-1.73±1.75</td>
</tr>
<tr>
<td>Poland</td>
<td>11</td>
<td>-0.1±2.3</td>
<td>-0.1±0.9</td>
<td>4</td>
<td>0.00±1.79</td>
</tr>
</tbody>
</table>

\( \text{NO}_x \) trends lie between - 0.14 (Vredepeel) – (+0.25) ppbv yr\(^{-1}\) (La Tardière) from observations, -0.10 – (+0.12) ppbv yr\(^{-1}\) for interpolation field, the highest in La Tardière, close to zero in southeastern UK and downward as dominant.

Considering Europe as a whole, near surface \( \text{NO}_2 \), \( \text{NO} \) and \( \text{NO}_x \) average seasonal cycles display minimum in the warm season (May - August) and maximum in winter months up to 1.5, 0.62 and 2.26 ppbv respectively (Fig. 2). As for \( \text{NO}_2 \) (the major part in \( \text{NO}_x \), especially in summer), average annual trend is -0.01±0.05 (1σ error) ppbv yr\(^{-1}\) and seasonal ones are 0.00±0.02 in winter, -0.01±0.06 in spring, 0.02±0.12 in summer and -0.01±0.08 ppbv yr\(^{-1}\) in fall (not shown here).
Fig. 3. Interpolation field of near surface NO\textsubscript{2}, NO and NO\textsubscript{x} annual trends (ppbv yr\textsuperscript{-1}), based on deseasonalised monthly mean mixing ratio values from EMEP measurements sites (circles).

4 Conclusions

The mapping of rural/background near surface nitrogen oxides’ spatial and temporal distribution over Europe, the issue of this study, showed that:

1. Close to zero/negative NO\textsubscript{x}, NO\textsubscript{2}, NO annual trends prevail across Europe during 2004-2011, except for NO\textsubscript{2} slight positive (statistically significant, p<0.1) values in Estonia and in French La Tardière towards Atlantic, NO positive in southeastern UK and La Tardière and NO\textsubscript{x} small increasing rate in La Tardière.
2. Enhanced interannual NO\textsubscript{2} levels in The Netherlands, Estonia, southeastern England and La Tardière area (nearby country road) may be attributed to ship traffic emissions, meteorological factors, domestic industry and transport patterns respectively (Colette et al. 2011).
3. Emissions abatement strategies plus the economic recession after 2008 (Castellanos and Boersma 2012, Vrekoussis et al. 2013) seem to be effective in Europe since the spatial pattern of declining nitrogen oxides is evident, despite sparse slight increases in northern and eastern sites, as it is confirmed by model and satellite estimates (Schneider and van der A 2012 and references therein).

Acknowledgments. The authors would like to thank EMEP acidifying compounds measurement network for providing rural stations surface nitrogen oxides monthly data during 2004-2011.

References

Estimating near surface ozone trends over Europe for the time period 1996-2006 using the RegCM3/CAMx modeling system

Akritidis D., Zanis P., Pytharoulis I., Karacostas Th.

The air quality model CAMx driven off-line by the regional climate model RegCM3 is used to estimate near surface ozone trends over Europe during 1996-2006. Two simulations were performed in order to assess the contribution of meteorology and anthropogenic emissions change on modeled ozone trends. The first simulation (RUN1) was forced from constant emissions based on the EMEP emissions of the year 1996, considering only the evolution of meteorological conditions. The second simulation (RUN2) was forced from emissions with interannual variability, considering both the evolution of meteorological conditions and emissions. Average monthly concentration values for the year 1996, obtained from the global chemistry climate model ECHAM5-MOZ, were used as lateral chemical boundary conditions for both CAMx simulations. Modeled and observed ozone trends are calculated for various stations of the EMEP network in annual and seasonal basis, in order to both evaluate the ability of the modeling system to reproduce ozone trends and study the impact of meteorology and emissions on ozone trends.

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1 Introduction

According to observations, background ozone concentrations over Europe are rising (Jenkin 2008, Wilson et al. 2012). Although emissions of ozone precursors in Europe have been substantially reduced over recent years due to control strategies (Derwent et al. 2003), models have shown (Szopa et al. 2006) that this benefit can be significantly counterbalanced by increasing background ozone. Ozone exhibits substantial interannual variability, mostly driven by meteorology, year to year variations in anthropogenic emissions, stratosphere-troposphere exchange and air-mass transport patterns.

While most of the works are focusing on hemispheric ozone trends, there are a limited number of studies investigating regional scale trends across Europe based on model calculations (Solberg et al. 2009, Colette et al. 2011, Wilson et al. 2012).

This work aims to estimate observed and modeled surface ozone trends over Europe for the time period 1996-2006, using the RegCM3/CAMx modeling system. Furthermore, the impact of meteorology and emissions on surface ozone trends is assessed by performing two simulations.

2 Data and Methodology

The climatic simulations were performed with the regional climate model RegCM version 3 (http://users.ictp.it/RegCNET/model.html) driven by data from the NCEP reanalysis. RegCM3 was used to simulate the time period 1996-2006 for a large European domain with a grid resolution of 50 km x 50 km, in order to provide the meteorological forcing for the air quality simulations carried out by CAMx.

CAMx version 5.2 (ENVIRON, 2010) is a Comprehensive Air quality Model with extensions which is widely used for regional climate-chemistry studies (Katragkou et al. 2010, Zanis et al. 2011, Akritidis et al. 2013). The spatial resolution of CAMx was set to 50 km x 50 km, while the vertical profile of the domain contains 12 layers of varying thickness extending to about 6.7 km. The chemistry mechanism used is Carbon Bond version 4 (CB4) including 113 reactions and up 28 gas species, but not including aerosol chemistry. Anthropogenic emissions were processed (spatial disaggregation, temporal and chemical splitting) using the MOSESS emission model (Markakis et al. 2013). The emissions were provided in annual basis and the temporal analysis (monthly, weekly, diurnal) was completed using the profiles of Friedrich (1997) for all countries found inside the domain. Average monthly concentration values for the year 1996 obtained from the global chemistry climate model ECHAM5-MOZ were used as chemical boundary conditions. More details for the modeling system can be found in Akritidis et al. (2013). The modeling set-up even though has limitations in capturing urban scale processes related to air quality and peak values, it is useful in studying climatic features of ozone variability at rural scale in a decadal time framework.

Two simulations were performed to investigate the influence of meteorology and emissions on ozone trends:

RUN1 Varying meteorology (1996-2006) and constant anthropogenic emissions based on the EMEP emissions of the year 1996.

RUN2 Varying meteorology (1996-2006) and anthropogenic emissions with interannual variability based on the EMEP emissions of the years 1996-2006.

Lateral boundary conditions and biogenic emissions were kept identical for both simulations. Therefore, RUN1 simulation considers only the evolution of meteorology, while RUN2 considers the evolution of both meteorology and anthropogenic emissions. In order to evaluate the ability of the modeling system to reproduce the observed ozone trends, near surface ozone measurements from the EMEP network were used, from 74 stations selected under the 75% data availability criterion. Annual and seasonal trends were calculated by implementing linear regression analysis on deseasonalized monthly values and
seasonal values respectively. The significance of the trends (p<0.1) was assessed by the Mann Kendall approach.

3 Results

Fig. 1 shows the spatial distribution of annual trends over Europe for both model and observations. Concerning the observations 60 sites exhibit positive trends, 43 of which are significant with a range of 0.13 to 1.02 ppb/year, mainly found over Central Europe, UK and Benelux. The highest positive trends are seen in Stara Lesna (Slovakia) (1.01±0.34 ppb/year) and several Austrian sites as Forsthof (0.59±0.24 ppb/year) and Gänserndorf (0.57±0.2 ppb/year). Significant negative trends were detected in 4 of the remaining 14 stations with a range of -0.25 to -0.44 ppb/year.

Regarding model (RUN2) results, significant positive ozone trends are mostly found over UK, Benelux, Germany and Czech Republic with a range of 0.13 to 0.31 ppb/year (16 sites), with just 3 sites displaying significant negative trends with a range of -0.08 to -0.15 ppb/year. The largest discrepancies between model and observations are located over Austria, likely due to underestimation of NOx trends (not shown here).

The scatter between observed and modeled (RUN1, RUN2) trends (Fig. 2) indicates that despite the weaker display of the trends, the modeling system reproduces the correct sign as the majority of the symbols (representing stations) are lying on the 1st and 3rd quadrant. Considering only sites where a significant trend is observed the percentage of stations where the sign of the trend is correctly captured is 75% for RUN2 simulation. No significant annual trend is found due to meteorological variability (RUN1). The comparison between RUN1 and RUN2 simulations shows that year to year varying anthropogenic emissions improve the approximation to the observed trends for some sites in Britain, Benelux, Germany and Poland, stressing the role of emissions in ozone trends over these regions.
The maps of annual and seasonal (winter and summer) ozone trends over Europe for the period 1996-2006 are provided in Fig. 3 for both RUN1 and RUN2 simulations. Concerning RUN1 simulation, no significant contribution of meteorology to annual and winter ozone trends is found, as the calculated trends are not statistically significant (Fig. 3a and 3b). During the summer period significant positive trends are found in areas of France, Switzerland and Germany (Fig. 3c). Analysis of modeled ozone summer anomalies (not shown here) for various sites of the above regions indicates that ozone summer trends are strongly associated with the heat wave of 2003.

As concerns the role of changing emissions and meteorology in ozone annual trends the strongest pattern is a significant positive ozone trend over Southern UK, Benelux and Germany (Fig. 3d) and is also detected in the observations. The above-mentioned ozone increase is related with the fact that local scale removal of ozone by direct reaction with emitted NO has gradually decreased as a result of NOx emissions control policies. Significant small negative annual ozone trends are found mainly over the Mediterranean region. Taking into account that there is no significant negative trend over this region due to meteorology (RUN1) the current trend may be related to emissions reduction over continental Europe. In summer the same but more intense pattern is occurred over the Mediterranean (Fig. 3f), probably due to more intensive photochemistry during summer over this region. In winter no notable significant trend is found probably due to masking by meteorology.

**Fig. 3.** Modeled a) annual b) winter c) summer ozone trends for RUN1 simulation over the time period 1996-2006. Same for RUN2 simulation at d) e) f.)
4 Conclusions

The key findings from this study are summarized as follows:
1. The modeling system reproduces in a satisfactory way the sign of the observed annual ozone trends, but mostly underestimates its magnitude.
2. No significant modeled annual ozone trends were found due to meteorology, while during the summer period significant modeled ozone trends are detected over parts of Central Europe directly linked to the heat wave event of 2003.
3. Year to year varying emissions improved the performance of the model especially over the emissions hotspots. Significant positive trends are found over UK, Beelux and Germany, associated to a decrease of ozone titration by NOx.
4. Our results are in line with the results of other studies focusing on the assessment of ozone trends over Europe using models, for similar time periods (Colette et al. 2011, Wilson et al. 2012).

References

Trends in population exposure to particulate matter in urban areas of Greece during the last decade

Aleksandropoulou V., Lazaridis M.

Assessment of population exposure is very important for the evaluation of the adverse health effects of PM$_{10}$ and PM$_{2.5}$ pollution. In this work is evaluated the population exposure to PM$_{10}$ and PM$_{2.5}$ at local outdoor environments in the Athens (AMA) and Thessaloniki (TMA) metropolitan areas during the period 2001 – 2010. The methodology used is based on combining spatiotemporally allocated PM$_{10}$ and PM$_{2.5}$ concentration fields with the geographical distribution of population. The results showed that the number of people living in AMA exposed to PM$_{10}$ and PM$_{2.5}$ concentrations above the annual air quality standards (AQS), has dropped 18% since 2001 and 98% since 2008, respectively. Likewise, in 2010 8% less, compared to 2001, of AMA population lived in areas where the daily AQS for PM$_{10}$ was exceeded more than 35 times. The results as regards TMA indicated the decrease in the number of people exposed to PM$_{10}$ concentrations over the annual AQS value (78% decrease). However, the number of people living in areas with PM$_{10}$ concentrations over the daily AQS for more than 35 times in a year doubled since 2001. Finally, the spatial distribution of the normalized population load which reflects populated areas with concentrations above the daily AQS was evaluated. The hot spots for both areas correspond to urban areas and areas with significant primary PM$_{10}$ emissions.

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1 Introduction

Air pollution by particulate matter (PM) in the atmosphere of urban areas results from emissions directly by sources (primary particles) such as fuel combustion (e.g. transportation, domestic and commercial heating), re-suspension of settled particles, pollen and sea salt or from particles formed in the atmosphere (secondary particles) by transformation of gaseous particulate precursors (NOx, SOx, NH3, VOCs) emitted from a variety of sources (Hinds, 1999). Ambient PM exert a significant impact on climate biogeochemical cycles, atmospheric chemistry and adversely affect public health (Pope et al. 2002, Almeida et al. 2007). In order to protect human health the European Union has set limit values for PM10 annual (40 μg/m³) and day (50 μg/m³) concentration averages, an annual limit value for PM2.5 concentrations to be set in force in two stages (2015 and by 2020; in the years preceding 2015 the AQS is 30 μg/m³ on 11 June 2008) and an annual target value (25 μg/m³) to be met by 2010 for PM2.5 with the Directive 2008/50/EC.

In the European Union, 18-41% of the urban population was exposed to PM10 concentrations in excess of the EU daily AQS in the period 2001 - 2010 (EEA, 2012). Specifically in Greece the Average Exposure Indicator (defined in Directive 2008/50/EC) for 2010 was 20 μg/m³ (de Leeuw 2012). In the AMA and TMA, PM10 levels have dropped significantly during the decade 2001 - 2010, however still are areas where the EU AQS for the protection of human health are frequently exceeded (Aleksandropoulou et al. 2012a). In addition, PM2.5 concentrations in AMA exceeded the target value of 25 μg/m³ in 2010. In this work the population exposure to PM10 and PM2.5 at outdoor environments in Athens and Thessaloniki metropolitan areas, during the period 2001 – 2010 is evaluated.

2 Data and Methodology

The methodology for the assessment of population exposure is based on combining population maps with maps of the PM concentrations. Consequently the uncertainty of the results mainly relies on the accuracy of the spatiotemporal PM concentration fields which were derived from modelling and monitoring data using data interpolation techniques. A review of interpolation and assimilation methods for air quality assessment and mapping on European scale is presented by the European topic centre on air quality and climate change (Denby et al. 2005). Although the data interpolation approach probably cannot capture the spatial variation within the urban area, it is based on common procedures and is appropriate in calculating population exposure estimates (Horalek et al. 2007). Several interpolation approaches with different supplementary data have been initially used to derive spatiotemporal PM concentrations over AMA. The variables included in the proposed spatial disaggregation models for particulate matter concentrations were selected based on the evaluation of model performance criteria in terms of the root mean square error (RMSE) and the index of agreement (d; Willmott 1981). Also, it must be noted that the exposure calculations in this study are based on the current AQS.

2.1 Data

The exposure concentration was estimated using monitor and modelling data. Monitor data were available from the Hellenic Ministry for the Environment, Energy and Climate Change (H.M.E.E.C.C.) and the European Air quality database (AirBase), whereas the PM10 background levels were retrieved from the EMEP Unified model results database (EMEP/MSC-W). The metropolitan area was divided to rural and urban/suburban land based on the Corine Land Cover (CLC) 2000 database. The geographical distribution of population was derived from the EEA dataset (based on 2001 census, considered unchanged throughout
the period). Additionally, spatially (1×1 km²) and temporally (1 h) distributed emission inventories of particulate matter from anthropogenic and natural sources for AMA and TMA for the period 2001–2010 were used to derive weighting factors for the interpolation. The methodology for inventory compilation is given in Aleksandropoulou et al. (2011, 2013). The emissions of secondary particles were estimated as PM₁₀ equivalents using the methodology of de Leeuw (2002).

2.2 Methodology

Multivariate statistical analysis was used for the spatiotemporal allocation of PM₁₀ concentrations at rural areas, using as variables the background PM₁₀ concentrations, the anthropogenic primary emissions of PM₁₀ (in particular zonal aggregates of emissions within an area of ~25km²), the variation in rural monthly averaged PM₁₀ concentrations and the day-to-day variation in background suburban concentrations. At artificial surfaces, the local outdoor PM₁₀ levels were estimated using the inverse-squared-distance weighted average of the background suburban monitor values scaled with anthropogenic primary PM₁₀ emissions. Monitor values at traffic and industrial stations affect the PM₁₀ concentration gradient only in their vicinity (the “vicinity” radius was chosen based on the results of the FAIRMODE survey to elicit expert opinion on the spatial representativeness of ground based monitoring data and the criteria for macroscale siting of sampling points directed at the protection of human health given in Directive 2008/50/EC).

Exposure metrics were calculated for the areas of interest. The population exposed to concentrations above the annual AQS value was calculated by combining the annual concentration map with the map of the geographical distribution of population. In addition, by combining the map with exceedances of the daily AQS with the map of the geographical distribution of population, the population exposed to concentrations above the daily AQS was calculated. Moreover, other exposure metrics were calculated, specifically the “person dose”, Di, and the “population load”, Li, using the following equations (Walker et al. 1999):

\[
D_i = \frac{1}{N} \sum_{n=1}^{N} \max \{ C_i^n - C_T \}, \quad \text{and} \quad L_i = D_i \times P_i
\]

where \( C_i^n \) is the calculated grid cell concentration at time \( n \), CT is the AQS value, \( N \) is the number of values within the time period, and \( P_i \) is the population living in the grid cell \( i \) with person dose \( D_i \). The person dose is a concentration value which can be interpreted as the average exceedance of the threshold value and points to areas with potentially low air quality while on the other hand the population load gives information on the populated regions with concentrations above the threshold values (Walker et al. 1999).

3 Results

Population exposure to PM₁₀ and PM₂.₅ in AMA was estimated for the periods 2001–2010 and 2008–2010, respectively. The values of model performance indicators, RMSE and d, for annual PM₁₀ concentrations varied from 0.35 to 6.21 and from 0.83 to 1.00, respectively. It was found that the annual average of PM₁₀ concentrations over agricultural and natural (rural) areas in AMA has increased since 2001 (almost fivefold increase to 19 \( \mu g/m^3 \)). This increase can be attributed to several factors (forest fires, African dust outbreaks, changes in primary emissions and secondary particles, meteorological and atmospheric conditions) which vary from year to year. On the other hand the annual average concentration of PM₁₀ over artificial surfaces in AMA has decreased almost 40 % (to 45.4 \( \mu g/m^3 \)). The attenuation of PM₁₀ concentrations over built up (urban) areas was anticipated since anthropogenic emissions have dropped significantly in the area from 2001 to 2010 (Aleksandropoulou et al. 2012b). It was
found that more than 69% of the population living in the area was exposed to PM$_{10}$ concentrations above the annual EU AQS in 2010 compared to 87.5% in 2001. The above percentages correspond to approximately 2.9 and 3.5 millions of people of the approximately 4 million inhabitants of the area.

The map of the estimated probability of exceedance of the daily AQS for the year 2001 (Figure 1) depicts that it was mainly exceeded in areas in and around the city of Athens, over smaller cities in the domain as well as in areas close to significant anthropogenic emission sources (e.g. P.P.C. plants). Although the spatial distribution of exceedances was significantly altered in 2010, the probability remained at values above the EU daily AQS in the city where the majority of the population in the area lives. Also the probability for exceedances has significantly increased at the smaller cities of the domain probably due to the increase of traffic and urbanisation in those areas, industrial activities in their vicinity, increase in background concentrations and perhaps the small increase in primary PM emissions from agricultural activities (Aleksandropoulou et al. 2012b). The distribution of the normalised population load depicted in Figure 1 reflects the populated areas with concentrations above the daily AQS. The percentage of the population living in areas of AMA where the daily AQS was exceeded more than 35 times was 90.4% in 2001 whereas in 2010 it dropped to 83%. The above percentages correspond to approximately 3.6 and 3.3 millions of people.

Fig. 1. Maps depicting the probability of exceedance of daily AQS for PM$_{10}$ in AMA in 2001 and 2010 and the normalised 2010 population load distribution in AMA and TMA (%).

In addition, the exposure to PM$_{2.5}$ concentrations was estimated for the period 2008 – 2010. The supplementary data used for the spatial distribution of PM$_{2.5}$ concentrations were aggregates of primary and secondary emissions. The concentration of PM$_{2.5}$ averaged for the whole area dropped 4% during the studied period (from 10.5 to 10.06 μg/m$^3$). In particular, at agricultural and natural vegetation areas the concentration increased approximately 13% (to 8.8 μg/m$^3$) whereas over artificial surfaces decreased 28% (from 30.9 to 22.3 μg/m$^3$). The percentage of the population living in areas of AMA where the EU target value for PM$_{2.5}$ was exceeded changed from 80.7% in 2008 to 1.4% in 2010.

Likewise the population exposure to PM$_{10}$ in TMA was estimated for the period 2001 - 2010. It was found that the annual average of PM$_{10}$ concentrations over agricultural and natural (rural) areas in TMA has almost doubled since 2001. On the other hand the annual average concentration of PM$_{10}$ over artificial surfaces in TMA has significantly decreased since anthropogenic emissions have dropped significantly in the area from 2001 to 2010 (Aleksandropoulou et al. 2012b). In particular, the annual PM$_{10}$ concentrations over urban areas were 70 μg/m$^3$ and 26 μg/m$^3$ for the years 2001 and 2010, respectively. Approximately 14% of the population living in the area was exposed to PM$_{10}$ concentrations above the annual EU AQS in 2010. The corresponding value for 2001 was 65%. The percentage of the population living in areas of TMA where the daily AQS was exceeded more than 35 times was 64.5% in 2001 whereas in 2010 it dropped to 19.8%.

4 Conclusions

During the period 2001 – 2010 the measured concentrations of PM$_{10}$ and PM$_{2.5}$ have decreased. This is probably associated with the decrease in primary PM emissions and air pollutants precursor to PM in AMA and TMA during the period. However, still the majority
of people living in the AMA are exposed to PM concentrations over the AQS for annual and
daily averaged values, therefore pollution abatement measures need to be taken.

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Modeling surface solar radiation over Eastern Mediterranean

Alexandri G., Georgoulias A.K., Meleti C., Balis D.S.

Surface solar radiation (SSR) simulations are performed with the Santa Barbara DISORT Atmospheric Radiative Transfer (SBDART) model for the region of Eastern Mediterranean. We have developed an IDL tool that “feeds” SBDART with satellite and ground-based input data and performs simulations with a time step of 1 hour and a spatial resolution of 0.1x0.1 degrees. Specifically, level-2 aerosol optical depth, cloud optical depth, cloud fraction, effective droplet radius, cloud top pressure, precipitable water and surface albedo data from MODIS, as well as ozone total column data from Earth Probe TOMS and OMI satellite sensors, coarse resolution cloud data from the ISCCP and single scattering albedo, asymmetry factor and Angström exponent sunphotometric data from the AERONET are used in our radiative transfer simulations. Simulations are performed over different spots within Eastern Mediterranean for clear, liquid cloud and ice cloud covered skies. Our results are validated against high and coarse resolution satellite-based SSR data from CM SAF and ISCCP, respectively, and ground-based pyranometric observations. The good agreement of our simulations with ground and satellite-based observations highlights the potential of using our method in order to examine the spatiotemporal variability of SSR and the radiative effect of aerosols and clouds at a resolution of 0.1 degrees.

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1 Introduction

Variations in surface solar radiation (SSR) affect many climatic elements such as the hydrological cycle, the atmospheric and oceanic circulation, plant productivity, etc (e.g. Wild et al. 2008, Mercado et al. 2009). Because of the central role of the energy balance in the climate system, the solar radiation observations started early in 20th century (Wild 2009). During the last decades SSR measurements are available via ground-based radiation networks. Our knowledge on the Earth energy balance has been improved through various satellite missions. Satellite sensors measure directly the down and up-welling solar radiation at the top of the atmosphere (TOA). Thus, they are capable of capturing accurately the variability of the radiative fluxes at the top of the atmosphere (Loeb et al. 2012). On the other hand, the surface solar radiation fluxes cannot be directly measured from the satellites. They can only be estimated indirectly with the synergistic use of radiative transfer models or empirical models with satellite and ground-based measurements of various physical parameters. A number of artifacts which are related to the accuracy of the measured input parameters as well as the accuracy of the applied methods explain why surface radiation fluxes are less well quantified than the TOA fluxes. Satellite-based observations of SSR are available from the early 1980s. Some of the well established SSR satellite-based products that are available today suffer from a low spatial resolution that makes them improper for regional studies (e.g. ISCCP, ERBE, etc). Other products, which are available at high spatial resolutions (e.g. CM SAF), are derived taking into account aerosol climatologies. This makes them incapable of detecting and determining SSR trends that are related to aerosol changes. In this work, we present a method that combines high spatial resolution with the ability of capturing the effect of aerosols and clouds on the SSR. A variety of satellite and ground-based data are used as an input to a radiation transfer model (SBDART) that simulates the SSR radiation over different sites around Eastern Mediterranean, a region of particular interest since it is affected by aerosols of various origins (Lelieveld et al. 2002). Here, we present a case study for the city of Thessaloniki, a typical coastal city in the heart of Eastern Mediterranean.

2 Data and Methodology

Within QUADIEEMS (QUantifying the Aerosol Direct and Indirect Effect over Eastern Mediterranean) project an IDL automated programming tool was developed that “feeds” the SBDART radiative transfer model with satellite and ground-based input data and executes the model with a time step of 1 hour (see Fig. 1). The core dataset consists of level-2 single pixel aerosol (~10km at nadir) and cloud (~5km at nadir) related parameters from MODIS TERRA for the period 2/2000-12/2012. Specifically, aerosol optical depth at 550nm (AOD_{550}), cloud optical depth (liquid and ice clouds), total, ice and liquid cloud fraction, cloud effective particle radius (liquid and ice clouds), cloud top pressure, precipitable water and surface albedo at 7 wavelengths were used from the 0.1-degree gridded aerosol-cloud product that was compiled within QUADIEEMS project. In addition, ozone total column data were used from Earth Probe TOMS (2/2000-9/2004) and OMI (10/2004-12/2012) satellite sensors and cloud fraction satellite data from the ISCCP. Finally, Angström exponent (AE) (440-870nm), single scattering albedo (SSA) and asymmetry factor (g) observations at 4 wavelengths (440, 675, 870 and 1020nm) were obtained from the AERONET sunphotometer network.

Monthly mean values were calculated for the aerosol and cloud data from MODIS and the total ozone data from TOMS and OMI. The liquid and ice cloud fractions were scaled on a daily basis in order to make sure that their sum equals the total cloud fraction. This is done since SBDART cannot account for mixed phase clouds. MODIS TERRA has an overpass time at ~9:40 UTC over Thessaloniki. So, to get an insight into the diurnal variability of the cloud coverage we used 3-hourly climatological total cloud cover data from the ISCCP (1984-2009). The data were temporally interpolated in order to have 1 value per hour for each month.
of the year and were used to scale the MODIS cloud fraction data according to the time of the simulation. Three different sets of simulation were performed, one for clear, one for liquid cloud and one for ice cloud covered skies. The results of the simulations were afterwards weighted with the clear sky fraction, liquid cloud fraction and ice cloud fraction correspondingly and the total SSR emerged from their sum.

The simulations are validated here against high resolution satellite data from the CM SAF (Satellite Application Facility for Climate Monitoring) and ground-based data from a Kipp and Zonen CM-11 pyranometer which is located at the facilities of the Laboratory of Atmospheric Physics (LAP) in the center of Thessaloniki (Meleti et al. 2008). The CM SAF dataset is derived from Meteosat first generation satellites (Meteosat 2-7) and covers the period 1983-2005 with a resolution of 0.03°x0.03° (Posselt et al. 2011). The common SBDART-CM SAF-LAP period 2000-2005 is used here for the validation of our simulations.

![Flowchart](image)

**Fig. 1.** Flowchart with the methodology followed for the simulation of SSR.

## 3 Results

Compared to our ground-based pyranometric observations (thereafter denoted as LAP) for the period 2000-2005, CM SAF overestimates SSR by ~5% [100·Σ(y_i-x_i)/x_i: mean percentage difference-MPD]. SBDART overestimates SSR compared to LAP and CM SAF by ~6% and ~1%, respectively. The linear regression between SBDART and CM SAF and LAP is expressed by the following equations: y=1.131x-17.599 and y=1.172x-14.579 (see Fig. 2). The SBDART simulations, offer a good estimate of the SSR, taking into account that monthly mean values were used in our simulations and that cloud data from a sun synchronous near polar orbit satellite were used. It has to be highlighted that these data are only a snapshot of the daily cloud conditions over a region. However, the scaling method that was applied with the use of ISCCP diurnal data improves the results significantly. In both cases, the Pearson's correlation coefficient (R) is over ~0.98.
The seasonal variability shown in Figure 3 (left upper panel), reveals that the SSR is significantly overestimated during July and August and significantly underestimated in January. The overestimation appearing in July is also observed in the ISCCP dataset. We repeated the same procedure omitting the ISCCP diurnal correction in our simulations and the results were very similar. This shows that the SBDART overestimation is not an artifact inserted by the use of ISCCP input data. In Figure 3 (right upper panel), we present the contribution of each component (clear sky, liquid cover, ice cover) to the total SSR for each month of the year. We observe that for the clear part of the area of Thessaloniki a clear maximum is observed in summer due to the limited cloud coverage and the increased incoming solar radiation during this period compared to winter, spring and autumn. The cloud fraction seems to drive the relative contribution of liquid and ice clouds to the total SSR. The importance of other factors cannot be ignored (e.g. cloud reflectivity, optical thickness, etc.); however, the comparison of the two lower panels of Figure 3, highlights the major role of cloud fraction. The clear part of the sky is responsible for 63.6% of the total SSR on an annual basis. The corresponding values for the liquid and ice covered part are 21.6% and 14.8%. Liquid clouds cover 29% of the greater Thessaloniki area on an annual basis. The corresponding values for ice clouds and clear skies are 20% and 51%.
4 Conclusions

In this paper, we present a method that allows for the calculation of SSR at a high spatial resolution of 0.1 degrees using a radiative transfer model with input data from various satellite sensors and ground-based observations. A case study is presented for Thessaloniki, a coastal city situated in the heart of Eastern Mediterranean. Our results overestimate SSR; however, they agree reasonably well with satellite-based observations from CM SAF (MPD of 1%) and ground-based pyranometric measurements from LAP (MPD of ~6%). The cloud fraction seems to drive the relative contribution of liquid and ice clouds to the total SSR. The clear, liquid covered and ice covered part of the sky is responsible for 63.6%, 21.6% and 14.8% of the total SSR, respectively with the average liquid/ice cloud fraction being 29%/20%. The method presented has been tested successfully for other locations within Eastern Mediterranean, showing the potential of being used in spatiotemporal studies in the near future.

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References

Meteorological characteristics, postfire effects and soil erosion risk in the lake Marathon basin (Attica, Greece), using the PESERA model.

Alexiou D.S., Papanikolaou I., Kairis O., Tsiros I.

Soil erosion risk assessment in the Marathon artificial lake basin in Attica, Greece was estimated through extended geomorphological analysis and a comparative study on soil erosion before and after the severe wildfire of 21st August 2009 (data for the years 2008 and 2011 respectively). The assessment of the spatial distribution of soil erosion was achieved through the well-known and semi-detailed European PESERA soil erosion model. The Marathon basin has been significantly affected by fire events resulting on topsoil losses. In respect to this, the differentiated meteorological characteristics seem to partially control the erosion rates as shown by the higher erosion rate of the unburned area in 2008, in comparison to the year 2011. For example in 2008 the extreme upper and lower values of erosion rates extend to a wider area compared to the 2011 values. There are 8.6km$^2$ of additional area in 2008 characterized of negligible or no erosion and 11.9km$^2$ of additional area characterized of very high erosion risk compared to the 2011 values. Overall, moderate erosion rates are severely stretched in 2008 in comparison to the 2011. Meteorological parameters and the post fire effects can explain these effects. These areas may define environmentally sensitive areas to desertification.

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1 Introduction

The Marathon basin is one of the most important basins for the Attica region due to the Marathon artificial lake and the extended drainage which is being regarded as the main water resource for the wider area. This lake has recreated the surrounding area, forming a valuable environmental zone. A dam was constructed in 1929 to water Athens, which resulted in significant environmental alterations. The generally degraded environment and the differentiated land-uses in regard with the increase of the extreme fire events make the soil erosion an important issue. The studied area is mainly covered by cultivated fields which are very important for the far-reaching economy. The reduction on soil productivity caused by the enhanced soil erosion makes the prevention's measures a necessity.

In this study, a correlation has been established between the soil erosion, the increase of fire events, the geomorphology and the climatic characteristics of the Marathon basin. The combination of the PESERA erosion model with the GIS system was applied before and after the fire of 21st of August 2009 by inserting the available geomorphological, geological, soil, satellite, forest and climatic data followed by methodical field work.

2 Studied area

The Marathon basin is characterized by a complex relief and drainage network as a result of active tectonics processes, meteorological characteristics, erosion and human interventions. The hydrographic network is complicated because of the existing active faults and the artificial junction between the Haradros and Varnavas rivers after the construction of the dam. It has to be referred that the Afidnes fault is the main active tectonic structure which is responsible for the present day setting of Haradros basin. Due to Afidnes fault there is being noticed headward erosion within the footwall catchments producing perpendicular flow directions in the hanging wall. In addition, due to the fact that the Haradros’s basin is placed on the hanging wall and as a result it is being subsided, several catchments are clearly deflected into a fault parallel flow direction (Papanikolaou and Papanikolaou 2007, Ganas et al. 2005).

The main area is covered mostly by post-Alpine sediments of Late Miocene, and minor outcrops of Pleistocene and Holocene alluvial (Mettos 1992). Nevertheless, the Marathon basin comprises also both metamorphic and non-metamorphic rocks. The Almyropotamos unit constitutes the metamorphic basement, while the Afidnes and Katsimidi units comprise the non-metamorphic rocks. A narrow zone with low-grade metamorphic rocks (Marathon’s schist and marbles) was observed along the tectonic contact of the metamorphic and the non-metamorphic units with no correlation to each other (Papanikolaou et al. 2004).

2.1 Methodology

The delineating of the burnt area was a primary target so, the NDVI factor was chosen (Rouse et al. 1973). The algorithm was executed through the ERDAS Imagine 2010 software by processing the satellite images (Landsat TM5) of May and September 2009.

For the soil erosion estimation the PESERA model was selected since it is a spatial distributed model developed for quantifying soil erosion in environmentally sensitive areas based on a European scale (Kirkby et al. 2003). This method combines primary data such as the DEM, the soil depth, the soil grain size analysis, the regional climatic data and the slope map which through a close-box process, results in the final erosion risk map. For the year after the fire the climatic data were not the only fields that it had to be changed. The coverage percentage field for every month and the use type for the demarcated burnt area field was also affected by the degradation of the vegetation coverage. In the studied area other erosion
models have also been applied. Xanthakis (2011) applied the RUSLE equation, the RMMF model and the Gavrilovic method in the Marathon basin. The required data were also collated from field surveys and remote sensing techniques. Overall, the upcoming conclusions were extracted from the comparison of both erosion maps and evaluated through systematic field work.

3 Results

The fire of 21st of August 2009 lasted 4 days destroying 210,000 acres. It was characterized as an unprecedented fire event for the Attica region. The human interventions in the drainage by constructing the dam imprinted on the reduction of the principal stream’s class, the number of streams by class, the change in streams’s length by class and the change in hydrographic density. The remarkable alteration in land uses in the last decades leads to environmental demoting and increase of runoff. According to Xanthakis and Xanthopoulos (2007) there was high increase of agricultural land and a significant decrease of wetlands and forests from 1880 to 2000. This fact combined to the extraordinary raise in fire events (Migiros et al. 2010) has resulted in reduction on vegetation’s productivity. More specifically, an abandonment of arable land due to declining productivity is a land use change that may result from soil erosion (Kosmas et al. 2000, Bakker et al. 2005).

The PESERA model was applied two years after the wildfire, so the burnt area was not regarded as bare land; on the contrary the vegetation coverage had been differentiated enough from 2009. In 2011, it was noticed that there was a significant ecosystem’s recovery which according to the satellite images of that year fluctuated between 20-25%. For example, the previous burnt forestry areas had been replaced by scrubs. There is an important diversification between the soil erosion of the year 2008 compared to the year 2011 (Fig. 1). In 2008, the total basin shows higher percentages of potential eroded zones compared to 2011, due to different rainfall heights.

Based on meteorological data, in 2008 the rainfall was higher for about 120mm (Fig. 2). Additionally, in 2011, more rainfall was distributed on March-June (Fig. 3). During this period, there was enough vegetation to decrease the energy of falling water, the runoff and consequently, the erosion. On the contrary, during the year 2008, the main rainfall was located on the autumnal-hibernal period (October-December) in which, most of the region was bared of vegetation and the topsoil coverage had been exposed. It is clear that the burnt area corresponds to an area of high erosion risk due to lack of vegetation.
4 Discussion- Conclusions

The geomorphology of the basin is being affected by the active tectonic faults and also, by the human interventions regarding, principally, to the construction of the Marathon dam. Such dam is an important engineering project, because it has been fully integrated into the environment, forming the microclimate of the entire Attica, demarcating an area of environmental protection and defining a crucial environmental zone between the National Parnitha’s forest, the Penteli’s massif and the Southern Euboea’s Gulf.

The recent fire events in NE Attica have increased the soil erosion processes. The regional climatic characteristics enhance the risk and some precaution measures need to be taken. The annual runoff is being correlated with the annual erosion risk. In respect to this, the PESERA method is a spatial analysis model which is defined by the primary data that are being entered to the algorithm. The soil erosion risk maps that have been exported by the PESERA model are being regarded as accurate because of the detailed processing of the embedded data. The slope factor is being taken into such a serious consideration, so to characterize some forest fields as high risk areas due to slope value greater that 25°.

It has to be noticed that when a correlation of the erosion risk per class (both extracted by the PESERA model) was made for both years, it was clarified that the year 2011 was characterized by less percentage of high and extremely high erosion risk zones, even though it would be expected that after the fire the greater part of the basin would be of extreme erosion risk. This could be explained by the decrease in the rainfall of the year 2011 in comparison to the rainfall rates of 2008.

Tables 1 and 2. Soil erosion risk classes expressed as percentage of the total area for 2008 and 2011.

<table>
<thead>
<tr>
<th>Erosion (2008)</th>
<th>Area (Km²)</th>
<th>Area (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Erosion</td>
<td>35,6</td>
<td>30,48</td>
</tr>
<tr>
<td>Very Low</td>
<td>3,5</td>
<td>3,03</td>
</tr>
<tr>
<td>Low</td>
<td>1,3</td>
<td>1,09</td>
</tr>
<tr>
<td>Moderate</td>
<td>3,7</td>
<td>3,17</td>
</tr>
<tr>
<td>High</td>
<td>12,6</td>
<td>10,8</td>
</tr>
<tr>
<td>Very high</td>
<td>60,2</td>
<td>51,43</td>
</tr>
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</table>

<table>
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<tr>
<th>Erosion (2011)</th>
<th>Area (Km²)</th>
<th>Area (%)</th>
</tr>
</thead>
<tbody>
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<td>No Erosion</td>
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<td>23,9</td>
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<tr>
<td>Very Low</td>
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<td>Low</td>
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<td>Moderate</td>
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<td>High</td>
<td>5,8</td>
<td>5,1</td>
</tr>
<tr>
<td>Very high</td>
<td>48,3</td>
<td>41,3</td>
</tr>
</tbody>
</table>

These changes on the erosion classes of 2011 correlated with the ones of the year 2008 are being imprinted in the map below (Fig. 4). A large part of the map is being characterized as an area with no alteration on soil erosion risk’s classes, even within the burnt area of 2009. Generally, the part of the map that remained unchanged is mainly related to the forestry areas. The most vulnerable sites correspond to agricultural land because of the agricultural practices which reduce the vegetation coverage and leave the ground almost bare.
By examining only the burnt area a significant alteration in erosion classes is being observed. In tables 3 and 4, all classes have increased in 2011 apart from the “high erosion risk” class, which has decreased. The affected areas with higher erosion rates correspond to cultivated areas, grasslands and scrubs, while some forestry areas have not been affected by the change due to the adequate soil depth.

**Tables 3 and 4.** Soil erosion risk classes expressed as percentage of the burnt-only area for 2008 and 2011.

<table>
<thead>
<tr>
<th>Erosion (2008)</th>
<th>Area (km²)</th>
<th>Area (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Erosion</td>
<td>0.9</td>
<td>4.5</td>
</tr>
<tr>
<td>Very Low</td>
<td>0.1</td>
<td>0.7</td>
</tr>
<tr>
<td>Low</td>
<td>0.7</td>
<td>3.8</td>
</tr>
<tr>
<td>Moderate</td>
<td>1.2</td>
<td>6.1</td>
</tr>
<tr>
<td>High</td>
<td>5.7</td>
<td>29.8</td>
</tr>
<tr>
<td>Very high</td>
<td>10.6</td>
<td>55.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Erosion (2011)</th>
<th>Area (km²)</th>
<th>Area (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Erosion</td>
<td>1.1</td>
<td>5.6</td>
</tr>
<tr>
<td>Very Low</td>
<td>0.3</td>
<td>1.7</td>
</tr>
<tr>
<td>Low</td>
<td>1.3</td>
<td>6.8</td>
</tr>
<tr>
<td>Moderate</td>
<td>2</td>
<td>10.4</td>
</tr>
<tr>
<td>High</td>
<td>1.1</td>
<td>5.9</td>
</tr>
<tr>
<td>Very high</td>
<td>13.4</td>
<td>69.6</td>
</tr>
</tbody>
</table>

During field work the severe soil removal in the basin has been noted in a small artificial dam in the Spartorrema river, NE of the Marathon’s lake, which was constructed by gabions soon after the fire event to prevent the soil transfer downstream. A significant increase on the sediments was observed after the intense flood season on December 2012 and January 2013. It is estimated that the sediments’ height in this small dam was raised with a mean range of 50cm over the last 3.5 years. Both the PESERA (this paper) and the RUSLE models (see Xanthakis 2011) recognized and highlighted the spatial distribution of soil erosion risk. Controlling erosion rates is of major importance in order to prevent the diminishing soil productivity and to proceed to a rational management of the Marathon’s artificial lake.

**Fig. 5.** The first photo displays the first flooding event after the construction of the dam, while the second photo represents the status of the dam on January 2013; the apparent raise on sediments’ height is very important for the validation of the soil erosion risk’s models.

In conclusion, all these methods require validation to standardize the differences between abundant combinations of different soil types, meteorological and geomorphological characteristics.
References


Cosmas K, Gerontidis St, Marathianoy M (2000). The effect of land use change on soils and vegetation over various lithological formations on Lesvos (Greece). Catena, 40, 51-68 (DOI: 1 0.1016/S0341-8162(99)00064-8)


Analyses of Cd, Cr and Pb concentration in the aerosols using different digestion methods

Alushllari M., Civici N., Mico S.

Heavy metals are present in environmental components, especially in the air from both natural and anthropogenic sources. Atomic Absorption Spectrometry (AAS) is one of the destructive methods used to determine total metals in environmental samples. The purpose of this study is to determine the toxic metals lead (Pb), cadmium (Cd) and chromium (Cr) in aerosol samples using different analytical methods for digestion air filters. We have selected 13 aerosols samples, (air filters) of which five samples are divided in two parts and one in four parts. We have analyzed a total 23 filter samples. Aerosol samples were analyzed for their content of Cd, Cr and Pb by using Graphite furnace Atomic Absorption Spectrometry (GF_AAS) in the Institute of Applied Nuclear Physics, University of Tirana, Albania. The current study reports the presence of toxic metals Cd, Cr and Pb in most of the analyzed samples. The results obtained show that the levels of metals in the aerosol samples collected in Elbasan are higher than in samples collected in Tirana. In the aerosol samples, the concentrations in descending order are: Pb> Cr> Cd. From the average levels of metals measured in the aerosol samples, were: Pb (536.1 ng/m$^3$), Cr (54.4 ng/m$^3$) and Cd (9.5 ng/m$^3$).

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Introduction

Air pollution represents one of the main problems of environmental pollution, especially in urban and industrial areas. Both natural and anthropogenic sources contribute to air pollution. The development of technology and production of primary products also, produces secondary production, solid, liquid and gaseous waste, whose presence is associated with significant environmental impacts. Quality of air is very important to ecosystems and human health. Atmospheric pollutants are responsible for both acute and chronic effects on human health (WHO 2000). Trace metals, are the most common components in atmospheric particulate material. Different studies have shown that low concentrations of metals in particulate material significantly influence on environment and human health. These health effects are more noticeable in the elderly and children (US EPA 2006). Clean air is a basic health requirement for every human being. However, air pollution across the globe is constantly threatening human health. Presence of heavy metals in environment above maximum concentration level causes toxic effects in environment and on human’s health. They enter the human body through food, water, and air. Lead and its compounds are toxic; they can enter the human body through food, water, and air (Alushillari and Civici 2014). Also, the presence of lead causes anemia and damage of nervous system (Bastawy et al. 2006). Cadmium is an extremely toxic metal, is commonly found in industrial areas, especially where ore is processing and smelting. Exposure to cadmium can cause a number of harmful health effects due to the ability to induce disturbances in several organs and tissues following either acute or chronic exposure (Marisela 2006). Chromium is a steely gray and non-oxidation hard metal that is in basic state malleable and lustrous (Costa and Klein 2006). The purpose of this study is to determine metals Cd, Cr and Pb in atmospheric particulate matter after several extractions. One of the methods of total contents determination of heavy metal concentrations is Atomic Absorption Spectroscopy. Standard procedures of used analytic methods of AAS are specified in detail below.

Material and methods

Samples were collected at two stations in the cities of Tirana and Elbasan. The first station in Tirana, was put on the terrace of the building of the Ministry of Environment at a height of about 15 m from the road. At this station sampled aerosols were representative of the center of Tirana. The second station was set on Mount Dajti building near the former Pioneer Camp. Pumps at this station were placed at about 3 m above the ground level. These aerosol samples were representative of a clean area. In the city of Elbasan, samples were collected in parallel at a station in the city center (the building of the Public Health Center) and near the station Metallurgical Combine. At the first station, in the center of the Elbasan, samples were collected at 15 m height from ground level, while at the station near the former Metallurgical Combine, most of samples were collected near the Metallurgical Combine in height about 4 m from ground level. Other samples were collected at the entrance and inside area of the Complex. In Table 1 the date for the analyzed samples is presented.

Some of the filter samples were divided into two or more parts and were analyzed as part of a special sample. To assess the repeatability of the measurement filter No.105 was divided into four parts, of which three were analyzed by one of the analytical procedures and the fourth by one of the other procedures. Blank samples are filters used to clean the box.

Represented aerosol samples analyzed using Atomic Absorption Spectrometer, Analyst 800 Perkin Elmer with Graphite furnace Atomic Absorption Spectrometry (Perkin Elmer, 1999). Hollow cathode lamp (HCL) is used as radiation source for the determination of lead according recommended conditions. Acids used for the digestion of samples, stock solutions of lead have high grade purity. Air filter samples are digested according Analytic Method Atomic Absorption Spectrometry. Analytic methods that are used for digestion samples as follow: (1): Cut the filters into small pieces and digest for 30 minutes in 100 mL of HCl over
low heat. Remove the solution and extract the solids three times for 15 minutes each time, with water. Combine the extracts and the HCl and evaporate nearly to dryness. Dissolve in 10 mL HCl and add 10 drops HNO₃. Transfer solutions to a 50-mL volumetric flask and make to volume with deionized water. (2): Cut the filters into small pieces and transferred to 100 ml glass beaker. Add 10 ml concentrated nitric acid, heated at 80°C-90°C temperature for 30 minutes. Samples evaporated until were dried and the sample solution color would be light white. Samples cooled and added to 1 ml of nitric acid and 2 ml bidistilled water. Samples passed in the balloons (25 ml) and filled with bidistilled water. (3): Cut the filters into small pieces and transferred to 100 ml glass beaker, add 7 ml aqua regia and 100 microliter of gallium as internal standard and are left all night. The next day were heated until dry samples. Then removed from the hot plate, cooled and 3 ml of 2 M HNO₃ were added to each sample that was left for one hour at room temperature. Samples were then passed in the balloons (25 ml) and filled with bidistilled water.

Instrumental conditions for lead are based on the Analytical Methods of Atomic Absorption Spectrometry, from Perkin Elmer. Three applications were carried out for the measurement of calibration standards and the measurement of samples. For each element calibration curve equation is linear and passing through point zero. To check the instrumental drift, an aqueous standard solution was analyzed after every three samples.

3 Results

In the table 1 the sampling locations of representative aerosols samples are presented together with the code in AAS, and the mean concentration of Cd, Cr and Pb as determined by using three different methods for the digestion of the samples.

<table>
<thead>
<tr>
<th>Stations point _Pb</th>
<th>Code</th>
<th>Method 2</th>
<th>Method 1</th>
<th>Method 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elbasan, Kurum 1M</td>
<td>1018</td>
<td>846</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elbasan, Kurum 2M</td>
<td>660</td>
<td>700.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elbasan, Kurum 3M</td>
<td>2705.5</td>
<td>2705</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elbasan, Kurum 4M</td>
<td>132.6</td>
<td>161.6</td>
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<td></td>
</tr>
<tr>
<td>Elbasan, Center 8M</td>
<td>18.4</td>
<td>22.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elbasan, Kurum 9M</td>
<td>478</td>
<td>432.1</td>
<td></td>
<td></td>
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<td>Elbasan, Kurum 10M</td>
<td>699</td>
<td>522</td>
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<tr>
<td>Tirane, Center 11M</td>
<td>11.6</td>
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<table>
<thead>
<tr>
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<tr>
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<td>28.6</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Elbasan, Kurum 2M</td>
<td>28.1</td>
<td>36.6</td>
<td></td>
<td></td>
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<tr>
<td>Elbasan, Kurum 3M</td>
<td>233</td>
<td>275</td>
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<td></td>
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<tr>
<td>Elbasan, Kurum 4M</td>
<td>11.7</td>
<td>18.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elbasan, Center 8M</td>
<td>26.39</td>
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</tr>
<tr>
<td>Elbasan, Kurum 9M</td>
<td>86.1</td>
<td>83.3</td>
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<td>Tirane, Center 11M</td>
<td>15.4</td>
<td>19.95</td>
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</table>

<table>
<thead>
<tr>
<th>Stations point _Cd</th>
<th>Code</th>
<th>Method 2</th>
<th>Method 1</th>
<th>Method 3</th>
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</thead>
<tbody>
<tr>
<td>Elbasan, Kurum 1M</td>
<td>1.8</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elbasan, Kurum 2M</td>
<td>5.7</td>
<td>5.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elbasan, Kurum 3M</td>
<td>24.3</td>
<td>13.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elbasan, Center 4M</td>
<td>6.9</td>
<td>6.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elbasan, Kurum 8M</td>
<td>3.28</td>
<td>2.75</td>
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</tr>
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</table>
Figures 1, 2 and 3 present the dependence of Cd, Cr and Pb content in samples, respectively. Figure 4 presents average concentration of all three metals in aerosol samples.

![Fig. 1](image1.png) Concentration of Cd in aerosols.  
![Fig. 2](image2.png) Concentration of Cr in aerosols.  
![Fig. 3](image3.png) Concentration of Pb in aerosols.  
![Fig. 4](image4.png) Concentrations of Cd, Cr, Pb in aerosols

The results show that the concentrations of lead in aerosols samples are high, from 1.8 ng/m$^3$ to 2705 ng/m$^3$. The concentration of Chromium is measured to range from 0.8 ng/m$^3$ to 254 ng/m$^3$ and that of cadmium is measured to be between 0.2 ng/m$^3$ and 21.7 ng/m$^3$. The concentrations of metals in analyzed samples were high, so they have a negative impact on the environment and the human health.

### 3 Conclusions

Our results obtained show that the concentrations of elements Pb, Cr, and Cd in aerosols in the city of Elbasaninit were higher than in Tirana. While the most contaminated area was near metallurgical areas. The ranking of elements in the descending order of their total concentrations found in aerosol samples was as follows: Pb> Cr> Cd.

In the descending order of content in aerosols, elements analyzed in selected sampling stations, were ranked: Elbasan metallurgical> Elbasan Center > Tirana Center.

As the main sources of air pollution by metals in Elbasan and Tirana cities were emissions from fuel burning, burning of urban wastes, dust particles transported by wind, construction and inert materials. In the city of Elbasan, partial work in Metallurgical Combine significantly contributes to the emission of gases in the air and solid waste in the ground.

### References


An evaluation of the mesoscale chemistry model (WRF-CHEM) over the Mediterranean region

Amanatidis D., Daskalakis N., Im U., Kanakidou M.

In this study we evaluate the coupled mesoscale meteorology and chemistry model WRF/Chem adapted for simulation of the Mediterranean atmosphere. The applied model version uses the Mozart gas-phase chemical mechanism and a spatial resolution of 30x30km. The anthropogenic surface emissions developed in the ECLIPSE EU FP7 project are used in the model. Biomass burning emissions are based on the FINN database. Biogenic emissions are calculated online by the MEGAN model. Climatological emissions of mineral dust aerosol are derived from GOCART dust model (Georgia Tech/Goddard Global Ozone Chemistry Aerosol Radiation Transport). Simulations are carried out for July 2010. Model evaluation is made by comparison with observations of ozone and aerosol components taken from the EMEP ground stations. The results are presented and discussed in view of processes that are missing or are not adequately presented in the model.

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Lidar climatology of Vertical Aerosol Structure (LIVAS): a 3-dimentional global aerosol database

Amiridis V., Marinou E., Tsekeri A., Giannakaki E., Mamouri R.E., Kazadzis S., Gerasopoulos E., Herekakis T., Papayannis A., Balis D. S.

We present LIVAS, an online database that provides a global 3-dimentional 4-year aerosol and cloud climatology of backscatter and extinction coefficient vertical distributions at a spatial resolution of 1x1 degree. LIVAS has been developed at the National Observatory of Athens and has been made publically available, aiming to provide a coherent global aerosol/cloud dataset that can be used for model validation studies and radiative transfer simulations. In order to cover the extinction spectral range from UV (355 nm) to IR (2050 nm), LIVAS provides multi-wavelength products that are based on NASA-CALIPSO satellite observations at VIS (532 nm) and aerosol-type dependent spectral conversion factors derived from EARLINET and AERONET ground-based measurements. LIVAS has been validated against global AERONET multi-wavelength aerosol optical depths, showing good agreement.

Dual-Polarization X-band Mobile Radar Observations as a Hydrologic Support Tool during the HyMeX Special Observation Period in North-East Italian Alpine Region


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1 Introduction

A general methodology to test candidate future space-borne remote-sensing instruments for their ability of observing atmospheric quantities is the application of appropriate processing algorithms on simulated datasets. Especially for active remote sensors as lidars, the vertical dimension should be included in simulations. Such global distributions are available today and since the launch of the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) instrument on board the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) mission of NASA/CNES in June 2006 (Winker et al. 2009). The technique of active remote sensing of the atmosphere by lidar has been also chosen for two of the present ESA Earth Explorer Missions, ADM-Aeolus and EarthCARE, and was further proposed for A-SCOPE, one of the candidates for the 7th Earth Explorer mission. The correct performance assessment of current and future ESA lidar instruments requires the development of a refined aerosol and cloud optical database with high spatial resolution.

In this paper we present the “LIdar climatology of Vertical Aerosol Structure for space-based lidar simulation studies”, (LIVAS), which is an atmospheric database aiming to provide a global and extensive aerosol and cloud optical properties dataset that can be used for the simulation of realistic atmospheric scenarios in current and future lidar end-to-end simulations and retrieval algorithm testing activities. For the ADM-Aeolus, EarthCARE and A-SCOPE lidar applications, the database addresses the wavelength dependency of aerosol optical properties for the following laser operating wavelengths: 355 nm, 523 nm, 1064 nm, 1.57 μm and 2.05 μm. LIVAS includes regional and seasonal statistics of aerosol and cloud extensive and intensive optical properties in terms of backscatter coefficient, extinction coefficient and depolarization ratio. Moreover, vertical profiles of extensive and intensive optical properties referring to specific atmospheric scenes for a set of selected scenarios are provided (i.e. Saharan dust, smoke from biomass burning, ash from volcano eruptions, polar stratospheric clouds).

2 Data and Methodology

2.1 Data

CALIOP is a standard dual-wavelength (532 and 1064 nm) backscatter lidar, operating a polarization channel at 532 nm (Winker et al. 2009). CALIOP has been acquiring global atmospheric profiles since June 2006. In this study, we use the CALIOP Version 3 of the Level 2 product (Young and Vaughan 2009) derived from the Level 1 product using a succession of algorithms that are described in detail in a special issue of the Journal of Atmospheric and Oceanic Technology (e.g., Winker et al. 2009).

Ancillary datasets are used in our analysis as well. These are provided from the European Aerosol Research Lidar Network (EARLINET - http://www.earlinet.org) and the Aerosol Robotic Network of NASA (AERONET, Holben et al. 1998). The EARLINET dataset can be used to retrieve extinction and –especially- backscatter-related spectral conversion factors for different aerosol types after a proper layer identification and characterization. The AERONET dataset provides column properties for (1) the aerosol optical depth (AOD) at several wavelengths of the solar spectrum and the Ångström exponent at 440/870 nm, (2) the size-distribution and (3) the spectral complex refractive index and the spectral single scattering albedo (SSA) (Dubovik and King 2000).
2.2 Methodology

LIVAS climatology is based on CALIPSO observations at 532 and 1064 nm and aerosol-type dependent spectral conversion factors derived from ground-based measurements or suitable optical models. For the conversion of 532 nm CALIPSO aerosol backscatter and extinction to 355 nm, the aerosol-type-dependent extinction- and backscatter-related conversion factors are extracted from EARLINET measurements, provided in the ESA-CALIPSO database (Wandinger et al. 2011).

EARLINET ground-based lidars are spectrally limited between 355 and 1064 nm, thus, for converting CALIPSO backscatter and extinction products at 532 nm to 1570 and 2050 nm in LIVAS, we calculate the conversion factors using well-known scattering codes like the Mie code (Mie 1908) and the T-matrix code for non-spherical particles (Mishchenko and Travis 1998). Typical size distributions and refractive indexes are initialized for scattering calculations for each CALIPSO aerosol type based on the AERONET as well as the OPAC dataset and aerosol models from related literature. For each aerosol type we simulate the optical properties also in the UV and we choose the simulations that fit better with ESA-CALIPSO in the UV in order to ensure the consistency of the conversions from the UV to IR.

For the production of the final LIVAS profiles, we use the methodology developed by the CALIPSO team for the Level 3 aerosol product (Winker et al. 2013). Our algorithm has been tested for reproducing the CALIPSO Level 3 product, which is an aggregation onto a global 2x5 degree latitude-longitude grid. Then, the algorithm is applied on Level 2 CALIPSO observations at 532 and 1064 nm but also on the LIVAS spectrally converted profiles at 355, 1570 and 2050 nm, in order to derive 1x1 degree latitude-longitude averaged vertical distributions. The vertical resolution of the LIVAS product is identical to CALIPSO Level 3, namely 60 m in the tropospheric region between the surface and 20 km and 180 m in the stratospheric region between 20 and 30 km.

In the averaging algorithm, all Level 3 parameters are derived from the Version 3 CALIOP Level 2 aerosol profile product and are quality screened prior of averaging, to eliminate samples and layers that are detected or classified with very low confidence, or that contain untrustworthy extinction retrievals. A detailed summary of the methodology followed for the production of the Level 3 product and respective filtering is provided in the Appendix found at Winker et al. (2013). A schematic outline of LIVAS processing chain is given in Figure 1.

![Schematic outline of LIVAS processing chain](image-url)
3 Results

The final LIVAS climatology contains multi-wavelength 4-year averaged vertical distributions and statistics for a global grid of 1X1 degree. In Figure 2 we demonstrate the LIVAS products through an example for one grid cell corresponding to Athens, Greece (centroid latitude of 38.5° North and longitude of 23.5° East).

![Aerosol Extinction @ 532 nm Per Aerosol Type](image1)

Fig. 2. Left: 4-year average of the aerosol extinction coefficient at 532 nm per aerosol type. All data correspond to a 1x1 degree cell over Athens, Greece (centroid latitude of 38.5° North and longitude of 23.5° East). Right: Number of observations used.

Figure 3 shows a validation of LIVAS 4-year averaged AODs at 532 nm with coincident 4-year averaged AERONET AODs at 532 nm. We see that the two means correlate very well (left panel) and the same applies to their standard deviations (right panel).

![Pearson's r = 0.85, Slope = 0.79](image2)

Fig. 3. Comparison of coincident LIVAS and AERONET 4-year averaged AODs at 532 nm (left) and their standard deviations (right).

LIVAS products are available through LIVAS web portal under the following url: http://lidar.space.noa.gr:8080/livas, providing:
- Real-time visualization tools with graph parameterizing options and downloading capability of images in raster and vector format
- Quick-views
- Downloading of products in ASCII and NetCDF-4 format
4 Conclusions

With global profile statistics of aerosol and cloud properties, as well as a set of complex atmospheric scenes, LIVAS provides a complete new database, which will contribute to more realistic lidar instrument performance simulation and robust testing of retrieval algorithms. Moreover, LIVAS global 3D aerosol/cloud climatology will hopefully be continued for several more years and eventually be extended by ATLID on the EarthCARE satellite. LIVAS database is freely available and it is envisaged that it will be initialized by research communities to address climatological aspects related to air quality, radiative transfer, weather and climate.

Acknowledgments This work has been developed under the auspices of the ESA-ESTEC project: Lidar Climatology of Vertical Aerosol Structure for Space-Based LIDAR Simulation Studies (LIVAS) contract N4000104106/11/NL/FF/k. CALIPSO data were obtained from the NASA Langley Research Center Atmospheric Science Data Center. The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement no 262254 (ACTRIS). EARLINET, AERONET, ACTRIS Thanks to ICARE, +Tacket BEYOND

References

The future perspective of Etesian wind patterns over Aegean Sea

Anagnostopoulou C., Zanis P., Katragkou E., Tolika K., Tegoulias I.

Etesian winds blow over the Aegean Sea and eastern Mediterranean during the warm period (June to September). Etesians are widely known as the most stable localized wind systems in the world. This research will focus on the study of the Etesian wind persistence during the 21st century using regional climate model simulations (RegCM3). An anticyclonic action centre over central Europe or over Balkan Peninsula and the south Asian thermal Low proved to be the synoptic patterns resulting in northerly air flow over Aegean Sea. Using an objective statistical classification method on wind components, three distinct Etesian patterns are defined for present and future period. Sea level pressure (SLP), geopotential height at 500hPa, vertical velocity and wind speed at different vertical levels were used for the synoptic and dynamic scale analysis for each Etesian pattern. The first results for the future period show a slight increase of the Etesian wind speed in the Aegean Sea that is in consistent with a slightly increase of the pressure gradient resulting by a deepening of the low pressure centre and slight strengthening of the high pressure centre.

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1 Introduction

One of the most persistent localized wind systems in the world are Etesian winds over Aegean Sea. The main flow of Etesians is northeasterly in the northern Aegean, northerly in the central and southern Aegean, and north-westerly near the south-western Turkish coasts (Karapiperis 1951, Kotroni et al. 2001). Anagnostopoulou et al. (2014) established three Etesian Patterns with distinct synoptic and dynamic characteristics. The Middle East low pressure and the Balkan Peninsula high pressure are the two action centers that control the wind Etesian system. Also, Anagnostopoulou et al. (2014) showed that the anticyclonic action center over central Europe or Balkan Peninsula is detached from the Azores high pressure system (Metaxas 1977, Maheras 1980, Lionello and Sanna 2005). There are also studies focusing on the role of the Asian Low in the Etesian winds. The linkage between Asian monsoon and eastern Mediterranean during summer has been investigated by examining the variations of the Etesians and the subsidence in Eastern Mediterranean (Ziv et al. 2004) and the vertical distribution of the etesian summer circulation patterns (Tyrlis et al. 2012).

2 Data and Methodology

Different daily datasets from June to September are used in the present study:

a) daily u and v components of ECHAM simulation for the control (1961-1990) and future (2071-2100) periods and,

b) daily u and v components of ECHAM/RegCM simulation for the control (1961-1990) and future (2071-2100) periods.

The spatial resolution of the datasets is 25 km x 25 km for RegCM and roughly about 200 km for ECHAM5. Additionally, sea level pressure (SLP), wind speed (WS) and vertical velocity (Omega) fields at different vertical levels were used for the synoptic and dynamic scale analysis of the Etesian patterns.

The dominant wind patterns of Etesians were derived using the Two Step Cluster Analysis (TSCA) statistical method. It was applied on near surface wind data (u and v components) at three characteristic sub-regions of Aegean Sea (1st sub-region: Northeastern Aegean Sea; 2nd sub-region: Central Aegean Sea and 3rd sub-region: southeastern Aegean Sea) for the ECHAM/RegCM datasets for the future time period.

The procedure of TSCA follows two steps (pre-clustering and clustering). In “pre-clustering” step, a sequential clustering approach is applied to pre-cluster cases into many sub-clusters. A variable in a certain cluster should be as similar as possible to other variables in the same cluster. One by one all variables are checked if they should be merged within the previously formed clusters or a new cluster should be started based on the distance criterion. In the present study, the Euclidean distance is used. The results of the pre-clustering (1st step) are used as new cases in the next step, the clustering. The clusters are determined automatically and Schwarz’z Bayesian criterion (BIC) is used as clustering criterion, by taking into account the lowest information criterion measure and the highest ratio of distance measures.

Based on the derived wind clusters from TSCA, the mean and the anomalies of the SLP and the omega vertical motion were calculated for each cluster individually.

3 Results

Following the methodology of Anagnostopoulou et al (2014), three distinct Etesian Patterns (EPs) of the wind system blowing over Aegean Sea are detected for the future period 1971-2100. A detailed analysis based on the mean synoptic and dynamic fields of the future EPs is presented here.
The respective days from each pattern were selected and the mean SLP fields were constructed. Two main action centers control the intensity and the duration of Etesian winds over Aegean Sea, the Eastern Mediterranean/Middle East (EMME) low pressure and a high pressure, the exact location of which depends on the Etesian Pattern.

The high pressure in EP1 is located mainly over western Europe (Fig. 1a). The EP2 anticyclone shifts over central Europe and central Mediterranean (Fig. 1c), while the EP3 high pressure is shifted further eastwards over Balkan Peninsula and eastern Europe (Fig. 1e). Regarding the future changes in the Etesian Patterns, there is consistency between the RCM and GCM results. The mean sea level pressure is projected to decrease over eastern Mediterranean until the end of the 21st century for both ECHAM and ECHAM/RegCM datasets (Fig. 1). The main differences between the three patterns are the positive anomaly centers. The first EP is characterized by a positive anomaly center over central-eastern Europe extending also over Balkan in the RCM while this positive center extends further over northern Europe in the GCM (Fig. 1a and Fig. 1b). The EP2 positive anomaly center is weakening over the study region in 2071-2100. The corresponding anomaly pattern of EP3 shows a general decrease of SLP all over eastern Europe and eastern Mediterranean. The deepening of the EMME low presumably has a teleconnection with the weakening of Islandic Low in the north Atlantic (Fig. 1e and Fig. 1f).

**Fig. 1.** Mean changes in sea level pressure (hPa) for future period 2071-2100 relative to control period 1961-1990 for each Etesian pattern based on the regional simulation ECHAM/RegCM (a, c, e) and ECHAM (b,d,f). The contours indicate the mean sea level pressure for each Etesian Pattern (EP).
The variability of omega vertical motion was analysed for the three future EPs compared to the control period. In Fig.2, the longitudinal distribution of vertical velocity (Pa/s) at 500 hPa averaged over the 38°N-42°N latitudinal zone is presented for the future period 2071-2100. Generally, omega velocity variability (Fig. 2a) presents two maxima, the primary maximum over eastern Europe and Balkan and the second one over Atlantic. The negative vertical motions between the two maxima indicate that the anticyclonic action center over central Europe or Balkan Peninsula is detached from the Azores high pressure system. It is apparent from Fig. 2a that future vertical velocity over Balkan decreases for EP1, increases for EP2 and remains stable or slightly decreases for EP3. That is partially in correspondence with ECHAM results where a tension for weakening of the subsidence over EMME is apparent (Fig. 2b).

The weakening of the subsidence over eastern Mediterranean in combination with a deepening of the Asian thermal low pressure centre and a slight strengthening of the Balkan high pressure system, results in strengthening of the Etesian winds with increasing of the northerly wind (blue color) or increasing of the southerly wind (red color) for the future period 2071-2100 (Fig. 3). Stippling denotes areas where the changes are not statistical significant at 95%.

4 Conclusions

In the present study, an attempt was made to study the future perspectives of Etesian winds over Aegean. In accordance to the reference period, it is found that a seasonal low-pressure system over East Mediterranean (the Asia thermal low) and a high-pressure system over the Balkan Peninsula controls the direction and strength of northerly winds into Aegean Sea. Furthermore, the detachment of upward motions between the two descending centres proves that the anticyclonic action center over central Europe or Balkan Peninsula is detached from the Azores high pressure system (Prezerakos 1984).
Fig. 3. Mean changes in near surface (at 10 m) meridional v-wind (m/s) in future periods 2071-2100: ECHAM/RegCM (a, c, e) and ECHAM/GCM (b,d,f) relative to control period 1961-1990 for each Etesian pattern.

The relative strengths and positions of the aforementioned systems vary from year to year and this variation results into three distinct Etesian Patterns over Aegean. It is evident that for the future period 2071-2100 the strengthening of the Etesian winds in EP1 and EP2 is mainly associated with a deepening of the low pressure centre and a slight strengthening of the high pressure centre over eastern Europe and Balkan. Furthermore both RCM and GCM indicate a weakening of the subsidence over eastern Mediterranean (especially in EP1 and EP2) which is rather controlled from the deepening of the EMME low pressure action center in line with the projected in future weakening of South Asian monsoon (Ueda et al. 2006).

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References


Dual-Polarization X-band Mobile Radar Observations as a Hydrologic Support Tool during the HyMeX Special Observation Period in North-East Italian Alpine Region


This study focuses on a precipitation observation with an X-band polarimetric weather radar (XPOL) over small mountainous basins (~64 km²) located in Alps, North Italy in the framework of Hydrological cycle in Mediterranean Experiment (HyMeX) 2012 observational period. Ground validation rainfall observations provided from a dense network of raingauges, two disdrometers and stream flow sensors installed at different locations. The experimental area is also covered from operational C-band weather radars. Data from four storm events are used to explore differences between X-band and C-band rain estimation error statistics for varying spatial resolutions. The XPOL rainfall estimation algorithm corrects for the rain attenuation and the enhancement effect due to the melting layer. A hydrological model is forced from hourly X-band, C-band and raingauge precipitation observations and the temperature data provided from the meteorological stations. Results reveal that X-band observations offer an improved representation of orographic enhancement of precipitation, which turns to have a significant impact in simulating peak stream flows.

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1 Introduction

Precipitation estimation in mountainous regions remains a challenging task due to the complex interaction of physical processes involved (e.g. orographic enhancement) taking place at small spatial scales and the associated observational difficulties posed on measurement networks (Anagnostou et al. 2010, Borga et al. 2008). Precipitation estimates based on raingauge networks are usually associated with low coverage density, particularly at high altitudes. On the other hand, operational weather radar networks may provide valuable information of precipitation at these regimes (White et al. 2003, Smith et al. 2005), but reliability of their estimates is often limited due to retrieval (e.g. variability in the reflectivity-to-rainfall relationship) and spatial extent constrains (e.g. blockage issues, overshooting effects). As a result, we currently lack accurate precipitation estimates over complex terrain areas, which essentially means that we lack accurate knowledge of the triggering factor for a number of hazards like flash floods and debris flows/landslides occurring in those areas (Tarolli et al. 2011). A potential solution to overcome sampling as well as retrieval uncertainty limitations of current observational networks might be the use of network of low-power dual-polarization X-band radars as complement to raingauges and gap-filling to operational, low-frequency (C-band or S-band) and high-power weather radars. The major question of this work is to explore the advantage of the locally deployed mobile X-band radar in the mountainous area, in order to fill in critical gaps in the coverage of the large (C-band and S-band) radar operational networks in complex terrain.

2 Data and Methodology

2.1 Data

The above hypothesis is examined using data collected during the HyMEX 2012 Special Observation Period (Aug-Oct) at the Northeast Italy Hydrometeorological Observatory (Fig. 1). Data include observations from: i) an X-band polarimetric weather radar, ii) a dense network of raingauges and iii) two disdrometers (a Parsivel type and a 2D-video type). In addition, the experimental area is also covered from operational C-band weather radars, which were involved also in the analysis.

Figure 1 shows the experimental area with the two (Gardia and Mazia) observation water catchments. The National Observatory of Athens high-resolution XPOL radar was deployed in the area southeast of the two major water catchments, while the two disdrometers and raingauges installed within the bigger water catchment (Gardia) as shown in the middle of
Fig.1. The range of the XPOL radars was ~35 km with a resolution of 120 m. Radar observations included the horizontal reflectivity $Z_H$, the differential reflectivity $Z_{DR}$ and the differential phase $\Phi_{DP}$, which is insensitive to radar calibration. Plan Position Indicator (PPI) scans at low elevation angles (up to 3.5°) were performed as well as Range Height Indicator (RHI) scans in selected azimuth angles in order to estimate the vertical structure of the rain field. The time period for a full volume scan was about 3 minutes. The disdrometer data was used for the analysis of droplet size distribution, shape (axis ratio) and orientation of rain droplets, and the theoretical estimation (simulation) of polarimetric radar products.

### Table 1. Rain events with total average rain accumulation from rain gauges > 10 mm in Gardia and Mazia water catchments

<table>
<thead>
<tr>
<th>Time period (UTC)</th>
<th>Total rain</th>
<th>Available Observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>06/08/12 11:00 - 05/08/12</td>
<td>10</td>
<td>Rain gauges (all 4 sites), 2DVD, Parsivel, XPOL, Valluga</td>
</tr>
<tr>
<td>10/09/12 08:00 - 12/09/12 21:00</td>
<td>13</td>
<td>Rain gauges (all 4 sites), 2DVD, Parsivel, XPOL, Valluga</td>
</tr>
<tr>
<td>24/09/12 07:00 - 27/09/12 06:30</td>
<td>29</td>
<td>Rain gauges (all 4 sites), 2DVD, Parsivel, XPOL, Valluga</td>
</tr>
<tr>
<td>29/09/12 12:00 - 30/09/12 23:59</td>
<td>11</td>
<td>Rain gauges (all 4 sites), 2DVD, Parsivel, XPOL, Valluga</td>
</tr>
</tbody>
</table>

The intensity of the events was moderate and no flash floods were observed in the experimental area, but according to the first inspection of flow data (they will be shown in the conference presentation together with raingauge data and hydrological modeling results) there was significant stream flow in the catchments. Table 1 presents the main rain events and availability of instruments during the experimental period.

### 2.2 Methodology

The major question of this work is to explore the advantage of the locally deployed mobile X-band radar in the mountainous area of the Italian Alps in the region of Bolzano, in order to fill in critical gaps in the coverage of the large (C-band and S-band) radar operational networks in complex terrain. Our approach will be to compare rain estimates from XPOL within 20-km range to estimates derived by the two operational C-band radars associated with 60 to 120-km radar ranges, respectively. For the XPOL rain estimation we will use the algorithms on attenuation correction and rain estimation discussed in Kalogiros et al. (2013) and Anagnostou et al (2013). This work will seek to explore differences between X-band and C-band rain estimation error statistics (bias, variance of error) for varying resolutions (i.e., spatial scales of aggregation). Unfortunately, due to blockage of the Italian radar (Macaion shown in Fig.1) in the vicinity of the experimental area it is not included in the analysis. We worked only with the Austrian radar (Valluga). The statistical metrics for the evaluation of the algorithms include: (1) the correlation; (2) the normalized error (NE), which is defined as the sum of the errors (i.e. difference between the reference values and radar estimates) divided by the sum of the reference values; (3) bias ratio, which is defined as the sum of radar estimate versus reference values; and (4) the relative root mean square error (rRMSE) defined as the RMSE divided by the sum of reference values. All the above bulk statistics are conditional for both reference and radar values greater than zero. Finally, as reference we group the rainfalls from all the available in situ observations in different elevations. We present all the statistical merits, for both the reference and the radar estimates in hourly values, as a function of different in situ terrain elevations (in meters).
3 Results

The XPOL estimates were made for two different range resolutions (i.e. 200x200 meters and 1x1 km) in order to show any potential spatial aggregation effect compared to the Austrian radar. Figure 2 shows the NE of the Valluga and the two XPOL radar estimates compared to the reference values. We notice that there is no significant effect on the radar estimates due to elevation. We also notice that in some cases the XPOL estimates make a slight underestimation compared to the Valluga ones. However, there is no significant effect due to the different aggregation in the XPOL estimates.

The correlation values shown in Fig. 3 indicates that the XPOL estimates follow better the reference values compared to the Valluga radar estimates. Again we notice that the estimates are independent to the different elevation sites of the references. This also explains the low relative RMSE shown in Fig. 4, where the XPOL estimates has smaller error compared to the Valluga estimates which in some cases is two and three times larger than the XPOL error. Again we do not notice any significance difference of the XPOL rRMSE for the different reference site elevations. However, we should pay significant attention to the XPOL 1x1 km resolution rRMSE between the 2200 and 2400 meters reference elevation where the relative error is greater than four (possibly the result of clutter effect).

We also present two cases (Fig. 5a, b) of the accumulated rainfall comparing the Valluga and XPOL rainfall estimations. The problem of underestimation and lack of sufficient spatial resolution of large operational C-band weather radars, especially, in long ranges is evident.
4 Conclusions

Weather and hydrologic hazards are at the top of environmental issues worldwide. The large C-band operational radars have limitations on detecting isolated convective storms in long distances, which turns to have a significant impact in simulating peak stream flows. This is due to broaden of the radar beam and the implied low resolution in such long ranges. Our results show that a solution to this problem is the use of small inexpensive X-band radars that can give reliable estimates of rainfall. A network of such systems can cover broader areas in complex terrain where large expensive systems cannot achieve this.

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References


Cart-based association analysis of meteorological data with PM$_{10}$, CO and NO$_{x}$ concentrations in Athens

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This work investigated the effect of meteorological conditions in terms of their impact on PM$_{10}$, CO, NO, NO$_2$ concentrations over the urban area of metropolitan Athens. To meet this goal, the Classification and Regression Trees (CART) were used, aiming to develop an association analysis of a measured parameter with multiple predictor variables. In our case, the daily PM$_{10}$ concentration at the Aristotelous station and the maximum daily CO and NO$_x$ concentrations at the Athinas station are the response variables, whereas surface meteorological parameters in the period 2005-2010 are the predictor variables, obtained from the nearby site of the National Observatory of Athens (NOA). The mean daily air temperature, wind speed, relative humidity, precipitation, cloud cover, solar radiation and sunshine duration, along with the daily maximum and minimum air temperature are used as predictor variables. For each air pollutant a classification and regression tree with about 350 nodes was initially developed. Since a large number of nodes are not physically meaningful, pruning was applied to the tree produced in the first approach. The number of the final nodes depends on the pollutant under consideration, due to the different effect of the meteorological conditions. The results essentially indicate that the method produces node-splitting decision rules and identifies the most important predictors that control the air pollution concentrations over the examined area.

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1 Introduction

Urban air quality is considered worldwide to be one of the most important environmental issues. Current research focuses on modeling the relationship of air quality with the physical and chemical mechanisms that govern the transport, dispersion and transformation of pollutants in the atmosphere. Air pollution episodes in urban areas are correlated with unfavorable meteorological conditions (Mavrankou et al. 2012, Flocas et al. 2009) and they are associated with a wide spectrum of health effects. This work employs the CART methodology to assess, within an urban environment, the relationship between air pollution and meteorology, aiming to develop better forecasting tools for improved regulatory and precautionary air quality measures. The CART method is rather new (Choi et al. 2013, Neto et al. 2009) in environmental sciences, offering a straightforward approach in quantifying the relationship of air quality and meteorology.

2 Area of study, Data and Methodology

2.1 Area of study and data

The area of study is metropolitan Athens within the Attica basin in Greece. The complex geophysical features along with the prevailing meteorological conditions, land–use types and pollution sources (mainly vehicular traffic and central heating emissions) create a complex spatial pattern of air pollutant concentrations. The air quality data are obtained from two monitoring stations operated by the Hellenic Ministry of Environment, Energy and Climate Change (MEECC), cover a six year period (2005 – 2010) and consist of hourly CO, NO and NO₂ concentrations from the Athinas station and daily values of PM₁₀ from the Aristotelous station. Both monitoring sites are mainly affected by traffic related sources and are located in the urban core of metropolitan Athens. The meteorological parameters are obtained from the nearby representative site at NOA and consist of hourly values of air temperature, wind speed, relative humidity, total solar radiation and daily measurements of precipitation, cloud cover and sunshine duration for the aforementioned time period.

2.2 Methodology

The applied methodology consists of the following three steps:
— Selection of the relevant target - predictor variables and averaging periods and pre-processing of the air quality and meteorological data
— CART model building and pruning
— Assessment of the CART trees.

The association of air pollution and meteorological conditions is performed between the maximum daily CO, NO and NO₂ ([CO]ₘₐₓ, [NO]ₘₐₓ and [NO₂]ₘₐₓ) and the daily PM₁₀ ([PM₁₀]) concentrations, which are considered the response variables, and the mean daily (Tₘₑᵃⁿ, maximum (Tₘₐₓ) and minimum (Tₘᵟᵓ) air temperature (all of them in °C) , the mean daily wind speed (WS in m/s), relative humidity (RH in %), solar radiation (H in W/m²), precipitation (P in mm), cloud cover (CC in octals) and sunshine duration (SD in hours) which are the explanatory variables. The [CO]ₘₐₓ along with the [NO]ₘₐₓ and [NO₂]ₘₐₓ are representative indicators of traffic related pollution, whereas the primary parameters that influence air pollution levels are the WS and air temperature, which govern the diffusion and dispersion of ground level emitted pollutants. Furthermore, precipitation accelerates the
deposition of PM$_{10}$, while solar radiation has a direct effect on the photochemical reactions in the atmosphere.

Classification and Regression Trees (CART) are proposed by Breiman et al. (1984) and employ decision trees to explain the linear or non-linear relationship between a target variable and a number of explanatory parameters. The CART methodology employs a recursive partitioning algorithm and is based on node-splitting decision rules to divide the learning sample into subgroups until a set of terminal nodes is reached. In each step the algorithm splits the dataset into two groups with maximum homogeneity in a way that the variation in the two subsets is minimized (Timofeev 2004), by identifying the ‘splitting’ variable and its value based on an extensive search of all possible rules (Lewis 2000). The CART methodology consists initially of the construction of the maximum tree and subsequently the choice of the optimum tree. The latter process is called tree pruning and it aims to avoid creating a highly complex tree (overfitting to the learning sample) by eliminating increasingly important nodes. In this work for the tree pruning procedure, we employed a widely used empirical criterion that defines the minimum number of cases in each node to be less than the 10% of the original size of the learning sample.

3 Results

The regression trees for the daily PM$_{10}$ concentrations and for daily maximum concentrations of CO, NO and NO$_2$ are illustrated in Fig. 1, 2, 3 and 4 respectively. The split criteria of explanatory variables are shown at the top of each box. Each node (box) indicates the mean maximum concentration, the standard deviation (σ) and the number of data (N) in the node. Gray boxes represent the terminal nodes. A general remark is that for all trees the 1$^{st}$ split-level is based on the mean WS and in all cases, higher number of days is classified in the higher wind speed regime, which is associated with lower pollutant concentrations. This finding is attributed to the importance of dispersion conditions in air pollutant concentrations at or near the ground level.

Regarding the mean daily [PM$_{10}$] regression tree (Fig. 1) an important finding is the high concentration values regardless of the node, which in many cases are above the health based air quality standard of 50 $\mu$g/m$^3$. The higher wind regime node (WS > 2.4 m/s) is further divided by $T_{\text{max}}$ and SD (indicators of warm period) at the 2$^{nd}$ and 3$^{rd}$ level respectively. In total, the 70.44% of the high wind speed regime cases are associated with $T_{\text{max}}$ values ranging from 14 °C to 35°C and with days where at least a small amount of SD is reported. The node with the higher mean daily [PM$_{10}$] (73 $\mu$g/m$^3$) is associated with lower than 1.6 m/s mean wind speed and with increased solar radiation (H > 99 W/m$^2$) whereas the lower mean [PM$_{10}$] (30 $\mu$g/m$^3$) are observed in almost the opposite meteorological conditions (WS >2.4 m/s and $T_{\text{max}} < 14$ °C), typically observed during wintertime. The daily [CO]$_{\text{max}}$ regression tree (Fig. 2) is consisted of 13 final nodes and the primary mean WS limit value is 1.9 m/s. Regarding the higher wind speed regime, the subsequent splits are based on RH, SD and more detailed WS split levels, CC and H. On the contrary the lower wind speed regime, which is associated with higher pollution levels, is further split based on $T_{\text{min}}$, CC and H, RH and finally SD. The node with the higher mean [CO]$_{\text{max}}$ concentrations (8 mg/m$^3$) is associated with lower WS and $T_{\text{min}}$ (less than 1.9 m/s and 12 °C respectively) and with low CC and therefore its cases (31 days) are related to a typically lower boundary layer (decreased surface heating and mechanical turbulence).
In relation to the $[\text{NO}]_{\text{max}}$ regression tree, following the initial WS node-splitting decision rule of 1.9 m/s, the 2nd level splitting is based on either $T_{\text{min}}$ or on more detailed WS rules, followed by SD and further more detailed $T_{\text{min}}$ limit values. The pruned tree is composed of 13 final nodes, which are mainly associated with RH and H. The maximum mean $[\text{NO}]_{\text{max}}$ (408 $\mu$g/m$^3$) is observed for the low wind speed regime ($WS < 1.9$ m/s), associated with $T_{\text{min}} < 14.9$ °C and with greater than 7.5 hours of SD. The major splits for $[\text{NO}_2]_{\text{max}}$ are with decreasing importance the mean WS, $T_{\text{max}}$ or CC for the 2nd level followed by P and RH for the 3rd and 4th splitting level respectively. In all cases the nodes’ mean $[\text{NO}_2]$ is below the air quality limit value (200 $\mu$g/m$^3$) and the lower values are clearly associated with summertime conditions of increased ventilation ($WS > 2.1$ m/s) and with strong thermally induced turbulence (high $T_{\text{max}}$ and $T_{\text{min}}$).
Fig. 3. Regression tree for the daily maximum \([\text{NO}]\) in \(\mu g/m^3\).

Fig. 4. Regression tree for the daily maximum \([\text{NO}_2]\) in \(\mu g/m^3\).

4 Conclusions

The analysis initially indicates the capability of CART to explicitly describe the association of air pollutant concentrations and meteorological conditions over the urban area of metropolitan Athens. An important advantage of the CART approach, compared to other methodologies, is that it allows the use of an explanatory variable in more than one level and its ability to model non-linear relationships. In all trees the initial node-splitting decision rule is based on the mean daily wind speed as a result of the importance of dispersion in terms of mechanical turbulence and transport of airborne pollution, followed in most cases by either \(T_{\text{max}}\) or \(T_{\text{min}}\) which are indirect indicators of atmospheric stability and thermally induced turbulence. Future work is proposed in extending the CART methodology by using a comprehensive set...
of explanatory variables, including surface and upper air meteorological parameters, atmospheric circulation indicators along with emission inventory air pollution data towards the application of the CART approach for air quality prediction.

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References

Effect of climatic conditions on the energy performance of typical dwellings across Europe

Assimakopoulos M.N., Efstratiou D., Assimakopoulos V.D.

Buildings are responsible for more than 40% of the global energy use and one third of global greenhouse gas emissions. They contribute to climate change on a global scale and to climate modification on a local scale due to change of landscape. In this respect, building energy performance needs to be improved in order to reduce the overall energy demand taking also into account the local climatic characteristics. Thus, the dynamic thermal model TRNSYS was applied for typical domestic buildings in Greece, the U.K. and Cyprus for the cold and warm periods of a typical year. The heating and cooling energy demand differs depending on the local climatic characteristics that generate higher heating needs for the U.K. buildings and higher cooling demand for the Cypriot ones.

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1 Introduction

The total contribution of buildings’ energy consumption has reached 40% in developed countries exceeding the sectors of industry and transport. The modern way of life that is steadily growing the demand for building services, the time spent inside, and the requirements of comfort coupled with climate change ensure the continuing upward trend in energy demand. Population growth of a city by 1% causes an increase in energy consumption by 2%. For this reason, the energy efficiency of buildings is one of the most important issues that societies have to deal with today through technologies and strategies to reduce energy consumption. Of the most prominent effects of urbanization that are increasingly felt is the urban heat island (UHI). As a direct consequence of the increase in temperature in a city there is a greater need for air conditioning. Additionally, energy consumption in buildings depends on the envelope, age distribution of the existing building stock, thermal insulation use, building size, type, external weather conditions and efficiency of the equipment. As 75% of the housing stock is set to still be used in 2050, the priority is to retrofit existing dwellings to become more energy efficient. With the recast of the EPBD, retrofitting existing dwellings is and will continue to be more common, despite being extremely challenging, both methodologically and financially. The current approach for retrofitting housing is often targeted at the individual level and delivered inefficiently, (Perez-Lombard et al. 2008, Santamouris et al. 2001, Zhu et al. 2009).

The purpose of the present work is to study the energy behavior of three typical European domestic buildings in Greece, Cyprus and Britain, before and after applying retrofit strategies in order to assess the effect of local climatic conditions. The dynamical simulation code TRNSYS 17 (TRaNsient System Simulation Program) was applied for the calculation of the buildings’ cooling and heating loads before and after the application of retrofit schemes.

2 Methodology

2.1 Description of TRNSYS

TRNSYS is a complete and extensible simulation environment primarily used for dynamic simulation systems, including multi-zone buildings. This software is used by engineers and researchers worldwide to validate new designs from simple energy systems for domestic hot water, to the design and simulation of buildings including control strategies, user behavior. It has a graphical interface, a simulation engine, a library of components that include various building models, standard HVAC equipment, renewable energy and emerging technologies and a method for creating new components that do not exist in the standard package. It allows for specific input data such as multiple zones, characteristics of system components, weather data, details of the structure of the building, optical properties of windows, heating and cooling schedules, etc. (www.trnsys.com).

2.2 Short climatic description of countries

The Greek building is located in Athens, the capital of Greece where a subtropical Mediterranean climate prevails, its dominant feature being the alternation between prolonged hot and dry summers and mild, wet winters. Winter months bring about mild temperatures averaging between 8 and 10 °C and a higher level of precipitation. The city of Athens is affected by the UHI. It holds the World Meteorological Organization record for the highest temperature ever recorded in Europe, at 48.0 °C, on July 10, 1977, (Bartzokas and Metaxas
1995). The Cypriot building is located at the suburbs of Larnaca a seaside city of the island. The climate is characterized by long summers with high temperatures and humidity and winters with long periods of sunlight during the year. The cooling period starts in May and ends in October and heating period starts in November and ends in March (Price et al. 1999). The English house is located in the Midlands. The sea surrounding the British Isles gives a varied climate allowing convergence between moist maritime air and dry continental air. The large temperature variation creates atmospheric instability and this which influences the often unsettled weather the country experiences, where many types of weather can be experienced in a single day. The country is subject to temperatures not much lower than 0ºC in winter and not much higher than 32ºC in summer. The warmest month in England is normally July and the coldest is February (Moore et al. 1997).

### 2.3 Description of buildings

The selected buildings from the three countries were assumed to share the same main characteristics apart from the construction materials in order to compare their energy performance with regard to the outdoor climatic conditions. In all cases a two story house is taken where the heating/cooling systems operated constantly to maintain the desired indoor temperatures. The Cyprus house was built in 1985 on a South-Southwest orientation. The lack of insulation in the envelope, alike the majority of buildings in Cyprus, and the presence of single glazing enhance the heat transfer with the external environment resulting in augmented heating and cooling energy demands. This fact reveals the high potential of limitation of the energy consumption from retrofit strategies. The Greek building was constructed around 1980 and the English in 1920.

**Table 1.** Construction characteristics of all domestic buildings.

<table>
<thead>
<tr>
<th>Characteristics / Value – description</th>
<th>Cyprus</th>
<th>Greece</th>
<th>Britain</th>
</tr>
</thead>
<tbody>
<tr>
<td>No of stories</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Thermal zones</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Total Surface (m²)</td>
<td>205</td>
<td>205</td>
<td>205</td>
</tr>
<tr>
<td>Wall construction</td>
<td>40mm brick, 80mm cement mortar</td>
<td>40mm cement mortar, 20mm brick, 10mm foam insulation, 20mm brick, 40mm cement mortar</td>
<td>100 mm brick, insulation, 100 mm brick, 15mm plasterboard</td>
</tr>
<tr>
<td>Roof Construction</td>
<td>Horizontal 40mm limestone, 150mm reinforced concrete, no insulation</td>
<td>Horizontal 40mm limestone, 150mm reinforced concrete, 10mm foam insulation</td>
<td>Horizontal, 40mm limestone, 100mm mineral wool, 150mm concrete block</td>
</tr>
<tr>
<td>Window type</td>
<td>Single glazed</td>
<td>Single glazed</td>
<td>Single glazed</td>
</tr>
<tr>
<td>Internal gains</td>
<td>Electric equipment, lighting: 7.3 kW</td>
<td>Electric equipment, lighting: 7.3 kW</td>
<td>Electric equipment, lighting: 7.3 kW</td>
</tr>
<tr>
<td>Infiltration rate</td>
<td>Constant 0.6</td>
<td>Constant 0.6</td>
<td>Constant 0.6</td>
</tr>
<tr>
<td>Ground floor construction</td>
<td>40mm limestone, 100mm sand, 150mm concrete block, 9mm timber flooring</td>
<td>40mm limestone, 100mm sand, 150mm concrete block, 9mm timber flooring</td>
<td>40mm limestone, 100mm sand, 150mm concrete block, 9mm timber flooring</td>
</tr>
<tr>
<td>Preset indoor temperature (⁰C)</td>
<td>Cold period: 21</td>
<td>Cold period: 21</td>
<td>Cold period: 21</td>
</tr>
<tr>
<td></td>
<td>Hot period: 24</td>
<td>Hot period: 24</td>
<td>Hot period: 24</td>
</tr>
</tbody>
</table>
2.4 Description of primary retrofit scenarios

With regard to the Cyprus building, exterior insulation was placed on the roof and double glazing in all windows. As insulation material of the roof, polyurethane 0.02mm was chosen. Moreover, the infiltration rate was set to 0.5 to simulate better air tightness of the double glazing. The retrofit scenario for the Greek house was similar to the Cyprus case, as a 10mm layer of polyurethane and double glazing in all windows was placed on the roof. Regarding the English house all windows were changed into double glazed, all the external walls were covered with extra 50mm wood siding and 200 mm mineral wool were placed into the roof. The infiltration rate was the same as above.

3 Results

Regarding the Cypriot house, the simulation results showed that the heating demand is 1978 kW, while the cooling reaches 9278 kW (not shown here). In the case of Greece, both the heating and cooling demands are lower, 1400 kW and 8750 kW respectively, as shown in Fig. 1. For comparison purposes, the Greek Statistical Authority conducted a nationwide survey, from October 2011 to September 2012, of household energy consumption. According to the results, every household in the country consumes 13.994 kWh per year to meet the energy needs, where 85.9% is for space heating. For the English home the simulation results showed that the heating demand is 1645 kW and surprisingly the cooling reaches 3056 kW, which may be attributed to the heavy thermal insulation, Fig. 3.

When the retrofit measures were applied the results showed that the heating demand decreased by 1511 kW (23.6% reduction) and the cooling demand to 8139 kW (12.3% reduction) in the case of Cyprus, (not shown here). A greater decrease in heating demand was observed for the Greek house 33.9% reduction, while the cooling demand decreased less compared to the Cyprus one probably because of less severe summer weather conditions or better construction characteristics, (5.7% reduction) Fig.2. A significant reduction in heating demand after the retrofit scheme is observed in the English house case of the order of 68.2%, while the cooling demand increased by 37.3%, which indicates that further addition of thermal insulation is not an appropriate strategy if one wants to reduce the energy consumption during summer, Fig. 4.
4 Concluding Remarks

Three typical domestic buildings located in Cyprus, Greece and Britain, were checked for their energy consumption characteristics before and after small scale retrofits. From the obtained results it becomes evident that the local climate is one of the most important parameters that should be taken into account when constructing or retrofitting buildings. Addition of thermal insulation resulted in energy saving (thermal and cooling) for the Greek and Cypriot buildings, but increased the need for cooling energy of the British building. This may be attributed to the hot and humid British summer with temperatures up to 32°C that require different types of measures to deal with the cold and hot seasons. Further work is currently taking place in order to extend the above methodology to more types of houses with different structural characteristics and more varied retrofit scenarios.

Fig. 2. Greek building T(°C) for all zones and heating/cooling demand (kJ/h) after retrofitting scenario for a typical year.

Fig. 3. British building T(°C) for all zones and heating/cooling demand (kJ/h) for a typical year.

Fig. 4. British building T(°C) for all zones and heating/cooling demand (kJ/h) after retrofitting scenario for a typical year.
References


http://www.trnsys.com
Spatial distribution of aerosol species over the Aegean Sea: model coupling and evaluation during a recent Etesian period


Aerosol model predictions (September 2011) are coupled to concurrent airborne and ground measurements over the Aegean Sea, towards a thorough evaluation of predictions. An extensive air quality coupling between the regional model PMCAMx and the global model GEOS-CHEM (nested over Europe) is performed for 104 chemical species, 63 of which are in the aerosol phase. Model evaluation shows an average to good performance for most aerosol species. Model discrepancies are attributed to high ammonia emissions from Turkey, and to the high temporal variability of pollution downwind Athens and Peloponnese. Sensitivity runs underlie the effect of long-range transport, thus of model coupling, on model skills over the Aegean during Etesian outbreaks and show that the organic aerosol model performance is mostly dependent on, mainly, biogenic oxidation rates.

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1 Introduction

The atmosphere over the Aegean Sea, a substantial part of the Eastern (E.) Mediterranean, is an area where primary pollutants from non-local big sources (e.g. sulfur and nitrogen oxides, volatile organic compounds from Istanbul) are chemically transformed into secondary aerosol species (sulfates, nitrates, organics) during their transport. A meteorological regime that favors such long-range transport and transformation conditions is the strong winds from the northeast (NE) sector. These winds are often bound to the Etesian flow, which transports air masses downwind southern Russia.

Past modeling studies that cover the E. Mediterranean (Astitha and Kallos 2008, Athanasopoulou et al. 2008, Tombrou et al. 2009, Poupkou et al. 2010, Fountoukis et al. 2011, Megaritis et al. 2013) have not focused on the aerosol chemical composition over the Aegean Sea during strong NE winds. What is more, such a study necessitates a coupling with a global chemical model, so that long-range transport of aerosol and its precursors is effectively simulated.

A satisfactory representation of aerosol chemical species by model applications is a challenging task. Predictions from the aforementioned studies have mostly been evaluated against observations at the ground station of Finokalia (Crete). However, the three-dimensional structure of aerosol predictions over the greater Aegean Sea has not yet been studied and evaluated.

This study attempts to provide insights to the aforementioned topics and gaps. Chemically and size-resolved aerosol predictions are provided by PMCAMx applications during strong NE winds over the greater Aegean Sea. A detailed chemical coupling with a GEOS-CHEM application, based on the methodology by Tombrou et al. (2009), is developed and applied, so that the contribution of non-local sources to the aerosol composition over the Aegean Sea is estimated. Ground and airborne aerosol measurements are analyzed and used for a consistent model evaluation. Sensitivity tests on the aging rate constants of organic aerosol aim to investigate model discrepancies.

2 Methodology and Data

PMCAMx is the research version of a former version of the publicly available 3D, Eulerian chemical transport model CAMx. Aerosols are represented by a detailed aerosol composition (K⁺, Ca²⁺, Mg²⁺, NH₄⁺, Na⁺, SO₄²⁻, NO₃⁻, Cl⁻, H₂O, EC, and OC: primary, oxidized primary, anthropogenic & biogenic secondary), distributed over ten discrete and internally mixed size sections, in the diameter range 0.04-40μm (cut-off diameters: 0.04, 0.08, 0.1, 0.3, 0.6, 1.2, 2.5, 5, 10, 20, 40 μm). The aerosol related dynamical processes considered in PMCAMx include primary emissions, new particle formation by nucleation, condensation, evaporation, wet and dry deposition, coagulation and chemistry.

The model version used for this study couples SAPRC with ISORROPIA II and VBS modules for gaseous, inorganic and organic aerosol chemistry, respectively (Fountoukis et al. 2011). The aging rate constant for primary organic aerosols is 4·10⁻¹¹ cm³ mol⁻¹ s⁻¹ and for secondary organic aerosols (anthropogenic and biogenic) is set to 1·10⁻¹¹ cm³ mol⁻¹ s⁻¹ (Murphy et al. 2011).

The simulation domain is the greater area of Greece (34.1 to 42.5°N, 18.4 to 29°E) with 0.056° horizontal resolution and 4.5 km vertical extent. The meteorological conditions are provided by a WRF/ARW model application over Europe (up to 20 km) nested over the aforementioned domain. A detailed national emission database is used (including emissions from industry, transport and forest activity), while sea-salt particles, road and soil dust emission fluxes are calculated online with meteorology (Athanasopoulou et al. 2008, 2010).

In the frame of this study, emission rates from Turkey are processed and used after being retrieved from the EMEP database (see Table 1 in Appendix).
Long-range transport of air masses towards the Aegean area is handled through simulations during the same period by the global model GEOS-CHEM v8-03-01 nested (0.5x0.67°) over Europe (Protonotariou et al. 2012). The latter provides the hourly 3-dimensional boundary and top conditions, as well as an initialization field to PMCAMx. The chemical bond between the two air quality models is 33 gaseous species (20 of which are VOCs) and 13 chemical aerosol components, distributed in size bins (63 species).

These simulations are realized during the period of 29.08-09.09.2011, so that they are directly comparable with measurements by an airborne platform and at two ground stations (Tombrou et al. 2012, Bezantakos et al. 2013). The airborne observations were made using the UK Facility for Airborne Atmospheric Measurements (FAAM) BAe-14 research aircraft having performed 9 flights over the Aegean Sea. High time-resolution measurements of the chemical composition (sulfates, nitrates, ammonium, chloride and organics) of the ultrafine particles (PM₁) were determined by an airborne compact Time-of-Flight Aerosol Mass Spectrometer (cToF-AMS).

Ground aerosol observations were conducted at two remote stations located at Vigla, Lemnos (39°58’N, 25°04’E, 420m a.s.l.) and Finokalia, Crete (35°20’ N, 25°40’ E, 250m a.s.l.). Filter samplers were installed to measure elemental and organic carbon in PM₁₀ mass (6- and 8-hour sampling, respectively), as well as total PM₁₀ mass and PM₁ sulfates (hourly sampling only at Finokalia).

3 Results

3.1 Aerosol species performance

The model performance is fairly good for ground PM₁₀, ground sulfates, ground elemental carbon, airborne ammonium and airborne chloride (186, 184, 73, 4331, 1149 number of pairs, respectively) with 65-90% of the pairs meeting the goals and 40-90% meeting the criteria set by the methodology of Boylan and Russel (2006). All the rest species (73-5887 data pairs) exhibit average model performance (goals and criteria are met for 20-65%) except for airborne nitrates, which largely fall outside the criteria zone (for the average estimation of model performance, see Table 2 in Appendix). These results can be attributed to good estimates of SO₂ and EC but overestimations of NH₃ emissions, to accurate meteorological fields, to sulfate chemistry being less complex than nitrates and organics and to the fact that during summer the majority of the ammonium is associated with sulfate rather than nitrate. Aerosol species concentration measurements and model performance are presented for selected domain-wide averages in Fig. 1. The reproduction of the observed data (up to 2.5 km altitude) reaches 85-100% for the airborne sulfates, ammonium and organics above E. Crete and for sulfates and ammonium above the island of Lemnos. Conversely, a large number of modeling results at the greater area of Chania fall outside the criteria zone. These findings roughly represent the whole Aegean area, with the observed inorganics being better reproduced at the east and the north parts of Aegean (namely for strong NE winds) and with the large underestimations found in the SW Aegean area during high NW winds. Such deviations in the airborne comparison are expected, since the hourly average predictions are compared against high time resolution AMS measurements, which are highly variable downwind Athens and Peloponnese.

On average, the predominance of sulfate against organic aerosol mass in both data sets indicates a greater influence from industrial than urban sources on the Aegean atmosphere, which is also reproduced by model runs. Organics in the area are largely aged (OC/EC ratio more than unity), which explains their higher spatial homogeneity compared to the other species. This explains the good correlation between organic aerosol predictions and observations (r² = 0.4–0.6). Likewise, even higher model accuracy (r² = 0.6–0.7) is observed
for sulfates, ammonium and organics away from their sources (at altitudes higher than 2.5 km).

Fig. 1. Bugle plots of the mean fractional bias (MFB) for: (a) organic and elemental carbon (PM$_{10}$) at the Finokalia (Crete) and Vigla (Lemnos) ground locations, (b) airborne organic aerosol mass (PM$_1$), (c) Sulfates (PM$_1$) at Finokalia, (d) airborne sulfates (PM$_1$), (e) airborne ammonium (PM$_1$), (f) airborne nitrates and chloride (PM$_1$), along with the performance goals (green lines) and criteria (red lines) suggested by Boylan and Russell (2006). Data points are color-coded by area and marker-coded by chemistry. Areas are shown in the embedded map. It is noted that ground organic aerosol predictions are divided by 2.1 (OM/OC ratio for aged/nonurban aerosols, proposed by Turpin and Lin, (2010)) to be compared to organic carbon observations.

### 3.2 Sensitivity studies on long-range transport and on organic aerosol aging

In order to assess the long-range transport of pollutants towards the Aegean atmosphere, which is captured by the coupling between PMCAMx and GEOS-CHEM, two simulations are compared: the standard run and a scenario where the emissions from Turkey and boundary concentrations are switched off (scenario 1).

Organic, sulfate and ammonium aerosol mass and precursors from Turkey, Balkans and NE shape the 50-70, 70-90 and more than 90% of their total concentration levels over the Aegean Sea, respectively, during a representative Etesian event (04.09). The effect of plumes from Attica and Peloponnesian power plants during NW winds (31.08) reduces the role of long-range transport to 40-60% for sulfates over SW Aegean.

As a consequence, the applied scenario provides unrealistically low aerosol values of these species over the Aegean Sea during the whole simulation period. Nevertheless, nitrate performance over and downwind Turkey (SE Aegean) is greatly improved (meets the criteria), supporting the above statement for NH$_3$ overestimations from Turkey.

The chemical analysis of organics, as calculated by the standard run shows that secondary organic aerosol of biogenic origin (BSOA) shapes on average from 80% (W. Aegean) to 75% (E. Aegean) of the total organic mass (OA) (2.8 and 2μgm$^{-3}$, respectively, up to 2.5 km altitude). This 5% difference is due to an analogous increase of (oxidized) primary organics closer and downwind the organic aerosol sources in Turkey and further NE.

Two additional scenarios were investigated, following previous model studies (Tsimpidi et al. 2010, Fountoukis et al. 2011): one with the BSOA aging switched off (scenario 2) and another with the anthropogenic SOA (ASOA) aging quadrupled (scenario 3). Scenario 2 had a major effect on OA predictions (an average decrease by a factor of 4), while aged BSOA are found to shape the 20% of OA predictions. The sensitivity of model results on ASOA aging was limited to 5% both for the average OA predictions and chemical composition. Such a different model response to BSOA/ASOA changes stems from the isoprene/aromatics concentration ratio from GEOS-CHEM, which takes the average value of 9/1 over the Aegean (standard run-scenario 1).

As a consequence, switching off BSOA aging changed the model skills for organics from average to poor (average observed values of 4.8 and 4.2μgm$^{-3}$ for W. and E. Aegean,
respectively, up to 2.5 km altitude). Scenario 3 had a positive though minor effect on performance metrics.

4 Conclusions

An extensive PMCAMx evaluation against ground and airborne data over the Aegean Sea shows an average to good performance of the model for most aerosol species. Discrepancies in the concentration of nitrates are possibly caused by overestimations of the NH$_3$ emissions from Turkey. Model underestimations over SW Aegean during NW winds reflect the bigger effect of pollution plumes on high-time AMS measurements compared to hourly-averaged model outputs.

The large oxygenated fraction of organics in the Aegean atmosphere, mainly of biogenic origin, creates a homogeneous field, which makes model predictions being better correlated to the observed organic aerosol distribution.

More than half of the predicted aerosol mass over the Aegean during strong NE and NW winds is related to transport of aerosols and their precursors from Turkey, the Balkans and upwind. This finding underlines the significance of the detailed gaseous and aerosol model coupling developed in this study, which evidently can provide more accurate predictions. Moreover, it proves the difficulty for abatement strategies to reduce PM levels in Greece.

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5 Appendix

Table 1. Emission rates for the gaseous and aerosol species in PM$_{40}$. Numbers correspond to daily sums for the two parts of the simulation domain.

<table>
<thead>
<tr>
<th>Gas and aerosol (PM$_{40}$) species</th>
<th>Total emission rates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Greece$^1$</td>
</tr>
<tr>
<td></td>
<td>Area sources</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>140.348.064</td>
</tr>
<tr>
<td>Sulfur dioxide</td>
<td>3.360.941</td>
</tr>
<tr>
<td>Nitric oxide</td>
<td>44.174.448</td>
</tr>
<tr>
<td>Nitrogen dioxide</td>
<td>3.200.770</td>
</tr>
<tr>
<td>Ammonia</td>
<td>35.442.760</td>
</tr>
<tr>
<td>Non-methane hydrocarbons$^3$</td>
<td>52.486.772</td>
</tr>
<tr>
<td>Large chain hydrocarbons$^4$</td>
<td>485.060</td>
</tr>
<tr>
<td>Organic aerosols</td>
<td>30.823.516</td>
</tr>
<tr>
<td>Sulfates</td>
<td>2.302.347.776</td>
</tr>
<tr>
<td>Elemental carbon</td>
<td>60.818.276</td>
</tr>
<tr>
<td>Sodium chloride$^5$</td>
<td>23.898.716.160</td>
</tr>
<tr>
<td>Crustal species$^5$ (calcium, potassium, magnesium)</td>
<td>2.366.440.960</td>
</tr>
<tr>
<td>Rest aerosol components</td>
<td>702.736.128</td>
</tr>
<tr>
<td>Nitrates (re-suspended)$^5$</td>
<td>29.293</td>
</tr>
</tbody>
</table>
Emissions for the area of Greece (NO\textsubscript{x}, SO\textsubscript{2}, NMVOC, CO, NH\textsubscript{3}, isoprene, terpenes and bulk PM\textsubscript{10} from industries, road transport, central heating, maritime activities, railways, air traffic, agricultural activities and forests) are provided initially by the Ministry of Environment for 2002 and have been refined to account for the AO highway inside the Athens basin. It is noted that these emissions vary against season and day of the week. These values correspond to a summer weekday.

More information on the size and chemical distribution of total aerosol mass are given in Athanasopoulou et al. (2010, 2011).

Emissions for the area of Turkey are acquired from the EMEP database (http://www.ceip.at/webdab-emission-database/officially-reported-emission-data/) and processed so as to be compatible with the Greek database (and PMCAMx requirements). It is noted that EMEP provides annual emission rates, which were converted to hourly emission rates for a winter and a summer weekday and weekend, in analogy to the Greek National emissions.

The non-methane hydrocarbons speciation profiles used are described by Bossioli et al. (2002).

Sodium chloride corresponds to sea-salt emissions developed as described in Athanasopoulou et al. (2008). It is noted that sea-salt emissions are calculated online with meteorology, thus they differ from day-to-day. This value corresponds to the date 29.08.2011.

Soil and road dust emissions (tire, brake wear and road abrasion) and re-suspension (not only crustal, but also the rest of aerosol components) are calculated as described in Athanasopoulou et al. (2010). It is noted that soil dust emissions are calculated online with meteorology, thus they differ from day-to-day. This value corresponds to the date 29.08.2011.

Table 2. Prediction skill metrics of PMCAMx aerosol concentrations against airborne and ground measurements from 9 flights and at 2 stations, respectively, during 29 August - 9 September 2011.

![Table 2](image-url)

\[ MFB = \frac{1}{N} \sum \left( \frac{C_m - C_o}{C_o} \right), \quad MFE = \frac{1}{N} \sum \left( \frac{C_o - C_m}{C_o} \right) \]

where \( C_m \) is the modeled and \( C_o \) the observed concentration (µg m\textsuperscript{-3}) for each aerosol component at the location \( i \) of \( N \).

Good performance: MFB and MFE satisfy the goals\(^\text{**}^\); Average performance: MFB and MFE satisfy the criteria\(^**\); Poor performance: MFB and MFE do not satisfy the goals and criteria (Boylan and Russell, 2006).

The proposed model performance goals and criteria for aerosol components are given by the equations below (Boylan and Russell 2006):\[ MFB = \pm 170 e^{0.5 \left( \frac{(C_m/C_o) - 1}{88/80} \right)^2}, \quad MFE = \pm 150 e^{0.5 \left( \frac{C_o/C_m - 1}{88/80} \right)^2}, \]

where \( \bar{C_m} \) is the mean modeled and \( \bar{C_o} \) the mean observed concentration (µg m\textsuperscript{-3}) for each aerosol component.

Ground organic aerosol predictions are divided by 2.1 (=OM/OC ratio for aged/nonurban aerosols, as proposed by Turpin and Lin (2010)) to be compared to organic carbon observations.

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Use of a Synthetic Satellite Imagery towards Cloud Evaluation over the Southeastern Europe

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The meteorological satellite images provide a substantial and extensive source of support to the evaluation of the various physics modules implemented in numerical weather prediction models. Consequently, important guidelines for possible improvements might follow in the challenging area of model physics. Towards this direction, the synthetic satellite images produced by the COSMO.GR non-hydrostatic local numerical weather prediction model are examined in reference to METEOSAT (MSG) data. These satellite data are available on real time to the Hellenic National Meteorological Service and are manipulated through CineSat software for operational use. In particular, the infrared of 3.9μm and 10.8μm as well as the water-vapor channels of 6.2μm and 7.3μm are considered for a selected autumn case over the southeastern Europe. Furthermore, the low, medium, high and total cloud cover, derived by the model is directly compared to the corresponding MSG products produced by the Meteorological Products Extraction Facility Algorithms. The brightness temperatures derived by the model were found to be lower than those of MSG. In reference to cloud cover, the model overestimated medium and high cloud cover while for low clouds the situation was more complex, especially over marine areas.

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1 Introduction

Meteorological satellites play currently a key role in almost every aspect of the atmospheric sciences. The Hellenic National Meteorological Service (HNMS) considers satellite data of strategic importance to its operational framework. Therefore, HNMS invests heavily in this sector of remote sensing industry, especially as a founding member of the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT).

Apart from their operational value, meteorological satellite data can be used for a refined validation of numerical weather prediction (NWP) models (Reichert et al. 2005). Additionally, they can provide valuable insights towards improvements in various aspects of NWP parameterization schemes, such as radiation and turbulence algorithms (Avgoustoglou et al. 2010, Probst et al. 2012, Avgoustoglou 2013). These features are usually supported by advanced visualization software for the satellite data in connection to the possibility of NWP models to provide synthetic satellite images for direct comparisons. In particular, the artificial satellite images produced by the COSMO.GR model over the greater area of Greece are examined for a representative autumn case with extended areas of low stratiform clouds in comparison to METEOSAT (MSG) satellite data. The motivation behind this effort lies towards a better understanding of a systematic problem of NWP models (including COSMO), on the formation and dissolution of low stratus/stratocumulus clouds over land and sea (Heise 2006).

2 Methodology and Data

In this investigation, the brightness temperatures derived by artificial satellite images from the COSMO.GR model are directly compared with those of MSG. There are also direct comparisons of the model cloud cover with the cloud analysis produced by the Meteorological Products Extraction Facility Algorithms (MPEF) on MSG satellite data. These parameters are extensively used operationally and provide a pragmatic approach to our analysis.

These products are visualized and averaged over the considered domain using the CineSat software which is available locally at HNMS. The synthetic satellite images produced by the COSMO.GR model are based on COSMO model version 4.6 and are compared with MSG data for a 36-hour period starting from November the 4th 2011 at 12 UTC and in 3-hour intervals. The satellite data were available on real time at HNMS for operational use. In particular, the infrared channels of 3.9, 7.3, 6.2 and 10.8 μm are considered. The 3.9 μm channel is considered more sensitive in the detection of low clouds, while the 10.8 μm channel is representative for general cloudiness. The 6.2 μm and 7.3 μm channels are mainly associated with atmospheric water vapor. Furthermore, the model low, medium, high and total cloud cover is directly compared with the corresponding MPEF products.
The model run is parameterized with minimum turbulent diffusion coefficients for heat and momentum of a relatively low value 0.1 m²/sec. This choice was made in order to get an enhanced low cloud cover (Heise 2006, Szintai and Kaufmann 2008) which is the trend in our case regarding the synoptic analysis and satellite data. The domain covered by COSMO.GR model is that of southeastern Europe centered over Greece and it consists of 273x273 grid points with 0.0625° (~7 km) horizontal resolution and 40 vertical levels. The analysis boundary conditions were from DWD Global Model (GME) in 3-hour intervals and of horizontal grid of 0.5° (~50 km) in order to control the synoptic forecast errors.

3 Results

During the period of interest, there is a combination of moderate cyclonic activity over the Adriatic and over the central Mediterranean, leading to a southern surface wind field over Greece, while a weak northern wind field prevails over the Aegean Sea and the eastern Mediterranean (Fig. 1). This is a typical autumn weather situation that gives extensive low cloudiness over most of the area, over both land and sea, along with medium and high clouds mainly over the north northwest parts, as it is shown by the MPEF analysis of MSG data (Fig. 2. upper 4-figure panel).

![Fig. 2](https://example.com/image.png)

*Fig. 2. From left to right: High (HCLC), medium (MCLC), low (LCLC) and total (TCLC) cloud-cover (%) for November 5 2011 at 6 UTC. The upper row refers to the satellite pictures (MSG (MPEF)) while the lower refers to the corresponding cloud cover evaluated by COSMO.GR model. Note the different background colors for each map that refer to no cloudiness.*
Regarding high and medium cloud cover from a representative hourly situation of the comparison period, there is satisfactory spatial agreement between the satellite pictures and the model results (Fig. 2 first and second columns). However, absolute values are overestimated by the model, especially for high clouds as can also be seen from the areal average (Fig. 3b and c).

For low clouds, the southwestern and northeastern parts of the considered area exhibit a nice agreement, but there are substantial differences over the rest parts and in particular over the central and southeastern areas (Fig. 2c and g). The best average performance for low cloud forecasts is during the middle and the end of the period under consideration but an average model underestimation is found (Fig. 3d).

With respect to the average total cloud cover (Fig. 3a), the comparisons between the model and MSG are similar to the low cloud cover over the first 12 hours but remains in good agreement over the rest of the 36-hour period.

![Figure 3](image-url)

**Fig. 3.** Total, high, medium and low cloud-cover (%) domain-wide averages corresponding to upper left, upper right, lower left and lower right figures respectively from November 4 2011 12 UTC to November 5 2011 24 UTC denoted as "4_12" to "5_24" over the horizontal axis.
It is worth to mention, that the poor agreement in the total cloud cover of the southeast area of the domain is mostly related to the low cloud underestimation (Fig. 2d and h). Also, the good agreement on the northwest part of the domain is somewhat artificial since medium and high clouds restore the cloud cover difference for the low clouds. The results of this study could be used for the optimization of the applied cloud scheme within the COSMO model (Raschendorfer 2008, Avgoustoglou 2013).

In general, clouds of different heights are characterized by different brightness temperatures. As a consequence, the differences in cloudiness can be inferred from the comparisons between the brightness temperatures of the MSG data and COSMO model artificial satellite images for the infrared channels of 3.9, 10.8, 6.2 and 7.3 μm. (Fig. 4). Over the southeast part of the considered domain, the preponderance of low clouds from MSG in comparison to the model is depicted with lower brightness temperatures than those of the model. Over the northwest parts of the domain the situation reverses since the model produces more medium and high clouds than MSG. It should be mentioned however that for these parts, there are small areas on the MSG images with much lower brightness temperatures (less than -40 °C) than the model images.

On the areal average (Fig. 5), the model estimated brightness temperatures tend to be lower than those of MSG approximately after the first 12 hours of the period for all the channels under consideration. For the 3.9 μm channel however, the difference tends to be reduced after its peak value around November 5 at 12 UTC. During the first half of the period, there is an excellent agreement between the model and MSG for 3.9 μm and 6.2 μm channels while for the 7.3 μm and 10.8 μm channels the model brightness temperatures are lower than those of MSG.
4 Conclusions

The possibility for direct comparison of the cloud cover and the synthetic satellite images of COSMO.GR model with the corresponding remote sensing products is a valuable feature towards both the validation of the model but also for research purposes. In reference to cloud cover figures, the model overestimates medium and high cloud cover while for low clouds the situation is more complex, especially over marine areas. This is also illustrated in the comparisons of area average brightness temperatures derived by the model which are, in general, lower than those of MSG. These features are related to the challenges of the proper evaluation of the cloud formation in numerical weather prediction models like the assessment of cloud ice or the right height of the cloud condensate formation. A more systematic testing will be of great importance towards possible improvements in the demanding areas of model radiation and turbulence schemes.

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Variations of Sea Level Pressure during Explosive Cyclogenesis in the Mediterranean

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The understanding of explosive cyclogenesis in the Mediterranean constitutes a formidable scientific challenge both from the meteorological as well as the oceanographic standpoint. Sea level models presently used for operational prediction underestimate the size of sea level extremes. One factor that may be relevant is the low spatial and temporal resolution of the atmospheric forcing. This work explores the extent to which higher resolution sea level pressure (SLP) and wind forcing improve the sea level predictions, as evaluated against tide-gauge observations. Under this motivation, SLP is studied, as it is evaluated from COSMO.GR, a non-hydrostatic numerical weather prediction local model that is used at the Hellenic National Meteorological Service (HNMS). The COSMO.GR model performed simulations at a horizontal resolution of 0.0625 degrees (approximately 7 km) for twenty-three cases of explosive cyclogenesis, spanning over the period 2002-2010 with initial conditions from ECMWF analyses and forecasts. The preliminary results from three of these cases are shown in the present work. It was found that the SLP derived by COSMO.GR is in good to excellent correlation with the sea level recorded by most of the tide-gauge stations.


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1 Introduction

The response of the sea level to atmospheric pressure forcing over the ocean and especially in the Mediterranean Sea has been observed from the analysis of tide gauge data and its quantitative understanding still remains a subject of extensive research in many areas of the geophysical sciences (e.g. Le Traon and Gauzelin 1997, Wunsch and Stammer 1997, Tsimpis et al. 2005, Calafat et al. 2012, Tsimpis et al. 2013). The response of the sea surface to atmospheric pressure is commonly approximated by the inverse barometer effect, denoting the correction for variations in sea surface height due to atmospheric pressure variations. It can reach about ±15 cm and is calculated from meteorological models. More specifically, the atmospheric pressure change of 1 mbar corresponds to a linear response of the sea level about 1 cm (Willebrand et al. 1980; Ponte and Gaspar 1999; Carrère and Lyard 2003). Consequently, numerical weather prediction models may provide a substantial insight to the correlation of the sea level changes to the sea level pressure (SLP) or improve the performance of barotropic ocean models through pressure and wind forcing (Mathers and Woodworth 2004). Towards this direction, the high resolution numerical weather prediction model COSMO was utilized in the operational domain of the Hellenic National Meteorological Service (HNMS) for the Mediterranean area (Fig.1). The model results were directly correlated to the records of a number of tide gauge stations. They are also currently used towards the improvement of the performance of an oceanic model based on the barotropic version of the HAMSOM ocean model (Jordà et al. 2012).

2 Data and Methodology

Hourly tide gauge data from thirty seven stations over a network all around the Mediterranean region (Fig.1) are investigated for twenty three events of explosive cyclogenesis (ECE) over the period 2002-2010. The preliminary results from three of them are examined in the present work. These events were derived according to a climatology developed by Kouroutzoglou et al. (2013), considering those with central pressure less than or equal to 995hPa (Maheras et al. 2001) in the maritime-coastal environment of Mediterranean basin (Floca et al. 2010, Kouroutzoglou et al. 2011).

Fig. 1. The domain of COSMO.GR and the positions of the tide gauge stations in the Mediterranean area.

The hourly values of surface pressure over the sea (SLP) were derived by the COSMO.GR local numerical weather prediction model over the operational domain of (HNMS) (Fig.1). COSMO model is a non-hydrostatic state of the art limited-area atmospheric model that runs operationally as well as for research purposes (Avgoustoglou and Tzeferi 2013) by the National Meteorological Services of COSMO (COsortium for Small-scale MOdelling) countries, Germany, Greece, Italy, Poland, Romania, Russia and Switzerland and several licenced Institutes. The model values are statistically correlated with the sea level recorded by the tide gauge stations. The considered time is over a period of 60 or 72 hours divided in two intervals of 30 or 36 hours before and after the time of occurrence of ECEs. The horizontal model resolution is 0.0625° (~7km) and it is driven by boundary conditions from the global model of the European Center of Medium Range Forecast (ECMWF). There are
two model runs per case; one with 6-hour analysis and the other with 3-hour forecast boundary conditions respectively, in order to estimate the differences due to atmospheric synoptic scale conditions. All the presented simulations were driven by 6-hourly analysis as boundary conditions. Prior to the evaluation of the statistical parameters an estimation of the astronomical tides obtained by means of a harmonic analysis using the standard program \textit{t-tide} (Pawlowicz et al. 2002) was removed from the tide gauge records. The gauge station records were also directly compared to a 2D barotropic ocean model.

3 Results

In the present effort study, the preliminary findings are presented in reference to three ECE cases out of the twenty three currently examined. It is expected that during these events, rapid changes in SLP will have a strong impact on the sea level recordings of the tide gauge stations spanned over the whole Mediterranean (Fig.1). Such impact can be investigated by comparing the sea level from the tide gauge records with the SLP, as evaluated by the COSMO.GR model according to the inverse barometric approximation (Wunsch and Stammer 1997). All the model runs presented are driven with boundary conditions from ECMWF analyses in 6-hour intervals.

![Fig. 2. Difference between Surface Pressure and PMSL (colored scale in Pa) and PMSL (contours in 2hPa) from COSMO.GR for 23-3-2002 at 06 UTC.](image)

The first ECE is observed over the Northeast Aegean (26.89E, 40.00N) on 23-3-2002 at 06 UTC (Fig.2) and was characterized by synoptic central pressure of 993 hPa. The model run covered a period of 60 hours starting 30 hours before the ECE. The model sensitivity was estimated through the differences between SLP and PMSL which is found to be of order less than 1 hPa for all ECEs considered in this work. The correlation of the model SLP with the observed sea level is positive for most of the tide gauge stations while it is more than 0.6 for approximately one third of them (Fig.5 first column, upper figure). It should be noted that the correlation appears positive due to the adoption of the inverse barometer approximation of 1cm sea-level rise per 1hPa fall of the SLP.

The second ECE is localized over the Central Aegean (26.57E, 37.84N) on 22-1-2004 at 12 UTC (Fig.3) and was characterized by central pressure of 977 hPa. The model run covered a period of 72 hours starting 36 hours before the ECE.
Fig. 3. Difference between Surface Pressure and PMSL (colored scale in Pa) and PMSL (contours in 2hPa) for 22-1-2004 at 12 UTC.

Fig. 4. Difference between Surface Pressure and PMSL (colored scale in Pa) and PMSL (contours in 2hPa) for 8-11-2004 at 12 UTC.

The correlation of the model SLP with the observed sea level is positive for the vast majority of the tide gauge stations while it is more than 0.6 for approximately half of them (Fig.5 second column, upper figure). The third ECE occurred over the east coast of South Adriatic (18.43E, 41.48N) on 8-11-2004 12 UTC (Fig.4) and was characterized by central pressure of 994 hPa. The model run covered a period of 72 hours starting 36 hours before the ECE. The correlation of the model SLP with the observed sea level is positive for almost all the tide gauge stations while it is more than 0.6 for more than half of them (Fig.5 third column, upper figure). For all cases, the corresponding regression coefficients for the vast majority of the stations are close to the theoretical expectation which should be approximate 1cm/hPa (Fig.5 lower row).

Fig. 5. Correlation (upper row) and regression coefficients (lower row) between SLP evaluated by COSMO.GR and sea level records for 37 stations (horizontal axis). The first column refers to a 60-hour period starting from 22-3-2002 at 00 UTC while the second and third columns refer to 72-hour periods starting from 22-1-2004 and 7-11-2004 at 00 UTC respectively.
4 Conclusions

The SLP derived by COSMO.GR was found in good to excellent correlation with the sea level recorded by most of the tide gauge stations while the regression coefficients are in good agreement with the theoretical values. Although the work is still in progress, the results look similar for all considered ECE cases providing an important alternative method of sea level changes estimations to that of the use of barotropic ocean models. Also, from a tentative outlook on work in progress, the performance of an oceanic model based on the barotropic version of the HAMSOM ocean model and forced by SLP and wind data from COSMO.GR appears to be improved. Consequently, the background is set for further systematic evaluation of the meteorological impact to oceanographic parameters both from the observation and the high resolution modeling standpoint.

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References

The Study of Atmospheric Blocking Associated with Negative Precipitation Anomaly in Iran

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Over the period of 22-31 Jan 2007, Iran experienced precipitation that tends to be lower than normal. On January 25, the central pressure reached around 1030 hPa. The coincidence of precipitation anomaly with blocking event was identified. Using the National Center for Environmental Prediction–National Center for Atmospheric Research (NCEP-NCAR), horizontal components of the zonal and meridional wind and derived dataset, as well as vorticity advection and omega were analyzed. The blocking criteria developed by Weidenmann (2002) that gives a “blocking index” was used for analysis. Analysis revealed Quasi-stationary characteristic of blocking lead to negative vorticity advection increased from West to East of Iran; So, the amounts of the negative vorticity were maintained between -1.3 to -3.9 r/s. Subtropical Jetstream (STJ) was observed at 200hPa. Its central velocity was registered around 36 m/s. It appears in such a placement that cannot allow STJ to influx in the middle and lower levels of the atmosphere. Moreover, while developing a secondary ridge whithin the whole troposphere, it causes the non- integration of STJ and Polar Front Jet stream (PFJ). At the end, if Iran was located under intense high pressure of blocking, it would cause a long term negative anomaly of precipitation (dry period) in the region.

Key Words: Precipitation, Atmospheric Blocking, Anomaly

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1 Introduction

Blocking phenomenon is defined as a strong anticyclonic circulation within the whole troposphere that blocks the usual eastward flow of baroclinic disturbances. Hampering the zonal flow, anticyclones cause the durable (from a week to a season) anomalies of meteorological fields, for instance temperature and precipitation (Tishchenkoa et al. 2013). One notable example of the persistent existence of stationary anticyclone in entire Iran was the January 2007, when many of synoptic stations had recorded no rainfall (Iran Meteorological Organization). By examining of Iran’s positive precipitation anomalies in relation to atmospheric blocking, Azizi and Khalili (2012) detected dipole-type blocking anticyclones for a period of 1978–2007 and found that if a southern trough of dipole structure of blocking was situated over a region, it would lead to precipitation in longer period. De Vries et al. (2013) demonstrated the decrease of the blocking frequency over the Atlantic and the enhanced frequency of easterly upper-level flow of 60°N are well described by the changes of mean zonal flow. Furthermore Latysheva et al. (2007) revealed that meridional flow is increasing in Siberia. This increase is related to the intensification of energy exchange between the tropic, and middle/high latitudes. The turbulence of zonal circulation and the reinforcement of meridional circulation lead to amplify the atmospheric blocking. The main features of this system are synoptic- and planetary-scale and quasi-stationary which causes to strengthen meridional circulation. It seems that such system can lead to precipitation anomalies (Schwierz et al. 2004). Konrad and Colucci (1988) and Lupo et al. (2008) showed that the enduring and quasi-stationary nature of the blocking is effective on climatic upstream and downstream of the blocking. In this case study, the relationship between blocking and occurrence of negative precipitation anomaly is investigated.

2 Data and Methodology

Although there is no consensus on the definition of atmospheric blocking, in the present study the blocking index developed by Weidenmann (2002) is used for analysis; blocking index (BI), takes values from one to ten. A value closer to ten gives a stronger blocking, while values closer to one yields weaker events. \[ BI = 100.0[(MZ/RC) - 1.0], \] where \( MZ \) is the maximum height of the 500hPa isobaric level in the closed anticyclone region or on a line associated with the ridge axis, and \( RC \) is the subjectively chosen representative contour (Glisan and Lupo 2008). BI stratifies weak (\( BI < 2.0 \)), moderate (\( 2.0 < BI < 4.3 \)), and strong (\( BI > 4.3 \)) based on Weidenmann’s (2002) classification. BI is calculated for this study subsequently.

In addition, the precipitation anomaly was determined using z scores and Kutiel Classification Criterion. The standard score is: \[ z = \frac{(x_i - \bar{x})}{sd}, \] (Kutiel 1996). Standard scores less than -0.5 were defined as negative precipitation anomalies. In the next step, the relationship between blocking occurrence and negative precipitation anomaly was investigated based on synoptic analysis and examination of vorticity advection, vertical motion (Omega) of the air and Jet-streams. Because blocking event has a quasi-stationary nature, during the blocking, the atmospheric flux will show an enduring time-and place feature as well.
3 Results

3.1 Analysis of 500hPa Mean Geopotential Height

Analysis of the mean geopotential height of 500hPa isobaric level corresponding to 22-31 January 2007 showed that the blocking ridge produced an omega-like structure that began to form over the 20°W (Fig.1). As the blocking was amplified, the strongest anticyclone became obvious over 20°W in 25th Jan. In other words, the most active day of the examined period was 25 January. Simultaneously a geopotential height minimum was located over 0° and registered around 5400 gpm. At the same time, amplifying meridional flows and a secondary ridge became evident between 40 to 60°E (Fig.1). The intensity of the blocking event was calculated 4.58. As mentioned this value gives a stronger (BI>4.3) blocking based on classification of Weidenmann et al. (2002). The duration of its life cycle was 10 days.

3.2 Synoptic Analysis

In the 25 January, analysis showed the secondary ridge appeared to deepen over the northwest of Iran. On the one hand, the positive omega was developed in the whole vertical section of atmosphere indicating 0.15Pa/s over the center of positive Omega; this signifies the presence of descending air (Fig. 2). On the other hand, the analysis of upper level of the atmosphere showed that the subtropical Jet-stream was observed at 200hPa. Its central velocity was registered around 36 m/s. It appears in such placement that it cannot allow STJ to influx in the middle and lower levels of the atmosphere. The maximum speed of Polar jet-stream was observed on the latitudes of 45-65° N. While developing the secondary ridge in northwestern of Iran, it causes the non- integration of STJ and PFJ (Fig. 2). Other evidence showed that negative value of the vorticity advection (-1.3 R/s) was observed over the west of Iran. The vorticity advection continued to amplify in the East and Southern of Iran. In these regions the maximum value of the vorticity advection reached -3.9 R/s. Also, the negative value of the vorticity advection (-5.2 R/s, Fig. 1) was observed in the center of ridge.

Fig. 1. Vorticity advection (R/s) (derived by U/V wind) and NCEP-NCAR daily 500-hPa gridded (2.5°lat. x 2.5°lon.).
3.3 the Tropopause anomaly

NCEP-NCAR daily tropopause reanalysis was investigated with respect to the 25 January 2007 blocking. A negative tropopause anomaly was found over the region, while a secondary ridge in the middle atmosphere and a high sea level pressure exist respectively (Fig. 3). It is clear that the distribution of tropopause anomaly results from the noticeable blocking nature. This is in agreement to the results demonstrated by Silmann (2008).

3.4 Surface Analysis

Sea level pressure (SLP) plots were used to appraise the characteristics of anticyclone and their interaction with the atmospheric blocking. This synoptic features help to analyze how the negative precipitation anomalies were related to blocking event. As secondary height/ridge was situated over the northwest of Iran, a good agreement was observed between the fields of H 20°W and H 50°E, a good agreement was observed between two high pressure located at 20°W and 50°E A strong closed isobar of high pressure (1030 hPa) was recognized, with the 1025hPa isobar covering entire Iran (Fig. 4). This indicates that when anticyclone was extending over the Iran, negative precipitation anomalies could be justified consequently. In fact, on one hand, the anticyclone with cold and arid air seemed to be advected into the secondary ridge via a clockwise circulation from Siberia, and on the other hand, the developing anticyclone did not allow air to converge process, reducing horizontal extent and increasing vertical extent. Due to enough air mass that has been accumulated, the airflow is forced to descent. Moreover, the air flow cannot ascend from both air mass and water resources. Corresponding to these surface pressure features, a wide region of non-precipitation values extending to entire Iran was registered for the period of 22 – 31 January (Fig. 4).
4 Conclusion

In this case study, we have analyzed the relationship between the blocking and non-precipitation/dry period from 22 to 31 January 2007. Our findings showed how blocking event can affect atmospheric flows. These large-scale events reinforced meridional flows causing the development of secondary ridge. The omega analysis indicated the descending air in the regions, where the strong high pressure isobar is closed. In other words, positive omega (0.15 Pa/s) with descending air leads to expand divergence of the air. Furthermore, the development of the secondary ridge in northwest of Iran caused the non-integration of STJ and PFJ. The negative vorticity advection became evident over the entire Iran. The developing anticyclone did not allow air to converge. Due to enough air mass that has been accumulated, the flow is forced to descent, resulting in non-precipitation over the whole Iran.
References

The Hellenic Solar Energy Network: validation of products


The Hellenic Network of Solar Energy (HNSE, www.helionet.gr) has been developed to support applications of solar energy with the combined use of ground-based measurements, satellite images and theoretical calculations with radiative transfer and weather forecasting models. In this study, we present a summary of the project, providing concisely the data and the methods that are operationally applied. The systems provide data of global horizontal, direct normal and global tilted irradiance. Forecasts of global irradiance (GHI) are provided by the Weather Research and Forecasting model on an hourly basis for 3 days ahead at a grid of 10x10 km². Validation of forecasts against measurements showed an overestimation by a few per cent due to insufficient treatment of aerosols, with an overall agreement to within about ±10%. Satellite images and model calculations provide near real time maps of the available solar power at a resolution of 0.05°x0.05°, with accuracy in the daily GHI of within ±10%.


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1 Introduction

Global consumption of electricity is expected to double by 2050 based on current estimates for the increase rate of population. Predictions suggest that the demand for electricity between 2006 and 2030 would increase by 80% (IEA, 2009). To avoid an uncontrolled increase in greenhouse gases energy-related policies should act to replace fossil fuel dependency by renewable energy sources. To respond to this situation, the European Union has adopted the goal to cover 20% of its electricity supply from renewable energy sources by 2020. Nowadays research on sustainable energy is focused onto the most abundant renewable resource, the solar energy (Szuromi et al. 2007). Electricity producing systems use different quantities of solar radiation: the Direct Normal Irradiance (DNI) is applicable in Solar Thermal Power Plants while the Global Horizontal Irradiance (GHI) in Photovoltaic systems. For these systems, the weather-dependent production plays a key role and determines the balance between production and demand. To enhance their efficient control, quality solar radiation data and validated forecasts are essential for planning and deployment purposes.

The Hellenic Network of Solar Energy (HNSE) is an innovative system for monitoring solar energy over the Eastern Mediterranean region and involves ground- and space-based measurements and modelling. In addition to measurements at 14 locations, estimates of the available solar power are produced in near real time, based on satellite data and radiative transfer modelling for the entire country. In order to meet the need for an a priori knowledge of the available solar power, model simulations are used to derive 3-day hourly forecasts. In this study, we present results from the evaluation of the products offered by the HNSE.

2 The HNSE network

To satisfy the scientific objectives of the HNSE, 14 monitoring stations were established during 2011, selected to represent different atmospheric environments and climatologic characteristics. Emphasis is given on the cloud coverage of each sector following the methodology proposed by Zagouras et al. (2013, see right panel of Fig. 1), accounting also for the available infrastructure that is needed for the appropriate operation of the instruments. The area covered and the network stations are shown in Fig. 1 (left).

![Fig. 1. Locations of the HNSE stations (left) and the clustering of Greece into 22 domains with common cloud characteristics (right, from Zagouras et al. 2013).](image-url)

All stations are equipped with Kipp&Zonen pyranometers (types CM21, CM11 and CM10) providing measurements of the GHI. Eight of them are sites of the UVNET Network (www.uvnet.gr) which were upgraded to include pyranometers in addition to NILU-UV radiometers, which provide solar irradiance data in 5 different UV wavelength bands and the Photosynthetically Active Radiation (PAR). The data are recorded every 1s and stored as one minute mean values with the corresponding standard deviation.
3 Product descriptions

In order to produce maps with instantaneous solar power, as well as daily, monthly and yearly climatologies of the solar energy, satellite images data and simulations with the libRadtran (Mayer and Kylling, 2005) radiative transfer model (RTM) were used. The cloud modification factor (CMF) is derived from images of the Meteosat Second Generation (MSG) satellites with a time step of 15 min. The algorithm is based on the methodology proposed by Verdebout (2000) modified accordingly for all shortwave spectral area. The solar irradiance at the Earth’s surface is the product of the RTM derived clear-sky irradiance and the CMF which is derived from the MSG images at spatial resolution 0.05°×0.05°.

The RTM provides also the direct and diffuse irradiances as a function of solar zenith angle (SZA) and aerosol optical depth (AOD) that are used to calculate the DNI and the Global Tilted Irradiance (GTI) at the optimum angle. The climatological monthly mean AOD at 550 nm from the Moderate Resolution Imaging Spectroradiometer (MODIS) onboard the AQUA and TERRA platforms data for the period 2000-2010 is used in the RTM calculations. For each pixel (0.05°×0.05°) the three quantities derived, GHI, DNI and GTI, were subsequently adjusted to the average altitude of each pixel. With integration over time, the daily, monthly and yearly maps for GHI, DNI and GTI are produced for the period 2002-2012.

Short-term forecasts of hourly GHI at the Earth’s surface under all-sky conditions are produced with the middle-scale atmospheric model Weather Research and Forecasting (WRF) for up to 3 days ahead. The Mesoscale Model 5 (MM5) shortwave radiation scheme (Dudhia 1989) is used, including absorption, scattering and reflection in the entire solar spectrum. By applying empirical relationships the corresponding DNI and GTI are derived. WRF V 3.2.1 cannot take into account the effects from aerosols; therefore partitioning of GHI to its direct and diffuse components is achieved with the use of RTM calculations based on mean monthly AOD at 550 nm from MODIS over the entire grid. For clear skies, empirical relations were derived for the ratio DNI over GHI in dependence of SZA and AOD; subsequently, the DNI is calculated from the predicted GHI by WRF. Similar empirical relations from the RTM simulations were derived for the ratio GTI to GHI, as a function of the AOD, the SZA and the azimuthal solar angle. Since the latitude over Greece varies from 35° to 41.5°, the differences introduced in the optimum tilting angle, as derived from RTM calculations, were found insignificant, thus an average inclination angle of 38° is assumed representative for the entire area and used in the calculations of GTI. These methods are applied even for situations with the sun disk un-obscured by clouds, since, at least for moderate to small SZAs, the GHI does not change significantly when the direct component is unaffected. Furthermore, it is assumed that the distribution of the diffuse radiation under cloudy conditions does not deviate appreciably from isotropic, at least no more than by Rayleigh scattering.

For cloudy conditions, a similar approach is followed based on simulations of the direct and diffuse irradiance with the RTM for cloud optical depths varying between 2 and 50. In the RTM calculations, the AOD at 550 nm was set to 0.3 for the entire area and all seasons, since the cloud attenuation is the dominant factor. The ratio of DNI to GHI is parameterized as a function of the SZA for the different cloud optical depths. It appears that this ratio varies very little with cloud optical depth, therefore it and can be simulated as an ensemble by a linear regression. The standard deviation of the deviations from the regression for cloud optical depths ≥2 and SZAs 35°-55° is within ±1%. The ratio GTI to GHI, once again, is expressed as a function of SZA and azimuth angle, but since its variation is too small, the mean value of 0.8±0.1 is used for all cases.

Depending on the atmospheric conditions, clear- or cloudy-skies, the most appropriate scheme is applied. However, WRF does not provide information that could be useful to identify if the Sun’s disk is covered by clouds. Using RTM simulations of irradiance for AOD at 550 nm equal to 1.2, the maximum possible value for Greece as suggested from AERONET data, a polynomial function was derived to describe the minimum GHI as a function of the SZA for clear skies. By comparing the predicted GHI from WRF with those
produced by the polynomial, the periods likely contaminated by clouds are determined; therefore the appropriate method for each case is applied. The specific value of the polynomial is first adjusted for the altitude of the particular location and the actual Sun-Earth distance. RTM simulations revealed differences of ~3% per km in GHI for altitudes of up to 3 km, where solar energy systems can be potentially installed.

Fig. 2. Validation of daily solar energy on horizontal surface (kWh/m²) for 2012 as derived from the combined use of model calculations and MSG images.

4 Validation of products

The validation of the GHI products derived from MSG was done by comparing the daily integral of GHI with the measurements of the HNSE stations. An example for six stations and for the year 2012 is shown in Fig. 2. The agreement is very satisfying for the majority of HNSE sites since the slopes of the regression lines are within ±8%. The scatter in the data is relatively small and similar among stations.

With a similar methodology, the WRF-derived GHI forecasts were validated against the hourly means of GHI from the HNSE stations. The majority of the fractional differences between the model estimated values (on a grid of 10x10 km²) and the measurements are within ±10%. An example of this validation for three locations over a period of about 2 years is shown in Fig. 3. It appears that, on average, more than 60% of the hourly forecasts agree with the measurements to within about ±7%.

Fig. 3. Comparison of forecasted and measured hourly GHI at three stations of NHSE for 2012, as scatter diagrams (upper panels) and frequency distribution of differences (lower panels).
It should be noted that the estimations and the data are different in terms of geometry: The measurements are sampled at one particular point, while both the satellite-derived and the WRF estimates are representative of the average GHI over a grid of much larger size. Although hourly or daily integrals smooth these differences, inherent uncertainties do exist in such comparisons. In addition, at polluted locations it is expected that the forecasts are overestimated because aerosols are not taken into account in the WRF radiation scheme.

4 Conclusions

Due to low efficiency in harvesting solar energy, improving the accuracy of information on the availability of solar radiation is of primary importance for the design, implementation and efficient operation of such systems. The Hellenic Network for Solar Energy provides horizontal, tilted and sun-tracking surfaces: real-time measurements of solar power at 14 locations, satellite-based near real time maps, maps of hourly forecasts for 3-days, and climatological maps of daily, monthly and yearly solar energy.

Both solar energy products, the near real time maps (time resolution: 15 min, spatial resolution: 0.5°x0.5°) and the forecasts (time resolution: 1 hour, spatial resolution: 10x10 km²) were validated against ground-based measurements and the revealed accuracy is within ±5% for the stations at Mytilene, Orestiada, Pylos, Xanthi, Finokalia, Thessaloniki and Volos, and to within ±10% for Argos, Kozani, Patras, Athens and Preveza. Although this agreement confirms the consistency of the produced maps with the measurements, effort is ongoing to further improve the algorithms and the products of the system, such as the inclusion of aerosol correction in the forecasts.

Acknowledgments

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References

Emergence of non-zonal coherent structures in barotropic turbulence

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Atmospheric turbulence is observed to self-organize into large scale structures such as zonal jets and coherent vortices. One of the simplest models that retains the relevant dynamics is a barotropic flow in a beta-plane channel with turbulence sustained by random stirring. Non-linear integrations of this model show that as the energy input rate of the forcing is increased, the homogeneity of the flow is first broken by the emergence of non-zonal, coherent, westward propagating structures and at larger energy input rates by the emergence of zonal jets. We study the emergence of non-zonal coherent structures using a statistical theory, Stochastic Structural Stability Theory (S3T). S3T directly models a second order approximation to the statistical mean turbulent state and allows identification of statistical turbulent equilibria and study of their stability. We find that when the homogeneous turbulent state becomes S3T unstable, non-zonal large scale structures emerge and we obtain analytic expressions for their characteristics (scale, amplitude and phase speed). Numerical simulations of the non-linear equations are found to reproduce the characteristics of the structures predicted by S3T.

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1 Introduction

Atmospheric turbulence is commonly observed to be organized into large scale zonal jets with long-lasting coherent vortices embedded in them. The jets control the transports of heat and chemical species in the atmosphere, while the coherent vortices sequester chemical species and heat and produce significant spatiotemporal variability. It is therefore important to understand the mechanisms for the emergence, equilibration, and maintenance of these coherent structures.

The simplest model that retains the relevant dynamics is a turbulent barotropic flow on a $\beta$-plane. Numerical simulations of this model have shown that robust, large scale zonal jets emerge in the flow and are sustained at finite amplitude. In addition, large scale westward propagating coherent waves were found to coexist with the zonal jets (Galperin et al. 2010). These large scale waves either obey a Rossby wave dispersion, or propagate with different phase speeds and appear to be sustained by non-linear interactions between Rossby waves. However the mechanism for their excitation and maintenance remains elusive. In this work, we present a theory that predicts the formation and nonlinear equilibration of large scale coherent structures in barotropic $\beta$-plane turbulence and then test this theory against nonlinear simulations.

Since turbulent dynamics involve complex interactions among many degrees of freedom, an attractive approach for understanding the emergence of coherent structures is to study the evolution of the flow statistics rather than the evolution of the complex flow itself, investigate the dynamics of the corresponding equations and the stability of the statistical equilibria that emerge. This approach is followed in Stochastic Structural Stability Theory (S3T) (Farrell and Ioannou 2003), which is a non-equilibrium statistical theory applied to atmospheric turbulence (Farrell and Ioannou 2008). While recent studies have demonstrated that S3T can predict the structure of zonal flows in turbulent fluids (Constantinou et al. 2013), the results presented in this work demonstrate that an extended version of S3T can predict the emergence of both zonal and non-zonal coherent structures and can capture their finite amplitude manifestations.

2 Formulation of Stochastic Structural Stability Theory

Consider a non-divergent barotropic flow on a $\beta$-plane with cartesian coordinates $x=(x,y)$. The velocity field, $u=(u,v)$, is given by $(u,v) = (-\partial_y \psi, \partial_x \psi)$, where $\psi$ is the streamfunction. Relative vorticity $\zeta(x, y, t) = \Delta \psi$, evolves according to the non-linear (NL) equation:

$$ (\partial_t + u \cdot \nabla)\zeta + \beta v = -r\zeta - v\Delta^2\zeta + f_e \tag{1} $$

where $\Delta = \partial^2_{xx} + \partial^2_{yy}$ is the horizontal Laplacian, $\beta$ is the gradient of planetary vorticity, $r$ is the coefficient of linear dissipation that typically parameterizes Ekman drag and $v$ is the coefficient of hyper-diffusion that dissipates enstrophy flowing into unresolved scales. The exogenous forcing term $f_e$ parameterizes processes such as small scale convection or baroclinic instability, that are missing from the barotropic dynamics and is necessary to sustain turbulence. We assume that $f_e$ is a temporally delta correlated and spatially homogeneous random stirring. We also assume that the forcing is isotropic, injecting energy at a rate $e$ in a narrow ring of wavenumbers with radius $K_f=10$. The calculations in this work are for $\beta=10$, $r=0.01$ and $v=1.9x10^{-6}$.

S3T describes the statistical dynamics of the first two same time moments of (1). The first moment is the ensemble mean of the vorticity $Z(x, t) = \langle \zeta_i \rangle$, where the brackets denote an ensemble average over forcing realizations. The second moment $C(x_1, x_2, t) = \langle \zeta_i' \zeta_j' \rangle$, is the two point correlation function of the vorticity deviation from the mean $\zeta_i' = \zeta_i - \langle \zeta \rangle$, where the subscript $i=1, 2$ refers to the value of the relative vorticity at $x_i = (x_i, y_i)$. We adopt the
general interpretation that the ensemble average is a Reynolds average over the fast turbulent motions (Bernstein and Farrell 2010). With this definition of the ensemble mean, we seek to obtain the statistical dynamics of the interaction of the coarse-grained ensemble average field, which can be zonal or non-zonal coherent structures represented by their vorticity $Z$, with the fine-grained incoherent field represented by the vorticity covariance $C$. The equations governing the evolution of the first two moments are obtained as follows. Under the decomposition of vorticity into an ensemble mean and a deviation from the mean, (1) is split into two equations governing the evolution of the vorticity of the coherent structures $Z$ and of the eddy (deviation from the mean) vorticity $\zeta'$. The mean vorticity $Z$ evolves according to:

$$\left(\partial_t + \mathbf{U} \cdot \nabla\right)Z + \beta V + rZ + \nu \Delta^2 Z = -\nabla \cdot \langle \mathbf{u}' \zeta' \rangle = G(C)$$

where $\mathbf{U}$, $\mathbf{u}'$ are the ensemble mean and the eddy velocity fields respectively. The mean vorticity $Z$ is therefore forced by the divergence of the ensemble mean vorticity fluxes that can be expressed as a function of the vorticity covariance $\mathbf{V} \cdot \langle \mathbf{u}' \zeta' \rangle = G(C)$. The covariance evolves as:

$$\partial_t C + (A_1 + A_2)C = \Xi$$

where

$$A = -\mathbf{U} \cdot \nabla - \left(\beta + \partial_y Z\right)\partial_x \Delta^{-1} + \partial_x Z \partial_y \Delta^{-1} - r + \nu \Delta^2$$

governs the dynamics of linear perturbations about the instantaneous mean flow $\mathbf{U}$ and $\Xi$ is the spatial correlation function of the external forcing. In obtaining (3), we have ignored the $f_{nl}$ term describing the eddy-eddy interactions, so that (2)-(3) form a closed deterministic system that governs the joint evolution of the coherent flow field and of the eddy statistics. The S3T system has bounded solutions and the fixed points $Z^E$ and $C^E$, if they exist, define statistical equilibria of the coherent structures with vorticity $Z^E$, in the presence of an eddy field with covariance $C^E$.

3 Results

The S3T system (2), (3) has for $\nu=0$ the equilibrium $Z^E=0$, $C^E=\Xi/2r$, that has zero large scale flow and a homogeneous eddy field with the spatial covariance of the forcing. We now investigate the stability of this equilibrium as a function of the energy input rate $\varepsilon$ and the characteristics of the equilibrated unstable structures and relate the outcome of the analysis to the results in the nonlinear simulations of (1). The stability of the homogeneous equilibrium is assessed by introducing perturbations $\delta Z = e^{inx+imy} + \sigma t$, $\delta C$, linearizing (2), (3) about the equilibrium and calculating the eigenvalues $\sigma$. The resulting stability equation for $\sigma(n, m)$ can be solved explicitly (Bakas and Ioannou 2013). For small values of the energy input rate of the forcing $\varepsilon$, the homogeneous state is stable. When $\varepsilon$ exceeds a critical $\varepsilon_c$, the homogeneous flow becomes S3T unstable and coherent structures emerge.

Fig. 1. Growth rate Re($\sigma$) as a function of the integer valued wavenumbers $(|n|, |m|)$ of the emerging structure for (a) $\varepsilon=4\varepsilon_c$ and (b) $\varepsilon=30\varepsilon_c$. 
The growth rates as a function of the integer valued wave numbers \((n, m)\) of the structure are shown in Fig. 1. For \(\varepsilon = 4\varepsilon_c\), the structure with the largest growth rate is non-zonal with \((|n|, |m|) = (1,5)\) and has \(\text{Im}(\sigma) > 0\), implying westward propagation of the eigenstructure. Note also that for this energy input rate, zonal flows \((n=0)\) are stable. For \(\varepsilon = 30\varepsilon_c\), both stationary zonal jets (having \(\text{Im}(\sigma) = 0\)) and westward propagating non-zonal structures are unstable, but the zonal jets have smaller growth rates compared to the non-zonal structures. Numerical integration of the S3T system (2)-(3) shows that for \(\varepsilon > \varepsilon_c\) the unstable structures equilibrate at finite amplitude after an initial period of exponential growth. Fig. 2 shows the equilibrated structure arising from random initial conditions when \(\varepsilon = 4\varepsilon_c\). This structure coincides with the finite amplitude equilibrium of the fastest growing eigenfunction and propagates as shown in Fig. 2 westwards with a speed approximately equal to the phase speed of this eigenfunction. For \(\varepsilon = 30\varepsilon_c\), a mixed structure that consisted of a zonal jet with \((|n|, |m|) = (0,5)\) and lower amplitude \((|n|, |m|) = (1,5)\) westward propagating waves embedded in it, is the finite amplitude equilibrium of the S3T system (not shown).

![Fig. 2. (a) Streamfunction of the equilibrated structure for \(\varepsilon = 4\varepsilon_c\). (b) Hovmoller diagram of \(\psi(x, y=\pi/4, t)\). The phase speed of the most unstable eigenfunction is also shown (dashed line).](image)

A proxy for the amplitude of these equilibrated structures are the zmf and nzmf indices defined as the ratio of the energy of zonal jets and non-zonal structures respectively with scales lower than the scale of the forcing over the total energy:

\[
zmf = \frac{\sum_{l<k_f} \hat{E}(k=0,l)}{\sum_{k,l} \hat{E}(k,l)}, \quad nzmf = \frac{\sum_{k,l} \hat{E}(k,l)}{\sum_{k,l} \hat{E}(k,l)} - zmf, \quad (4)
\]

where \(\hat{E}(k,l)\) is the time averaged energy power spectrum of the flow and \(k, l\) are the zonal and meridional wave numbers, respectively. These indices that are calculated for the S3T integrations, are shown in Fig. 3.

![Fig. 3. zmf and nzmf indices defined in (4) as a function of the energy input rate, for the NL and S3T integrations.](image)

As the energy input rate increases, the non-zonal structures equilibrate at larger amplitudes and nzmf increases. However, for \(\varepsilon / \varepsilon_c > 15\) the finite amplitude non-zonal equilibria are S3T unstable to zonal jet perturbations. As a result, the structures with the largest domain of attraction are zonal jets and the flow is dominated by these structures resulting in an increase of zmf and a concomitant decrease of nzmf.
The results of the S3T analysis are now compared to nonlinear simulations for which the zmf and nzmf indices are calculated as well. The stability analysis accurately predicts the critical \( \varepsilon_c \) for emergence of non-zonal structures in the nonlinear simulations as shown in Fig. 3. The finite amplitude equilibria obtained when \( \varepsilon > \varepsilon_c \) also correspond to the dominant structures in the nonlinear simulations. For \( \varepsilon = 4\varepsilon_c \), the time averaged energy spectra shown in Fig. 4 exhibit significant power at \((|k|,|l|)=(1,5)\), corresponding to the equilibrated S3T structure shown in Fig. 2. Remarkably, the phase speed of these waves observed in the nonlinear simulations and the amplitude of these structures as illustrated by the nzmf index are approximately equal to the phase speed and amplitude of the corresponding S3T translating equilibrium structure (cf. Figs. 2, 4). In addition, the spectra for \( \varepsilon = 30\varepsilon_c \) exhibit a peak at \((|k|,|l|)=(0,5)\), as in the S3T integrations (not shown).

![Fig. 4.](image)

**Fig. 4.** (a) Time averaged energy power spectra obtained from the NL simulations for \( \varepsilon = 4\varepsilon_c \). (b) Hovmoller diagram of \( \psi(x,y=\pi/4,t) \). The phase speed of the most unstable eigenfunction is also shown (dashed line).

### 4 Conclusions

In summary, we presented a theory (S3T) that shows that large scale structure in barotropic turbulence arises through systematic self-organization of the turbulent Reynolds stresses, a process that is captured by a second order closure of the flow statistics. The theory allowed the determination of conditions for the emergence of westward propagating, coherent non-zonal structures in homogeneously forced flows and we have demonstrated, through comparison with nonlinear simulations, that it predicts both the emergence and the finite amplitude equilibration of these structures. The relation of these states to westward propagating vortex rings in the ocean and the atmosphere will be the subject of future research.

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**References**


The Pindus mountainous range effect on the temperature-precipitation relation


The objective on this study is to investigate and deeper understand the relation developed between air temperature and precipitation and more importantly the effect produced to it by the existence of the Pindus mountainous range. Daily measurements of air temperature and precipitation, for 43 years for Kerkyra and Larissa and for 28 years for Agrinio and Lamia, are used. These four meteorological stations, as it is known, are being located on either side of the Pindus mountainous range. Given the different nature of these two examined parameters, the dissimilar physical processes and natural mechanisms that influence them, and most importantly the effect of the Pindus mountainous range, the relation of the two variables is explored. The relative frequencies of the precipitation amounts are calculated and depicted, as a function of the mean daily air temperature values, providing thus an integrated picture and important information characteristics of the temperature-precipitation relation. A comparison of the demonstrated relation is performed among the meteorological stations located on the same side of the mountainous range and against the ones on the other side. Preliminary results indicate more precipitation amount during the cold period of the year, probably due to the cold rain process mechanism. The resulted difference of the temperature-precipitation relation patterns, upwind and downwind of the mountainous range, clearly demonstrates the important role that the Pindus mountain plays upon the local weather and climate.


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1 Introduction

Temperature and precipitation are two of the most important weather variables that define the climate of a region. The relationship between these two variables consists the main objective of this study. Moreover, this relationship is investigated for four meteorological stations being located on either side of the Pindus mountainous range in order to study the effect produced to it by the existence of the Pindus mountainous range.

Although these two meteorological parameters consist the means for many well studied investigations, the temperature – precipitation relationship, especially on a daily basis, is not well defined in a quantitative way. Isaac and Stuart (1992) were the pioneers on this investigation theme with their attempt to determine the temperature – precipitation relationship for 56 stations in Canada for different months. Pennas et al. (1998) studied the temperature – precipitation relationship for the station of Thessaloniki, Greece, while Koliou (2008) and Koliou et al. (2008) performed similar studies for the west part of Greece and Kerkyra, respectively.

In this particular study, an attempt is made by integrating the Pindus mountainous range effect on the investigation of the temperature-precipitation relationship.

2 Data and Methodology

Daily measurements of air temperature and precipitation amount for four meteorological stations are used in this study. These stations are evenly located to the west side of Pindus mountainous range (Kerkyra and Agrinio) and to the east side (Larissa and Lamia). Daily data cover the common periods, of 43 years (1955-1997) for Kerkyra and Larissa and of 28 years (1973-2000) for Agrinio and Lamia. These specific stations were chosen for in pair comparison, as they lie almost at the same geographical longitude and latitude, and also, at similar distances away from the Pindus mountainous range.

Although precipitation exhibits complex spatiotemporal distribution, a rather easily understood methodology was applied for the purposes of this study. Precipitation episodes with daily rainfall amount more than 0.1mm were selected and their relative frequency of occurrence was calculated as a function of the total precipitation amount, for each temperature degree of the mean daily value. At the same time, relative frequencies of occurrence of mean daily temperature with an interval of one degree were also calculated using the total number of temperature data. Finally, the relative frequencies of precipitation and temperature were plotted, on the same diagram, as a function of mean daily temperature for each of the examined station. The temperature median was also calculated and depicted.

3 Results

By applying the aforementioned methodology, the distribution of the precipitation relative frequency (blue, solid line) for each degree of the mean daily temperature and the temperature relative frequency (red, dashed line), are superimposed for each station in Figure 1. The solid vertical line on the graph depicts the median of the daily temperature values record. As is evident from the graphs, the precipitation relative frequency distributions show an obvious and systematic skewness to the right, while the peaks come about on relatively cool or cold daily temperature values for all of the four examined stations. Although there are noticeable similarities between the stations located on the same side to the Pindus mountainous range, significant and pronounced differences are encountered between the stations being located on the opposite sides. Unlike precipitation, the temperature relative frequency distributions indicate similarities among the four examined stations.
Fig. 1. Relative frequency distribution of precipitation (solid line) and temperature (dashed line) as a function of the mean daily temperature.

On the other hand, the temperature relative frequency distribution exhibits bimodality for all the stations, indicating the cold and warm seasons of the year. The level off area between the observed two modes seems to lie, in general, from 14°C to 23°C. This area is probably due to the limited time duration of the intermediate transitional periods between the cold and warm seasons, and vice-versa. These particular areas, contribute to the total precipitation amount for Kerkyra by 41% (temperature interval: 15-23°C), for Agrinio by 36% (temperature interval: 14-23°C), for Larissa by 32% (temperature interval: 15-22°C) and for Lamia by 31% (temperature interval: 14-22°C).

The Pindus mountainous range effect is evident from comparisons conducted between the stations being located on the same side of Pindus and among those located on the other side. Almost similar temperature and precipitation distributions are observed between: Kerkyra-Agrinio, and Larissa-Lamia. The encountered minor differences are probably attributed to
geographical and geomorphological characteristics e.g. the pick of precipitation in Lamia at about 8°C is probably attributed to the fact that Lamia is more significantly affected by humid N-NE flow than Larissa. The differences are getting pronounced between Kerkrya-Larissa and Agrinio-Lamia, that is, stations on the same latitude, but located on the other sides of the mountain. The stations on the west side of Pindus, which are experiencing the highest amount of yearly precipitation (Kerkrya and Agrinio), exhibit maximum precipitation relative frequency values, almost up to 12%, at daily temperature values 9°C to 13°C. On the other hand, the stations on the east side (rain-shadow) of Pindus (Larissa and Lamia), with relatively less yearly precipitation amount, do not indicate similar peaks, exhibit much lower precipitation relative frequency values, between 4% and 7%, encountered within a broader area of daily temperature values (6°C to 16°C).

Table 1. Climatological and other characteristics related to the temperature-precipitation relation.

<table>
<thead>
<tr>
<th>Station</th>
<th>Precip. (mm)</th>
<th>Median (°C)</th>
<th>Rel. Freq. (%)</th>
<th>Contr. (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kerkyra</td>
<td>1097</td>
<td>16.9</td>
<td>74.5</td>
<td>817.3</td>
</tr>
<tr>
<td>Agrinio</td>
<td>865</td>
<td>16.6</td>
<td>80.0</td>
<td>692.0</td>
</tr>
<tr>
<td>Larissa</td>
<td>428</td>
<td>15.2</td>
<td>66.5</td>
<td>284.6</td>
</tr>
<tr>
<td>Lamia</td>
<td>527</td>
<td>15.9</td>
<td>75.3</td>
<td>396.8</td>
</tr>
</tbody>
</table>

(*): precipitation contribution amount below the Median value.

Table 1 demonstrates some climatological and other characteristics, which are related to the temperature-precipitation relation. Taking into consideration the plotted temperature median, from Fig. 1 becomes clear that the average percentage of precipitation occurring below the temperature median is 77% for the west stations and 71% for the east stations. This is resulted from the integration of the area under the precipitation relative frequency distribution for temperatures less than the median. Detailed information is presented on Table 1, demonstrating clearly the high contribution of the cool and cold season on the precipitation regime. Although, percentage wise, the Pindus mountainous range effect is not very noticeable (74.5% and 80% for the west stations versus 66.5% and 75.3% for the east), the contribution to the precipitation regime is of paramount importance (817.3mm and 692.0mm for the west stations versus 284.6mm and 396.8mm for the east). With a few degrees of freedom, somebody could argue, that, the cold rain process, that is, the Bergeron Findeisen mechanism, could be the dominant mechanism for the cool and cold period, in spite of the fact that the warm rain process, that is the collision and coalescence mechanism, is the initial mechanism for rain formation for both of the examined west stations.

From Fig. 1 is evident that the precipitation relative frequency distributions decrease as the mean temperature increase, explaining thus the limited contribution of the warm period upon the precipitation amounts. In this particular case, it is worth noticing the increased contribution to the precipitation regime for Larissa during the warm period (33.5%, 143.4mm). It is known, from the application of the Greek National Hail Suppression program that thunderstorm-hailstorm activities occur in the Thessaly plain (Karacostas, 1989 and 2005).

Finally, no precipitation episodes observed with daily temperatures warmer than 29°C, for all the examined stations.

4 Conclusions

An attempt is made to study and evaluate the temperature-precipitation relation by investigating the different nature and behavior of these two examined parameters, the similar or dissimilar physical processes and natural mechanisms that influence them, and most importantly, to explore and demonstrate the effect of the Pindus mountainous range upon these two variables. For this reason, the relative frequencies of the precipitation amounts are calculated and depicted, as a function of the mean daily air temperature values, providing a thorough and integrated picture, with important information characteristics of the
temperature-precipitation relation. A comparison is performed among the four selected meteorological stations, being located on the same side of the mountainous range and against the ones on the other side.

For the four examined stations, results clearly indicate more precipitation amounts during the cold season of the year, probably due to the cold rain mechanism (Bergeron – Findeisen process). The comparison between the stations lying on the same side of Pindus revealed no significant differences, on both, precipitation and temperature frequency distributions. The most significant differences observed in precipitation frequency distribution between the upwind (west) and downwind (east) stations. Temperature frequency follows similar distribution, indicating the minimum effect of Pindus on temperature regime.

The resulted differences on the temperature-precipitation relation patterns, clearly demonstrated the important role that Pindus mountainous range plays upon the local weather and climate. Certainly, additional knowledge, such as, instability information, upper air flow, temperature-dewpoint depressions and -for sure- microphysical characteristics, is more directly related to precipitation formation mechanisms.

This research effort has only outlined some of the major influences on temperature-precipitation relation, which are probably attributed to the geographical and geomorphological features existing between the west and east of the Pindus mountainous range stations.

References


Radar storm characteristics based upon their synoptic situations over Thessaly

Bampzelis D., Karacostas Th.

Using the cell tracker TITAN (Thunderstorm Identification, Tracking, Analysis, and Nowcasting) and a manual synoptic classification scheme, individual storms are obtained and classified for the period 2006 to 2010 for Thessaly into seven distinct synoptic patterns. Following a strict storm-tracking procedure, 2875 single cell storms are identified during the months April to September for the five-year period. The aim of this study is to identify differences in formation, structure, intensity and behavior of the storms among the recognized storm producing synoptic patterns over the area. Storms are characterized through their initiation time, duration, speed, direction, maximum top, maximum reflectivity, rain rate, volume, area and precipitation area. Results indicate that certain differences exist in storm characteristics among different synoptic patterns such as speed, direction, maximum top, maximum reflectivity and area. Storms following NW to SE movement are well organized exhibiting higher intensities and lifetime. Storms following SW to NE movement exhibit more complex structure, move faster, cover wider area and form in bigger numbers. In both cases orographic forced lifting is the dominant storm producing mechanism.

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1 Introduction

Convective storms are meteorological phenomena that cannot be effectively monitored from conventional observing systems due to their small spatial scale, complicated and interactive mechanisms and short time duration. Therefore, the use of weather radars has greatly improved our ability for monitoring, analyzing and studying the convective storms.

Radar data-based storm characteristics studies appeared in the USA in the 1950s following the invention and first use of weather radars (Braham, 1958). Numerous studies followed that first effort during the next decades incorporating advances in radar technology as well as in analysis tools. In Greece radar-based storm studies have been performed by several scientists that analyzed data from the operation of the Greek National Hail Suppression Program (GHSP), to mention, Karacostas (1991), Foris (2006) Chatzi et al. (2006), Christodoulou and Karacostas (2010) and Bampzelis (2012) covering areas of central Macedonia and Thessaly.

The purpose on this study is to analyze the relationship between thunderstorm activity and synoptic circulation patterns over Thessaly in central Greece. The classification scheme proposed by Karacostas et al. (1992) is adopted for the purposes of this study, which is mainly based on the isobaric level of 500hPa and the position and orientation of the trough or ridge axis.

Storm characteristics are obtained and identified from weather radar reflectivity images received and analyzed from a C-band (5-cm) weather radar, being located at Liopraso area, within the area of interest (Fig.1). The cell tracker TITAN (Thunderstorm Identification, Tracking, Analysis, and Nowcasting) (Dixon and Wiener, 1993) has been used to retrieve convective storm tracks from the radar data. TITAN algorithm presents a relatively simple but powerful method based on centroid tracking. Storms are identified as three-dimensional objects with reflectivity above a prespecified threshold. The ensemble of storms detected on consecutive radar scans are logically matched using combinational optimization with a maximum speed constraint.

![Fig. 1. Study Area and weather radar position.](image)

2 Data and Methodology

The analysis of this study covers an area of 19,600km$^2$ (square 140x140km), as seen in Figure 1. Only storm cells that developed (gave their first radar echo) within the area of interest are used in the analysis.

Following the climatic storm occurrence of the selected area the dataset used focuses on months from April to September for five consecutive years starting from 2006. Storm characteristics are obtained from radar reflectivity measurements that roughly have 750x750m spatial and 3.5min temporal resolution using the TITAN algorithm. Storm characteristics include: storm initiation time (UTC hour), storm duration (minutes), storm
direction (°), storm speed (km/hr), storm volume (km³), storm area and precipitation area (km²), rain rate (mm/hr), storm maximum reflectivity (dBZ) and storm cloud top (km).

Several sets of criteria and threshold values concerning the storm characteristics must be satisfied, in order that storm will be considered valid one. This is essential, since radar data are sometimes contaminated from several non meteorological echoes. A strict storm tracking procedure was applied by Bampzelis and Karacostas (2012) for storm track identification.

Days with at least one valid storm cell initiation, were classified into seven synoptic types and cells are grouped according the day’s synoptic condition. The number of cells grouped under the seven synoptic types, the number of days per synoptic type, as well as a short description of each synoptic condition for the five year period is indicated in Table 1. Relative frequency distributions of storm characteristics were calculated from cells occurred under every synoptic situation and differences among different synoptic types were analyzed.

Table 1. Synoptic type short description, number of cells and number of days per synoptic type.

<table>
<thead>
<tr>
<th>Synoptic type and brief explanation</th>
<th>Number of cells</th>
<th>Number of days</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Southwest flow (SW):</strong> long wave trough to the west and a ridge to the east-northeast.</td>
<td>385</td>
<td>59</td>
</tr>
<tr>
<td><em>Long Wave Trough (L1):</em> a slow moving long wave trough passes over the area. Absence of closed isobars in the upper atmosphere.</td>
<td>481</td>
<td>33</td>
</tr>
<tr>
<td><strong>Short wave trough (L2):</strong> a short wave trough rapidly moving through the area, sometimes associated with a closed low to the north.</td>
<td>628</td>
<td>37</td>
</tr>
<tr>
<td><strong>Zonal flow (ZON):</strong> West to east flow associated with a low amplitude trough to the north and a low amplitude ridge to the south.</td>
<td>303</td>
<td>46</td>
</tr>
<tr>
<td><strong>Northwest Flow (NW):</strong> a long wave trough to the east and a ridge to the west of the area.</td>
<td>794</td>
<td>105</td>
</tr>
<tr>
<td><strong>Closed Low (CLO):</strong> closed iso-height low over the examined area with the presence of a surface low pressure system with fronts.</td>
<td>175</td>
<td>26</td>
</tr>
<tr>
<td><strong>Cut Off Low (CUT):</strong> closed, cutoff from the general circulation low with the presence of a surface low pressure system without fronts.</td>
<td>109</td>
<td>18</td>
</tr>
</tbody>
</table>

3 Results

The analysis indicated that the total number of storms (2875 cells) is grouped into 324 days of convective activity which are classified under seven synoptic situations for the five year period of study. The mean number of days per period (April to September) of occurrence of each synoptic situation as well as the mean number of cells initiated per day is shown in Figure 2. Cell direction is highly associated with upper air wind, especially with SW, ZON and NW synoptic situations. The cells occurred for the L1 synoptic situation mostly exhibit northwest to southeast movement, while the equivalent for L2 cells exhibit southwest to northeast. No certain direction can be established for CLO and CUT occurring cells (Fig. 3).

![Fig. 2. Days of occurrence of each synoptic situation per period and number of cells per occurrence.](image-url)
Although cell initiation is maximized according the diurnal heating cycle, minor differences exist as follows: L1, L2 and NW observed cells develop earlier within the day, while SW and ZON later. CLO and CUT observed cells exhibit high distribution values throughout the day as they tend to develop, regardless the daily maximum heating, probably due to dynamic causes (Fig. 4a). Short-lived cells are predominant under every synoptic situation (Fig. 4b). Cell speed is also associated with upper air winds. Thus, SW and ZON occurred cells indicate the highest speeds, while CLO and CUT cells the lowest (Fig. 4c). Cell volume (Fig. 4d) and cell area (Fig 5a) do not exhibit significant changes, although NW observed cells exhibit higher volume and SW observed cells higher area than the other synoptic situation cells. Cloud top frequency distribution of cells peaks at two intervals, [4km-5km] and [7km-8km] (Fig. 5b). Cells observed under SW, L2, ZON, CLO and CUT synoptic situations peak between 4km and 5km, while L1 and NW peak between 7km and 8km. Frequency distribution of rain rate of cells (Fig. 5c) peaks between 10mm/hr and 30mm/hr. Slightly higher rain rates exhibit cells developing under L1, L2, ZON, NW and CUT synoptic situations. Finally, relative frequency of cell reflectivity exhibit normal distribution (Fig. 5d). L1 and NW observed cells exhibit higher reflectivity values than SW and CLO observed cells.

4 Conclusions

The analysis of storm characteristics indicated that certain differences exist in storm development and behavior under different synoptic situations. Since synoptic situations, in a way, define different air mass properties that pass over the area, this potential was also explored. Thus, air masses coming from southwest directions (SW synoptic type) are more unstable, rich in humidity and move faster. This particular synoptic situation produces high number of cells over the area, easily reacting with each other, but in most cases, these cells tend to form and dissipate without reaching intense characteristics. On the other hand, cell that forms under NW synoptic situation are fewer, as they usually form in environment with
restricted humidity, due to air mass origin, but upon formation they tend to develop more intense characteristics than any other synoptic situation cells.

Cells developed under ZON synoptic situation present a more complicated structure, which incorporates actually mixed characteristics of both SW and NW synoptic situations, according air mass origin and properties.

In any case, orographic forced lifting acts also as a triggering mechanism for cell development, especially for cells developed under NW synoptic situation. Another remarkable aspect is that cell characteristics are intensified during July, as a result of the maximized atmospheric instability during that period of the year for all synoptic situations.

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References


The impact of model resolution and cloud microphysics on the simulation of extreme flash-flood triggering storms

Bartsotas N., Nikolopoulos E.I., Solomos S., Anagnostou E.N., Kallos G.

Flash flood inducing storms account for a constant hazard in the Mediterranean region. Frontal disturbances that are slowed down and strengthened by the mountain ranges often result in heavy precipitation events and devastating floods that have tremendous societal and economical impacts. The generation and evolution of these multi-hundred-year return storms is a particularly challenging task due to the increased susceptibility of orographic convection towards aerosol forcing. Therefore, a high resolution integrated atmospheric model that is capable of resolving both the convective activity and aerosol-cloud interactions, is expected to provide a better insight on the mechanisms of such events. Four extreme flash-flood cases in the Italian Alps (Fella and Sesia basins) as well as two in France (Gard basin) were simulated with RAMS/ICLAMS model at very fine resolutions (250m) with an improved implemented topographic representation from the NASA SRTM mission (3 arcsec) in this study. The analysis of results and comparison with raingauge-adjusted radar-rainfall datasets indicated that the detailed representation of ice-driven processes in the model resulted in an improved model performance regarding precipitation accumulation and spatial distribution as well as highlighted the potential of using this high-resolution modeling scheme for flood forecasting applications.

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1 Introduction

Flash flood inducing storms develop at small space and short time scales, making their predictability a challenging task. The tremendous societal and economical impact of this hazard necessitates the development of accurate forecasting systems in order to advance warnings and mitigate the risk. To be able to develop a forecasting system that can accurately represent flash flood storms, we first need to understand the key elements that control the generation and evolution of this type of events. Towards this direction, the present study examines the effect of model grid resolution and cloud microphysical properties in the simulation of six signature flash flood inducing storms in the Mediterranean.

2 Data and Methodology

2.1 Area of study

Two hydrological basins in northern Italy and one in southern France were selected as the area of study. The Sesia river basin lies southeast of the Monte Rosa massif, on the northwestern part of Italy and has a drainage area of 2587 km$^2$ and elevation ranging from 108 to 4555 m. The Fella basin is placed along Italy's borderline with Austria and Slovenia, has a drainage area of 705 km$^2$ and a mean altitude of 1140 m. Gard is located on the southern part of France and its basin area is notably flat compared to the Italian basins, with heights ranging from 50 m to 300 m.

2.2 Model and Data used

The high-resolution integrated atmospheric model RAMS / ICLAMS (Solomos et al. 2011) implemented with a high resolution topography dataset of 3 arcsec from the NASA SRTM mission (Farr et al, 2007) was used to simulate the selected heavy precipitation events. The Fella results were compared to a Doppler, dual-polarised C-band OSMER radar, located at Fossalon di Grado (time resolution of 5 min and spatial resolution of 250 m), whereas in Sesia the volume scans of the the Bric della Croce Doppler weather radar were used (1 km spatial resolution and 10 min timescale). Both datasets incorporated accumulated values of available rain gauge stations within the basin. The Gard radar rainfall estimates were hourly and available on a 1 km grid.

2.3 Methodology

The sensitivity of model resolution as well as microphysical properties (aerosol cloud interactions) towards convection and precipitation over the area were examined through various model setups and simulations. In order to properly resolve the complex physical processes and deep convective activity of the events, grid resolutions of 1 km were initially used for most of the the model simulations. Increasing the resolution from 1 km to 250 m allowed for a more detailed description of the local sensible and latent heat fluxes while the convection processes were better estimated.

To examine the contribution of cloud microphysical mechanisms towards accurately reproducing events of this nature, a direct comparison was made between the original RAMS 6.0 code and the recently developed ICLAMS 1.3 code (Fig. 1 a-c). The two-moment cloud microphysics parameterisation was used in both model simulations, for reference. A major difference was that the original RAMS uses the Standard Meyers formula for the computation
of ice elements, whereas ICLAMS is implemented with the new Barahona-Nenes parameterisation (Barahona and Nenes 2009).

3 Results

3.1 Model Resolution

The 2002 storm in Sesia was a result of a low pressure system that was established over western Europe in June 4th and transferred moist air masses from the Mediterranean towards the Alps. Orographic triggering of convection resulted in a severe flood event. A comparison between the two model setups of 1 km and 250 m showed that the 1 km simulation overestimated the mean total rainfall of the basin by 6.2% whereas the 250m simulation had a mere underestimation of 3.2%. The maximum accumulation was 438mm and 431mm respectively, but the substantial improvement was in the rainfall spatial distribution over the basin and the significantly better estimation of the core of the rainfall (fig. 1 e,f).

Fig. 1. Accumulated rainfall for the 2002 and 2005 storms in Sesia. Comparison between ICLAMS 1.3 and RAMS 6.0 model outputs (fig. a-c) as well as two different ICLAMS setups (250 m and 1 km, fig. d-i), with radar-rainfall estimates.

The 2005 event had lower rainfall accumulation values. The rain-gauge calibrated radar recorded peak accumulations of 336mm over a period of 23 hours. The model successfully estimated the rainfall pattern but underestimated the overall basin quantity in both setups. The maximum accumulations were 209mm in the 1km simulation and 221mm in the 250m simulation (fig. 1 h-i). The higher resolution run, though, provided a considerably better
placement of the peak accumulation area towards the southwest of the mountainous range, in better agreement with the radar.

### 3.2 Cloud Microphysical Properties

Two of the cases were further analysed in terms of microphysical cloud structure. A vertical cross section at the time and place of extreme activity of the Sesia 2002 storm gave further insight on this type of events: a seeder-feeder mechanism was revealed (fig 2a), with the upper part of the cloud that stretched to 12 km supplementing the lower part with ice aggregates. Ice mixing ratio values reached 3.6 g/kg. Updrafts of 20 m/s (fig. 2b) in the core of the cloud clearly supported the assertions of deep convection. Significant amounts of liquid droplets were transferred along the intense updraft towards the upper layers of the cloud at temperatures below 0°C (supercooled droplets, fig. 2c). High concentrations of graupel and hail condensates were present (fig. 2d) and contributed to the total rainfall rates through riming and melting.

![Fig. 2. Vertical cross sections: a/Ice mixing ratio (g/kg), b/Wind speed (m/s), c/Temperature (°C) and liquid mixing ratio (g/kg) and d/Graupel and hail concentrations (g/kg).](image)

The contribution of dust particles to both cloud condensation nuclei (CCN) and ice nuclei (IN) activation in the Fella 2003 storm were examined through various sensitivity tests. The final model setup showcased an excellent estimation in terms of spatial distribution, as well as small underestimation in the maximum accumulation values (419 vs 441 mm of the radar, within 12 h). The rain bands were more accurately represented around the core of the storm, with neighbouring areas of the basin receiving less rainfall quantities than those measured by the radar. The contribution of dust particles as CCN was examined through the use of Fountoukis-Nenes-Seinfeld cloud activation parameterisation, but proved not to be the dominant process in this specific event, in contradiction to the ice processes. The activation of dust particles as IN through the Barahona-Nenes ice formation parameterisation resulted in the most realistic run of the series (fig. 3b).
4 Conclusions

Results from the sensitivity tests denote that both the fine grid resolution and the advanced cloud microphysical scheme of ICLAMS played an essential role towards the accurate simulation of heavy precipitation events over complex terrain areas. Many of the signature storms in the Alps are ice-driven processes, thus implementing the model with a parameterisation scheme that improves the representation of such processes, lead to a more detailed description of cloud structure and rainfall amounts. The higher resolution allowed for a more accurate reproduction of the deep convection processes and contributed in the correct spatial distribution of rainfall. Further research on similar events and linking with a hydrological model can improve our predictive understanding and allow the development of an integrative hydro-meteorological forecasting tool.

References


Fig. 3. Fella 2003 storm: Comparison between radar estimates and ICLAMS sensitivity tests
WRF input parameter updates based on recent and long-term satellite observations

Benas N., Chrysoulakis N., Christakis N., Kossioris G., Plexousakis M.

Recent satellite-derived products are analyzed and processed in order to update input parameters of the meso-scale model WRF (Weather Research and Forecasting), used for the study and prediction of extreme weather events in Greece, in the framework of the AKAIPO1 project. Updated input parameters include: the ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer, onboard Terra satellite) derived GDEM (Global Digital Elevation Model), which substantially improves the original WRF elevation spatial resolution and surface emissivity and albedo derived from MODIS (Moderate Resolution Imaging Spectroradiometer, onboard Terra and Aqua satellites) multi-year observations. These emissivity and albedo timeseries, covering Europe, northern Africa and the Middle East, were used to update corresponding WRF input tables based on land cover classification after statistical processing. Updated input parameters also include land cover maps extracted from ESA’s GlobCOVER product, based on MERIS (Medium Resolution Imaging Spectrometer, onboard Envisat platform) data. The processing and implementation procedures for updating the WRF input parameters are described in this study. WRF numerical simulations results and comparisons with data from meteorological stations are also presented, in order to assess the impact of the performed updates on the effectiveness of WRF in severe weather predictions.

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1 Study of extreme weather phenomena at a local scale and prediction of their impact on sectors of civil protection and the economy, Research Grant no. 09ΣΥΝ-31-1115, Program COOPERATION 2011, Ministry of Education and Religious Affairs, Greek Secretariat of Research Technology and EEYΔΕ-ΕΤΑΚ.
1 Introduction

Severe weather events are expected to change under changing climatic conditions, in terms of both their frequency and intensity. Among the most susceptible regions, the wider area of Greece is already witnessing such changes. The IPCC report on extreme events (IPCC 2012) concludes that there have been major increases in warm temperature extremes across the Mediterranean, while Trenberth (2011) found an increase in convective storm intensity over the same region. Extreme rainfall events are also increasing, according to e.g. Kioutsioukis et al. (2010).

Mesoscale numerical weather prediction models, such as the Weather Research and Forecasting (WRF) model, are essential for simulating and studying extreme events. In the AKAIPRO project, the WRF model is used for the study of extreme weather events in Greece during the last years, and their short-term prediction.

In the present study, recent satellite-derived products were analyzed and processed, in order to update important WRF input parameters, including topography, land cover, land surface emissivity (LSE) and land surface albedo (LSA). Topography, and especially its spatial resolution, is crucial for the accuracy of WRF simulations. Although increasing spatial resolution from 3km to 1km does not necessarily improve spatial verification statistics, higher resolution is needed to simulate correctly topography induced characteristics and structures (e.g. Mass et al. 2012). Land surface cover type variability, which determines the microclimate of a region but also affects local scale and mesoscale atmospheric circulation (e.g. Hartmann 1994), requires continuous updates. Updated LSE and LSA are needed for the computation of both shortwave and longwave radiation fluxes, which play a key role in surface-atmosphere interactions.

2 Data and Methodology

WRF represents topography using a Digital Elevation Model (DEM), derived from global observations of the Shuttle Radar Topography Mission (SRTM, Farr et al. 2007). The SRTM product is available at 900 m × 900 m spatial resolution, and was replaced in this study by the recently available Global DEM (GDEM), generated from data collected from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), using photogrammetry and stereoscopy (Abrams et al. 2010). GDEM spatial resolution is 30 m × 30 m, having the potential to substantially improve the topography representation in the WRF.

The original WRF land cover data originate from the US Geological Survey (USGS) Global Land Cover Characteristics (GLCC) database, whereby land is divided in 24 categories, with a 900 m × 900 m spatial resolution. The data set was derived from AVHRR (Advanced Very High Resolution Radiometer) data, spanning from April 1992 through March 1993 (Loveland et al. 2000). These data were replaced by corresponding data from ESA’s GlobCOVER product (2009), based on MERIS (Medium Resolution Imaging Spectrometer) data.

LSE and LSA in WRF are based on land cover types; two values of LSA (and similarly LSE) are assigned in each land cover category, for summer (16th April–15th October) and winter (16th October – 15th April). These data were derived from measurements by AVHRR (Csizsar and Gutman 1999), and were updated by data from MODIS, spanning the period 2000–2012.

2.1 Methodology for Topography, Land Cover, LSE and LSA Updates

For the GDEM incorporation in the WRF, a large number of GDEM tiles was initially retrieved, covering the wider Balkan and Central Mediterranean regions. These tiles were
used to create a mosaic image in GeoTIFF format, and in Geographic/WGS84 and EGM96 horizontal and vertical geodetic datums, respectively, as described in Chrysoulakis et al. (2011). The next step involved modification of this product into binary file format, compatible with the geogrid program of the WRF Preprocessing System (WPS), in order to be exploitable by the WRF, as well as changes in corresponding WPS input files. For this purpose, the methodology and software described in Beezley et al. (2011) were used. In the new topography, the GLCC land cover classification and topography interpolation method remained unchanged. Due to limitations in the number of topography input files used by the WRF, the spatial resolution of the GDEM data set was upscaled to 60 m × 60 m, using bilinear interpolation.

The number of land cover types differs between the USGS GLCC data set, used by the WRF, and GlobCOVER, which was used for updating these input data. Due to this difference, and in order to maintain the GLCC classification while updating its spatial distribution, land cover types of GlobCOVER were assigned to corresponding values of GLCC, based on their similarity.

In order to update the land cover types in the wider area of WRF simulations, 32 GLCC land cover tiles were converted from generic binary to GeoTIFF format and used for the creation of a mosaic image, which was then collocated with the corresponding GlobCOVER data. Furthermore, since the two data sets differ in their spatial resolution, (900 m × 900 m in GLCC and 300 m × 300 m in GlobCOVER), necessitating a correspondence of 9 GlobCOVER pixels for each GLCC pixel, the updated value of each pixel was assigned based on the GlobCOVER land cover type which occupied the majority of these 9 pixels. Finally, the new data set was divided into 32 tiles, which replaced the initial GLCC WRF input.

WRF input LSE and LSA values were replaced by corresponding more recently available data from Terra MODIS Level 3, 8–day mean products, available at 1 km × 1 km spatial resolution. For this purpose, 23 MODIS tiles, covering Europe, Northern Africa and the Middle East, were downloaded for each 8–day for the entire available time series (2000–2012), and processed accordingly (format conversion, data extraction and descaling).

LSE was initially calculated on a pixel basis, as the average of LSE in MODIS bands 31 and 32. Temporally averaged LSE values were then computed for the entire area, corresponding to summer and winter means. For the assignment of summer/winter value in each WRF land cover type, these seasonal mean LSE data were collocated with the corresponding land cover spatial distribution data, and the average LSE value for each land cover type was calculated.

LSA values were computed as a linear combination of black and white sky albedo values (BSA and WSA, respectively), as described in Schaaf et al. (2002). Specifically, 8–day mean BSA, which is a function of solar zenith angle (SZA), was first calculated on a pixel basis by averaging corresponding BSA values calculated at 9:00, 12:00, 15:00 and 18:00 local time SZAs, according to equation (2) in Schaaf et al. (2002). LSA was then calculated based on equation (3) in Schaaf et al. (2002), whereby it is a function of the fraction of diffuse skylight, which, in turn, is a function of aerosol optical thickness (AOT). For this purpose, AOT data from the corresponding MODIS Level 3 8–day product were used, covering the entire region, and LSA was computed by averaging results acquired using different SZAs, as previously described. The assignment of LSA values in each land cover type was performed with the same procedure described for LSE.

3 Case Study

The case study focused on a heat wave event (Metaxas and Kallos 1980) in Athens, in July 15th, 2012. Two WRF runs were performed, both with the new GDEM, and with the old and new land cover data, respectively. To represent the thermal and dynamic effects of urban surfaces, a single-layer Urban Canopy Model (UCM, Kusaka et al. 2001) was coupled in Noah Land Surface Model (LSM, Chen and Dudhia 2001).
Figure 1 shows the differences in the obtained WRF results for near surface air temperature, evaluated with the two land covers, at 2012-07-15 and 23:00 local time. The simulation based on the new land cover gave higher temperatures (by 0-5°C) in the northern and southern peri-urban areas of Athens, as well as in the eastern Attica (Mesogeia area), which was affected by substantial urban sprawl during the last decades (Chrysoulakis et al. 2013).

Two indicative comparative time series plots for selected stations are also presented. It should be noted, however, that comparisons with surface point measurements at specific locations can be misleading, given the specific local environment characteristics. In Fig. 2 (left, Gkazi station of the National Observatory of Athens), the new land cover slightly improves the simulated temperature. At Ano Liosia station, operated by the Hydrological Observatory of Athens (Fig. 2 right), the WRF simulation with the new land cover overestimates air temperature by 8.5% during the night of 15-07-2012. It follows, however, the exact temperature pattern during the night of 16-07-2012. On the other hand, the simulation with the old land cover underestimates by the same order of magnitude the temperatures during the nights of 15 and 16 -07-2012. Similar comparisons with other stations showed minor differences when the land cover type remained unchanged between the two data sets (relative error of the order of 5% or less). Moreover, daytime temperatures for all stations were underpredicted by the numerical model (for both land cover data sets) by 2-3°C on average, a fact which is in agreement with previous studies (Roux et al. 2008).

**Fig. 1.** Spatial distribution of the difference in near surface temperature (2m a.g.l.), between the two WRF runs, with the new and the old land cover, in July 15th, 2012, 23:00 local time.

**Fig. 2.** Intercomparison of the near surface temperature between the two WRF runs and Gkazi (left) and Ano Liosia (right) stations.

### 4 Conclusions

Important input parameters of the meso-scale WRF model were updated based on recently derived satellite products, in the framework of the AKAIPRO project, aiming to study
extreme weather events in Greece. These parameters included topography, land cover types distribution, LSE and LSA.

ASTER GDEM data were used for the topography update, improving its spatial resolution by two orders of magnitude. Recent land cover data from ESA’s GlobCOVER product were also used to update the original, outdated WRF data set. For the LSE and LSA, MODIS data were used, covering a wide area (including Europe, Northern Africa and the Middle East), and spanning the period 2000-2012.

WRF simulations with the new land cover capture correctly the tendency for a stronger Urban Heat Island (UHI) effect in the Athens Greater Area, where extensive urbanization took place in the last decade (e.g. Giannaros et al. 2013). However, comparison of the simulated surface temperature with surface measurements at specific locations can be misleading given the specific local environment the measuring stations operate in. Further investigations are already under way, in order to assess these issues.

These preliminary results highlight the importance of up to date input parameters in WRF simulations, concerning regional climatic and environmental changes, which can lead to significant ecological and social consequences.

References


The aerosol effect on potential evaporation at the Athens main water supply reservoirs

Benas N., Matsoukas C., Fotiadi A., Hatzianastassiou N., Pavlakis K.G., Vardavas I.

A radiative transfer model was used for the estimation of the atmospheric radiation budget and the potential evaporation during the period 2001-2010, at the water reservoirs of Evinos, Mornos, Marathonas and Yliki, located in Central Greece, that constitute the main water supply of Athens. High resolution (10 km × 10 km) MODIS Level 2 data of aerosols and other atmospheric parameters were used as input to the model, supplemented by surface wind data from local stations. The model output was validated against in situ measurements of the downwelling solar radiation. The seasonal characteristics of the potential evaporation and the aerosol effect on a daily, monthly and seasonal basis were analyzed. Results show a similar decreasing trend of the aerosol optical thickness and effect over all reservoirs, while variations in the corresponding trends of potential evaporation are explained by cloud cover changes during the period examined. An estimation of the water amount surplus, on an annual basis, caused by the attenuation of potential evaporation due to the presence of aerosols, highlights the importance of the latter in studies of water resources.

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1 Introduction

Climate change is expected to significantly alter the hydrological cycle in different ways, which depend on local and regional conditions (e.g. Bengtsson 2010). The Mediterranean basin is one of the areas where numerous studies, including past observations and future projections, suggest that these changes are expected to manifest strongly, especially as decreased precipitation rates, increased droughts and water deficits, and consequent desertification.

Evaporation from oceans and lakes is a crucial parameter of the hydrological cycle, since it constitutes the main mechanism for the return of water to the atmosphere. Moreover, evaporation from a lake is a primary factor controlling the local water budget and climate. Hence, the evaluation of evaporation, its possible changes and the corresponding assessment of the factors affecting it, are significant in a wider context. Over small, shallow lakes, where heat storage can be ignored, the Penman Potential Evaporation (PE) can be assumed to be the actual lake evaporation (Vardavas 1987).

In the present study, the daily mean PE and the corresponding aerosol direct effect (DRE) through the attenuation of the downwelling shortwave radiation (DSR), are evaluated using a spectral radiative transfer model (RTM), over four lakes in Central Greece, which constitute the main water supply reservoirs for the city of Athens (Evinos, Mornos, Marathonas and Yliki). The study examines the PE and the DRE on a daily, monthly and seasonal basis, the corresponding trends and the factors affecting them, using Terra MODIS input data from the decade 2001-2010. The aerosol effect on the water budget is also assessed.

2 Model and Input Data

The RTM used (Vardavas and Taylor 2011), takes into account all physical parameters and processes affecting the solar radiation transfer, including absorption by O₃, H₂O, CO₂ and CH₄, scattering and absorption by clouds and aerosols, Rayleigh scattering and surface reflection. RTM computations are performed separately at 118 wavelengths in the range 0.2-1.0 μm and 10 spectral bands in the range 1.0-10 μm. For each wavelength and spectral band, a set of monochromatic radiative flux transfer equations is solved for an absorbing and multiple-scattering atmosphere, using the Delta-Eddington approximation method (Joseph et al. 1976).

Almost all data needed for the model simulations and the evaluation of the net DSR at the lake’s surface, which is the main factor controlling evaporation, are available from MODIS Level 2 products, on 10 km × 10 km and 5 km × 5 km spatial resolution. These data include properties of clouds, aerosols and the Earth’s surface. Pre-processing of these data, to be used as input to the RTM, is described in detail in (Benas et al. 2011). Single-scattering albedo data, not available from MODIS, were taken from the GADS (Global Aerosol Data Set) data base (Koepke et al. 1997).

The procedure for the estimation of PE (in mm day⁻¹) is described in detail in (Vardavas 1987). Additional data required for the PE evaluation include wind speed, available from local stations, and net upwelling longwave (LW) flux, which is an output of the LW RTM version (Matsoukas et al. 2011).

For the estimation of the DRE on PE (ΔPE), PE was calculated separately by including and omitting the aerosol layer in the RTM. ΔPE is defined as the difference between these two outputs:

\[ ΔPE = PE - PE_{no-aerosol} \]

Thus, negative values of ΔPE correspond to decreased PE due to the presence of aerosols.
3 Results

3.1 Model DSR validation

The model-derived DSR was validated against corresponding surface measurements near Marathonas, Mornos and Yliki lakes. These measurements were available from pyranometers operated by the Athens Water Supply and Sewerage Company (EYDAP SA), for the period 2002-2007. Table 1 shows the determination coefficient and slope validation results of the linear regression over these lakes.

Table 1. Determination coefficients ($R^2$) and slopes of the model-derived DSR against surface measurements at Marathonas, Mornos and Yliki.

<table>
<thead>
<tr>
<th></th>
<th>$R^2$</th>
<th>slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marathonas</td>
<td>0.87</td>
<td>0.96</td>
</tr>
<tr>
<td>Mornos</td>
<td>0.82</td>
<td>0.90</td>
</tr>
<tr>
<td>Yliki</td>
<td>0.90</td>
<td>0.96</td>
</tr>
</tbody>
</table>

It is obvious from Table 1 that the model DSR is in very good agreement with corresponding surface measurements, representing efficiently the daily mean conditions.

3.2 Seasonal characteristics of evaporation and the aerosol effect

Daily mean PE values were used for the computation of the corresponding seasonal mean PE, during the period 2001-2010. Similar results were obtained over all lakes, showing that PE acquires its higher values during summer (June and July), reaching over 8 mm day$^{-1}$ in most cases. During winter, when the available solar radiation reaches its minimum values, PE is less than 2 mm day$^{-1}$ in all cases. The contribution of solar radiation to PE was found to dominate throughout the year, ranging between 70% and 90%. Based on the seasonal PE results, the total evaporation on an annual basis (mm year$^{-1}$) was calculated, by multiplying the monthly mean values (in mm day$^{-1}$), by the corresponding days in month. The results (Table 2) show that Evinos and Mornos lose slightly more water due to evaporation on an annual basis, compared to Marathonas and Yliki. This difference should be attributed to the higher aerosol loads over Marathonas and Yliki (e.g. Athanassiou et al. 2013), which decrease the total water lost through PE.

Table 2. Total water (mm year$^{-1}$, mean values during the studied period) lost through PE on an annual basis in Evinos, Mornos, Marathonas and Yliki.

<table>
<thead>
<tr>
<th></th>
<th>mm year$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evinos</td>
<td>1755</td>
</tr>
<tr>
<td>Mornos</td>
<td>1805</td>
</tr>
<tr>
<td>Marathonas</td>
<td>1620</td>
</tr>
<tr>
<td>Yliki</td>
<td>1704</td>
</tr>
</tbody>
</table>

Daily mean $\Delta$PE during the period 2001-2010 was found to range between about -0.4 mm day$^{-1}$ at Evinos and Mornos and -0.6 mm day$^{-1}$ at Marathonas and Yliki, corresponding to a reduction in PE by 7% and 10%, respectively. Peak values of $\Delta$PE were found in summer, reaching -2 mm day$^{-1}$ or -25% in PE. These summer extremes of $\Delta$PE should be attributed to corresponding maxima in Aerosol Optical Thickness (AOT), while the difference between Evinos/Mornos and Marathonas/Yliki is explained by the higher AOT values above the latter, due to their proximity to urban and industrial areas (e.g. Athanassiou et al. 2013).
3.3 Trends in potential evaporation and operating factors

Table 3 shows the percent change during the period 2001-2010 in PE, DSR, ΔPE, AOT and cloud cover over all four lakes.

Table 3. Changes (%) in PE and operating factors, during the period 2001-2010.

<table>
<thead>
<tr>
<th></th>
<th>PE</th>
<th>DSR</th>
<th>ΔPE</th>
<th>AOT</th>
<th>Cloud cover</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evinos</td>
<td>-3.9</td>
<td>-2.5</td>
<td>-27.1</td>
<td>-28.2</td>
<td>+12.9</td>
</tr>
<tr>
<td>Mornos</td>
<td>-2.1</td>
<td>-1.0</td>
<td>-31.8</td>
<td>-36.1</td>
<td>+12.4</td>
</tr>
<tr>
<td>Marathonas</td>
<td>+4.1</td>
<td>+4.2</td>
<td>-40.4</td>
<td>-35.9</td>
<td>-2.1</td>
</tr>
<tr>
<td>Yliki</td>
<td>+5.6</td>
<td>+4.0</td>
<td>-25.4</td>
<td>-26.5</td>
<td>+1.1</td>
</tr>
</tbody>
</table>

The results show that the four lakes can be grouped into two pairs (Evinos/Mornos and Marathonas/Yliki), based on their geographical proximity. PE has increased by about 4-6% in Marathonas and Yliki, while it has decreased by about 2-4% in Evinos and Mornos. Trends in DSR are similar, since it dominates among the factors affecting PE. The aerosol effect has substantially decreased in all four lakes, due to a corresponding decrease in AOT, tending to increase PE. This decrease, however, caused an increase in PE only over Marathonas and Yliki. Over Evinos and Mornos, an increase in cloud cover by about 12% caused a reduction in DSR, thus masking the PE increase, which would arise from a reduction in AOT, with all other factors unchanged.

3.4 Aerosol effect on the water budget

Based on the monthly mean values of PE and ΔPE, and the maximum surface area of each lake (due to lack of corresponding actual surface area data), the amount of water lost through PE, and the surplus due to the presence of aerosols, were calculated on an annual basis (Table 4).

Table 4. Maximum surface areas of the four lakes (in km²), water lost due to PE and water surplus due to aerosols (ΔPE). Water amounts are given in 10⁶ m³.

<table>
<thead>
<tr>
<th></th>
<th>Maximum surface area</th>
<th>Water lost through PE</th>
<th>Water surplus due to ΔPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evinos</td>
<td>3.6</td>
<td>6.3</td>
<td>0.4</td>
</tr>
<tr>
<td>Mornos</td>
<td>13.9</td>
<td>25.1</td>
<td>1.7</td>
</tr>
<tr>
<td>Marathonas</td>
<td>2.6</td>
<td>4.2</td>
<td>0.4</td>
</tr>
<tr>
<td>Yliki</td>
<td>27.8</td>
<td>47.3</td>
<td>4.7</td>
</tr>
</tbody>
</table>

The results show that, over Marathonas and Yliki, where aerosol loads are higher due to human activities (Athanassiou et al. 2013), the water surplus due to aerosols can reach about 10% of the amount lost through PE.

Figure 1 shows the time series of the annual water surplus due to aerosols and the change in this amount over each lake, due to the reduction in AOT. The importance of this amount of water surplus is highlighted when compared with the annual water consumption over the wider area of Athens, which, according to EYDAP SA data, was about 200 Mm³ during the last years. Hence, the annual water surplus due to the presence of aerosols would suffice to supply water in the wider area of Athens for about 2 weeks, or about 3.5% of annual consumption.
4 Summary and conclusions

A SW RTM, with MODIS Level 2 input data, was used for the evaluation of evaporation at lakes Evinos, Mornos, Marathonas and Yliki, during the period 2001-2010, and the assessment of the corresponding aerosol direct effect.

The model DSR was validated against corresponding in situ measurements at three of the four lakes, showing very good agreement. PE is primarily driven by DSR, acquiring maximum values of about 8 mm day\(^{-1}\) during summer. Aerosols were found to reduce PE by about 7%-10%.

![Fig. 1. Inter-annual variation of the water surplus available in each lake (in Mm\(^3\)), due to ΔPE.](image)

While AOT and the aerosol effect are decreasing over all lakes, an increase in cloud cover over Evinos and Mornos masked the consequent increase in PE.

Comparison of the water surplus caused by the presence of aerosols, with the annual water consumption in Athens, highlights the importance of the aerosol effect assessment in research including water use and management.

References


Weather impacts on human’s health in a Mediterranean coastal city

Bleta A.G., Nastos P.T., Agouridakis P., Notas G., Kampanis N.A.

The aim of this study is to evaluate the relationship between the daily weather types and hospital admissions for respiratory and cardiovascular problems in Heraklion, Crete during the period 2008-2012. Crete located in the southeast border of East Mediterranean basin confront exacerbating atmospheric conditions due to the tracks of passing air masses, as well as Saharan dust outbreaks and Föhn winds, which are associated with either short or long term effects on human health. The medical data concern daily admissions of outpatients with respiratory and cardiovascular diseases, recorded by the emergency departments of the two main hospitals in Heraklion city. The meteorological data analyzed consist of daily values of 20 parameters, which were acquired from the Hellenic National Meteorological Service during the study period: maximum temperature (Tmax); minimum temperature (Tmin); mean temperature (Tmean); diurnal temperature range (Trange = Tmax – Tmin); mean relative humidity (RH); mean water vapor pressure (e); mean atmospheric pressure at sea level (P); mean irradiance (I); mean sunshine (S); mean wind speed (v) and day-to-day change of each of the above parameters. The performed analysis was based on statistical methods, such as Factor and Cluster analysis and Pearson’s $\chi^2$ test using contingency tables. The application of this multivariate analysis revealed the relationship between the extracted weather types and the frequency of respiratory and cardiovascular diseases in Heraklion, Crete Island.
1 Introduction

Weather variability is associated with fluctuations of cardiovascular and respiratory diseases in a direct or indirect way, causing short or long term impacts. Different studies have revealed that respiratory and cardiovascular symptoms may be related to temperature prevailing during cold periods (Beer et al. 1991, Yuksel et al. 1996), changes in temperature (Panagiotakos et al. 2004, Nastos et al. 2006, Crighton et al. 2001), relative humidity and rainfall (Celenza et al. 1996), fog (Kashiwabara et al. 2002), wind speed (Hashimoto et al. 2004), and changes in barometric pressure and storms (Sutherland and Hall 1994, Newson et al. 1997). Furthermore, Grass and Cane (2008) studying the effects of weather and air pollution on cardiovascular and respiratory mortality in Santiago, Chile, found that high mortality weather classes were associated with cold, dry and high-pressure conditions. In a more recent work, Nastos and Matzarakis (2012) studying the effect of air temperature and human thermal biometeorological indices on mortality in Athens found that significant effects of 3-day lag during the cold period appears against 1-day lag during the warm period. Besides, the daily temperature range contributes more in the mortality frequency during the warm period than the cold period of the year.

Weather conditions are a significant driver of respiratory infections (Danielides et al. 2002). Similarly, Gonzalves et al. (2005) in Sao Paulo found a decrease in respiratory morbidity under hot and dry weather conditions. Finally, Nastos and Matzarakis (2006) revealed a weather lag effect on respiratory infections in Athens, Greece. Specifically, the influence of air temperature and absolute humidity on consultations on the same day is weaker than the lag effect (~2 weeks) related to cold existence and absolute humidity, while a strong wind during the preceding 3 days drives a peak in general practitioner consultations.

The objective of this study is to evaluate the relationship between the daily weather types and hospital admissions for respiratory and cardiovascular problems in Heraklion, Crete during the period 2008-2012. This can be useful for drawing up appropriate health plans and implementing suitable preventive measures and interventions.

2 Data and Methodology

Crete Island is located in a climatic sensitive area affected by frequent Saharan dust episodes specifically during spring and summer, period that encourage the development of suitable synoptic meteorological conditions (Kaskaoutis et al. 2008). The blow of southern winds (associated with Saharan dust episodes in spring/summer time) exacerbates the bioclimatic conditions at northern coastal urban areas in Crete (such as Heraklion), because of the development of the hot and dry Fohn winds coming from the lees of the mountain ranges (Bleta et al. 2013). The last ones combined with the atmospheric pollution in the urban environment cause a great impact on public health.

The medical data were obtained from the two main hospitals in Heraklion city, Crete, during 2008 – 2012, and concern daily counts of admissions for respiratory diseases (pulmonary infection, acute exacerbation of chronic obstructive pulmonary disease, acute asthma crisis etc) and cardiovascular syndromes (acute coronary syndrome, arrhythmia, myocardial infarction etc).

The meteorological data, which were acquired from the Hellenic National Meteorological Service during the study period analyzed, consist of daily values of 10 meteorological parameters along with their day to day change; namely, maximum temperature (Tmax), minimum temperature (Tmin), mean temperature (Tmean), diurnal temperature range (Trange = Tmax – Tmin), mean relative humidity (RH), mean water vapor pressure (e), mean atmospheric pressure at sea level (P), mean irradiance (I), mean sunshine (S), mean wind speed (v) and day-to-day change of each of these parameters.

The relationship between respiratory and cardiovascular diseases in Heraklion city and the aforementioned meteorological parameters was calculated by the application of a) Factor
Analysis (FA), b) Cluster Analysis (CA) and c) Pearson $\chi^2$ test. The applied Factor analysis is based on the Principal Components Analysis technique (Jolliffe 1986, Manly 1986), using Varimax rotation of the axes (Richman 1986). The number $m$ of the retained factors has to be decided, by using various rules (eigenvalue 1, scree plot) and considering the physical interpretation of the results.

Cluster Analysis is a way of grouping cases of data based on the similarity of responses to several variables. The clustering method used here is the average linkage method, which is considered the most efficient one in clustering meteorological variables (Kalkstein et al. 1987, Nastos et al. 2006). In our analysis, we applied the average linkage cluster analysis based on the calculation of the Euclidean distances of already standardized data (Sharma, 1995).

Finally, the Pearson $\chi^2$ test was applied in the contingency table, checking the null hypothesis that the weather types are not related to the daily number of admissions with cardiovascular and respiratory diseases. The use of contingency tables instead of Pearson correlation considered more accurate, because the medical data present large divergence from a Gaussian (regular) distribution.

3 Results

Weather types classification was performed by using FA and CA. The first step was to apply FA to the 20 meteorological parameters; this resulted in 8 factors, which explained 80% of the variability of the weather in Crete. In the process, CA was applied to the 1824 factor scores cases (days) in order to group them into classes of days with a characteristic type of weather and this procedure led to 8 clusters.

Table 1 presents the mean values of the meteorological parameters for each weather type (cluster). Weather types 1, 4, 5, 6 and 7 are mostly during warm period of the year, against weather types 2, 3 and 8, which prevail during cold period of the year. In order to reveal which weather type influences more the cardiovascular and respiratory diseases, the Pearson $\chi^2$ test was applied to a contingency table constructed within quintiles of cardiovascular/respiratory admissions (2008-2012) in relation to the eight weather types.

Table 1. Mean values of the meteorological parameters for each weather type (cluster).

<table>
<thead>
<tr>
<th>Meteor/cal</th>
<th>wt_1</th>
<th>wt_2</th>
<th>wt_3</th>
<th>wt_4</th>
<th>wt_5</th>
<th>wt_6</th>
<th>wt_7</th>
<th>wt_8</th>
</tr>
</thead>
<tbody>
<tr>
<td>T&lt;sub&gt;max&lt;/sub&gt; (°C)</td>
<td>22.9</td>
<td>18.6</td>
<td>20.9</td>
<td>23.9</td>
<td>28.4</td>
<td>25.4</td>
<td>20.9</td>
<td>15.9</td>
</tr>
<tr>
<td>T&lt;sub&gt;min&lt;/sub&gt; (°C)</td>
<td>16.6</td>
<td>12.8</td>
<td>14.3</td>
<td>16.6</td>
<td>23.1</td>
<td>16.9</td>
<td>16.5</td>
<td>12.4</td>
</tr>
<tr>
<td>T&lt;sub&gt;range&lt;/sub&gt; (°C)</td>
<td>6.33</td>
<td>5.8</td>
<td>8.5</td>
<td>6.7</td>
<td>5.3</td>
<td>9.3</td>
<td>4.4</td>
<td>3.5</td>
</tr>
<tr>
<td>T&lt;sub&gt;mean&lt;/sub&gt; (°C)</td>
<td>19.8</td>
<td>15.7</td>
<td>17.6</td>
<td>19.9</td>
<td>25.8</td>
<td>20.6</td>
<td>18.7</td>
<td>14.1</td>
</tr>
<tr>
<td>RH (%)</td>
<td>67.2</td>
<td>76.2</td>
<td>73.9</td>
<td>70.4</td>
<td>67.3</td>
<td>58.0</td>
<td>69.8</td>
<td>70.2</td>
</tr>
<tr>
<td>s (mm Hg)</td>
<td>15.7</td>
<td>13.6</td>
<td>15.2</td>
<td>15.7</td>
<td>22.2</td>
<td>14.3</td>
<td>15.1</td>
<td>11.3</td>
</tr>
<tr>
<td>P (hPa)</td>
<td>1013.4</td>
<td>1015.5</td>
<td>1015.9</td>
<td>1013.8</td>
<td>1010.2</td>
<td>1011.9</td>
<td>1014.1</td>
<td>1015.3</td>
</tr>
<tr>
<td>T (W/m²)</td>
<td>191.4</td>
<td>154.8</td>
<td>40.3</td>
<td>68.3</td>
<td>221.9</td>
<td>93.6</td>
<td>32.7</td>
<td>30.0</td>
</tr>
<tr>
<td>S (hrs)</td>
<td>1.9</td>
<td>3.2</td>
<td>4.3</td>
<td>4.7</td>
<td>8.4</td>
<td>3.8</td>
<td>7.5</td>
<td>3.0</td>
</tr>
<tr>
<td>v (m/sec)</td>
<td>4.3</td>
<td>3.4</td>
<td>3.7</td>
<td>4.4</td>
<td>5.0</td>
<td>5.4</td>
<td>5.8</td>
<td>7.0</td>
</tr>
<tr>
<td>ΔT&lt;sub&gt;max&lt;/sub&gt; (°C)</td>
<td>0.4</td>
<td>-0.1</td>
<td>-0.2</td>
<td>0.1</td>
<td>0.2</td>
<td>3.6</td>
<td>0.5</td>
<td>1.9</td>
</tr>
<tr>
<td>ΔT&lt;sub&gt;min&lt;/sub&gt; (°C)</td>
<td>-0.7</td>
<td>-0.1</td>
<td>-1.5</td>
<td>-0.2</td>
<td>0.3</td>
<td>1.1</td>
<td>2.2</td>
<td>-0.9</td>
</tr>
<tr>
<td>ΔT&lt;sub&gt;range&lt;/sub&gt; (°C)</td>
<td>1.1</td>
<td>-0.2</td>
<td>1.3</td>
<td>0.4</td>
<td>-0.4</td>
<td>2.4</td>
<td>-1.6</td>
<td>-1.1</td>
</tr>
<tr>
<td>ΔT&lt;sub&gt;mean&lt;/sub&gt; (°C)</td>
<td>-0.1</td>
<td>0.1</td>
<td>-0.8</td>
<td>0.1</td>
<td>0.1</td>
<td>2.3</td>
<td>1.4</td>
<td>-1.4</td>
</tr>
<tr>
<td>ΔRH (%)</td>
<td>-0.1</td>
<td>4.5</td>
<td>2.2</td>
<td>-0.5</td>
<td>0.7</td>
<td>-11.9</td>
<td>-1.9</td>
<td>-3.3</td>
</tr>
<tr>
<td>Δe (mm Hg)</td>
<td>0.1</td>
<td>0.8</td>
<td>-0.1</td>
<td>-0.8</td>
<td>0.2</td>
<td>-0.6</td>
<td>0.4</td>
<td>-1.4</td>
</tr>
<tr>
<td>ΔP (hPa)</td>
<td>0.5</td>
<td>0.4</td>
<td>1.8</td>
<td>0.5</td>
<td>1.4</td>
<td>3.3</td>
<td>0.2</td>
<td>4.6</td>
</tr>
<tr>
<td>ΔL (W/m²)</td>
<td>35.0</td>
<td>-7.5</td>
<td>0.8</td>
<td>-3.3</td>
<td>-3.9</td>
<td>-13.8</td>
<td>-1.1</td>
<td>-0.7</td>
</tr>
<tr>
<td>ΔS (hrs)</td>
<td>0.1</td>
<td>-1.4</td>
<td>2.0</td>
<td>-0.5</td>
<td>-0.1</td>
<td>0.9</td>
<td>1.0</td>
<td>0.9</td>
</tr>
<tr>
<td>Δv (m/sec)</td>
<td>-1.4</td>
<td>-0.8</td>
<td>-0.8</td>
<td>-0.5</td>
<td>0.21</td>
<td>1.9</td>
<td>1.1</td>
<td>1.2</td>
</tr>
</tbody>
</table>
Table 2. Number of days within quintiles of cardiovascular (upper) and respiratory admissions (lower) in relation to the eight weather types, within the period 2008-2012.

<table>
<thead>
<tr>
<th>Quintiles of cardiovascular admissions</th>
<th>weather types</th>
<th>&lt;22 (20%)</th>
<th>22-27 (20%-40%)</th>
<th>27-32 (40%-60%)</th>
<th>32-39 (60%-80%)</th>
<th>&gt;39 (80%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>28</td>
<td>38</td>
<td>35</td>
<td>37</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>66</td>
<td>85</td>
<td>69</td>
<td>66</td>
<td>79</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>62</td>
<td>60</td>
<td>69</td>
<td>51</td>
<td>54</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>1</td>
<td>5</td>
<td>4</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>116</td>
<td>95</td>
<td>78</td>
<td>61</td>
<td>42</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>7</td>
<td>28</td>
<td>26</td>
<td>19</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>54</td>
<td>36</td>
<td>34</td>
<td>49</td>
<td>51</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>52</td>
<td>47</td>
<td>49</td>
<td>48</td>
<td>46</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Quintiles of respiratory admissions</th>
<th>weather types</th>
<th>&lt;13 (20%)</th>
<th>13-16 (20%-40%)</th>
<th>16-20 (40%-60%)</th>
<th>20-26 (60%-80%)</th>
<th>&gt;26 (80%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>51</td>
<td>24</td>
<td>33</td>
<td>34</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>77</td>
<td>43</td>
<td>77</td>
<td>82</td>
<td>86</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>83</td>
<td>42</td>
<td>53</td>
<td>60</td>
<td>58</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>2</td>
<td>5</td>
<td>3</td>
<td>6</td>
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</tr>
<tr>
<td>5</td>
<td>150</td>
<td>87</td>
<td>78</td>
<td>57</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>27</td>
<td>20</td>
<td>26</td>
<td>30</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>48</td>
<td>36</td>
<td>54</td>
<td>39</td>
<td>47</td>
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</tr>
<tr>
<td>8</td>
<td>45</td>
<td>25</td>
<td>56</td>
<td>52</td>
<td>64</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 1. Relative frequency (%) of cardiovascular admissions (a) and respiratory admissions (b) per ten-days Intervals as a function of weather types (clusters) along with the variation of the total number of admissions per ten-days Interval (black curve) and the polynomial fitting (white curve).

The analysis showed that many days (79) with cardiovascular admissions in the upper 20% quintile are related to weather type 2, while many days (116) with cardiovascular admissions in the lower 20% quintile appear in weather type 5 (Table 2 upper). More specifically, the
weather type 5, which is identified by high air temperature, high total solar radiation and sunshine, minimizes the cardiovascular admissions, while the weather types 2 and 8, characterized by cold anticyclonic conditions after the passage of a cold front, are the drivers for the onset of high cardiovascular admissions.

Similar results were found as far as the respiratory admissions are concerned (Table 2 lower). More specifically, weather type 5, occurred mainly during the warm period of the year seems to be associated with many days (150) with respiratory admissions in the lower 20% quintile. On the other hand, weather types 2 and 8, prevailed mainly during the cold period of the year, are responsible for worsening respiratory diseases.

A more descriptive analysis appears in Fig. 1, where the relative frequency (%) of the cardiovascular (Fig. 1a) and respiratory (Fig. 1b) admissions per 10-days interval as a function of the eight weather types (clusters) along with the variation of the total number of admissions per 10-days interval (white line) and the polynomial fitting (black line) are illustrated. The bars appeared in each interval represent the percentages of admissions associated with the particular weather types. It is well depicted that the weather type 5 (red colour) is associated with lower admissions and weather types 2, 8 (blue and dark blue) are mainly related with higher admissions for both cardiovascular and respiratory problems.

4 Conclusions

The meteorological conditions that appear mainly during the cold period of the year are the most favorable for worsening cardiovascular and respiratory admissions. On the contrary, weather types characterized by high air temperature, high absolute humidity, high total solar radiation and sunshine, mainly appeared in the warm period in the year, are related to lower admissions. The present work shows that weather types 2 and 8 influence more the cardiovascular and respiratory diseases, as well. However weather type 5 is associated with minima in both cardiovascular and respiratory diseases.

Our future work is to examine how sex, season, month and day of the week control the hospital admissions of cardiovascular and respiratory problems. Also our intention is to investigate the impact of future climate change on hospital admissions using projected simulations of meteorological parameters by regional climate models.

Acknowledgments This research is supported by HERAKLEITOS project, which is cofounded by the EU and National Resources. The authors would like to acknowledge Dr. A. Sarantopoulos from Hellenic National Meteorological Service for providing the long term meteorological data sets. Besides the authors kindly acknowledge Dr.G.Kouvarakis for his experimental support to the research.

References


Assessment of ground based particulate matter measurements at two Mediterranean places during Saharan dust events

Bleta A.G., Nastos P.T., Kaminski U., Dietze V.

Crete Island, located in the Southeastern Mediterranean basin, is of significant vulnerability with respect to Saharan dust episodes, which can be identified by ground based measurements, satellite products, model simulations (e.g. Skiron Forecast System) and backward-trajectory analysis. These episodes are more frequently during spring and autumn due to specific synoptic conditions established over the Saharan region. In this work, specific case studies with Saharan dust episodes were investigated focusing on ground-level particle sampling sites (passive sampler technique Sigma-2) at Crete Island and Athens. Specifically, an automated optical microscopy analysis system identifies total and opaque particles with subsequent calculation of particulate mass concentration ($\mu g/m^3$) for atmospheric particles between 2.5$\mu m$-80$\mu m$ which showed higher concentrations of the larger particle fraction (dp >10$\mu m$) at the sampling sites of Crete Island against smaller ones (dp <5$\mu m$) in Athens. Further, in order to examine the chemical composition of the Saharan dust episodes, single particle analysis based on scanning electron microscopy was used.

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1 Introduction

Today, it is of great importance to identify and quantify individual sources of particles for a better understanding of potential sources of particle mass concentrations. The interest in particulate matter is of high concern because of their effect on human health and their role in climate change by influencing the radiation balance in the atmosphere due to the scattering and absorption of radiation (IPCC 2001). Coarse particles are predominantly produced mechanically (e.g. road, tire and brake abrasion and material resulting from weathering, as well as mineral dust, sea salt and biological material) (Kassomenos et al. 2012). The most important natural dust source region in the world is the Saharan desert (Engelstaedter et al. 2006), exporting dust plumes to the North Atlantic and Mediterranean Sea throughout the year (Moulin et al. 1998). Desert dust can be transported over long distances from the source regions (Prospero et al. 2002), with the larger particles to be deposited near the source, while the smaller ones to be suspended in the air for a few days or weeks and could be transported over long distances, having impact on increased morbidity and mortality (Delfino et al. 1997, Dockery and Pope 1996, Nastos 2008, Nastos et al. 2010). In a recent work, Nastos et al. (2011) showed that the Saharan dust episode on March 22-23, 2008 affected Crete Island, Greece, caused respiratory syndromes outbreak, but without impact on cardiovascular syndromes; the existence of coarse-mode particles along the dust pathway trigger respiratory syndromes more than cardiovascular, which are associated to ultra-fine particles.

In the last years, several studies have applied passive sampling methodologies to assess particulate matter (Seethapathy et al. 2008, Kaminski et al. 2013) as well as Wagner and Leith (2001a, 2001b). The objective of this study is to present and analyze ground based particulate matter concentration at Athens and Crete Island, based on passive sampling techniques focusing on Saharan dust episodes over the examined region. Crete Island is a climate-sensitive area, affected by frequent Saharan dust episodes especially during the transition seasons spring and autumn and secondary in winter, when the development of suitable synoptic meteorological conditions often occurs (Gerasopoulos et al. 2006, Kaskaoutis et al. 2008, Nastos 2012).

2 Data and Methodology

The mass concentrations of atmospheric aerosols with geometric diameters from 2.5-80μm (VDI, 2013) were calculated from 7-day samples during the period November 18, 2011 – May 31, 2013. The subject of VDI guideline (2013) is a passive system for dust and supplies technical guidance for the characterisation of particles with geometric diameters greater that 2.5μm, for the distinction of particle types (e.g. soil minerals, tyre abrasion, salts, pollen) and for the calculation of the particle mass concentration based on transmitted light microscopy data. Moreover it defines the requirements for additional chemical or mineralogical analyses (e.g. ion chromatography, ICP-MS). Weekly sampling was carried out at two sites in Crete Island and one in Athens. Regarding Crete Island, one site represents an urban-like site at Heraklion Airport; the second one is Finokalia, a background, remote coastal site in the northeast part of the island. The Finokalia station (150 m a.s.l.) is situated 70 km northeast of Heraklion city and a description of the site is given by Mihalopoulos et al (1997). The third sampling site is located in the Athens University Campus, which is out of the urban area and could be characterized as an urban background station.

In our study, we used the Sigma-2 passive sampler for collecting airborne particles with diameter >2.5μm. Optical microscopy (bright field) was performed with 20x magnification lens whereby the acceptor plates were being embedded in a non-aqueous immersion medium (silicone oil). A subsequently fully automated light microscope image analysis system allows for single particle detection and individual particle measurement, to determine size and optical density of individual particles for a distinction of total atmospheric particles (e.g. minerals, water-soluble particles like sea salt, biogenic material), and the “opaque”
atmospheric particle fraction, mainly anthropogenic particles (e.g. fly ash, tire wear, break wear). Our study, focusing on Saharan dust events, presents data of the total atmospheric particle fraction.

Back-trajectory calculations were performed on a daily basis during the measurement period to elucidate the origin of air masses arriving at the land-based stations. Back trajectories were computed with the computational system Cm-Hysplit (Customized Meteorology-Hybrid Single Langrangian Particle Integrated Trajectory). As clearly attested by its name, Cm-Hysplit is an extended version of the well-known atmospheric model Hysplit (Draxler and Hess 1998, NOAA Air Resources Laboratory, 2001). In addition the back-trajectory analysis is completed by Skiron dust simulations (Kallos et al. 2003) and satellite images, in order to identify dust episodes from Saharan regions; additionally we applied specific Scanning Electron Microscopy (SEM) single particle analysis for twelve Saharan dust events.

3 Results and Discussion

3.1 Total Particulate matter distribution over the examined period

The maximum concentrations of all size bins of particulates appear at Heraklion; namely 8.7 μg/m$^3$ in the size range between 2.5-5 μm diameter, 10.2 μg/m$^3$ between 5-10 μm, 7.7 μg/m$^3$ between 10-20μm, 4.5 μg/m$^3$ between 20-40 μm and finally 1.3 μg/m$^3$ in the size range between 40-80 μm (Fig. 1a).

3.2 Total Particle concentration for Saharan dust episodes

Our analysis showed that the maximum of the PM mass concentration during the Saharan dust episodes is mostly attributed to geometrical particle diameters from 5 to 10 μm. During almost all examined Saharan dust events (Fig. 1b) the highest concentrations of particles between 2.5 to 40 μm are found at Heraklion followed by Finokalia and Athens stations. These findings can be interpreted taking into consideration the additional load from local sources at the urban site of Heraklion against background sites at Finokalia and Athens (University Campus). Similar results concerning the contrast of particle concentrations between Heraklion and Finokalia sites have been found by Gerasopoulos et. al. (2006), who reveal that the PM$_{10}$ concentrations at Heraklion and Finokalia lie within the range found for urban and background-rural sites in the Eastern Mediterranean, respectively.

![Fig. 1. Box and whisker plots of total particle mass concentrations (November 2011-May 2013) at Heraklion (HT), Finokalia (FT) and Athens (AT) stations for (a) the whole time period without the Saharan dust events and (b) for the ten weeks of Saharan dust episodes. The bottom and top of the boxes are always the 25th and 75th percentile (the lower and upper quartiles, respectively), and the band near the middle of the box is always the 50th percentile (the median). The ends of the whiskers represent the lowest and the highest mass concentrations.](image-url)
It is difficult to assess whether or not the collected particles are locally produced or originate only from long-range transport (Saharan dust) (Gerasopoulou et al. 2006). More information and a confirmation about an additional particle load from the Saharan desert could be realized by a detailed SEM/EDS single particle analysis. The right size distribution in Athens during the ten weeks of Saharan dust episodes (Fig. 1b) indicates an increase in the levels and interquartile range for the lower size bins against higher ones; normally expected for such a long-range transport.

Fig. 2a depicts the air mass trajectories for all twelve Saharan dust episodes during the examined period, calculated at three altitudes: 500m, 1500m and 4000m AGL. An endorsed Saharan dust episode affected Crete Island and Athens on May 29, 2013 (Fig. 2b and Fig. 3), in which the dust concentration is well depicted, being transported from Libya and Egypt over the Eastern Mediterranean and especially Greece, covering an extended area. For that date a scanning electron microscope (SEM) was used to investigate the composition of individual dust grains in two different samples in Heraklion (Fig. 2c) and in Athens (Fig. 2d). The first image shows a rutile grain (TiO₂) (Fig. 2c), with a possible origin from the Saharan desert (Harris et al. 2012), while the second image presents a grain from mica from local rocks of Athens (Fig. 2d).

4 Conclusions

The performed analyses showed that the highest concentrations of all classes of total particulates with and without Saharan dust episodes appear in Heraklion. Heraklion station presents the highest mass concentration of particles between 2.5 and 80μm. During Saharan dust episodes, higher particles concentrations within the range 2.5 to 40 μm appear in Crete Island against Athens, where the range 2.5 to 10 μm dominates. The SEM analyses revealed that rutile has been found in collected samples in Crete indicating the trans-boundary transport of dust.
Fig. 3. The Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA’s Terra satellite captured this image of dust from North Africa swirling over the Mediterranean Sea on May 29, 2013. NASA image courtesy Jeff Schmaltz, MODIS Rapid Response Team at NASA GSFC. Caption by Adam Voiland. The additional dust loads from the Saharan dust event on May 29 were calculated with 80 µg at Crete and 23 µg at Athens for total particles in the size from 2.5-80 µm (average mass concentration for the sampling week from May 24 – May 31 minus average mass concentration for all non-event Saharan dust weeks from November 18, 2011 – May 31, 2013).

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Atmospheric Pollution at the University of Patras Campus during fire events

Bloutsos A., Yannopoulos P.

This study presents the levels of suspended particulate matter of diameter less than 10μm (PM_{10}) and 2.5μm (PM_{2.5}) in the atmospheric environment of the University of Patras Campus during the period from May to September 2012, when a major fire episode took place in the wider territory. The continuous measurements of PM_{10} and PM_{2.5} were carried out by the fixed air pollution monitoring station of the Environmental Engineering Laboratory of the Civil Engineering Department. During this summer period, the mean daily values for PM_{10} and PM_{2.5} concentrations were 22.2±9.8 μg m^{-3} and 13.2±5.5 μg m^{-3}, respectively, giving a ratio PM_{2.5}/PM_{10} 0.61±0.09. PM levels were affected by casual occurrences of Saharan dust and a major fire event on 18-28 of July 2012. The aim of this work is to identify and assess the effect of fire events to the air quality of the University of Patras Campus.

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1 Introduction

The airborne particulate matter (PM) is one of the most significant air pollutants (WHO 2006, EEA 2012). They consist of a mixture of solids and liquid droplets that are suspended in air with a wide range in size and chemical composition. Human health is affected mainly by the “inhalable particles” of a diameter less than 10μm (PM$_{10}$), and more specifically by the “fine particles” of diameter less than 2.5μm (PM$_{2.5}$). PM is originated by anthropogenic combustion and non-combustion sources as well as by natural sources, like sea salt emissions, re-suspended dust and Saharan transported dust (EEA 2013).

The existence of particle pollution affects both health and the environment. Health effects of the short or long term exposure to PM may be the appearance or aggravation of cardiovascular and respiratory diseases. The correlation between PM and mortality is also significant. The environmental impact may be assessed by the temporary occurrences of PM that affect visibility, climate and vegetation. In addition, building materials do not remain unaffected due to exposure to particulate pollution (WHO 2006, US-EPA 2009, EEA 2013).

Air quality standards and Guidelines (Table 1) are continuously updated according to the progress of research data (WHO 2006, US-EPA 2009, EEA 2012).

The University of Patras Campus occupies an area of 2.66 km$^2$, 12 km NNE of the city center, adjacent to Rion and at the foot of Panachaikon Mountain. It has 23 Departments with a total population of 30,000 approximately, including the University Hospital of Patras, where extensive infrastructure works, sports facilities, plantings and other significant activities take place (Pappas 2011).

Table 1. Air Quality Standards for PM$_{2.5}$ and PM$_{10}$

<table>
<thead>
<tr>
<th></th>
<th>Annual Mean (μg m$^{-3}$)</th>
<th>Daily Mean (μg m$^{-3}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PM$_{2.5}$</td>
<td>PM$_{10}$</td>
</tr>
<tr>
<td>European Union (EEA)</td>
<td>25$^1$</td>
<td>40</td>
</tr>
<tr>
<td>US Environmental Protection Agency (US-EPA)</td>
<td>12</td>
<td>-</td>
</tr>
<tr>
<td>World Health Organization (WHO)</td>
<td>10</td>
<td>20</td>
</tr>
</tbody>
</table>

$^1$ Target value entered into force 01/01/2010. Limit value enters into force into 01/01/2015
$^2$ 35 exceedances permitted per year
$^3$ Not to be exceeded more than once per year on average over 3 years
$^4$ 3 exceedances permitted per year

Every year a lot of forest fires occur in Greece and sometimes they affect suburban or urban areas and cause direct or indirect environmental impacts. Gases and particulates, carried by smoke plumes, downgrade the air quality, causing significant effects in the climate due to negative radiative forcing (Crutzen and Andreae 1990, Amiridis et al. 2012, Keywood et al. 2013) and adverse health effects (WHO 2006, WHO-UNEP-WMO 1999, Vedal and Dutton 2006).

The present study deals with the overall presentation of PM$_{10}$ and PM$_{2.5}$ concentrations measured by the Environmental Engineering Laboratory (EEL) of the Civil Engineering Department of the University of Patras during the summer period of 2012 (01/05/2012 - 30/09/2012), where three fire episodes close to Campus and several Saharan dust events occurred.

2 Data and Methodology

EEL has conducted seven air quality monitoring Programs for airborne particulates in Patras downtown (urban) areas and at the University of Patras Campus (sub-urban area). More details for these programs are given by Yannopoulos (2008). The eighth EEL Program started on April 2012 by installing a new fixed air pollution monitoring station, which is in continuous operation. The station is located at the western parking lot of the Building of the
Department of Civil Engineering (Location C2 with 21°47’22.5’’ geographical longitude, 38°17’22.5’’ geographical latitude and 60.60 m altitude above sea level). Campus inclination is 4–5% toward NW. Apart from asphalt-covered streets, the major area consists of natural soil with low vegetation, bushes, and sporadic trees, mainly pine and olive trees. The station is more than 15 m W from the 3-storey building of the Civil Engineering Department, while all other buildings are even further away. C2 is more than 1 km from the old National Road and the new Patras-Korinth Highway, while the University Hospital of Patras is located 1.5 km NE of C2. Also, more than 2 km toward the NE, there is a limited number of industrial activities of moderate size, while the local Rion-Antirrion ferry port is 3 km away to the north. C2 is free from nearby objects of any kind from the NE to SE wind sectors (i.e., for an angle of at least 247.5°). Campus air pollution originates from classic sources of a suburban-rural area, augmented by emissions due to central heating during winter and additional emissions from aforementioned activities and a cement factory operating 2-3 km NE of the Campus.

2.1 Data

The station includes an automatic analyzer of PM$_{10}$ and PM$_{2.5}$ (model Grimm 180) based on the 90° scattering light measurement principle. The analyzer records data every five minutes. These data are used to calculate daily average concentrations. The meteorological data for the present study were available by the weather station of the Department of Physics about 300 m NW of EEL station.

2.2 Methodology

The monitoring program produced a time series of 152 (out of 153 days) daily average concentrations of PM$_{10}$ and PM$_{2.5}$. Johnston et al. (2011) defined an extreme pollution event as the day on which the PM$_{10}$ concentration exceeds the 99$^{th}$ percentile of the time series. Following this reasoning for the University Campus, it is concluded that an extreme pollution event occurred at the days that concentrations were higher than the 95$^{th}$ percentile of PM$_{10}$ or PM$_{2.5}$ (35.89 and 21.62 μg m$^{-3}$, respectively). Using satellite images from AQUA/TERRA-MODIS sensors (http://rapidfire.sci.gsfc.nasa.gov) it is confirmed that the days when PM concentrations exceeded the 95$^{th}$ percentile, Saharan dust occurred. Moreover, utilizing information data that were provided by the Fire Service of Patras, we confirmed three fire episodes one of which was serious as affected the Campus. Useful characteristics of this extreme event are given in Fig.1.

![Fig. 1. The University of Patras Campus (dash dot line) and the 8.372 km$^2$–burnt areas by the 18–19$^{th}$ of July 2012’s fire episode (red area, http://ocean.space.noa.gr). Wind Charts (a) obtained by hourly values during fire event and (b) daily values May-Sep 2012 data.](image-url)
3 Results

During May-Oct 2012, the daily concentrations ranged from 6.4 to 91.3 μg m⁻³ and from 3.5 to 50.8 μg m⁻³ regarding PM_{10} and PM_{2.5} (Figure 2) with corresponding mean values of 22.2±9.8 μg m⁻³ and 13.2±5.5 μg m⁻³, respectively. These values are lower than the limit values of EEA, US-EPA and WHO (Table 1). The PM_{2.5}/PM_{10} ratio may identify PM sources, as low ratio values account for the presence of primary anthropogenic or natural matter and high values the prevalence of secondary air pollution. The daily PM_{2.5}/PM_{10} ratio ranges from 0.41 to 0.77 with a mean value of 0.61±0.09, which is comparable to those observed at Finokalia and Akrotiri sites of similar character (Table 2). PM_{10} and PM_{2.5} levels recorded at the University Campus (suburban background) were 1.97 and 1.67 times lower than Patras downtown, correspondingly, and 3 times lower than Athens downtown (Chaloulakou et al. 2003). Figure 3 shows the variation of PM_{10}, PM_{2.5} and PM_{2.5}/PM_{10} ratio for the whole period. At a typical day of the period, PM_{10} and PM_{2.5} concentrations range from 19.4 to 26.6 μg m⁻³ and from 11.2 to 14.2 μg m⁻³ with an average of 22.3±2.4 μg m⁻³ and 13.2±1.2 μg m⁻³, respectively. The PM_{2.5}/PM_{10} ratio ranges from 0.57 to 0.69 with an average of 0.61±0.04, showing insignificant diurnal variation.

The locations of the three fire events during summer 2012 are shown in Figure 1: F1 of June 28 and July 26 and F2 of July 18-28. The 28/06 and 26/07 fires were of small scale and didn’t affect daily PM levels. The fire that occurred during the 18-28th of July was more severe. It started on 02:30 (local time) of the 18th of July at the area between Argira and Sella villages and rapidly expanded to the NW. On 09:00 it approached the University Campus and the Rector ordered an evacuation. The fire came under control in the evening and continued until 28th of July with a reduced intensity. The PM_{10} and PM_{2.5} daily mean on the 18th of July was 91.3 and 50.8 μg/m³, respectively. These levels were affected by both the NW wind direction of 18/07 coming from the fire but also by the concurrent arrival of a Saharan dust event. The total area burnt by the fire was 8.372 km² (Figure 1).

![Fig. 2. Daily average values for (●)PM_{10} (○)PM_{2.5} and (▲) ratio PM_{2.5}/PM_{10}. Grey color indicates the days of forest fire episode.](image)

Table 2. Measurements of PM_{2.5}, PM_{10} and PM_{2.5}/PM_{10} at several monitoring stations

<table>
<thead>
<tr>
<th>Location</th>
<th>Site</th>
<th>Sampling Period</th>
<th>PM_{2.5} (μg m⁻³)</th>
<th>PM_{10} (μg m⁻³)</th>
<th>PM_{2.5}/PM_{10}</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>University Campus</td>
<td>SUB</td>
<td>01/05/2012-31/09/2012</td>
<td>13.2±5.5</td>
<td>22.2±9.8</td>
<td>0.61±0.09</td>
<td>Present study</td>
</tr>
<tr>
<td>Patras</td>
<td>DT-U</td>
<td>2001-2003²</td>
<td>13.9±5.7</td>
<td>39.0±3.0</td>
<td>0.39±0.04</td>
<td>Yannopoulos (2008)</td>
</tr>
<tr>
<td>Patras</td>
<td></td>
<td>01/01/2004-31/12/2004</td>
<td>38.1±4.3²</td>
<td>46±4</td>
<td>0.83±0.16</td>
<td>Yannopoulos (2008)</td>
</tr>
<tr>
<td>Patras – St. 1</td>
<td>DT-U</td>
<td>2001-2012²</td>
<td>22.1±11.1</td>
<td>41±14</td>
<td>0.55±0.16</td>
<td>Pikridas et al. (2013)</td>
</tr>
<tr>
<td>Patras – St. 2</td>
<td>UB-SR</td>
<td>01/09-12/2011</td>
<td>44±15</td>
<td>38.7±10.8</td>
<td></td>
<td><a href="http://www.ypeka.gr">http://www.ypeka.gr</a></td>
</tr>
<tr>
<td>Akrotiri</td>
<td></td>
<td>2001-2003²</td>
<td>27.9±9.2</td>
<td>28±30</td>
<td></td>
<td>Lazaridis et al. (2008)</td>
</tr>
<tr>
<td>Finokalia</td>
<td>B-R</td>
<td>09/2004-09/2005</td>
<td>18.2±16.2</td>
<td>37±54.2</td>
<td>0.58</td>
<td>Gerasopoulos et al. (2006)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>09/2005-08/2006</td>
<td>17.9±12.4</td>
<td>32.5±27.7</td>
<td></td>
<td>Theodosis et al. (2011)</td>
</tr>
</tbody>
</table>

¹ U:Urban, UB:Urban Background, SU:Sub-Urban, SUB:Sub-Urban Background, R:Rural, SR: Semi-Rural, DT:Downtown, B:Background
² summer period
The nearest front of the fire from the monitoring station was 3.5 km and the longest 6 km, approximately. The hourly average values of PM$_{10}$ and PM$_{2.5}$ ranged from 25.1 to 386.5 μg/m$^3$ and 17.4 to 157.0 μg/m$^3$, respectively, and the PM$_{2.5}$/PM$_{10}$ ratio from 0.42 to 0.78 during 18th of July 2012. The results showed a significant impact of the fire plume to the University Campus air quality.

4 Conclusions

PM$_{10}$ and PM$_{2.5}$ concentrations recorded at the University of Patras Campus during May–Sep 2012 show that the air quality is under the limits adopted by the EU. PM$_{10}$ exceeded only once the EU 50-μg/m$^3$ daily limit, while PM$_{2.5}$ exceeded twice the WHO 25-μg/m$^3$ daily limit. The fire episode near the Campus affected daily records causing limit exceedances. The situation was aggravated due to meteorological parameters and the Saharan dust events.

Acknowledgments The authors thank Professor A. Argiriou and Ms M.-Ch. Kotti of the Physics Department of the University of Patras for providing meteorological data. They thank also Mr. A. Kanavos of the Achaia Fire Service for available information.

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Pappas V (2011) The master plan of the University of Patras Campus. Chorographies 2 (1): 13-20, ISSN 1792 3913 (in Greek)

Fig. 3. Diurnal variation of (a) PM$_{10}$ and (c) PM$_{2.5}$ and (b) PM$_{2.5}$/PM$_{10}$ ratio
Simulation of physical and chemical processes of polluted air masses during the Aegean-Game airborne campaign using WRF-Chem model


The chemical and dynamic processes as well as the atmospheric composition over the Aegean Sea are investigated during two etesian days (4 and 7 July 2011) based on the on-line WRF-Chem simulations, ground and airborne measurements. Anthropogenic, on-line natural and off-line fire emissions are considered. It is shown that each one of the two Etellean patterns (strong northern winds) determine the levels and the chemical composition in the area creating differences between the two days up to 30% for gases and 50% for PM$_1$. Pollutants distribution over the eastern Aegean Sea is more homogeneous and significantly controlled by transport through the coastal and mainland Turkey. On the contrary, the southwestern part receives air masses of different origin, which are poorly simulated by the model.

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1 Introduction
The recent AEGEAN-GAME campaign integrates observations from ground stations and aircraft during an etesian outbreak over the Aegean Sea (AS). Its main objective is to characterize the chemical/physical transformations and the ultimate fate of pollutants over the AS (Tombrou et al. 2013, Bezantakos et al. 2013). The objective of the present modelling study is to investigate the ability of atmospheric models to process the dynamics and the chemical processes inside the planetary boundary layer (PBL) and in the lower-troposphere over an area where anthropogenic pollution meets natural emissions. It also aims to demonstrate how distinct patterns of the etesians determine the origin of the air masses reaching the area as well as the pollutants' distribution. The regional on-line chemical/dynamical model WRF-Chem is applied. The modelled horizontal and vertical structure, of various atmospheric parameters and concentrations species, is evaluated based on the airborne data. During this period the area was under the influence of mixed anthropogenic and biomass burning (BB) emission sources. HCN measurements conducted onboard reveal the existence of BB during the flights investigated in this study.

2 Data and Methodology
In this study, the on-line air quality model WRF-Chem (version 3.2) (Grell et al. 2005) was implemented over Europe. The numerical simulations were performed by applying triple nesting: a) the first domain covers the extended area of Europe (resolution 0.5º×0.5º), b) the second nested domain covers the extended area of Greece and Italy (0.167º×0.167º) and c) the third centred on the extended area of Greece (0.056º×0.056º). Meteorological initial and boundary conditions are provided by National Centers for Environmental Prediction (NCEP) operational Global Final (FNL) Analyses (1º×1º) every 6 hours. Simulations were performed from 29/8-9/9/2011 but results are presented for two days, 4 and 7 of September, characterised as etesian days (Tyrli and Lelieveld 2012). The chemical mechanisms considered are RADM2 for gaseous chemistry and the MADE (inorganic)/SORGAM (organic) approach for aerosols. MADE/SORGAM in WRF-Chem uses the modal approach (nuclei, accumulation, coarse). The chemical boundary conditions over the 1st domain are based on idealized profiles. The EMEP database was used for anthropogenic emissions for Europe (first and second domains) while for Greece (third domain) a national emission inventory (Ministry of Environment 2003) was used. Natural biogenic (Guenther et al. 1994) and sea-salt emissions are on-line calculated within WRF-Chem. BB emissions were also considered based on the FMI Fire Assimilation System (Sofiev et al. 2009). The height distribution of BB emissions is fixed. In order to examine the BB effect another set of simulations was performed ignoring the BB emissions.

In order to reveal different characteristics along the AS, the model results are compared along the eastern and western sector of the flight tracks. During both days, the flights involved horizontal tracks mainly at 150 m and above the aerosol layer, at 2.5 km above sea level (a.s.l.), and profiles up to 4.5 km. In order to avoid inflation that may be caused by low values of the observed quantities, the mean normalised factor bias (MNFB) (Yu et al. 2006) is used for the evaluation of the model performance. This symmetric metric is based on the factor by which the modelled and observed quantities differ (MNFB=∑Gi/N, where Gi=(M/O-1) if M≥O, and Gi=(1-O/M) if M< O).

3 Results
The patterns of the measured and modeled gaseous and aerosol species exhibited horizontal concentration gradients along the Aegean. In Fig. 1, the vertical cross-sections of the sum of
SO\textsubscript{4}, NH\textsubscript{4}, organic matter (OM), NO\textsubscript{3} and Cl (PM\textsubscript{1}) as measured by the Aerodyne compact Time-of-Flight Aerosol Mass Spectrometer (cToF-AMS) are depicted for the afternoon b641 (4 September) and b643 (7 September) flights. The HCN:CO onboard measured ratios (Fig. 1c) support the evidence of BB plumes mainly in the southern part of the b641 flight (35-36 deg). BB plumes are also detectable along the western part of the b643 flight (Fig. 1f).

During b641 flight, the measured concentrations inside the PBL are enhanced over the eastern in relation to the western part of the region. According to model simulations, the plume over the southeastern part is attributed both to industrial and BB activity over the mainland Turkey. During b643 flight, cleaner conditions prevailed over the AS, since the wind flow was less efficient in transporting air masses from the heavily polluted areas at the north-eastern Europe. The differences between the two days' concentrations, between the observed (and similarly between the modeled ones), are up to 30% for gases (CO, O\textsubscript{3}) and 50% for PM\textsubscript{1}. However, despite the low concentrations during b643, at the southwestern region, distinct aerosol layers, of different chemical composition, are evident up to 3.5 km (Fig.1). The weaker synoptic system favors the formation of successive temperature inversions over this region and the transport of air masses of different origin.

Pollutants' distribution follows the PBL structure and is successfully captured by the WRF-Chem model. In Figs. 2a,d, the vertical cross-section of the MNFB is presented for the water vapor mixing ratio along the eastern and western part of the AS for b641 flight. MNFB values lie within ±0.2 with positive values denoting model overestimation while negative ones model underestimation. The spatial distribution of this inert tracer shows that the model captures the physical processes inside the PBL. Also, the model adequately simulates the gaseous concentrations of O\textsubscript{3} and CO (not shown) with MNFB values less than ±0.2. The vertical cross-section of the MNFB for SO\textsubscript{4} (Fig. 2b,e) and NH\textsubscript{4} (not shown) follows the one of water vapor mixing ratio. For SO\textsubscript{4}, MNFB values lie within ±0.2 inside the PBL while the higher values (MNFB≥2) above the PBL, mainly over the northern AS, are probably associated with the persistent northeastern flow, that was incorrectly modeled at these altitudes (not shown). For OM, a clear model underestimation is evident up to a factor of 2.5 inside the PBL (Fig. 2c,f). The biases are related probably with underestimated primary organic emissions but also to limitations of the RADM2 mechanism regarding the treatment of SOA. Specifically, the mechanism does not include the oxidation of biogenic monoterpenes and has a limited treatment of anthropogenic VOC oxidation. Another possible source of negative bias could be linked to the emissions' chemical composition (possibly an overestimation of the fraction of unspecified PM\textsubscript{2.5}). The model underestimates the anyhow low OM (Fig. 2c,f) NH\textsubscript{4}, and EC concentrations measured over northern Aegean and above the PBL.
During b643, the physical processes are also well simulated (Fig. 3a,d), however, the weaker synoptic system during that day favours the transport of air masses from short and medium range distances therefore, the model does not always successfully captures their exact position. For example, the model overestimation of SO$_4$, OM (Fig. 3), NH$_4$ and EC (not shown) concentrations above the PBL of the northwestern part is associated with the transport of a possibly displaced plume of mixed anthropogenic and BB emissions from the neighboring Balkan region. On the contrary, the model successfully captures the BB plume eastern of Crete (Fig. 4).

The comparison of model results with ground observations at southern AS (Finokalia) reveals that the model captures the magnitude of CO observations, while a slight underestimation was found for O$_3$ and SO$_4$ (up to 20%). For the OM the underestimation was much higher up to a factor of 2 for PM$_1$ and 4 for PM$_{2.5}$. 

![Fig. 2. Altitude-latitude cross sections of the MNFB for a,d) water vapor mixing ratio, b,e) SO$_4$, c,f) OM, during 4 September 2011.](image)

![Fig. 3. As in Fig. 2 but for 7 September 2011 (flight b643).](image)

b641  b643
Fig. 4. Spatial distribution of modelled PM$_{2.5}$ concentrations and vertical cross-section of the effect of BB emissions on PM$_{2.5}$ model concentrations along eastern Aegean.

In agreement to the observations, the effect of BB on PM$_{2.5}$ (SO$_4$+NH$_4$+OM+NO$_3$+\text{primary_unspeciated}) modelled concentrations is intensified mainly over the eastern part contributing up to 6 and 4 µg m$^{-3}$ for b641 and b643 flights respectively (Fig. 4). In b641 plume, the contribution of BB emissions to SO$_4$, NH$_4$, OM and EC concentrations is 15%, 35%, 90% and 70%, respectively. In b643 plume (2 km a.s.l.), the contribution to SO$_4$, NH$_4$, OM and EC is 18%, 60%, 90% and 80%, respectively. In the rest of the AS (including the fire plume at the southwestern part of the flight) the contribution of BB emissions to SO$_4$, NH$_4$, OM and EC is less (10%, 20%, 60% and up to 40%, respectively).

4 Conclusions

This modelling study investigates the ability of atmospheric models to simulate the dynamics and the chemical processes over the AS. During the examined period the area was under the influence of anthropogenic and biomass burning sources. Physical processes are successfully simulated by the model and are proven critical for the spatial distribution of gaseous pollutants and aerosols. Model successfully captures O$_3$, CO, SO$_4$, NH$_4$ and PM$_1$ distribution while the organics’ underestimation is mainly attributed to mechanism’s limitations. Discrepancies are higher above the PBL and during weak synoptic patterns when distinct pollution layers are detected. The contribution of biomass burning emissions in PM$_{2.5}$ concentrations inside the PBL reaches up to 20% and is maximized, up to 40%, under cleaner conditions. Their contribution to EC and OM concentrations reach up to 80% and 90%, respectively.

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References

Hygroscopicity and CCN activity of aerosol in the Southeast U.S. during the SOAS/SENEX Field Campaign


The Southeast United States has not warmed as much as the rest of the US in response to climate change. This may be attributed to meteorological conditions, such as high relative humidity, cloudiness and active photochemistry, as well as interactions between high biogenic emissions mixed with the anthropogenic emissions. It has been hypothesized that anthropogenic emissions contribute to additional SOA formation to help explain the anomalous cooling in this region. During the June-July 2013 SOAS field campaign a suite of instruments were used to measure CCN activity, aerosol composition, solubility and oxidation of both ambient and water-soluble aerosol components, to investigate their difference in key aerosol properties. Concurrently CCN data were collected aboard the NOAA WP-3B during the NOAA SENEX mission. Eighteen research flights sampled biogenic sources, gas fields, power plants, and urban plumes with the scope of exploring the sensitivity of CCN activity and activation kinetics on aerosol size and chemistry, aerosol precursor sources, and plume mixing and aging. Analysis of these measurements will improve understanding of the hygroscopicity of the organic fraction in the southeastern U.S., which in turn should lead to improved predictions of total cloud droplet number concentration and regional radiative forcing.

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1 Introduction

Earth’s climate is changing as a result of the human activity that perturbs the atmospheric composition either directly (via emissions of gases or particles) or indirectly (via atmospheric chemistry) (IPCC 2013). Greenhouse gases such as carbon dioxide (CO$_2$), methane (NH$_3$), nitrous oxide (N$_2$O) and tropospheric ozone (O$_3$) warm the climate through the absorption of radiation, while aerosols are estimated to cool the surface climate as a net effect. Aerosols may affect the climate both directly through the scattering and absorption of radiation and indirectly through their ability to act as cloud condensation nuclei (CCN) and to form cloud droplets. Climate forcing agents such as ozone and aerosols are also air pollutants, making air quality and climate two issues that are intimately coupled.

Two of the main aerosol species over the U.S. are sulfate and organics. However, the extent to which the abundance of these climate forcing agents and air pollutants are controlled by natural vs. anthropogenic emissions is very poorly understood. Furthermore, the Southeast U.S. has not warmed like other parts of the U.S. in response to global climate change (Goldstein et al. 2009, Portmann et al. 2009), and the temperature anomaly has been suggested to be related to aerosols derived from a combination of biogenic and anthropogenic precursors (Leibensperger et al. 2011a,b). In lieu of that the Southeast Field Study was planned and conducted during the summer of 2013, with the goal to give answers to specific scientific questions, such as what is the composition and distribution of aerosol in the SE, what are the formation mechanisms of secondary species (ozone, sulfate and organics) and what are the climate-relevant properties of aerosol in the specific area.

2 Data and Methodology

2.1 Data

Data were collected from June-July 2013 at the ground site during the Southern Oxidant and Aerosol Study (SOAS) in Centreville, Alabama (+32° 54' 11.81", -87° 14' 59.79") which is a highly biogenic site with varying levels of anthropogenic influence, as well as aboard the NOAA WP-3B during the SENEX mission during 18 research flights which sampled diverse aerosols from different sources such as power plants, gas fields, biogenic and urban plumes. In Centerville the measurements were taken using the combination of a Particle-Into-Liquid-Sampler (PILS; Weber et al. 2001) and a thermal denuder (TD; Cerully et al. 2013) coupled with a Continuous-Flow Streamwise Thermal Gradient CCN counter (referred to hereafter as CCNc; Roberts and Nenes 2005) and a high-resolution time-of-flight aerosol mass spectrometer (referred to hereafter as High-Res AMS; DeCarlo et al. 2006). Aboard the NOAA WP-3B the measurements were taken again using another CCNc and data were combined with size-resolved non-refractory aerosol composition provided by a compact time-of-flight aerosol mass spectrometer and aerosol size distribution measurements. In both cases the CCNc was operated in Scanning Flow CCN Analysis (SFCA) mode (Moore and Nenes 2009), scanning flow rate sinusoidally from 0.2 to 0.9 L min$^{-1}$ then back to 0.2 L min$^{-1}$ over 2 minutes, resulting in a CCN spectrum between 0.1% and 0.6% supersaturation, $s$.

2.2 Methodology

The relationship between supersaturation and instantaneous flow rate was calibrated using the procedures of Moore and Nenes (2009), where ammonium sulfate solution is atomized, dried, charge-neutralized and then classified by a differential mobility analyzer (DMA) which is split between the CCNc and a condensation particle counter (CPC) giving the total number of condensation nuclei (CN). The activation ratio, or ratio of CN to CN concentration, is plotted against instantaneous flow rate and fit to a sigmoidal function. The point where half of
the total particles act as CCN corresponds to a critical flow rate. This flow rate corresponds to the known critical supersaturation, $s_c$, of the classified ammonium sulfate determined by Köhler Theory (Köhler 1936). This relationship is determined for a range of classified ammonium sulfate particles, resulting in a calibration curve.

If the instantaneous supersaturation (i.e., flow rate), $s$, in the CCNc column exceeds the critical supersaturation, $s_c$, of the aerosol, the particles activate and form droplets. This corresponds to a critical diameter, $d_{p,c}$. The $d_{p,c}$ is obtained by matching the concentration of CCN activated at a given $s$ (where $s=s_c$) with the backwards integrated SMPS number distribution (thus, the corresponding size bin and $d_{p,c}$) (described in further detail in Moore et al., 2011). These parameters are used to determine the aerosol hygroscopicity parameter, $\kappa$ (Petters and Kreidenweis 2007)

$$\kappa = \frac{4 A^3}{27 d^3 \rho S^2 c}$$

where $A=(4M_w\sigma_w)/(RT\rho_w)$, and $M_w$, $\sigma_w$, and $\rho_w$ are the molar mass, surface tension, and density, respectively, of water at the average mid-column temperature, $T$, in the CCNc (305 K). $R$ is the universal gas constant.

Total aerosol hygroscopicity can be described using a mixing rule

$$\kappa = \sum \varepsilon_j \kappa_j$$

where $\varepsilon_j$ and $\kappa_j$ are the volume fraction and hygroscopicity of species $j$, respectively (Petters and Kreidenweis 2007). Using this rule, aerosol can be further separated into its organic, $\text{org}$, and inorganic, $\text{inorg}$, contributions to the total, measured hygroscopicity, where

$$\kappa = \sum \varepsilon_j \kappa_j = \varepsilon_{\text{org}} \kappa_{\text{org}} + \varepsilon_{\text{inorg}} \kappa_{\text{inorg}}$$

Measurements of particle composition, in this case, can come from either AMS or PILS-IC measurements. Using the five ion concentrations measured by AMS, aerosol can be separated into its primarily inorganic ([NH$_4^+$], [SO$_4^{2-}$], [Cl$^-$], and [NO$_3^-$]) and organic ([Org]) mass concentrations. A typical organic density of 1.4 g cm$^{-3}$ is assumed for volume calculations (e.g., Lathem et al. 2013).

### 3 Results

The temporal variation of $\kappa$ and AMS-derived inorganic mass fraction for ambient and PILS water-soluble aerosol at $s=0.4\%$ are shown in Fig. 1. All $\kappa$ values for the SOAS study (Alabama) represent the average of all $\kappa$ values measured within a given 15 minute sampling period.

![Fig. 1. Temporal ambient (top) and PILS (bottom) $\kappa$ and AMS inorganic mass fractions for the entire study. Non-denuded and thermally-denuded measurements are indicated by color. Each point represents an average of all $\kappa$ values measured over each 15 minute sampling period.](image)
Throughout the study, the trends in ambient and PILS $\kappa$ are similar and the increase in hygroscopicity of ambient aerosol with decreasing supersaturation indicates that ambient particles have increasing hygroscopicity with size. Total (bulk) aerosol measured throughout this study was found to be nearly all water-soluble and PILS aerosol hygroscopicity is therefore expected to be representative of the bulk aerosol since PILS aerosol composition and hygroscopicity is dominated by the mass and composition of the larger sampled aerosol sizes.

Thermally-denuded aerosol hygroscopicity at the lowest supersaturation increased only slightly even after volatilization of ~35% of the total mass in the ambient aerosol, implying that aerosol volatility may impact hygroscopicity less than expected. Additionally, the organic hygroscopicity, $\kappa_{org}$, was found to decrease at increasing thermodenuder temperatures, going against the conventional idea that the highest volatility aerosol is also the least hygroscopic.

Results of a 3-factor PMF on PILS aerosol were used to perform linear regression on the PILS non-denuded $\kappa_{org}$ at $s=0.4\%$ by

$$\kappa_{org} = \epsilon_{Factor1}\kappa_{org1} + \epsilon_{Factor2}\kappa_{org2} + \epsilon_{Factor3}\kappa_{org3}$$

where the density of all organics is assumed to be equal. Factor 1, 2, 3 are representative of AMS low volatility oxidized organic aerosol (LV-OOA), semi-volatile oxidized organic aerosol (SV-OOA), and isoprene organic aerosol (Isoprene-OA) mass spectra. Results show that while the average $\kappa_{org,1}$ and $\kappa_{org,3}$ are similar at $0.17\pm0.03$ and $0.18\pm0.04$, respectively, they are approximately twice as large as the average $\kappa_{org,2}$ of $0.08\pm0.03$.

Similar to the ground site in Alabama, critical diameters and hygroscopicity of the sampled aerosol during the SENEX campaign show that aerosol in the SE U.S. is dominated by organics with a large Aitken mode peak (Figure 2). CCN activity is mostly restricted to the accumulation mode with maximum CCN activation ratios around 70%.

![Fig. 2. Aerosol hygroscopicity and size distribution of the different air masses sampled during SENEX.](image)

**4 Conclusions**

Ambient aerosol was sampled in the southeastern United States during the summer of 2013. Investigation of ambient aerosol and the water-soluble portion of it showed that ambient aerosol was found to be chemically size-resolved and the majority of the aerosol was found to be water-soluble. The low values of hygroscopicity measurements show the dominance of the organic fraction, especially in the lower particle sizes. Based on the results it was estimated that roughly 30% of the water uptake of particles is associated with these organics. At the ground site of Alabama it was found the thermally-denuded aerosol hygroscopicity increased.
only slightly even after volatilization of ~35% of the total mass in the ambient aerosol, implying that aerosol volatility may impact hygroscopicity less than expected.

Finally, the diversity of the air masses sampled during the SENEX campaign, compared to the output of the Community Atmosphere Model (CAM 5.1) show that even though the model predicts aerosol chemistry quite accurately, it does not capture the observed aerosol size. Most of the difference in the estimated droplet number is driven by a difference in aerosol number in the accumulation mode. These results (i.e. number size distributions), when included as input of the models, should lead to improved predictions of total cloud droplet number concentration and regional radiative forcing.

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References


Dry intrusion triggering explosive cyclogenesis in the Mediterranean

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The explosive cyclogenesis of Ikaria, 2004, began on the 21st of January as warm frontal cyclogenesis. When the warm front of the primary Saharan system entered the Mediterranean, it intensified under the frontogenetic influence of a synoptic scale SW – NE oriented col. The col formation was the manifestation at the surface of the upper air trough merger. The warm frontal wave of the incipient bomb emerged due to intense upper level (tropopause) forcing (Petterssen type B cyclogenesis). Widespread moist convection covered the area above the surface occluded and further east - warm fronts, as a light to moderate easterly flow ascended into the TROWAL, advecting warm and humid air. The above are clearly visible on satellite pictures. The most interesting finding, though, concerns the upper levels: the stratospheric air intrusion that triggered the incipient cyclone was a well defined dry intrusion, part of the 3D circulation of the primary Saharan low. Isentropic charts and vertical sections of this event are described and implications for cyclogenesis are discussed.

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1 Introduction

The Eastern Mediterranean explosive cyclogenesis (ECG) of January 22 2004 has been already studied by Lagouvardos et al. (2007), Pytharoulis (2008), Karacostas et al. (2010) and Brikas et al. (2012). In the latter two studies the incipient bomb is analyzed as a warm frontal wave. The importance is stressed of upper level (tropopause) forcing at this stage (Petterssen type B cyclogenesis). It is here intended to look a bit more into some aspects of the tropopause forcing of the explosive Mediterranean cyclogenesis, at its initial stage only.

Fig. 1. Left column: Infrared satellite pictures every ~ 6 h for the period 21 January 2004 00:00 – 12:00 UTC, with surface analysis overplotted. Small insets in the lower left corner are water vapour images of the area above the primary Saharan low. Right column: 300K isentropic charts or airflow relative to the Saharan system. Dry air is increasingly shaded, in terms of its mixing ratio. Dilatation axes are shown for the convergent flow at 285K. White SW – NE oriented dotted lines are vertical sections traces.

2 Large and synoptic scale features

Infrared (IR) and water vapour (WV, small insets) satellite observations, in the left column, and 300K isentropic ECMWF data, in the right column, are shown in Fig. 1 for the period 21
January 00:00 – 12:00 UTC. Surface frontal and MSLP (left only) analyses are overplotted as a reference to the synoptic situation. As a measure of low level horizontal frontogenesis, the dilatation axes of convergent 285K isentropic flow are illustrated by short segments, which are scaled by the magnitude of the resultant deformation.

Fig. 2. (left panels) Upper surface (shading): PV = 2 sfc. Lower surface: 300K isentropic sfc. Red (blue) shades show low (high) elevations. Bomb relative airflow at 300K is shown. Deep red color shows $\omega_{925-300\text{ hPa}} < -0.6 \text{ Pa/s}$. Stippling shows areas where the 300K mixing ratio is lower than 0.8 g/kg

Fig. 3. (right panels) as in Fig. 2, viewed from the ENE.

The cloud mass of the arctic front (drawn in white in Figs. 1b,d,f) covers Southern Italy, the Balkans, Ukraine and Russia and moves slowly southwards. The cloud mass of the Saharan system spirals cyclonically around the associated low center. This travels toward the ENE, with an average speed of 13 – 14 m/s. Between the two cloud masses, large scale deformation is indicated by elongated cloud elements (see for example Fig. 1c) above the Central Mediterranean, along an axis that stretches from Greece to Northern Algeria. This is the deep deformation induced by the trough merger (Lagouvardos et al. 2007). Down at the surface, upper air trough merger is manifested as a frontogenetic large scale col that forms between the highs (H) in the Biscay and the Eastern Mediterranean and the lows (L) in Algeria and Russia. The latter two are the Saharan and the arctic front lows, respectively. In terms of airflow, the northwesterly current that prevails above Europe and Northwest Africa converges with the southerly current that prevails above the southeastern part of the map. And the
surface of confluence between the two currents tilts from SE to NW with height. Apart from the satellite pictures, upper level confluence/deformation is also visible in the relative airflow pattern in the isentropic charts on the right column of Fig. 1, in the area between the arctic and Saharan systems; there is an area of light confluent winds. A bit to the south of this zone, there is another one of low level deformation (see dilatation axes in the Libyan Sea in Fig. 1b). The warm front of the occluded Saharan low is about to enter this low level ‘forcing’ zone. Indeed, when the warm front enters the frontogenetical area in the Libyan Sea (Figs. 1c,d), a small low appears on the warm front. This is the incipient Mediterranean bomb under study.

3 Dry intrusion

A dry air intrusion occurs behind the primary Saharan cold front. The cloud-free area which spirals cyclonically towards the low center is indeed occupied by very dry air, as the WV images reveal. In the charts of the relative isentropic airflow (right column of Fig. 1) dry air is in dark colors. The northern branch of the dry airstream of the occluded Saharan low can be clearly seen as a strong vortex behind the surface cold front.

To better visualize the dry intrusion, the 300K isentropic surface topography (colors) is shown in Fig. 2. A deep and quite steep cold air dome is cut off the cold air reservoir, which lies well behind the arctic front. As vorticity conservation requires, air on the cold air dome circulates cyclonically. Subtropical air in Eastern Sahara circulates anti-cyclonically and, after being enriched with moisture from the Mediterranean is squeezed between the two cold air masses and forced to ascend along the trough of warm air aloft (TROWAL). On its way, it provides the necessary warm and humid inflow to the bomb. The latter is visible as a much localized maximum of the layer – averaged (925 – 300 hPa) ascent (deep red).

From Figs. 2 and 1b,d,f it is obvious that the dry (stippling) airstream spirals cyclonically around the Saharan cold air dome, advecting dry air from aloft. As the Saharan occluded system progresses towards the Mediterranean (Figs. 1b,d), instability is generated by the superposition of the dry intrusion on the unstable marine air masses. As a result, moist convection occurs in the warm sector, as well as above the warm front (Fig. 1c). On the other hand, banded cloud masses – indicative of conditional - symmetric instability - are aligned parallel to the warm front, just to the south of the incipient bomb (Figs. 1c,e).

The upper surface of Fig. 2 is the dynamic tropopause (PV = 2 PVU surface). The tropopause above the cold Saharan air dome reaches levels as low as 600 hPa. The presence of stratospheric air so low down in the troposphere, just upstream an already convecting marine area of low stability, has important implications to the explosive cyclogenesis. Another perspective, from the east, of the topography of the same surfaces as in Fig. 2, is shown in Fig. 3.

4 Implications for cyclogenesis

In Fig. 4, vertical cross sections are drawn from the incipient bomb (left end) to the main branch of the dry airstream (right end). Their traces are shown in Fig 1. Dry air appears here increasingly shaded. The cross sections are right through the cold Saharan vortex. In accordance with the low tropo-pause, the stratosphere is warm above the vortex. Around the cold air dome wraps the polar jet. Its in/out-ward components are shown, as is the circulation that is parallel to the plane of the section.

Air in the cold dome is relatively humid, which is in consistency with its maritime history (Brikas et al. 2012). The cold front at ~12°E (see intersection of 285K with surface in Figs. 4a,b) is apparently a kata-front, with its cloud mass tilting forward and the dry intrusion air subsiding above the front. In Figs. 4a,b it can be seen that the main branch of the dry
airstream blows at ~2°E and 600 hPa and has a component into the page of ~ 30 m/s. The downward tongue of dry air is right below the southerly polar jet, which has an outward component of 18 (24) m/s at 00:00 (06:00) UTC. This is essentially the cyclonically wrapping branch of the dry airstream (compare with Figs 1b,d). Along with the dry air, this airstream also advects stratospheric air into the troposphere (see hatched area of high IPV advection) along its cyclonic flank. Initially this IPV advection is limited and at high levels (~ 300 hPa) only.

Significant changes occur at 12:00 UTC (Fig. 4c). Relative humidity above the cold air dome drops at zero and the dry air intrusion temporarily strengthens just ahead of the cold air dome. As seen in Fig. 3c, this is associated with an increase of the cold air advection (wind component down the gradient of the cold air dome). This is associated with a dramatic increase of the IPV advection in the layer from 350 to almost 600 hPa. The maximization of IPV advection along the anticyclonic flank of the ‘dry airstream’ is a hint of imbalance between the PV and the wind field.

As this PV advection takes place in a weakly stratified environment, the vorticity (not shown) immediately downstream increases dramatically. The same does the upward motion and intense convection breaks out, as can be verified from the IR image of Fig. 1e. These conditions are sufficient to support the formation of a frontal wave and the explosive deepening of the associated low.

Fig. 4. Vertical cross sections through the cold Saharan vortex (see Fig. 2 for traces). Dry air is increasingly shaded for values of relative humidity < 80%. Labeled lines: θ. Vectors: section – parallel circulation. Maximum values of wind components into and out of the page are given (m/s). Hatched area: isentropic PV advection > 3*10^{-4} PVU/s.

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Can irrigation decision support systems counterbalance the effect of increasing irrigation water prices?

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Agriculture is the largest water user in southern Europe. Climate change is affecting precipitation patterns, thereby increasing the need for irrigation both in northern and southern Europe. To safeguard agricultural production, while limiting the impact on our water resources, improvement of irrigation management is becoming increasingly more important. The European Union’s Water Framework Directive is providing an additional incentive, requiring all member states to charge water users for the financial, environmental and resource cost of water. In response to the above, the FP7 ENORASIS project has developed an integrated irrigation management decision support system that could save water and increase agricultural productivity. The aim of this study is to test the ENORASIS system at a citrus production farm in Cyprus. Hourly observations from wireless solar-powered soil moisture and meteorological sensors during the April 2013 to February 2014 growing season were analyzed to assess the efficiency of the irrigations. The first season of measurements indicate that the ENORASIS system could serve as an important tool for reducing on-farm irrigation water use.

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1 Introduction

Globally, agriculture makes use of 70% of all water withdrawn from aquifers, streams and lakes (FAO 2011). In southern Europe, agriculture uses more than half of the total national abstractions, rising to more than 80% in some countries (Eurostat 2014). Climate change is expected to stress the limited water resources of the Mediterranean countries even further, while increased precipitation variability will affect agriculture in many areas of the world (Fraser et al. 2013). Thus, irrigation is becoming increasingly more important for improving and stabilizing agricultural production.

On top of this, FAO (2011) foresees a 70% increase in the demand for food by 2050, relative to 2009, as a result of population growth and economic development. The increase in agricultural output will have to come to a large extent from intensification of agricultural production. This will require widespread adoption of sustainable land management practices, and more efficient use of irrigation water through enhanced flexibility and reliability of water supply. The application of technologies that could help crop producers achieve the highest return for the water they apply to their crops is a key issue for achieving food security and for safeguarding the sustainability of our water resources.

The European Water Framework Directive encourages the use of water charging as an incentive for the sustainable use of water resources (EC 2000). To play an effective role in enhancing the sustainability of water resources, water pricing policies need to be based on the assessment of costs and benefits of water use and consider both the financial costs of providing services, as well as the environmental and resource costs. In Cyprus, an irrigation water price increase of 40% per m$^3$ has been proposed (WDD, 2010).

In response to the above, the FP7 ENORASIS project developed a new integrated irrigation management decision support system. The system includes high-resolution, ensemble weather forecasting, a GIS widget to locate fields and sensors, and a decision support and database management system with a web and mobile app to optimize irrigation schedules. The field component includes wireless, solar-powered soil moisture sensors, small weather stations, and remotely controlled irrigation valves. The system is currently tested in research and production farms in Cyprus, Poland, Serbia and Turkey. The aim of this study is to use the ENORASIS system for analyzing the irrigation efficiency during the first season of field measurements at a citrus production farm in Cyprus.

2 Data and Methodology

The ENORASIS irrigation management system is tested in a citrus orchard in Cyprus. The orchard is located on the Akrotiri Peninsula at the southern coast of the island, at 32.95° longitude and 34.63° latitude, 8 m above sea level. The soil is a red Mediterranean clay soil (calcic and chromic-vertic Luvisols) with an organic matter content of 2% and a pH of 8.5.

The orchard was planted with Rio Red grapefruit in November 2004. Trees are planted at a spacing of 4.5 m (along the irrigation lines) by 6.25 m (between rows). The field covers 2 ha and has 768 trees. Tree canopy cover in 2013 ranged between 10 and 13 m$^2$ per tree (36-46%). The field is irrigated with mini sprinklers (120 L/hr), with one sprinkler located near the trunk per tree. The wetted diameter is approximately 3 m. Weeds (grasses) grow in between the trees. The field is mowed in March and mowed and tilled in August. Fruits are harvested in November and in February-March.

A small meteorological station (Davis) and six capacitance-based soil moisture sensors (Teknoset Ltd) were installed in the orchard on 2 and 3 April 2013. The sensors are connected to a modem, which is equipped with a sim card and powered with a 12 V 12 Ah battery and a small solar panel. All data are sent to the data server on an hourly basis and displayed in the ENORASIS web and mobile App.
Three trees were randomly selected for the soil moisture measurements. The sensors were installed below the tree canopy at approximately 90-cm from the tree trunk. To minimize soil disturbance, a hole was made with a soil auger and the sensors were inserted vertically at 15 and 40-cm depth. The observed output voltage of the sensors is a measure of the dielectric permittivity of the soil, which can be related to volumetric soil moisture content with a linear regression equation.

A total of 20 volumetric soil moisture samples were taken in June and September to calibrate the sensors. Capacitance sensors are affected by the conductivity and temperature of the soil. Rosenbaum et al. (2011) found an underestimation of the actual soil moisture at low temperatures and an overestimation at high temperatures, while the effect of conductivity was more complex. Bogena et al. (2007) showed that soil moisture content readings of a Decagon EC-5 capacitance sensor were 1 volume % higher at 30⁰ C than at 20⁰ C. Considering that the temperature range of the soil during irrigation season is not expected to be more than 10⁰ C, no temperature adjustments were made for this relatively small deviation. Similarly no conductivity adjustments were made. The soil moisture measurements captured the factory calibration quite well (soil moisture = 1.09 Voltage – 0.513). Therefore, this was what we used.

Reference evapotranspiration (ET₀) was computed using the FAO Penman-Monteith equation (Allen et al. 1998), using the daily data of the weather station. Incoming solar radiation was computed with the Hargreaves equation (Allen et al. 1998). Crop evapotranspiration (ET_c) can be computed by multiplying the ET₀ with a crop coefficient (K_c), specific to the crop and development stage.

In a comprehensive review of citrus K_c values, Carr (2012) concluded that the values provided in the FAO reference text of Allen et al. (1998) are reasonable. Villalobos et al. (2009) suggested that the wide range of citrus K_c found in the literature is due to soil evaporation, which is affected by the rainfall distribution and irrigation system, and differences in ground cover. Allen et al. (1998) give a year round value of 0.80 for an orchard with 50% canopy cover and active weeds. Without ground cover, the K_c is 0.60 during the June-September and 0.65 during the remainder of the year. Martin et al. (1997) found a K_c of 0.55 in February-March, 1.0 to 1.2 in July and 0.7 in October-November for seven-year old Redblush grapefruit trees in Arizona. However, they considered the soil water balance of the area under the effective tree cover only (3.05 x 3.05 m). Eliades (1994) conducted longterm irrigation trials on grapefruit in the southwest coastal region of Cyprus and found a K_c of 0.55 for Pan evaporation. This should give a K_c around 0.75 for ET₀.

Daily changes in soil moisture in the rootzone were computed, assuming that the sensor at 15-cm depth represents the soil moisture of the 0 to 22.5-cm soil layer and the sensor at 40-cm depth represent the soil moisture of the 22.5 to 52.5-cm soil layer. Due to lateral flow, the cross section of the wetted rootzone extends beyond the 3-m diameter wetted surface area. We assumed that the root zone wetted by irrigated had a 3.5-m diameter circular cross-sectional area (9.6 m²).

3 Results

The monthly meteorological data for the period between 4 April 2013 and 28 February 2014 are summarized in Table 1. Average daily maximum temperatures exceeded 30 ⁰C in July and August. There were a total of seven nights were the temperature above the orchard fell below 0⁰C. The coldest night was on 14-15 December, when the temperature reached -4.4⁰C. Observed relative humidities show the typical pattern of an irrigated environment, with the maximum relative humidity in the early morning always close to 100%. Wind speeds are generally mild with the exception of windy period during the second half of September and a few days in October. Total reference evapotranspiration was 1083 mm.
Table 1. Total monthly precipitation (PRCP), reference evapotranspiration (ET<sub>o</sub>), and average monthly daily minimum and maximum temperatures (T<sub>MAX</sub>, T<sub>MIN</sub>), relative humidities (RH<sub>max</sub>, RH<sub>min</sub>) and windspeed (WS) in the orchard, 4 April 2013 to 28 February 2014.

<table>
<thead>
<tr>
<th>Month</th>
<th>PRCP (mm)</th>
<th>T&lt;sub&gt;MAX&lt;/sub&gt; (°C)</th>
<th>T&lt;sub&gt;MIN&lt;/sub&gt; (°C)</th>
<th>RH&lt;sub&gt;max&lt;/sub&gt; (%)</th>
<th>RH&lt;sub&gt;min&lt;/sub&gt; (%)</th>
<th>WS (m/s)</th>
<th>ET&lt;sub&gt;o&lt;/sub&gt; (mm)</th>
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</thead>
<tbody>
<tr>
<td>Apr</td>
<td>86.6</td>
<td>22.7</td>
<td>8.7</td>
<td>93</td>
<td>52</td>
<td>1.6</td>
<td>101</td>
</tr>
<tr>
<td>May</td>
<td>1.6</td>
<td>26.9</td>
<td>12.9</td>
<td>93</td>
<td>51</td>
<td>1.3</td>
<td>137</td>
</tr>
<tr>
<td>Jun</td>
<td>0</td>
<td>28.6</td>
<td>15.1</td>
<td>92</td>
<td>56</td>
<td>1.7</td>
<td>145</td>
</tr>
<tr>
<td>Jul</td>
<td>0.2</td>
<td>30.6</td>
<td>16.3</td>
<td>92</td>
<td>54</td>
<td>1.3</td>
<td>153</td>
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<tr>
<td>Aug</td>
<td>0.4</td>
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<td>17.1</td>
<td>91</td>
<td>51</td>
<td>1.2</td>
<td>148</td>
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<tr>
<td>Sep</td>
<td>0</td>
<td>29.5</td>
<td>15.4</td>
<td>92</td>
<td>55</td>
<td>3.0</td>
<td>125</td>
</tr>
<tr>
<td>Oct</td>
<td>49.4</td>
<td>26.5</td>
<td>7.8</td>
<td>94</td>
<td>38</td>
<td>2.3</td>
<td>108</td>
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<tr>
<td>Nov</td>
<td>51.6</td>
<td>23.9</td>
<td>9.2</td>
<td>95</td>
<td>57</td>
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<tr>
<td>Dec</td>
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<td>4.6</td>
<td>90</td>
<td>53</td>
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<tr>
<td>Jan</td>
<td>56.4</td>
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<td>4.7</td>
<td>96</td>
<td>64</td>
<td>0.6</td>
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<tr>
<td>Feb</td>
<td>60</td>
<td>18.5</td>
<td>3.5</td>
<td>94</td>
<td>58</td>
<td>0.7</td>
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</tbody>
</table>

During the April to February season, 29 irrigations were applied, summing to 623 mm over the area of the field. Normally, no irrigation is applied during the winter months. However, rain during November 2013 to February 2014 was much below average. Therefore, five irrigations were also applied during these months.

The hourly soil moisture data of all six sensors during July to September are presented in Fig. 1. The figures show that there is quite some variability between the trees. As expected the soil at the 15-cm depth dries out faster than at 40-cm depth. Irrigations are generally applied before the plants will become stressed, at a soil moisture content around 30%. The lack of plant water stress can also be gleaned from the nearly straight diagonal lines, indicating that the plants take up soil moisture at the same rate, between the irrigations.

The daily change in soil moisture in the 52.5-cm deep root zone of Tree 3, together with the reference evapotranspiration (ET<sub>o</sub>), rain and irrigation is presented in Fig. 2. The figure shows that the daily evapotranspiration of the tree (plotted as negative values), is generally close to and even exceeds the reference evapotranspiration (ET<sub>o</sub>). This is more than the expected crop coefficient of 0.6-0.8 over the whole orchard area, including the dry area in between the trees. Thus there is definitely more than sufficient moisture for the transpiration of the trees.

These figures also show that the increase in soil moisture is always less than the amount of irrigation applied. This indicates that the irrigation water is moving below the 52.5-cm root zone and perhaps also further in horizontal direction. Thus, some of this applied irrigation water may get lost. Overall, the figure indicates that there is scope for reducing irrigation water use.
Fig. 1. Observed hourly soil moisture contents at 15 and 40-cm depth at three trees, irrigation and rainfall during July to August 2013 in the citrus orchard.

Fig. 2. Daily change in soil moisture in the 52.5-cm deep root zone of Tree 3, reference evapotranspiration (ET$_r$), rain and irrigation; negative values are losses.

4 Conclusions

ENORASIS, a new integrated irrigation decision support management system, has been developed by a consortium of researchers, water supply, environmental, software- and hardware companies. The ENORASIS system, including solar-powered wireless soil moisture and meteorological sensors, was tested in a citrus production farm in Cyprus during the April 2013 to February 2014 season. The soil moisture observations indicated that no plant water stress occurred during the irrigation season and that there is scope for reducing irrigation water supply. However, the results indicate that potential water savings may not be sufficient to offset proposed increases in irrigation water prices in Cyprus.

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References


Observing the Anthropocene from Space: from SCIAMACHY to GeoSCIA/Copernicus Sentinel 4, Sentinel 5, CarbonSat and SCIA-ISS

Burrows J.P.

From the beginning of the Neolithic revolution around 10000 BC and 1800 A.D., the earth’s human population is estimated to have risen from several million nomadic hunter gathers to 1 Billion rural settlement and city dwellers. This population increase and its related raising of the standard of living increase and life expectancy were fuelled by energy from the exploitation of biofuel and some use of coal. This rapid development is dwarfed by the impact of the industrial revolution over the past two centuries. There are no over 7 Billion people on earth with over half living in cities and urban areas, e.g. there are ~ 3 billion more citizens than when the author was born and 2 million more citizens than when the project SCIAMACHY (SCanning Imaging and Absorption spectroMeter for Atmospheric ChartographY) was proposed.

This industrialisation and urbanisation has been fuelled by the use of cheap energy from fossil fuel combustion. It has resulted in large scale changes in land use, air pollution, and the destruction of stratospheric ozone, the anthropogenic modification of biogeochemical cycling, the destruction of species, ecosystems and ecosystem services. In order to test our knowledge and understanding of the Earth system, accurate long term global measurements of atmospheric constituents and surface parameters are essential. The remote sounding of the atmosphere from instrumentation on satellite platforms provides a unique opportunity to retrieve regional and global observations of key trace atmospheric constituents (gases, aerosol and clouds) and surface parameters (ocean colour, ice extent, flora etc.). This talk describes results from the SCIAMACHY project and its spin offs, GOME (originally SCIA-mini - Global Ozone Monitoring Experiment), GOME-2, and their successors ESA Sentinel 4 (originally GeoSCIA), Sentinel 5, CarbonSat and SCIA-ISS.

The interpretation of the data from these instruments has provided a paradigm shift in our understanding of global atmospheric composition. In addition they deliver unique evidence for the development and verification of international environmental policy.

Fig. 1: SCIAMACHY a) schematic b) in test c) tropospheric nitrogen dioxide, NO2, in 2011.

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Long-term evolution of daily atmospheric circulation indices and types in European regions since 1850

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In this study we compare atmospheric circulation from two long datasets: the reconstructed “EMULATE” (EMSLP) dataset spanning back to 1850, and the NOAA “20th Century Reanalysis” (20CR) available since 1871. In the latter half of the 20th century, these long datasets are further compared with circulation from 6 reanalyses. Circulation is described by indices of flow strength, flow direction, and relative vorticity, calculated using mean daily sea-level pressure (SLP) fields in a 5x5 degrees latitude/longitude grid. The indices were used to classify daily circulation into pre-defined circulation types. We studied seasonal changes in the frequency of circulation types, as well as the overall and within-type changes of circulation indices. We have performed the analysis in six European regions: the British Isles, the Baltic region, Central Europe, Eastern Europe, Western Mediterranean, and Central Mediterranean. Circulation types and indices from different databases correspond with each other very well over the British Isles and Baltic region, especially in winter. The least accord is generally found in summer, particularly in the Mediterranean. The two long datasets of SLP proved useful for representing atmospheric circulation over large parts of Europe. However, some long-term trends found in one database are not always present in the others.

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Very high resolution daily precipitation and temperature projections for Cyprus: 2020-2050

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High-resolution gridded daily datasets are essential for natural resource management and the analysis of climate changes and their effects. This study aimed to create gridded datasets of daily precipitation and daily minimum and maximum temperature, both for the past (1980-2010) and the future (2020-2050). The horizontal resolution of the developed datasets is 1 x 1 km², covering the area under the direct control of the Republic of Cyprus. To create the gridded dataset for the past, observational data recorded at 145 stations for rainfall and 34 stations for temperature were used. The best fitting interpolations methods were selected from a set of 15 different techniques, based on cross-validation. Data from three different Regional Climate Models (EU ENSEMBLE project) were statistically downscaled at the station locations using a stochastic rainfall and temperature generator. The gridded dataset was subsequently created using the same interpolation methods as for the past. The resulting three datasets project a decrease of the mean annual rainfall over the study area between 5 and 70 mm for 2020-2050, relative to 1980-2010. Both mean annual minimum and maximum temperature are projected to increase between 1.2 and 1.5 °C.

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1 Introduction

Gridded datasets of meteorological variables are very useful for many applications: to evaluate and verify Regional Climate Model outputs (e.g., Maran et al. 2012), to assess the influence and relevance of climate change over a certain area (e.g., Barnett et al. 2005), and to serve as input in many hydrological studies, e.g., to validate spatial rainfall or weather generator outputs (e.g., Kilsby et al. 2007), and modeling purposes (e.g., Parkes et al. 2013). Moreover, they can be used for water resources analyses (e.g., Kizza et al. 2012) and water management applications, which are often related to agricultural activities (e.g., Supit et al. 2012). Other fields that will benefit from gridded datasets include investigations on biodiversity loss and terrestrial ecosystem studies (e.g., Avellan et al. 2012).

The aim of this study is to create daily gridded dataset of rainfall, and minimum and maximum temperature, with a horizontal resolution of 1 km², for two 31-years periods. The study makes use of observed data for the period 1980-2010, considered as the reference period, and RCMs data for both the reference and future target periods. Future time-series at the location of observations were created from the statistical downscaling of the RCMs data.

The Republic of Cyprus (Fig. 1) serves as the study area for this analysis. From a meteorological point of view, Cyprus is a very challenging island. Its overall area is not big but it has a very complex topography, which strongly affects the spatial patterns of the different meteorological variables. Meteorological variables are highly variable not only in space but also in time, with a well-defined annual cycle (Hadjinicolaou et al. 2011). Cyprus, therefore, provides an opportunity to analyze very different meteorological regimes that might be similar to those occurring in different areas around the world. Thus, our results are not restricted to the island of Cyprus, but provide insights on much larger, regional scales.

2 Data and Methodology

2.1 Data

For the period 1 January 1980 to 31 December 2010, daily rainfall and temperature time-series made available by the Cyprus Meteorological Service (CMS) were used. The rainfall database was made up of time-series recorded at 145 stations. Regarding minimum and maximum temperature, time-series from 34 stations were used.

Three Regional Climate Models (RCMs) from the EU ENSEMBLE project database (http://ensemblesr3.dmi.dk/) were selected as data sources for the period 1 January 2020 to 31 December 2050. The chosen models are all the dynamically-downscaled product of a Global Circulation Model (GCM) run under the A1B SRES emission scenario. In particular, RCMs for three different forcing GCMs were selected (Table 1).

Fig. 1. The island of Cyprus with its main physical and political characteristics. The area under the direct control of the Republic of Cyprus is located south of the buffer zone.
Table 1. The selected RCMs and the correspondent driving GCMs.

<table>
<thead>
<tr>
<th>Institution</th>
<th>Driving GCM</th>
<th>RCM</th>
</tr>
</thead>
<tbody>
<tr>
<td>CNRM</td>
<td>ARPEGE_RM5.1</td>
<td>Aladin</td>
</tr>
<tr>
<td>KNMI</td>
<td>ECHAM5-r3</td>
<td>RACMO</td>
</tr>
<tr>
<td>METO-HC</td>
<td>HadCM3Q0</td>
<td>HadRM3Q0</td>
</tr>
</tbody>
</table>

2.2 Methodology

For the interpolation of past data, 15 different interpolation techniques were tested and compared based on cross-validation and a system of scores, following the approach proposed by Hofstra et al. (2008). The resulting best interpolation techniques (different for precipitation and temperature) were then used to generate the gridded datasets. A complete and detailed description of the methods can be found in Camera et al. (2013, 2014).

Regarding the future time-span (2020-2050), RCMs outputs of daily precipitation and maximum and minimum temperature were downscaled, at the same locations where observations are available, on a monthly (precipitation) and half-monthly (temperature) basis using the change factors approach (Kilsby et al. 2007). Rainfall future time-series were subsequently generated from the calculated monthly statistics with the RainSim V3 spatial rainfall generator (Burton et al. 2008). Temperature time-series, conditioned on the dry/wet state of the day and therefore linked to the rainfall time-series, were generated using the approach of Richardson (1981), for which a code in R was developed. Finally, the same interpolation techniques, recognized as the best performing ones working with past data, were used to obtain the daily gridded datasets for the future period. Details on the downscaling process and on the used rainfall and temperature generators can be found in Camera et al. (2013).

3 Results

For precipitation, inverse distance weighting (IDW) performs best for local events, while a combination of step-wise geographically weighted regression and IDW proves to be the best method for large scale events. For minimum and maximum temperature, a combination of step-wise linear multiple regression and thin plate splines is recognized as the best method.

Data obtained for the future time-span were compared with past observations. For precipitation, analyses were made both on a station by station basis and on the whole study area using the final interpolated gridded dataset. Comparing annual averages, the CNRM and the KNMI models project a decrease of precipitation at all stations (ranging between -177 and -29 mm and -98 and -12 mm, respectively). The METO-HC model projects increasing rainfall at some stations located on the Troodos Mountains (range -48 to +56 mm). Considering the gridded database over the whole study area, all three models project a decreasing amount of rainfall over Cyprus. According to the CNRM model the expected decrease of the annual average rainfall over 31 years (comparison between 1980-2010 and 2020-2050) is around 70 mm, while it is around 40 and 5 mm for the KNMI and the METO-HC model respectively.

In Fig. 2, a comparison of the probability density functions of daily rainfall for recorded (1980-2010) and projected (2020-2050) events, at four different sites, is plotted. Independently from the projections, the form of the probability density curves, although similar, changes from station to station. The peak of probability at low daily rainfall values becomes higher and higher moving from the top of the mountains (station 270 – Troodos) to the Mesaoria Plain (station 660 – Kornos). Conversely, in the plain the tail of the distribution is shorter. These differences indicate the two different rainfall regimes. At all stations the future most probable events, according to all the RCMs used, are those characterized by a quite low daily rainfall, as for the period 1980-2010. However, these events are less
Fig. 2. Probability density functions of daily rainfall events (> 0.2 mm) at four different stations. The data compared are those recorded at the stations in the period 1980-2010, and those projected with the combination of the RCMs and the rainfall generator for the period 2020-2050.

probable than in the past. On the contrary, events with a daily rainfall between 5 and 50 mm are projected to happen more often at all the stations by all the RCMs. The highest increase in the probability of these events can be seen at the top of the mountains (station 270) and on their northern flank (station 310), the lowest at the station located in the Mesaoria Plain (station 660). In addition, except that in the Mesaoria Plain (station 660) projections usually show a longer tail compared to the observations, so revealing the possibility to observe, in the future, extreme events more intense than those already experienced in the past.

Regarding temperature, the recorded values for the period 1980-2010 were compared with those projected for the period 2020-2050 on a station by station basis and in Table 2 the average annual temperatures are presented. All three models project increasing daily minimum and maximum temperatures at all stations.

Table 2. Changes in the average annual values (hydrological years) of maximum and minimum temperature between observations (1980-2010) and future projections (2020-2050) from the downscaled three RCMs. Analysis carried out on the 34 temperature stations time-series.

<table>
<thead>
<tr>
<th>Model</th>
<th>Maximum temperature annual changes [ºC]</th>
<th>Minimum temperature yearly changes [ºC]</th>
</tr>
</thead>
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<tr>
<td></td>
<td>max</td>
<td>mean</td>
</tr>
<tr>
<td>CNRM</td>
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<td>METO-HC</td>
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4 Conclusions

The evaluation of interpolation methods of daily rainfall data indicated the importance of differentiating between large scale (frontal) and more local events. To best interpolate all the events,
we picked the average best two methods, IDW for local events and a combination of step-wise geographical weighted regression and IDW for large scale events.

Temperature presents a much smoother surface than precipitation, also for extremes, both for high and low values. Therefore, all daily values could be interpolated very well with X method.

The three downscaled datasets project a decrease of the mean annual rainfall over the study area between 5 and 70 mm for 2020-2050, relative to 1980-2010. Both mean annual minimum and maximum temperature are projected to increase between 1.2 and 1.5 °C.

The great detail of the created daily gridded (1 x 1 km²) datasets, as well as the joint analysis of past and future times with an uncertainty component represented by the three different projections, provide a very good reference for climate change impact and adaptation studies.

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References


Evaluation of WRF performance for the analysis of surface wind speeds over various Greek regions

Christakis N., Katsaounis Th., Kossioris G., Plexousakis M.

In this study we analyze the surface wind variability over selected areas of the Greek territory by comparing a 1-km-spatial resolution simulation performed with the Weather Research and Forecasting (WRF) model for the summer months of 2013 with actual measurements. Daily 48hrs runs at 12 UTC were driven by FNL (1° x 1°) data for the period of 1 June 2013 to 31 August 2013. Apart from standard verification statistics for wind speed and direction, a frequency domain comparison is carried out in order to gauge the mesoscale model performance. In addition, the performance of the newly introduced surface drag parameterization schemes is investigated.

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Modeling the East Mediterranean marine ecosystem response to the atmospheric deposition nutrient fluxes

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Atmospheric deposition of nutrients to the ocean is known to be of great importance for both carbon dioxide storage in the ocean and marine ecosystems life. The East Mediterranean is of interest for both its marine and atmospheric environment. The Mediterranean atmosphere is a cross road for air masses of distinct origin, highly affected by both natural and anthropogenic emissions into the atmosphere that strongly interact chemically, due to the high photochemical activity in the area, leading to the formation of nutrients such as nitrogen compounds. Dust aerosols from the African continent are also affecting the area as carriers of nutrients such as phosphorus and iron. Moreover, Mediterranean Sea is one of the world’s most oligotrophic ecosystems and presents an unusually high Nitrogen-to-Phosphorus analogy (N:P) in the eastern (28:1) basin.

In the present study, the impact of the inorganic N and P atmospheric deposition on the marine ecosystem in the East Mediterranean Sea is investigated by using a 1-D coupled physical/biogeochemical model. Analysis of this atmospheric nutrient supply impact on the planktonic community structure is performed. The impact of the atmospheric deposition on the N/P analogy in the seawater is investigated.

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1 Introduction

Biological pump in the sea water is controlled by the levels of nutrients. The atmospheric transport of nutrients to the ocean has been investigated for the past century and has been identified as a critical source of nutrients to the marine ecosystem (Okin et al. 2011, Krom et al. 2007, Mahowald et al. 2005, Jickells et al. 2005, Krom et al. 2004, Duce et al. 1991). Among the major nutrients for the marine ecosystems are nitrogen (N) and phosphorus (P).

After industrial revolution, human activities, largely associated with food production and fossil-fuel combustion, have greatly modified biogeochemical cycles of nutrients in terrestrial and aquatic ecosystems (Duce et al. 2008, Galloway et al. 2008). Anthropogenic reactive nitrogen deposition impact is larger in oceanic areas that are either perennially or seasonally depleted in surface nitrate, and has little effect in high nutrient, low-chlorophyll (HNLC) regions where the concentration of surface nitrate is always high. In addition to nitrogen, a recent review (Mahowald et al. 2005) suggests that there is a net loss of total phosphorus from land ecosystems and a net gain of total phosphorus by the oceans. Globally, averaged anthropogenic oceanic inputs of phosphates are estimated to be 15% and may contribute as much as 50% to the atmospheric deposition over the oligotrophic ocean, where productivity may be limited by phosphorus.

The Mediterranean Sea represents the 0.8% of the global marine area and is divided into sub-basins with different hydrological and biological characteristics. The Mediterranean Sea and especially the Eastern Basin is considered to be an ultra-oligotrophic system, in terms of both primary productivity and chlorophyll-a concentration, compared to the rest of the Mediterranean and to other oceans (e.g. North Atlantic). Its water has high nitrogen to phosphorus ratio ranging from 25 to 28, significantly higher than the normal oceanic Redfield ratio (16:1) (Kress and Herut 2001, Kress et al. 2003).

In the Eastern basin of the Mediterranean Sea, where riverine inputs are negligible or inexisten, nitrogen (mainly as nitrate, NO$_3^-$, and ammonium, NH$_4^+$) and phosphorus (as phosphate, PO$_4^{3-}$) atmospheric inputs, are believed to be the only source of nutrients in the euphotic zone of the open sea, other than the vertical mixing of water during winter.

The present study aims to assess the effect of dissolved inorganic nitrogen and dissolved inorganic phosphorus atmospheric deposition on the population distribution by the means of a one-dimension marine physical-biogeochemical model. The impact of the atmospheric deposition on the N/P analogy in the seawater is investigated.

2 Methodology - Model description

This study focuses on the oligotrophic ecosystem of the Eastern Mediterranean, using the Cretan Sea as a representative open sea area where marine and atmospheric observations are available from the M3A marine station and the Finokalia atmospheric station. The open sea character of the location in conjunction with the significant distance from the north Coast of Crete Island ensures absence of influence from land activities on the functioning of the marine ecosystem.

The model used is a coupled physical/biogeochemical 1-D water column model (Fig. 1), adapted to simulate the entire Eastern Mediterranean Basin (Christodoulaki et al. 2013). The model extends down to 1000m depth and is discretized in the vertical by 25 grids, with a finer resolution in the euphotic zone. The hydrodynamic properties of the water column (temperature, salinity and vertical diffusivity coefficient) were obtained (off-line) on a daily basis from the Poseidon (www.poseidon.hcmr.gr) operational 3-D hydrodynamic Mediterranean basin scale model (Korres et al. 2007) simulation for the year 2003.

The biogeochemical model is based on ERSEM-2004 (Blackford et al. 2004, Petihakis et al. 2002). It consists of modules describing the biological and chemical processes in the water column. It accounts for seawater stratification or mixing. The food-web representation
considers functional groups (producers, decomposers and consumers) that are further subdivided on the basis of trophic links and/or size. Model food-web has been modified from the standard configuration (Baretta et al. 1995) to represent Eastern Mediterranean ecosystem. The model accounts for the major biogeochemical processes affecting the flow of carbon, nitrogen, phosphorus and silicate. Additionally the breakdown of particulate matter and the remineralization of the dissolved matter have been modified to allow preferential phosphorus remineralization. Fluxes are introduced to the marine model to represent the atmospheric deposition based on monthly mean measurements over a five year period (Kouvarakis et al. 2001, Markaki et al. 2003), of dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP). DIN and DIP exchanges through the Sicily Straits, rivers and Black Sea Water nutrient inputs are also introduced into the marine model and have been based on in situ data for the Strait of Sicily (Krom et al. 2004). Losses due to sediment deposition and sediment denitrification are also included in the model (Krom et al. 2004). A detailed description of the model can be found in Christodoulaki et al. (2013).

Fig.1. Schematic diagram of the one-dimension physical biogeochemical ocean model and map of the Cretan Sea showing the location of the M3A oceanographic station and the atmospheric measurement station at Finokalia Crete.

3 Results

The impact of the atmospheric deposition of nutrients in the Eastern Mediterranean Sea and its effect on the primary marine productivity has been investigated. For this, two different 50-years simulations have been performed and compared. The reference simulation including atmospheric deposition is compared with a simulation where any exchange between the seawater and the atmosphere is neglected. Both simulations are initialized and forced with the same fields. The model has been run for 6 years; the first 5 years have been used as spin-up time whereas the results of the 6th year have been compared.

Fig. 2 a and b, show the overall results of the reference run for the pelagic community, after integration of the carbon fluxes and biomass stocks in the upper zone of the water column (0-100m) over the year. Heterotrophic organisms take most of their carbon from the small autotrophic organisms (pico- and nano-phytoplankton), followed by the larger ones (Dino-flagellates and Diatoms). Large quantities of carbon are recycled through bacteria that both act as phyto competitors in dissolved nutrients uptake as well as detritus consumers.
Fig. 2. Mean annual carbon fluxes (mgC/m³) and biomass stocks, within the planktonic community, integrated in the upper 100m seawater column, as computed by the 50-year simulations for the a) reference case and b) when omitting atmospheric deposition of nutrients.

Nutrients entering the seawater from the atmosphere are enhancing phytoplankton biomass in the upper 100 m of the seawater column by 16% and the bacterial biomass by 2%. Zooplankton biomass also increases when atmospheric deposition is taken into account, with microzooplankton presenting the higher increase (36%), followed by mesozooplankton (11%) and heterotrophic flagellates (6%).

The carbon budget indicates the complex microbial food web characterizing the Eastern Mediterranean's marine ecosystem, with detritus recycling being very important for the pelagic system. These results are confirmed also by in situ observations (Siokou-Frangou et al. 2010).

In the Eastern Mediterranean Basin dissolved inorganic nitrogen to dissolved inorganic phosphorus ratio (DIN/DIP) in the upper 200m of the water column increases by about 50% when the atmospheric deposition is taken into consideration in the nutrient balance of the marine ecosystem (Fig. 3). In the absence of atmospheric deposition, on a longer time of period, the system reaches a different state which is close to the Redfield ratio (16:1). Thus, suggesting that atmospheric deposition is a significant contribution to the unusually high N/P ratio observed in the basin.
4 Conclusions

For the present study a one-dimension marine physical-biogeochemical model has been used to assess the effect of dissolved inorganic nitrogen and dissolved inorganic phosphorous atmospheric deposition on the planktonic population distribution in the East Mediterranean Sea. A reference simulation has been compared with a simulation where any exchange between the seawater and the atmosphere has been neglected. This comparison shows that nutrient atmospheric deposition increases total Phytoplanktonic biomass in the upper 100m of the water column by 16% year-round. The highest effect is simulated for the small Phytoplanktonic groups. Nutrients entering the seawater from the atmosphere also enhance bacterial biomass and stimulate the recycling of large quantities of carbon through bacteria. This confirms the ecosystem complex microbial food web. When atmospheric deposition is taken into account, zooplankton biomass also increases by approximately 9%, over the year.

Moreover, in the Eastern Mediterranean Basin, DIN/DIP ratio in the upper 200m of the water column increases by about 50% due to atmospheric deposition of nutrients. Simulations show that atmospheric inputs over several decades can maintain the anomalous high N-to-P ratio measured in the East Mediterranean seawater.

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References

Supercell Storms in Northern and Central Greece

Christodoulou M., Sioutas M.

Supercell storms are severe events always accompanied by hail, lighting, gusty winds and occasionally tornadoes. They can cause significant damages to agriculture, property and infrastructure, with large economic losses. In this study, a thorough investigation of supercell storms occurred in Greece is undertaken, using a 10-year radar data of the period 2004-13. Based on specific radar reflectivity features, such as “hook echo” and “weak echo region”, a supercell definition criterion was derived. By applying this methodology, a total of 25 supercell events were identified and specific radars parameters were extracted. The majority of supercells moved from northerly and westerly directions and were discrete and isolated. The maximum number of supercells events occurred in 2009 and 2013 and the most of them were observed in June.

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1 Introduction

Severe thunderstorms are one of the most violent and dangerous weather events, capable of producing heavy rain, flash flood, intense lightning, hail, gusty winds and, sometimes, tornadoes. Supercells are highly organized severe thunderstorms with one principal deep rotating updraft and are the longest-lived form of deep convection. They are extremely powerful weather phenomena and can cause damages to extended areas, resulting to large economic losses.

In Greece, severe thunderstorms are not uncommon and in rare occasions they can exhibit supercell characteristics. Radar features include a quasi-steady structure, long lasting updraft, hook echo, weak echo region, anvil with a V-notch, particularly large dimensions and a motion that deviates from the mean winds. A supercell definition was given by Browning (1962) with considerable studies published by Marwitz (1972) and Bunkers (2006). European supercell literature includes studies of Schmid et al. (1977), House et al. (1993), while only a few exist for Greece (Christodoulou and Karacostas 2010; Sioutas et al. 2002).

In this paper, a research for the first climatology of supercells for Greece is developed, in order to understand their spatial and temporal distribution and to investigate their characteristics and their morphology.

2 Data and Methodology

The first conceptual models of supercells were developed on the basis of non-Doppler radar data and included specific features, such as: “hook echo” and “weak echo region - WER” (Browning 1977). Doppler radar observations showed that the WER is associated with vortex signatures, indicating substantial rotation of the airmass at midlevels (Donalson 1970). Based on many modeling studies, it is now generally accepted that rotating updrafts play a vital role in producing the specific storm motion and the radar features of supercells storms (Rotunno 1993).

Data from four conventional weather radars are used in this study (Fig. 1). Two of them are C-band radars located at Filyro and Liopraso and the other two are S-band radars located at the airports of Thessaloniki and Larissa. The radar positions are given in Fig. 2. The TITAN-software (Dixon and Wiener 1993) is used for storage the radar data that collected during the Greek National Hail Suppression Program. A detail analysis was undertaken in order to detect supercell storms from thunderstorms that affected Northern and Central Greece during the warm season (April–September) of each year from 2004 to 2013. In the present study supercells were identified with criteria based on radar reflectivity. Specifically, the criteria that were used to document and identify a supercell event were the following:

1. Radar maximum reflectivities equal or greater than 55 dBZ. The area denoted by the 55 dBZ reflectivity is attributed to hail and gave a good approximation of hail swath (Waldvogel et al. 1978).
2. Specific radar features in the reflectivity pattern for at least 10 consecutive minutes. Such features at low levels, often denoted as “hook echo”, “vault”, “weak echo region - WER” or “bounded weak echo region - BWER” (Fig. 1).
3. Thunderstorm long life time, greater than two hours. The criterion for the initiation and the dissipation time of a storm was the first and the last time, with radar reflectivity equal to 30 dBZ.

A supercell day is defined as a day with at least one supercell event. In the present study there were found supercell days with more than one supercell event.
3 Results

In the 10-year (2004-13) examined period and for the warm season of the year, a total of 25 supercell events were identified in 16 supercell days in Northern and Central Greece. The spatial distribution of the initiation point, termination point and tracks of supercell storms are depicted in Fig. 2. Supercell location tracking was defined by the latitude/longitude coordinate pair at the initiation and dissipation point. Spatial analysis showed that most supercells occur across Central Macedonia compared to Thessaly.

Examining the observed storm motion it was found that the majority of supercells storms (96%) moved from northerly and westerly directions (Fig. 3). Specifically, most of supercells (20%) tracked from northwest (NW) towards southeast (SE), while from each of other three directions, north-northwest (NNW), west (W) and west-southwest (WSW), moved a significant percentage (16%).

The supercells annual distribution is given in Fig. 4a, showing that the maximum number (5) of supercell events occurred in 2009 and 2013, although the maximum number (3) of supercell days was recorded in 2008 and 2011. In six (6) of these days more than one supercell events were detected.

Fig. 1. Specific radar features, “hook echo” and “bounded weak echo region”, in supercells thunderstorms on 11 July 2009 (a) and 10 June 2013 (b).

Fig. 2. Tracks of the 25 supercells thunderstorms that were observed in Northern and Central Greece during the 2004-2013 period. Each number indicates the storm_ID and the location of the initiation point. The positions of the four radars are indicated with a solid black triangle.
The monthly distribution (Fig. 4b), for the warm season of the year, indicated that June is the month with the most supercell storms (44%) and this attributes to maximum thunderstorm activity observed during May and June, according to data collected in the Greek National Hail Suppression Program.

The particular storms in some time of their life developed supercell specific features. Usually, this happened close to the time the storm reached its maximum reflectivity and maximum cloud tops. The diurnal frequencies of occurrence for the maximum characteristics and for the specific supercell features, with a resolution of 1 hour, is presented in Fig. 4c and it seems to follow the cycle of daytime heating, as well as the typical increase of thunderstorm activity throughout the spring and summer months. The peak frequency of occurrence is observed between 15:00 to 16:00 UTC.

More parameters are extracted, concerning the intensity and the motion of the supercell storm (Table 1). The maximum life time of the storms with supercell characteristics was 5.2 hours, while the mean was found to be 3.4 hours (Fig. 4d). The average distance traveled for such storms was 97.3 km and the mean speed was 28.4 km/h. The maximum reflectivity reached by a supercell was 75 dBZ, while the mean value was 66.2 dBZ. The maximum cloud tops fluctuate from 11 to 16 km, with an average at 13.3 km. Furthermore, a significant characteristic of a supercell is the large dimensions, thus why the maximum diameter of the 30-dBZ echo is examined and was found a maximum at 70 km with an average at 27.0 km.

The longevity of a supercell in combination with the strong updraft leads to an anvil which extends many kilometers ahead with a characteristic shape, namely V-notch. This “V” shaped notch on the leading edge of the cell, opening from the main downdraft, is an indication of
divergent flow around a powerful updraft. The longer anvil observed, at a level higher than 8 km, was 150 km.

**Table 1.** Characteristics of supercell storms in Northern and Central Greece.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Life time (hours)</th>
<th>Distance traveled (km)</th>
<th>Speed (km/h)</th>
<th>Max reflectiv. (dBZ)</th>
<th>Max cloud top (km)</th>
<th>Max diam. of 30 dBZ echo (km)</th>
<th>Anvil length (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min</td>
<td>2.1</td>
<td>24</td>
<td>11.4</td>
<td>55</td>
<td>11</td>
<td>17</td>
<td>44</td>
</tr>
<tr>
<td>Max</td>
<td>5.2</td>
<td>220</td>
<td>48.7</td>
<td>75</td>
<td>16</td>
<td>70</td>
<td>150</td>
</tr>
<tr>
<td>Mean</td>
<td>3.4</td>
<td>97.3</td>
<td>28.4</td>
<td>66.2</td>
<td>13.3</td>
<td>27.0</td>
<td>84.8</td>
</tr>
</tbody>
</table>

The convective mode of each supercell event was classified into one of three categories: Linear (L), Discrete (D) or Mixed (M), (Bunkers et al. 2006). For this particular study, in the linear mode, supercells were embedded in, or attached to a line of echoes (with a length to width ratio of at least 5:1). The discrete convective mode consisted of separate identifiable cells that remained distinct from one another. If a supercell event could not be classified into the linear or discrete convective mode categories, or it began as discrete and then transitioned to linear, it was considered to be in mixed mode. Furthermore, the discrete supercells can be isolated or non-isolated. A discrete supercell was considered isolated if it was separated from nearby cells by at least one storm average diameter of 30-dBZ echo (about 10 km), for time greater than 75% of its lifetime. The results showed that the most common convective mode of a supercell was the discrete one with a percentage of 76%, while the linear and mixed convective modes represent 12% each. From the discrete supercells, 68% were isolated and 32% were non-isolated.

Supercells are always associated with severe weather of some variety, such as hail, wind gusts and tornadoes. Hail reports for the days of supercell events were obtained from Hellenic Agricultural Insurance Organization (ELGA) and from a hailpad network that is dispersed in an area of Northern Greece. All of the examined supercells were accompanied by hail and in many times they produced long hail swaths and extreme agricultural damages.

### 4 Conclusions

The main goal of this work was to develop a radar climatology of supercells for Northern and Central Greece, in order to understand better their characteristics and their morphology and behaviour. The main conclusions are the following:

1. A criterion for supercell identification was suggested and 25 supercells events were identified in 16 supercell days, with the most across Central Macedonia.
2. The majority of supercells (96%) moved from northerly and westerly directions.
3. The most of supercells were discrete (76%), while the linear and mixed convective modes represent 12% of each category. From the discrete supercells, 68% were isolated and 32% were non-isolated.
4. The maximum number (5) of supercells events occurred in 2009 and 2013 and the maximum number (3) of supercell days were recorded in 2008 and 2011.
5. The most supercell storms (44%) were observed in June and developed their maximum characteristics and specific features between 15:00 to 16:00 UTC.
6. The mean characteristics of a supercell indicated life time 3.4 hours, distance traveled 97.3 km, speed 28.4 km/h, maximum reflectivity 66.2 dBZ, maximum cloud tops 13.3 km and anvil length 84.8 km.
References

An application of the numerical microclimatic model ENVI-met to evaluate thermal and bioclimatic conditions in an urban cluster with a vegetated courtyard.

Christopoulou V., Tsiros I.

Courtysards are common architectural solutions, traditionally associated with the Mediterranean region. Depending on their detailed design (geometry, vegetation presence and materials), they can be positive or negative climatic elements in the urban environment. Especially in the Mediterranean area, due to the extended use of both outdoor and semi-outdoor spaces during summertime where the urban heat island phenomenon is present, a more sustainable design becomes always a critical issue for their viability. The present study deals with microclimatic and thermal comfort conditions of a courtyard located in downtown Athens. Microclimatic conditions were estimated using the numerical microclimate model ENVI-met which integrates data from the area design, vegetation, climate, and building materials. Continuous measurements of selected microclimatic parameters were also carried out during a hot summer period and they were used to validate model simulations. Then, the model was used to evaluate design and vegetation scenarios that may improve microclimatic and bioclimatic conditions inside the courtyard and the surrounding area. It is concluded that appropriately designed semi-open spaces may function effectively as positive bioclimatic elements and may thus be integrated in a sustainable urban design context for Mediterranean climates.

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1 Introduction

It is well known that the geometry of an urban area, the choice of the building material and the surface properties of the dwellings, significantly affects its micro-climate (e.g., Johansson 2006). In this context, vegetation is considered to be one of the main strategies to mitigate the Urban Heat Island (UHI) effect, to reduce energy and improve air quality. Especially, in arid environments, the landscape planning, the composition of vegetation and water elements and also the choice of the planting material all have important consequences in creating a thermally – pleasant environment (e.g., Attia 2006).

Courtyards are common architectural solutions, traditionally associated with the Mediterranean region. In arid environments, the courtyards were used as cool reservoirs to improve the microclimate (Attia 2006). In addition to this, in warm and humid tropics, the courtyard as a passive cooling tool, may provide appropriate airflow from the courtyard to the building and improve thus indoor conditions (Rajapaksha et al. 2003). Multiple courtyards in semi-arid areas improve convective cooling and mitigate the heat load (Ernest and Ford 2012).

Outdoor conditions, however, may often be less comfortable within the courtyard than in the open surroundings depending on the orientation (Meir et al. 1995). Solar radiation and urban structure is the most important factors in determining the courtyard thermal environment (Yang et al. 2012). The correct orientation of semi-enclosed open spaces can improve their thermal behavior, while orienting them irrespective of solar angles and wind direction may create thermal discomfort in them (Meir et al. 1995). An appropriately designed vegetated courtyard is capable of functioning as a positive climatic element in urban design in the Mediterranean climate of Athens (Tsiros and Hoffman 2014).

The purpose of the present work is to evaluate the effects of vegetation and building form on the microclimate and the thermal conditions in a courtyard area and to evaluate alternative design and vegetation scenarios that may improve microclimatic and bioclimatic conditions inside the courtyard and the surrounding area.

2. Study area and methodology

2.1 Study area and data

For the purpose of the present study, an urban block with a courtyard in the city of Athens was selected. In Athens, the courtyard, as a result of regulations due to the high building density, is an irregularly shaped space, usually without plants and trees, designed mainly for daylight and ventilation to the backrooms (Tsianaka 2006). The chosen study area, however, has a vegetated courtyard and is characterized by a dense building morphology with a building of eight stores attached to the NW side of the courtyard. The courtyard has NNE orientation since it is attached to the NNE side of the two-storey building. The garden is a densely wooded area with high coverage of irrigated vegetation (more than 85% of the floor area). In the northern side is a three storey building school with front and back school’s courtyard. A detailed monitoring study inside the courtyard was carried out during the summer 2007 including continuous measurements of air temperature and humidity and sporadic measurements of wind speed and solar radiation. The present study makes use of the data reported in detail in Tsiros and Hoffman (2013). The experimental measurements of 2007 were used to calibrate an appropriate urban microclimate model in order to simulate the thermal conditions inside the courtyard.
Table 1. Weather conditions of the selected days for calibration the model recorded at NOA meteorological station (Tsiros and Hoffman, 2013).

<table>
<thead>
<tr>
<th>Date</th>
<th>Wind Speed (m/sec)</th>
<th>Wind Direction</th>
<th>RH (%)</th>
<th>Tair (ºC)</th>
<th>Tmax (ºC)</th>
<th>Tmin (ºC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30/7</td>
<td>2.6</td>
<td>NE</td>
<td>45</td>
<td>30.4</td>
<td>37.2</td>
<td>25.4</td>
</tr>
<tr>
<td>8/8</td>
<td>2.6</td>
<td>NNE</td>
<td>52</td>
<td>25.6</td>
<td>31.4</td>
<td>21.1</td>
</tr>
<tr>
<td>22/8</td>
<td>1.6</td>
<td>SW</td>
<td>49</td>
<td>30.8</td>
<td>37.2</td>
<td>25.2</td>
</tr>
</tbody>
</table>

2.2 Model parameterization

The model simulations have been carried out with the three-dimensional non-hydrostatic climate model ENVI-met Version 3.0 (Bruse and Fleer 1998). This model has been used in a number of studies to predict the thermal comfort under different design options. For model simulations, the area around the courtyard has been transformed in a model grid with the dimension 110 x 100 x 30 grids with a resolution of 1.8m x 2m x 2m resulting in a total area of 198 x 200 m in the horizontal extension. The model area is rotated 18° out of grid north. Figure 1b shows the arrangement of the model area as well as the position of the buildings, the vegetation and the reference points. The different shades of green indicate different densities of vegetation.

Model simulations were performed for 24 h starting 01:00 LST and ending 01:00 LST the day after. This is because the total running hour should be longer than 6 h to overcome the influence of the initialization. The selected simulation dates were July 30th and August 8th and 22nd. These days represent typical hot summer days in Athens. The meteorological entries are summarized in Table 1.

The experimental measurements of 2007 were used to calibrate the ENVI-Met. A variety of scenarios were then examined to evaluate the influence of vegetation and other ground surface materials on the microclimate of a courtyard.

3 Results

3.1 Measurements vs simulations

According to the monitored data the air temperature inside the courtyard on July 30th fluctuates from 26.3 to 34.ºC with an average of 32 ºC whereas the simulated air temperature fluctuates from 23.3 ºC to 32.4 ºC with an average of 29.4 ºC. On August 8th the measured air temperature varies from 24. to 31.5 ºC and the simulated from 22.2 to 30.8 ºC with an average of 27.9 ºC and on August 22nd the measured air temperature varies from 25.6 to 32.8 ºC with an average of 30.6 ºC and the simulated from 22 to 35 ºC with an average of 31 ºC. As it can be seen in fig. 2, the biggest difference is on the minimum temperature on August 22nd.
Fig. 2. Comparison of simulated and measured air temperature values (°C) for 3 different days inside the courtyard (above) and at the sidewalk of a nearby pedestrian way: 1.5 m away from the north facing street’s flanking buildings walls (North) and similarly away from the south facing walls (South) (below)

The simulation results of the study show that, in general, there is no significant difference between simulated and measured air temperature values. In addition, it is shown that the microclimatic parameters do not differ with each other despite the fact that the initial conditions were different. Furthermore, the 30/7 and 22/08 days had similar weather conditions (Table 1) but differ in wind speed and direction and the simulation results were found to be in line with this observation. In addition to this, August 8th has the same initial conditions with the July 30th, differing only in air temperature but the results do not show any discrepancy. In general, model results indicate that inside the courtyard area the micrometeorological conditions are quite stable and they are not affected, in principal, by mesoscale weather conditions. The effect of solar radiation is limited in this area due to the heavy shades of the buildings and the vegetation. The direct solar radiation acquires nonzero values between 08:00 LST and 14:00 LST. Wind speed values remain, in general, to low levels in relation to the initial conditions. The values of the mean radiant temperature are high during the morning hours and they start to decrease after 14:00 LST when solar radiation inside the courtyard is minimal.

3.2 Modeling design scenarios

Selected scenarios were examined to evaluate the influence of vegetation and ground surface materials on the microclimate of the courtyard. Figure 3 shows air temperature at 2m, PMV index (Fanger, 1972) and mean radiant temperature (Tmrt) in the study and surrounding area at 11:00 and 15:00 LST. In the first scenario all the vegetation from the courtyard has been removed and the ground surface is covered by concrete material. In the second and third scenario the vegetation is simply replaced by grass and loamy soil respectively, where it becomes clear that the vegetation has an important role in creating thermal comfort.
conditions. As shown the present situation is the best of all and only between 13:00 LST and 15:00 LST the conditions may be characterized as less comfortable since the first scenario indicates uncomfortable thermal comfort conditions during the whole daytime. The mean radiant temperature at 2m height stays in high level and it is greatly affected by the vegetation and ground surface materials in which the Tmrt is increased inside the courtyard up to 30°C. In the values of mean radiant temperature and PMV index there were not observable changes in relation to height.

4 Conclusions

The results of the present numerical study indicate that the microclimatic conditions inside a typical vegetated courtyard of an urban block are quite stable and they are not affected readily by the meso-scale prevailing weather conditions. The applied urban microclimate Envi-met model was able to predict reasonably air temperature values inside the courtyard and also at various sites close to it. It was found, however, that the model tended to underestimate air temperature values during the morning hours whereas during the afternoon hours there was a model overestimate. Furthermore, according to the examined scenarios there is a strong relationship between the vegetation and the thermal comfort conditions as expressed by the PMV index (predicted mean vote). It is concluded that the high vegetation coverage of the area has a positive affect on the thermal conditions whereas, according to the low cover vegetation scenario, vegetation does not affect the air temperature pattern at a height above ground surface.

![Fig. 3. Present situation and examined design scenarios: Patterns of air temperature at 2m height, PMV index and mean radiant temperature at 11:00 LST and 15:00 LST](image)

References


Stability of thermal conditions in Central Europe

Ciaranek D., Piotrowicz K.

This paper reports on a study of the variability of thermal conditions over a multi-year period. The study approaches the topic as a question of thermal stability and looks at the number of strings of consecutive days with the air temperature remaining within certain ranges. Thermal and percentile/quantile classification systems were used to determine specific ranges, which were then applied to records from five weather stations representing Central Europe (Potsdam, Krakow, Prague, Debrecen, Vienna) during the period 1775-2012. The study found a decrease in the numbers of strings of days with a certain temperature during the last 100 years at most of the stations. Fewer strings of days in a year means that they grew longer due to less day-to-day temperature change occurring when compared to the late 18th century and the 19th century.

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1 Introduction

Long-term air temperature and its trends of change are among the most popular research topics across the world in the context of the observed and widely debated issue of global warming (Brunetti et al. 2000, Klein Tank and Können 2003, Beniston and Stephenson 2004, Brohan et al. 2006).

Only very long and homogenous measurement records can yield reliable assessments of the variability and variability trends of thermal conditions (Jones et al. 2002). Very few such records are available in Europe and most of them represent large urban areas.

One way to increase the level of detail in climate variability research is to reverse the issue and determine trends in air temperature change by looking at its stability (persistence). If on subsequent days air temperature values remain very similar then it may be concluded that there is no change and the weather is thermally stable. Błażejczyk (1983) claims that stability is a measure of permanence of defined weather situations. This study follows his approach and investigates day-to-day changes between specifically defined bands of air temperature. It focuses on periods when the air temperature remained relatively stable for several days in a row. The permanence of such weather conditions was determined using the unbroken number of days when it prevailed as the measure.

Stability of thermal conditions is a very important factor due to its impact on the natural environment, human body and the economy. Indeed, the human adaptation mechanisms respond differently to weather with similar thermal conditions prevailing for several days than to weather when there is a radical day-to-day change in this respect.

2 Data and Methodology

Five weather stations were selected representing the urban climates of Central Europe (Table 1) and their average daily air temperature records were obtained from their archives and/or relevant national weather services; Hungarian Meteorological Service, Jagiellonian University (Poland) and Deutscher Wetterdienst (Germany). These data were also compared with records available from the on-line databases (ECA&D, OGIMET, Global Climate Data). The authors realised that it was virtually impossible to obtain a true assessment of the homogeneity of daily temperatures despite the ongoing application of homogeneity testing to data. This difficulty was taken into consideration in interpreting the results of this study (Klok and Klein Tank 2009). Findings that support the study’s validity include correlation coefficients (r) between daily air temperatures at all of the stations that were very high (0.89-0.97) and statistically significant at 0.01 (p<0.01).

<table>
<thead>
<tr>
<th>Station</th>
<th>Latitude (φ)</th>
<th>Longitude (λ)</th>
<th>H m a.s.l</th>
<th>Data periods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potsdam</td>
<td>52°38' N</td>
<td>13°07' E</td>
<td>100</td>
<td>1893-2012</td>
</tr>
<tr>
<td>Krakow</td>
<td>50°04' N</td>
<td>19°58' E</td>
<td>220</td>
<td>1792-2012</td>
</tr>
<tr>
<td>Prague</td>
<td>50°10' N</td>
<td>14°25' E</td>
<td>365</td>
<td>1775-2007</td>
</tr>
<tr>
<td>Debrecen</td>
<td>47°48' N</td>
<td>21°63' E</td>
<td>112</td>
<td>1901-2012</td>
</tr>
<tr>
<td>Vienna</td>
<td>48°25' N</td>
<td>16°37' E</td>
<td>209</td>
<td>1775-2012</td>
</tr>
</tbody>
</table>

In order to assess the variability of day-to-day temperature, or indeed its permanence, the temperatures had to be divided into defined ranges. There are a number of popular thermal classification systems that can be used for this purpose, as they determine what is the norm and what veers away from it or, in other words, anomalous and/or extreme values (Woś 2007, Piotrowicz 2010, Czarnecki and Miętus 2011). Banding of air temperatures is also used in classifications of weather types (Maheras 1984, 1989). In making the selection the authors noted that, for example, a breakdown obtained from the use of a percentile-based classification offered very similar results (−0.97, p<0.01) to those produced by a
classification based on the “three sigma” rule, i.e. taking into account long-duration average values +/- 0.5 to 2.5 standard deviation (Czarnecki and Miętus 2011). On the other hand, when comparing temperature breakdowns executed using the percentile and a thermal classification system, which was known to be the most widespread in determining weather types in Poland, it turned out that their correlation coefficient values were very low, even if statistically significant (r=±0.01, p<0.05). An added benefit of the thermal classification was that it considered not just average daily values, but also the maximum and minimum values. Eventually, the authors selected both the percentile-based system, and the thermal system (Table 2).

Table 2. Criteria for thermal and percentile (quantile) classification.

<table>
<thead>
<tr>
<th>No</th>
<th>Partition [°C]</th>
<th>Name of the days</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(t_{\text{mean}} &gt; 25.0; t_{\text{min}} &amp; t_{\text{max}} &gt; 0.0)</td>
<td>hot</td>
</tr>
<tr>
<td>2</td>
<td>(15.1 - 25.0; t_{\text{min}} &amp; t_{\text{max}} &gt; 0.0)</td>
<td>very warm</td>
</tr>
<tr>
<td>3</td>
<td>(10.1 - 15.0; t_{\text{min}} &amp; t_{\text{max}} &gt; 0.0)</td>
<td>warm</td>
</tr>
<tr>
<td>4</td>
<td>(5.1 - 10.0; t_{\text{min}} &amp; t_{\text{max}} &gt; 0.0)</td>
<td>moderately warm</td>
</tr>
<tr>
<td>5</td>
<td>(0.1 - 5.0; t_{\text{min}} &amp; t_{\text{max}} &gt; 0.0)</td>
<td>cool</td>
</tr>
<tr>
<td>6</td>
<td>(t_{\text{mean}} &gt; 5.0; t_{\text{min}}\leq 0.0; t_{\text{max}} &gt; 0.0)</td>
<td>ground-frost, moderately cool</td>
</tr>
<tr>
<td>7</td>
<td>(t_{\text{mean}} &gt; 0.1 - 5.0; t_{\text{min}}\leq 0.0; t_{\text{max}} &gt; 0.0)</td>
<td>ground-frost, very cool</td>
</tr>
<tr>
<td>8</td>
<td>(t_{\text{mean}} &gt; -5.0; t_{\text{min}}\leq 0.0; t_{\text{max}} &gt; 0.0)</td>
<td>ground-frost, moderately cold</td>
</tr>
<tr>
<td>9</td>
<td>(t_{\text{mean}} &lt; 5.0; t_{\text{min}}\leq 0.0; t_{\text{max}} &gt; 0.0)</td>
<td>ground-frost, very cold</td>
</tr>
<tr>
<td>10</td>
<td>(t_{\text{mean}} = 5.0 - 0.0; t_{\text{min}} &amp; t_{\text{max}}\leq 0.0)</td>
<td>moderately frosty</td>
</tr>
<tr>
<td>11</td>
<td>(t_{\text{mean}} = -15.0 - 5.0; t_{\text{min}} &amp; t_{\text{max}}\leq 0.0)</td>
<td>fairly frosty</td>
</tr>
<tr>
<td>12</td>
<td>(t_{\text{mean}} &lt; -15.0; t_{\text{min}} &amp; t_{\text{max}}\leq 0.0)</td>
<td>very frosty</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>No</th>
<th>Percentile classification ((t_{\text{mean}})) [%]</th>
<th>Name of the days</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&gt;95.00</td>
<td>extremely warm</td>
</tr>
<tr>
<td>2</td>
<td>90.01 - 95.00</td>
<td>anomalously warm</td>
</tr>
<tr>
<td>3</td>
<td>80.01 - 90.00</td>
<td>very warm</td>
</tr>
<tr>
<td>4</td>
<td>70.01 - 80.00</td>
<td>warm</td>
</tr>
<tr>
<td>5</td>
<td>60.01 - 70.00</td>
<td>slightly warm</td>
</tr>
<tr>
<td>6</td>
<td>40.01 - 60.00</td>
<td>normal</td>
</tr>
<tr>
<td>7</td>
<td>30.01 - 60.00</td>
<td>slightly cold</td>
</tr>
<tr>
<td>8</td>
<td>20.01 - 30.00</td>
<td>cold</td>
</tr>
<tr>
<td>9</td>
<td>10.01 - 20.00</td>
<td>very cold</td>
</tr>
<tr>
<td>10</td>
<td>5.00 - 10.00</td>
<td>anomalously cold</td>
</tr>
<tr>
<td>11</td>
<td>&lt;5.00</td>
<td>extremely cold</td>
</tr>
</tbody>
</table>

The next step was to assign each day to a specific range of temperatures (by giving it a number; Table 2). If there was no day-to-day change between ranges of temperature then this range started a string of days, which reflected the thermal permanence. Then, the number of such strings in each year of the study period was counted. The smaller the number the longer the strings and the more stable the specific kind of weather. Five types of strings of days were defined: one-day, short-duration (2-5 days), medium-duration (6-15), long-duration (16-30) and very long-duration (>30 days).

3 Results

The thermal classification was consistent in producing a lower average number of strings of days than the percentile classification at each station (Table 2).

On average, the greatest number of strings was recorded in Potsdam (146 and 190 strings) and the lowest, depending on the classification, was observed in Prague (123) or Debrecen (172 strings). The values of standard deviation of the annual number of strings of days are listed in Table 3 and show their low variability in the long-term at each station and a great deal of similarity between the two classification outcomes.
The fig. 1 and 2 show the long-term variability of the annual number of strings of days using both classification systems. It suggests a trend to decline in the number of strings of days, or an increase of the thermal stability, during the early 20th century regardless of the classification type across most of Central Europe (as represented by the weather stations adopted for the study). An increase in the number of strings when both classifications were applied to the entire data records (1775-2007) was only produced in Prague. Clearly, the trend was influenced by the very low number of strings that occurred at the turn of the 18th century and the lack of data from the last five years of the study period (2008-2012). For this reason an additional chart from Prague was also included for the period 1826-2007. In this case, both classification systems produced statistically non-significant trends of change in the number of strings and the trend produced by the thermal classification was to a decrease. In Vienna too, the trends of change differed between the classification systems and were statistically non-significant.

In view of the strong similarity between the results produced by the two classifications that are methodically so far apart a decision was taken to focus on just the percentile-based classification in looking for causes of the trend towards an increased thermal stability at most of the stations included in the study. The analysis started with the long-term variability of the number of days with the adopted temperature thresholds (i.e. days bearing code numbers 1-11 in the percentile classification; Table 2) and then looked at the variability of the number of strings overall and for each length category separately.
Table 4 shows the trend in the number of days in the ranges adopted. The greatest change in the long-duration periods analysed here occurred in the number of extremely hot (1) and extremely cold (11) days. This finding is compatible with other research by other authors, which indicates an increase in the number of hot and very hot days and a decrease in the numbers of cold and very cold days (Brunetti et al. 2000, Brohan et al. 2006, Piotrowicz 2009). Worthy of note here is also the fact that the stations with the longest measurement records, i.e. Krakow, Prague and Vienna, display a statistically significant increase in the number of days within the norm (6), i.e. with the temperature ranging from the 40.01 to the 60.00 percentile.

**Table 4.** Coefficients of the linear trend equation of the number of days with a range of air temperature determined according to the percentile-based classification system (days per 100 years).

<table>
<thead>
<tr>
<th>Number of interval in percentile classification (see Table 3)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potsdam (1893-2012); trend -12.3/100 years</td>
<td>9.4</td>
<td>4.0</td>
<td>4.5</td>
<td>-2.4</td>
<td>-0.8</td>
<td>1.3</td>
<td>-0.5</td>
<td>-5.0</td>
<td>-5.5</td>
<td>-1.9</td>
<td>-4.0</td>
</tr>
<tr>
<td>Krakow (1826-2012); trend -2.9/100 years</td>
<td>7.5</td>
<td>2.2</td>
<td>1.4</td>
<td>-1.2</td>
<td>0.0</td>
<td>6.9</td>
<td>2.0</td>
<td>-1.7</td>
<td>-4.8</td>
<td>-3.2</td>
<td>-9.3</td>
</tr>
<tr>
<td>Prague (1775-2007); trend 4.4/100 years</td>
<td>1.9</td>
<td>-0.3</td>
<td>-1.8</td>
<td>-0.8</td>
<td>2.0</td>
<td>5.9</td>
<td>1.5</td>
<td>-0.6</td>
<td>-2.2</td>
<td>-1.9</td>
<td>-4.4</td>
</tr>
<tr>
<td>Debrecen (1901-2012); trend -10.9/100 years</td>
<td>13.0</td>
<td>2.8</td>
<td>0.5</td>
<td>-2.5</td>
<td>-3.2</td>
<td>3.7</td>
<td>-3.9</td>
<td>0.1</td>
<td>-5.2</td>
<td>0.8</td>
<td>-7.0</td>
</tr>
<tr>
<td>Vienna (1865-2012); trend 0.1/100 years</td>
<td>6.4</td>
<td>3.0</td>
<td>0.9</td>
<td>-0.8</td>
<td>1.4</td>
<td>5.9</td>
<td>1.0</td>
<td>-0.2</td>
<td>-4.0</td>
<td>-3.9</td>
<td>-7.4</td>
</tr>
</tbody>
</table>

*Bold* – value statistically significant at p < 0.05

In order to explain the increase in the stability of thermal conditions the number of strings of days of different length in a year was analysed. It turned out that at stations, which displayed a clear decrease in the number of strings of days during the year (Potsdam, Krakow, Debrecen) this phenomenon was accounted for by a decrease in the number of single-day strings, while the medium (6-15) or long-duration (16-30) strings increased in frequency. The increase in the thermal stability of Prague since 1775 can, on the other hand, be explained by an increase in the number of single-day strings of days and a decrease in number of long-duration strings (16-30 days). The lack of statistically significant numbers of strings of days in Vienna was also confirmed in this part of the analysis.

A greater degree of detail about trends of thermal stability can be obtained by analysing strings of different lengths in each of the temperature ranges produced by the percentile-based classification system.

It was found that the increase in thermal stability in Potsdam, Krakow and Debrecen was a result of: (a) an increase in the number of strings of extremely hot (1) and/or anomalously hot
days (2), which occurred more frequently in strings of 2-5 and 6-15 days, (b) a decrease in the number single-day and short-duration (2-5 days) strings with anomalously cold (10) and extremely cold days (11), (c) in Potsdam, additionally, a decrease in the number of single-day strings with warm (4), normal (6) and somewhat cool days (7), while in Debrecen, additionally, a decrease in the number of single day strings with warm (4) and somewhat warm days (5), (d) in Krakow, additionally, an increase in the number of normal days (6) which formed longer types of strings (6-15).

In Prague, the increased thermal instability was explained primarily by an increase in the number of single-day strings ranging from normal (6) to very hot (3). In Vienna the lack of an apparent trend was caused by an offsetting effect that involved: (a) an increase in the number of extremely cold days (1), which mostly occurred in long strings (6-15), (b) an increase in the number of anomalously hot days (2) in short-duration strings, (c) a decrease in the number of extremely cold days (11) in strings ranging from 2 to 15 days (i.e. short and medium-duration), (d) a decrease in the number of very cold days (9) and anomalously cold days (10) in single-day strings.

4 Conclusions

This study of Central European thermal conditions has employed an extremely rare methodology that looked at their stability (permanence). By investigating very long records of daily air temperature at five weather stations representing the region’s urban environment from 1775 to 2012 it was found that at most of them the number of strings in a year decreased, which points to a growing thermal stability. The frequency of day-to-day change in air temperature has been decreasing, especially since the 1990s, when compared to the 19th century and the early 20th century. A particularly strong growth was found in extremely hot days, which formed longer strings, while extremely cold days were shrinking in numbers, with single-day strings falling in numbers, short-duration strings (2-5 days) growing in numbers and longer strings again falling in numbers.

References

Piotrowicz K (2010) Sezonowa i wieloletnia zmienność typów pogody w Krakowie. IGiGP UJ, Kraków.
Projections of potential crop yield of durum wheat in the Eastern Mediterranean and Middle East derived from the AEZ methodology and the PRECIS RCM

Constantinidou K., Hadjinicolaou P., Zittis G., Lelieveld J.

The region of the Eastern Mediterranean and the Middle East (EMME) is characterized as a climate change “hot spot”. The projected warming and drying of this region may have major consequences for both humans and natural ecosystems. One of the sectors that could be adversely impacted is agriculture and its potential implications for food security are critical for this region with increasing population, limited adaptive capacity and geopolitical sensitivity. Climate change can affect agriculture directly through meteorological conditions that influence crop growth and yield. Wheat is the most important crop cultivated worldwide. The aim of our work is to study the change in potential yield of durum wheat, an important crop for the region, due to change of mean temperature and incoming solar radiation. The climate input is obtained from simulations by the PRECIS regional climate model (RCM) over the EMME domain at a 25 x 25 km resolution, driven by the A1B moderate emissions scenario for the 20th and 21st centuries. For the crop yield calculation we utilize part of Module II of the Agro-Ecological Zones (AEZ) methodology, developed by FAO and IIASA. In particular, we calculate suitability and maximum attainable biomass and yield as determined only by radiation and temperature regimes derived from the RCM. In this study our aim is to reveal only the thermal effect on crop yields due to global warming and therefore do not take into account water availability or CO₂ fertilization (which a follow-up study will also address). The results show that the change in temperature and solar radiation projected by PRECIS leads to a decrease in potential wheat yield in the future, which confirm the overall expectations. We discuss these changes over specific sub-regions and time periods throughout the 21st century.

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1 Introduction

The region of the Eastern Mediterranean and the Middle East is the place of over 400 million population spread over an area with a 2000 km radius. After years of intense industrialization, rapid population growth and extensive conversion the region has become a global climate change “hot spot”.

The trends of the climate conditions documented by observations in the EMME indicate strong temperature increase and reduced precipitation during the 20th century (Tanarhite et al. 2012). This warming and drying is projected to intensify in the 21st century and may have major consequences for both humans and natural ecosystems (Lelieveld et al. 2012). One of the sectors that could be adversely impacted is agriculture and its potential implications for food security are critical for this region with increasing population, limited adaptive capacity and geopolitical sensitivity.

The EMME has a high biodiversity, notably of plant species, related to the large gradients in topography, soil fertility and climate conditions. During the past millennia the conversion of natural ecosystems into croplands and overgrazing have already strongly shaped the land cover. The EMME encompasses sub-regions that are very suitable for agriculture. Current climate conditions in the EMME allow for a large variety of crops, including C3 and C4 cereals, legumes and root crops (Leff et al. 2004).

Wheat is counted among the “big three” cereal crops, with over 600 million tons annual harvest (Shewry et al. 2009). Durum wheat (*Triticum turgidum*) is known as the hardest type of winter wheat that currently exists. Durum is originated in the eastern Mediterranean and has been farmed in the region for the last 12 thousand years (Key 2005). Whilst farming has spread globally, a premium is set on durum wheat quality cultivated in the Mediterranean basin and this can account for up to 75% of the world total production (Nachit et al.1998a). The major environmental constraints limiting the production of durum wheat in this region are drought and temperature extremes with productivity ranging from 0-6 tons/ha (Nachit and Elouafi 2004).

The effects of climate change on agriculture can be direct, by affecting crop production and yields. The aim of this work is to highlight the thermal effect on potential yields of durum wheat using the Agro-Ecological Zones (AEZ) methodology and regional climate projections simulated by the PRECIS RCM. Durum wheat is considered to have a growth cycle of 180 days, starting with planting on the 1st of November and ending with harvesting on the 30th of April. This crop calendar is selected because of the fact that wheat is usually cultivated in the EMME region during this period of the year, the beginning of which also coincides with the start of the rainy season in this area.

2 Data and Methodology

Calculations of potential yields of durum wheat are made using the first step of biomass and yield calculation model of Agro-Ecological Zones methodology developed by FAO and IIASA¹(Fischer et al. 2002, 2012).

This calculates the constrained-free crop yields, which reflect yield potentials with regard to temperature and radiation regimes prevailing in the respective grid cells and are based on the eco-physiological model developed by A.H. Kassam (Kassam et al.1977).²

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¹ http://webarchive.iiasa.ac.at/Research/LUC/GAEZv3.0/

²
2.1 Data

Climatic data needed as input to the biomass model are mean temperature and incoming short-wave solar radiation. These are obtained from simulations made by PRECIS RCM driven by the intermediate A1B scenario (for more details see Lelieveld et al. 2012).

PRECIS was run from 1950 to 2099 over a domain covering the EMME region at a horizontal resolution of 0.22° (~25 km) and 19 vertical levels. The domain boundaries are 22-44°N and 13-55°E latitude. The results from the simulation presented here have already been evaluated extensively and used in EMME climate change impact studies and assessments (Chenoweth et al. 2011; Lelieveld et al. 2012; Zittis et al. 2014).

The data used here are divided into four periods of time representing the past, current and future climate conditions. Baseline (BL) period used as control period is 1961-1990, first period (P1) is 2011-2040, second period (P2) is 2041-2070 and third period (P3) is 2071-2099.

2.2 Methodology

The first step done is a thermal suitability test. This test is performed using the temperature profile requirements; crop-specific rules that take into account crop growth cycle duration in different classes of mean daily temperatures (detailed description is available in Fischer et al. 2012 App. 4-3).

Potential crop calendar (November – April) of each grid box of the domain, domain for all 4 periods of time, in which the climatic data is divided into is tested for the match of crop temperature profile requirements and prevailing temperature profiles. Temperature profile conditions are tested against optimum and sub-optimum requirements of wheat (Table 1).

The calculation done here is for rain-fed conditions, because we consider only the growth cycle (L= 180 days). When the conditions are satisfied the grid box is considered suitable for cultivation of wheat, if not then the grid-boxes are marked as non-suitable. Further potential yield calculations are made only for suitable grid boxes.

Potential yield of each crop is affected by the intensity of input and management assumed to be applied (Fischer et al. 2012). In the EMME region intermediate level of input is the most appropriate choice.

Equations of the biomass and yield calculation model (AEZ methodology), which are described in details in App. 4-5 in Fischer et al. (2012), are transferred into a script in R programming language in order for the needed calculations to be performed.

<table>
<thead>
<tr>
<th>Table 1. Sub-optimum and optimum conditions for winter wheat (durum)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Crop</strong></td>
</tr>
<tr>
<td>Winter wheat (Durum)</td>
</tr>
<tr>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>

Potential yield \( Y_p \) is estimated from net biomass \( B_n \) using the equation:

\[
Y_p = H_i \times B_n \tag{1}
\]

where, \( H_i \) is the harvest index, i.e. proportion of the net biomass of a crop that is economically useful. Harvest index for winter wheat (durum) is equal to 0.35.

The net biomass production \( B_n \) of a crop is related to the incoming short-wave radiation \( (R_g) \) and the mean temperature \( (T) \) (both taken from PRECIS RCM). Hence by calculating \( B_n \) and then importing it in equation (1), the relation of potential yield \( Y_p \) with mean temperature \( (T) \) and solar radiation \( (R_g) \) can be studied.
3 Results

Projections of mean temperature and incoming short-wave radiation from PRECIS RCM (A1B emissions scenario) divided into four periods of time (BL=1961-90, P1=2011-40, P2=2041-70 and P3=2071-99) (1 November – 30 April average) are used here to calculate potential yield of durum wheat in the EMME region. Fig. 1 shows maps of changes in temperature (a) and solar radiation regimes (b) simulated for each future period compared to the baseline period (BL). The model projects an increase in temperature in the whole domain of 0.2-2.9 °C (P1-BL), 1.1-4.7 °C (P2-BL) and 2.1-6.2 °C (P3-BL). Radiation in the north-western part of the region seems to have an increasing trend in the future unlike its eastern part where the trend is decreasing.

The whole domain is tested for suitability to grow durum wheat, i.e., if optimum and sub-optimum conditions are satisfied. This is done by testing if temperature profile requirements and prevailing daily mean temperature regimes in each grid-box match. Only the subsequent suitable fields are used further for the potential yield calculations.

Yield potentials of durum wheat in the EMME region are presented in fig. 2 where results are presented only in the suitable grid-cells of the region. From this figure one can draw conclusions regarding two aspects. First, the change in suitability to cultivate durum in the future is shown. There is a shift towards the northern part of the region, which follows the trend of the agro-climatic zones. Higher temperatures simulated for the southern part of the domain lead to less suitable area to grow this specific crop, whereas higher temperatures projected for the northern part of this region, make it more suitable for cultivation.

Second aspect, is the change in potential yield in the future. The values calculated for the baseline period are compared with literature and are found within the limits of actual durum
production. As mentioned above the actual durum production in our area of interest ranges from 0-6 tones/ha (Nachit and Eliafi 2004, Habash et al. 2009). Our calculations give results in the following ranges: BL= 4030-6500 kg/ha, P1= 4460-6442 kg/ha, P2= 3970-6440 kg/ha and P3= 4040-6390 kg/ha. The outcome of the potential yield projections is variable. Overall there is a tendency for diminishing suitable areas, with the northern Africa, Sicily, Crete and Cyprus becoming, according to the calculations, unsuitable by the end of the century. Areas in Iran are becoming suitable by 2071-2099. This is due to the higher temperatures and incoming solar radiation projected for the future. Interestingly, some areas that remain suitable throughout the 21st century (mainland Greece, western Turkey) exhibit an increase of potential yield.

Fig. 2 Calculated potential yield for durum wheat.

4 Conclusions

Durum wheat is one of the most important crops cultivated in the region of the Eastern Mediterranean and Middle East. In this study we present projected changes on potential crop yields by taking into account only changes in temperature and incoming solar radiation. There is a loss of suitable areas in the southern parts of the EMME domain but also widening of the suitable areas at the eastern parts (Iran). Small increases in potential yield are projected for some areas in southeast Europe. Further work will incorporate water availability in the calculation of potential yield for a more complete assessment (thermally and water driven).

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References


Emergence and equilibration of zonal winds in turbulent planetary atmospheres

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Turbulent fluids often appear to self-organize forming large-scale zonal structures. Examples from meteorology are the midlatitude polar jet in the Earth’s atmosphere and the zonal winds in the atmosphere of Jupiter. These large-scale zonal structures are formed and also maintained by the small-scale baroclinic or barotropic turbulence with which they coexist. We present a new theory, named S3T, that explains the emergence and equilibration at finite amplitude of large-scale zonal flows in planetary turbulence. We apply this theory to make predictions for the emergence of zonal flows from a background of homogeneous turbulence as a function of parameters, in a barotropic fluid on a beta-plane. We show that the transition of a homogeneous turbulent state to an inhomogeneous state, dominated by large-scale zonal flows, occurs as a bifurcation phenomenon. We also show the accuracy of the theory by comparing its predictions to non-linear numerical simulations of the turbulent fluid. This theory provides a vehicle for studying the structural stability of large-scale atmospheric flows and can be used to determine climate sensitivity.

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1 Introduction

Spatially and temporally coherent jets are a common feature of turbulent flows in planetary atmospheres with the banded winds of the giant planets or the Earth’s polar front jet constituting familiar examples. Organization of turbulence into large-scale jets is an intriguing scientific problem in its own merit that has important consequences for every day life. In the atmosphere, the balance between the jet and its associated eddies controls the transport of heat, water vapor, trace gases and pollutants, as well as the equator to pole temperature gradient, and the location of storm tracks. Changes in its current structure can therefore have important consequences for both the regional and the global climate.

Fjørtoft (1953) noted that the conservation of both energy and enstrophy in a dissipationless barotropic flow implies that transfer of energy among spatial spectral components results in energy accumulating at the largest scales. This argument provides a conceptual basis for understanding the observed tendency for formation of large-scale structure from small-scale turbulence in planetary atmospheres. However, the observed large-scale structure is dominated by zonal jets with specific form and, moreover, the scale of these jets is distinct from the largest scale in the flow. Rhines (1975) argued that the observed spatial scale of jets in beta-plane turbulence results from arrest of upscale energy transport at the length scale $\sqrt{\beta u_s^2}$, where $\beta$ is the meridional gradient of planetary vorticity and $u$ is the root mean square velocity in the turbulent fluid. In Rhines’s interpretation this is the scale at which the turbulent energy cascade is intercepted by the formation of propagating Rossby waves.

While these results establish a conceptual basis for expecting large-scale zonal structures to form in beta-plane turbulence, the physical mechanism of jet formation, the structure of the jets, and their dependence on parameters remain to be determined.

Observations of the atmospheric circulation (Shepherd 1987) and analysis both of numerical simulations and laboratory experiments (Huang and Robinson 1998, Wordsworth et al. 2008) demonstrated that jets in 2-D planetary turbulent flows are maintained through spectrally non-local interactions rather than by cascade processes. Based on the above observations we will present a non-equilibrium statistical theory for jet formation, named S3T, in which the cascade process does not play a role (Farrell and Ioannou 2003). The S3T is also referred to as CE2 (for second-order cumulant expansion) because it is equivalently obtained by truncating the infinite hierarchy of cumulant expansions to second order (Marston et al. 2008). In S3T, jets initially arise as a linear instability of the interaction between an infinitesimal jet perturbation and the associated eddy field (cf. Bakas and Ioannou 2013), and finite amplitude jets result from nonlinear equilibria continuing from these instabilities (Farrell and Ioannou 2007, Srinivasan and Young 2012, Constantinou et al. 2013 (hereafter CFI)). Analysis of this jet formation instability determines the bifurcation structure of the jet formation process as a function of parameters. In addition to jet formation bifurcations, S3T predicts jet breakdown bifurcations as well as the structure of the emergent jets, the structure of the finite amplitude equilibrium jets they continue to, and the structure of the turbulence accompanying the jets.

2 Formulation

Consider quasi-geostrophic dynamics on a barotropic, doubly periodic, beta plane, $(x,y) \in [0,L_x] \times [0,L_y]$. The beta plane is a Cartesian approximation of the surface of a planet at midlatitudes with $x$ being in the zonal (latitudinal) direction and $y$ in the meridional direction. In the absence of forcing and dissipation potential vorticity is conserved, while in the presence of both forcing and dissipation it obeys:

$$\dot{\psi} + J(\psi) + \nabla \times \mathbf{F} = \mathbf{R} + \sqrt{f} \quad (1)$$
This will be referred to as the nonlinear system (NL). The Jacobian term \( J(A,B) \equiv (\partial_x A)(\partial_y B) - (\partial_x B)(\partial_y A) \) represents advection of the absolute vorticity by the velocity field. Linear drag is included with coefficient \( r \), which in geophysical applications represents Ekman dissipation. Term \( f \) is an external forcing that parameterizes processes absent in the dynamics (i.e. cascade of energy from baro-clinic to barotropic eddies or convection) and it is modeled here as homogeneous random stirring delta-correlated in time. The amplitude of the excitation is controlled through \( \varepsilon \). Inclusion of this term is necessary in this barotropic framework in order to sustain turbulence. The relative vorticity of the fluid is \( \zeta = \Delta \psi \), where \( \Delta \equiv \partial_{xx} + \partial_{yy} \) is the horizontal Laplacian, and \( \psi \) is the streamfunction. Zonal and meridional velocities are respectively: \( u = \partial_y \psi \) and \( v = \partial_x \psi \).

For the construction of the theory we proceed as follows:

1. We write (1) as a system for the evolution of the zonal-mean flow, \( U = \mathcal{E}_{1}^{\infty} \) and eddy vorticity \( \zeta' = \zeta - \zeta \). Zonal mean quantities are indicated with a bar or capitals and all deviations from the zonal mean (referred to also as eddies) with primes. The nonlinear interactions in the NL equation (1) are of three types (shown in Fig. 1): two eddies interact to form a mean flow (type (a)), the mean flow interacts with an eddy to produce a distorted eddy (type (b)), and two eddies interact to form another eddy (type (c)). Type (c) interactions redistribute energy among the various eddies and are responsible for the familiar cascade process that fills the eddy energy spectrum. We will neglect type (c) interactions and consider the dynamics that result when only type (a) and type (b) interactions are included. The equation for the evolution of the zonal-mean,

\[
\partial_t U = v' \zeta' - r U ,
\]

contains nonlinear interactions of only type (a) and is retained as is, while retaining only type (b) interactions in the evolution equation for the eddies we obtain

\[
\partial_t \zeta' = A(U) \zeta' + \sqrt{\varepsilon} f ,
\]

with \( A(U) = -U (\partial_x (\beta_x \partial_y U) \partial_y A^{-1} - r ) \). This nonlinear system is the quasi-linear (QL) system associated with the above NL. QL has the advantage that the turbulence associated with it produces without approximation a closure at second order (a CE2).

2. We consider an ensemble of eddy realizations over the latitude circle, characterized by the eddy spatial vorticity covariance between points \( x_o = (x_o, y_o) \) and \( x_p = (x_p, y_p) \) of the flow, \( C_{\alpha\beta}(t) \equiv \mathcal{C}(x_o, x_p, f) = \exp\left\{ \iota \frac{\beta_x}{2} \frac{(x_p-i x_o)}{2} \right\} \) (brackets denote ensemble average over realizations of the stochastic excitation \( f \)). Taking the ensemble average of (2b) we obtain the covariance evolution equation:

\[
\partial_t C_{\alpha\beta} = [A_x(U) + A_y(U)] C_{\alpha\beta} + \varepsilon C_{\alpha\beta} ,
\]

with \( A_x(U) \) evaluated at points \( x_o \).

\[ \Xi(x, x_p) \] is the spatial covariance of the forcing under the assumption that the forcing field has zero mean and satisfies \( \mathcal{C}(x_o, t_1) \mathcal{C}(x_p, t_2) = \Xi(x_o, x_p) \delta(t_1-t_2) \).

Note that while \( f \) is temporally delta-correlated, it will be assumed that it has a finite spatial correlation. Here we consider cases with \( \Xi = \Sigma_k k^2 \cos[k(x_o-x_p)] \exp[-(y_o-y_p)^2/(2s^2)] \) and \( s=0.02L \).
3. Under the ergodic assumption that the ensemble average is equal to the zonal average, $\frac{\partial}{\partial t} U = \frac{1}{2} \left[ (\partial_x^{-1} + \partial_x^{-1}) C_{ab} \right]_{a=b} \bar{r}_m U$, forming in this way with (3a) a closed, autonomous, fluctuation-free deterministic dynamical system for the evolution of the mean flow $U$ and its associated second order eddy statistics $C$. It constitutes a second order closure (a CE2) for the turbulent state dynamics and is referred to as the S3T system. Note that mean flow $U$ may be dissipated with coefficient $r_m$ which may be different from the damping coefficient of the eddies. This asymmetric damping can be regarded as a model for approximating jet dynamics in actual baroclinic flows in which the upper level jet is lightly damped, while the active baroclinic turbulence generating scales are strongly Ekman damped (for discussion cf. CFI).

The equilibrium solutions of the S3T system, denoted as $(U^*, C^*)$, define stationary statistical states of the turbulent flow. These turbulent equilibria comprise of a zonal mean flow, $U^*$, and of its second-order eddy statistics, $C^*$. When these equilibria are stable they correspond to statistically steady states of the flow. When they become unstable as a parameter changes, structural instability of the turbulent state occurs and the system bifurcates to a new regime. Such abrupt reorganizations can be seen in both observations and in general circulation models of the Earth’s atmosphere and have been proposed to provide a mechanism for abrupt climate change (Farrell and Ioannou 2003, Wunsch 2003).

3 Emergence of jets out of homogeneous turbulence

The NL system (1) for low values of the stochastic excitation amplitude, $\varepsilon$, produces a turbulent state that is homogeneous with no jets. As we increase the forcing amplitude jets emerge at some critical excitation amplitude. The jets are at first weak but as $\varepsilon$ increases the jets equilibrate to higher amplitude. The ratio of the zonal-mean flow energy $E_n = \int U^2 \, dy$ over the total energy of the flow $E = (L_x L_y)^{-1} \int \int (\frac{1}{2} (u^2 + v^2) \, dy \, dx$ measuring the relative strength of the jets, is plotted for this NL experiment as a function of $\varepsilon$ in Fig. 2. This figure suggests that a bifurcation phenomenon may underlie the symmetry breaking of the homogeneous state and the emergence of jets. The QL system (2) reproduces the behavior of the NL, as can be seen from Fig. 3. This shows that the cascade process, which is absent in the QL system, is not responsible for jet formation in this problem. The S3T system will now be used to make predictions for the emergence of jets and also make predictions for their equilibrated amplitudes. The homogeneous equilibrium $(U^*=0, C^*=\varepsilon \Xi/(2r))$ is always an equilibrium solution of the S3T system (3). However, this equilibrium becomes unstable at a critical value $\varepsilon_c$. At this forcing amplitude the S3T dynamics predict that the homogeneous equilibrium is no longer tenable and the flow bifurcates to a flow with jets.

When such stability analysis is performed for the specific forcing we obtain that the $\varepsilon_c$ predicted by S3T stability is precisely the value for which jets start emerging in both the NL.
and QL simulations (see Fig. 2). It can be seen that both predictions of S3T for the critical $\epsilon_{c}$
and also for the final equilibrium amplitude of the jets are very accurately reflected in sample NL and QL integrations.

![Image](image-url)

**Fig. 3.** Hovmöller diagrams of jet emergence in NL, QL and S3T simulations with typical non-isotropic forcing at $\epsilon_{c}/\epsilon_{c} = 20$. Shown are $U(y,t)$ for the (a) NL, (b) QL and (c) S3T simulations and (d) the equilibrium jets in the NL (dash-dot), QL (dashed), and S3T (solid) simulations. It can be seen that S3T predicts the structure, growth and equilibration of immoderately forced jets in both the QL and NL simulations. Other parameters as in Fig. 2. (Adapted from CFI, © 2013 AMS.)

4 Conclusions

We have shown that jet emergence in planetary atmospheres is a bifurcation phenomenon that can be fully analyzed and accounted by S3T. S3T shows that jets emerge from a cooperative instability of the interaction between an ensemble of turbulence realizations with the mean flow in the absence of turbulent cascades. This instability is a cooperative instability of the statistical dynamics of the turbulence and is accurately represented in the S3T system, which comprises a second-order cumulant closure of the full statistical dynamics of the turbulent flow. S3T also predicts the formation of jets at finite amplitude. We have shown that sample integrations of the nonlinear equations shadow the predictions about the statistics of the turbulence that are obtained from S3T.

In general, S3T provides the dynamics of the first two moments of the climate of a planet and can be used to obtain understanding of the structural stability of the present climate state to parameter changes. In this study we have verified that S3T can accurately predict abrupt transition to a different climate state, which is chara-cterized by another zonal state.

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References


Cloud-screening algorithm and determination of clear sky solar irradiance and cloud properties in the island of Lampedusa

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A cloud-screening algorithm has been applied to surface solar irradiance measurements to derive information on the sky conditions at Lampedusa island, Italy, in the Central Mediterranean. Data acquired in 2007 by means of an Eppley Precision Spectral Pyranometer (PSP) have been used in this study. Clear sky days characterized by low aerosol optical depth (AOD) have been first identified based on co-located measurements of the aerosol optical depth obtained with a Multi Filter Rotating Shadowband Radiometer (MFRSR). For these days the measured irradiances were fitted with an empirical function in order to estimate a reference curve for low AOD. The ratio between actual observations and the reference irradiance for low AOD, R, and its standard deviation $\sigma_{M}$, were calculated. Another empirical algorithm was also applied to surface solar irradiance measurements and the cloud optical thickness (COT) has been estimated. The method can be used to estimate surface solar radiation and COT at the specific site.

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1 Introduction

Understanding the effects of clouds and aerosols on solar radiation is very important since these two parameters are among the main factors affecting the incoming solar radiation at the Earth’s surface. A simple way of quantifying these effects is to compute the difference between the measured irradiance (under all-sky conditions) and the one expected under clear sky.

Surface solar irradiance measurements in cloud-free conditions are fitted with empirical formulas to derive reference clear-sky irradiances (Barnard and Long 2004). The produced fits can be used to obtain estimations of clear-sky total, diffuse, and direct shortwave irradiances. These empirical formulas, based on the fit to experimental data, are instrument-dependent and should be derived at each specific site.

In the present study, we apply the Long and Ackerman (2000) formula to the global shortwave irradiance measurements collected at Lampedusa island, which is one of the hot spot world areas in terms of current and future climate change (IPCC 2007). In a subsequent step, the empirical formula by Barnard et al. (2008) is applied in order to derive the cloud optical thickness (COT). The daily averaged COT values are presented and discussed.

2 Data and Methodology

The ENEA (National Agency for New Technologies, Energy, and Sustainable Economic Development of Italy) Station for Climate Observations at Lampedusa (35.5°N, 12.6°E) is operational since 1997. The station is equipped with a large variety of instruments to derive and monitor atmospheric parameters, including cloud occurrence and optical properties. In the present analysis we use measurements of surface shortwave irradiance in the spectral range 0.28 – 2.8μm, obtained with Eppley Precision Spectral Pyranometers (PSP) (Di Biagio et al. 2009) in the period from 1 March to 31 August 2007. This period was chosen in order to allow future comparisons of the outputs of the algorithm with satellite data and model radiative fluxes. Details of the cloud screening and the COT estimation algorithms are provided in the following.

At first, an algorithm that uses only measurements of PSP irradiance at the site of Lampedusa was implemented in order to detect cloud-free and cloudy periods. The dataset consists of 1-minute calibrated irradiances referred to the mean Sun-Earth distance. Based on pyranometer and MFRSR measurements, cloud-free days characterized by mean daily AOD at 500 nm lower than 0.2 were identified. For these days, the measured shortwave irradiance is fitted with the expression (Long and Ackerman 2000):

\[ I_{SW}(\theta) = A \cdot (\cos(\theta))^B \]  

(1)

where \( \theta \) is the solar zenith angle, \( A \) is a constant representing the clear-sky irradiance for a solar zenith angle of 0° and includes residual effects from water vapour and aerosols. \( A \) depends on the radiometer calibration, while \( B \) includes effects of the radiometer cosine response. In a first step, only measurements at solar zenith angles smaller than 60° were used as suggested by Harrison et al. (1997) since at these angles the algorithm performs better. More specifically, 154 hours of global irradiance under clear sky conditions for spring, and 243 for summer, were used, respectively.

In the second part of the analysis, the COT has been derived from PSP global irradiance measurements, applying the formula proposed by Barnard et al. (2008). The expression for empirical COT is:

\[ COT_{empirical} = \left( \frac{C_1 - 1}{r} \right) \frac{(1-A_{total})}{(1-g)} \]  

(2)
where $C_1$ is a fitting constant (1.16) determined by trial and error (Barnard et al. 2008). $A_{\text{ground}}$ is the broadband surface albedo and $g$ the cloud droplet or ice particle asymmetry factor. The parameter $r$ is defined by

$$r = \frac{T}{I_{SW} \mu_0^{1/4}} \quad (3)$$

where $T$ (in W/m$^2$) is the measured total irradiance, $\mu_0$ is the cosine of solar zenith angle.

The surface shortwave albedo was set to 0.09, the average value obtained from the monthly mean albedos estimated by Di Biagio et al. (2009), considering the contributions of both sea and land at the measurement site.

3 Results

The values of constants $A$ and $B$ in Eq. 1 were obtained by applying a linear regression fit to the irradiances of 10 clear sky days in spring and 17 in the summer period (Fig. 1). The spring average values are $A = (1119.7 \pm 11.4)$ W/m$^2$ and $B = (1.20 \pm 0.03)$, with a $R^2$ value of 0.998. The corresponding values for summer are $A = (1081.9 \pm 26.0)$ W/m$^2$, $B = (1.22 \pm 0.04)$ and $R^2 = 0.999$. The regression coefficients are determined using a least square estimation that minimizes the sum of absolute deviations. Subsequently, Eq. 1 was used to compute the pristine values of $I_{SW}$ for spring and summer days. The number of clear-sky days is shown in Fig. 2a (larger in summer than in spring), whereas the fitted curves for solar zenith angles smaller than 60° are shown in Fig. 2b separately for spring and summer.

![Fig. 1. Scatterplot comparison between fitted and measured surface solar irradiances at Lampedusa island for 10 spring days (left) and 17 summer days (right) of year 2007. The total number of 1-minute data and the computed correlation coefficients are shown.](image)

![Fig. 2. (a) Number of clear sky days at the site of Lampedusa (left y-axis) and their percentage of occurrence in each month (right y-axis). (b) Fitted (red symbols) and measured (black lines) global solar irradiance for two representative clear sky days (see section 2) in spring and summer of 2007 at Lampedusa.](image)
The application of the empirical algorithm (Eq. 2) to the shortwave irradiance data of 6 months resulted in the estimated daily mean cloud optical thickness values that are shown in Fig. 3. Note that this formula is applicable strictly to overcast days. To ensure this we removed from our analysis the COT values that were less than 1.5. The algorithm operates satisfactorily for both optically thick and thin ice clouds (Barnard et al. 2008) and therefore the value of asymmetry factor (g) in Eq. 2 was set equal to 0.815. According to our results, days with optical thickness smaller than 5 are predominant. Nevertheless, there are also days with mean COT values up to about 25 which are attributed to thick clouds. During these days, the surface SW irradiance drops down to 100-200 W/m², i.e. decreases by as much as 500 W/m² with respect to non cloudy days. A good anti-correlation between calculated COT and measured irradiance is found; the correlation coefficient is 0.82. As shown in Fig. 4, most days are characterized by COT values up to 15, but there are also days (about 20%) with COTs between 15 and 30.

![Figure 3](image1.png)

**Fig. 3.** Time series of estimated daily mean COT above Lampedusa for spring and summer of 2007 (top) and corresponding measured shortwave (SW) global irradiance (bottom).

![Figure 4](image2.png)

**Fig. 4.** Percentage of frequency distribution of estimated 1-minute cloud optical thickness values above 1.5 for spring and summer of 2007 in Lampedusa-island.
4 Conclusions

We presented the implementation of simple algorithms, which use only global shortwave irradiance measurements, to empirically derive the clear sky surface solar irradiance, and to calculate the cloud optical thickness. The COT values mainly range from 4 to 28 with larger values in spring than in summer. The method is applied to measurements made at Lampedusa island during the spring and summer of 2007. According to our results:
1. The clear sky SW irradiance can be successfully estimated using the Long and Ackerman (2000) methodology.
2. The COT retrieval can be applied to the SW irradiance measurements performed in numerous stations across the world, providing a large and useful database to check and validate radiative transfer modules of climate models. Preliminary comparisons have given encouraging results (e.g. correlation coefficients larger than 0.7).
3. Further development of our results may include a multi-annual analysis of Lampedusa SW irradiance database and a statistical discrimination among optically thin and thick cloud occurrence.

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References

Simulation of Marine Boundary Layer Evolution in the Aegean Sea during Etesians

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In order to study the marine boundary layer evolution over the Aegean Sea, the Weather Research and Forecast mesoscale model is implemented, using seven Planetary Boundary Layer (PBL) parameterization schemes: two ‘first-order’ non-local schemes and five ‘one-and-a half order’ local schemes. Model predictions are evaluated against airborne observations performed with the UK Facility for Airborne Atmospheric Measurements BAe-14 research aircraft during the AEGEAN-GAME field campaign. Given that the definitions and the criteria used for calculating the PBL depth are not the same among the PBL schemes, their results greatly diverge during both stable and unstable conditions. Preliminary intercomparison results show that PBL values range from 0.8km up to 1.8km over the western Aegean Sea region. Statistical analysis showed good agreement between measured and calculated values for all schemes as far as air temperature, humidity and wind direction are concerned. The wind speed varied from 14m/s to 20m/s at 150m altitude and all schemes reached the limit of Index of Agreement but not of Bias and Root Mean Square Error. Differences between the schemes should be taken into account because they may impact/influence the air quality simulations.
1 Introduction

Marine atmospheric boundary layer (MABL) is the part of the troposphere directly influenced by the presence of the ocean's surface where large amounts of heat, moisture, and momentum, primarily are exchanged via turbulent transport (Fairall et al. 1996). As a result, it plays an important role not only for surface energy and moisture fluxes, but also in global cloudiness and the earth’s radiation balance (Bretherton and Park 2009).

Due to the difficulty of directly measuring the air-sea interaction processes, numerical simulations, which use different planetary boundary layer (PBL) parameterization schemes, are widely used to estimate interface fluxes, exchange parameters, the thermodynamic structure of MABL in the vertical etc. These schemes usually adopt different assumptions regarding the transport of mass, moisture, and energy, which may lead to differences in the boundary layer and subsequently the whole model domain (Hu et al. 2010). The selection as well as the accuracy of the PBL scheme is critical in forecasting local thermally and mechanically driven flows and air quality, while it affects forecasts of larger-scale meteorological phenomena (Hacker and Snyder 2005).

In the present study, seven PBL parameterization schemes are applied in order to study the evolution of MABL over the Aegean Sea (AS) during Etesians (strong northeasterly winds), representing a very common synoptic regime during summer in Greece. The model’s results are evaluated against airborne observations.

2 Methodology and Data

For the numerical simulations, the non-hydrostatic Advanced Research WRF (ARW) meso-scale meteorological model (Skamarock et al. 2008) (http://www.wrf-model.org/index.php) is implemented, using seven PBL parameterization schemes. In particular, two ‘first-order’ closure schemes were applied: the Yonsei University (YSU) (Hong et al. 2006); the Asymmetric Convective Model version 2 (ACM2) (Pleim 2007a,b) and five ‘one-and-a half order’ closure schemes: Mellor-Yamada Janjic (MYJ) (Janjic 1990); Bougeault–Lacarrère (BOULAC), (Bougeault and Lacarrère 1989); Quasi-Normal Scale Elimination (QNSE), (Sukoriansky et al. 2005); Mellor-Yamada-Nakanishi-Niino (MYNN2.5), (Nakanishi and Niino 2006); University of Washington (UW) (Bretherton and Park 2009). From the above-mentioned schemes, YSU and ACM2 are non-local while the rest are local.

The PBL-computation method is not the same among the seven PBL schemes examined in this work. For example, the PBL depth in YSU and ACM2, under unstable conditions, is determined based on the bulk Richardson number (Hong et al. 2006, Pleim 2007b, Shin and Hong, 2011). In MYJ and QNSE schemes, the PBL depth is defined according to a turbulent kinetic energy (TKE) lower bound (Janjic 2002, LeMone et al. 2013) while the MYNN2.5 and BOULAC schemes determine PBL depth from thermal profile (LeMone et al. 2013). Finally, the UW scheme calculates the PBL depth up to an entrainment interface, at which the turbulent diffusivity is computed from an explicitly predicted entrainment rate (Bretherton and Park, 2009). Consequently, the calculated PBL depths greatly diverge among the examined PBL schemes, during all atmospheric conditions, despite the fact that they may present marginal differences in atmospheric boundary layer structure.

The initial, lateral and boundary conditions for the numerical simulations were obtained from the National Centers for Environmental Prediction (NCEP) operational Global Final (FNL) Analyses (1.0°×1.0° spatial resolution). The sea surface temperature (SST) data were obtained from the Real-Time Global SST (RTG_SST) analysis data (0.5°×0.5° spatial resolution). Land use and soil category data sets including 24 land use categories and 16 soil categories (US Geological Survey; USGS) were used as input to WRF's pre-processor static data.

The WRF numerical simulations were performed by applying triple nesting with the first domain covering the extended area of Europe (0.5°×0.5° spatial resolution), the second nested
domain covering the extended area of Greece and Italy (0.167º×0.167º) and the third centered on the extended area of Greece (0.056º×0.056º). In the vertical axis, 35 full sigma levels resolve the atmosphere (model top at 50hPa), with a finer resolution near the surface; the first level was at about 10m above ground level (agl).

A single continuous simulation was performed for the 2-week period of the AEGEAN-GAME field campaign over the AS (i.e., from 29/8 to 9/9 2011), excluding the spin-up days. The model predictions are evaluated against airborne observations performed with the UK Facility for Airborne Atmospheric Measurements BAe-14 research aircraft during the AEGEAN-GAME field campaign. In the present study, three selected flights (b640, b641 performed on 4 September 2011 and b643 on 7 September 2011) that involve low-level measurements (up to 5km) (Bezantakos et al. 2013; Tombrou et al. 2013) are presented.

3 Results

The 4th and 7th of September 2011 were typical Etesian days (strong-channeled northeasterly surface winds over the AS with measured wind speeds exceeding 15m/s at 150m above sea level and gusts over 20m/s). The relative strong winds favor near neutral atmospheric conditions, with most stable conditions observed over the central AS on 4 September and unstable conditions over the southeastern AS on 7 September. On 4 September, almost all schemes are in accordance with wind airborne observations, but on 7 September, all schemes underestimate wind speed (average calculated values up to 10m/s). The simulated lower wind speeds on 7 September resulted in lower PBL depth values (e.g. up to 500m agl in southwestern AS, MYJ scheme) compared to those calculated on 4 September.

Preliminary intercomparison results show that QNSE and MYJ schemes (TKE lower bound) predict the higher PBL depth values (Fig.1e,c), while UW scheme (entrainment interface) the lower ones (Fig. 1b). In particular, on the 4th of September at 13:00 UT (flight b641) QNSE scheme calculates PBL depth values up to 1.8km over the western AS region (Fig. 1e), while UW scheme lower values, up to 0.8km (Fig. 1b). Almost all schemes calculate lower PBL depth values in the eastern AS and higher in the western AS (Fig. 1), which is in accordance with the measurements (Tombrou et al. 2013), except from MYNN2.5 scheme that calculates a uniform field (Fig. 1d). In Fig. 1, three selected flight vertical paths are also presented.

The lower calculated PBL depth values over the eastern AS can be attributed mainly to the cold SST current, coming from the Black Sea, which results in a more stable MABL compared to the western areas. These low SST values, in combination with the high potential

Fig. 1. PBL depth (m) agl as calculated by a) BOULAC b) UW c) MYJ d) MYNN2.5 e) QNSE f) YSU, g) ACM2 PBL schemes, on 4 September 2011 at 13:00 UT (flight b641). The numbers indicate the position of three selected flight vertical paths.
temperature values calculated in the east (not presented), lead to negative sensible heat flux values (e.g. -30W/m² in the northeastern AS, flight b641), which is in agreement with measurements. Positive sensible heat flux values are calculated in the northwestern AS (up to 60W/m² by ACM2 scheme, flight b640) while negligible values are simulated in the central AS on flight b641 by all schemes (not presented), in accordance with the measurements. The calculated ‘Bowen ratio’ of sensible to latent heat flux is small (ranging from -0.1 in the southeastern AS up to 0.15 to the northwestern AS; data not presented). The positive values (~0.1) assign buoyancy ratio of about 0.4 which corresponds to 30% buoyancy production by humidity fluxes (Emeis 2011).

The friction velocity fields, in general agree with the simulated surface wind speed fields, with higher values calculated by all schemes on 4 September than on 7 September. In particular, the higher values (up to 0.9m/s) are calculated by the ACM2 scheme (flight b641 south of Crete), compared to the other schemes (not presented). During flight b640, the calculated values are higher than the measurements (differences up to 0.4m/s), while at the other two flights the predicted values agree with measurements (except from QNSE and ACM2 schemes that over predict on flight b641).

Water vapor mixing ratio flight vertical paths show that the measured MABL extends up to ~400m in the southeastern AS (Fig. 2a) and ~650m in the southwestern AS (Fig. 2c), which is well captured by the MYJ scheme. In the northern Aegean Sea, the observed MABL is high, up to 900m, and is well captured by almost all schemes except from QNSE and ACM2 schemes (Fig. 2b).

**Fig. 2.** Selected water vapor mixing ratio (g/kg) vertical paths as measured and calculated at a) point 1 b) point 2 and c) point 3, on 4 September 2011 (flight b641).

Model evaluation using statistical analysis, following the model-evaluation benchmarks suggested by Tesche et al. (2001) and Emery et al. (2001), for all schemes showed in general good agreement between measured and calculated values as far as air temperature, humidity and wind direction are concerned. Regarding the wind speed, all schemes reached the limit of Index of Agreement (IA≥0.6) but not the limit of Bias and Root Mean Square Error.

**4 Conclusions**

Regarding the PBL depth, preliminary intercomparison results show that QNSE and MYJ schemes predict the highest values while UW scheme the lowest ones. All schemes (except MYNN2.5 scheme) calculate lower PBL depth values in the eastern AS and higher in the western AS. The measured and calculated MABL is a) higher in the northern AS than in the south and b) higher in the southwestern AS than in the southeast. Differences between the schemes should be taken into account because they may lead to possible consequences for air quality simulations.

**Acknowledgments** This work was supported by the EUFAR Integrating Activity (227159) funded by the EC under FP7.
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Global Oxidant and Organic Aerosol sensitivity to biomass burning emission inventories.

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The present study investigates the sensitivity of atmospheric Organic Aerosol (OA) and oxidant simulations to the use of different biomass burning emission inventories, as well as different injection height of the fire emissions in the global chemistry-transport model TM4-ECPL. The 3 different inventories for biomass burning emissions (ACCMIP, GFEDv3 and ECLIPSE) have been investigated with regard to their impact on the calculated tropospheric budgets of ozone (O₃) and OA. Simulations have been evaluated for O₃ against observations from the EMEP monitoring network. Global OA simulations are further evaluated using the AEROCOM (Aerosol Comparisons between Observations and Models) OA database. Preliminary results show large impact of the different emission inventories on the concentrations of organic carbon, while smaller impacts are observed on O₃ and CO load. Global lifetimes of main pollutants do not seem to be affected by the use of different emission datasets, but lifetimes of CO, organics, O₃, HNO₃ and isoprene in the low troposphere can be highly affected locally (up to 50% difference).

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1 Introduction

Biomass burning represents an important source of aerosol and gas pollutants in the global troposphere. Biomass burning emissions have both local and global impacts on the oxidizing capacity and the aerosol load of the atmosphere influencing tropospheric chemistry and air quality. To evaluate these impacts, significant effort is being made to estimate global biomass burning emissions. Thus, different emission inventories exist and are used in chemistry transport models (CTM’s). These inventories differ in the temporal and spatial distribution, as well as in the amounts of the emitted pollutants. CTM’s use these inventories either assuming that all biomass burning emission occur at surface, or with a height-resolved profile in the lower atmosphere. Thus, differences in the intensity, the seasonality, and the vertical distribution of biomass burning emissions may impact the concentrations of pollutants in the vicinity of biomass burning hot spots, but also on larger scales. The aim of the present study is to evaluate the uncertainties in the computed atmospheric composition and lifetime of major pollutants that are associated with the use of different biomass burning emission inventories.

2 Model description a setup

The model used for this study is the well-documented Chemistry and Transport Model (CTM) TM4-ECPL (Kanakidou et al. 2012) updated to enable use of different emission databases (anthropogenic, biogenic and biomass burning). The model accounts for multiphase chemistry in the troposphere (Myriokefalitakis et al. 2011), secondary organic aerosol (SOA) formation (Myriokefalitakis et al. 2010) and aging of organic aerosol (OA). This aerosol ageing is driven by O$_3$ for primary organic aerosol (POA) and by hydroxyl radicals for SOA (Tsiganidis and Kanakidou 2003). The gas/aerosol equilibrium between HNO$_3$/NO$_3^-$ is solved using ISORROPIA II model (Fountoukis and Nenes 2007). For this study the model run on a 3°x2° grid and 34 hybrid levels up to 0.1 hPa and is driven by the European Centre for Medium-range Weather Forecasts (ECMWF) ERA-Interim meteorological data of the year 2008.

2.1 Natural emissions

The MEGANv2 product for biogenic emissions (Guenther et al. 2012) available at http://eccad.sedoo.fr is used. Dust emissions are from AEROCOM updated to the year 2008 (E. Vignatti personal communication, 2012). Marine emissions of POA, sea salt particles and hydrocarbons are calculated online as described in Myriokefalitakis et al. (2010).

2.2 Anthropogenic emissions

The ECLIPSE GAINS v4.0 anthropogenic emissions (Klimont et al. 2013) have been implemented in the model, taking into account temporal distribution of domestic burning. The option of including or excluding the agricultural waste burning (AWB) was added, to avoid double counting of these emissions, since most biomass burning emission inventories include agricultural waste burning emissions. All basic pollutants are considered (CO, NOx, BC, OC, SOx) as well as speciated NMVOC’s.
2.3 Biomass Burning emissions

Three different biomass burning emission inventories are used for this study. 1) The Global Fire Emission Database (GFEDv3) (van der Werf et al. 2010) excluding the AWB sector (hereafter ECLIPSE database, base case), 2) the GFEDv3 including AWB and 3) the ACCMIP fire emissions (Lamarque et al. 2013).

2.4 Experiment

For this study, six different scenarios have been investigated. For each of the biomass burning emission databases mentioned before, two scenarios have been derived: one assuming that all biomass burning emissions are released in the lowest model layer (ECLIPSE_surface, GFEDv3_surface, ACCMIP_surface) and the other one considering the height distribution of biomass burning emissions as described in Dentener et al. (2006) (ECLIPSE, GFEDv3, ACCMIP).

3 Results

The calculated atmospheric distributions of \( \text{O}_3 \), \( \text{OH} \), \( \text{HNO}_3 \), \( \text{OC} \), \( \text{SO}_2 \) and \( \text{CO} \) have been compared to the base case results as well as to observations where available. In addition the computed concentrations and lifetimes of key pollutants for the different simulations have been compared to provide insight to the robustness of the calculations and their dependence on the adopted emissions and their distribution.

3.1 Comparisons with measurements

Comparisons with measurements show that the use of the above mentioned different fire emissions databases has significant impact on the computed global distributions of \( \text{OC} \) and \( \text{CO} \) and less on \( \text{O}_3 \), while the assumptions on the emission height lead to smaller differences as shown in figure 1. For the different emission databases, simulated \( \text{CO} \) shows large differences in areas highly influenced by extreme biomass burning events (e.g. Canada). On the opposite, \( \text{O}_3 \) shows small sensitivity to the different biomass burning emission inventories and their vertical distribution. Organic carbon is the most sensitive to changes in biomass burning emission inventories and the height distribution of emissions.

![Fig. 1. Ozone (left panels), CO (center panels) and OC (right panels) comparison between model results for the studied scenarios and measurements.](image-url)
3.2 Differences in tropospheric concentrations

Small differences in the concentrations of pollutants are calculated for the different biomass burning emission inventories on a global scale. On the opposite, locally comparisons show significant concentration differences that maximize for OC (Fig. 1). Calculated concentration differences are up to a factor of 13 over biomass burning hotspots for the simulations assuming a height distribution of biomass burning emissions and up to a factor of 15 for the simulations assuming biomass burning emissions only at surface. Among studied pollutants, OC shows the largest response to emission inventory and distribution changes. Ozone shows small sensitivity to the emission database, with the largest differences being smaller than 25% in the troposphere. Isoprene is more sensitive to the biomass burning emission database used in the model biomass burning in the tropics is in close proximity to large isoprene emissions. Local differences calculated for CO and SO$_4^-$ are mainly due to the emitted amounts (up to 150% differences between the databases locally). The largest differences in pollutant concentrations were computed between simulations with larger differences in emitted amounts as well as with different height distributions (fig. 2).

![Fig. 2 Percent difference in calculated tropospheric concentration of CO between two simulations using different biomass burning emissions and different vertical distribution.](image)

3.3 Differences in calculated lifetimes of pollutants.

Global tropospheric lifetimes of main pollutants show very small sensitivity to the different biomass burning emission inventories and the vertical distribution of the emissions (Table 1).

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Average lifetime</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>39.40 days</td>
<td>0.160 days</td>
</tr>
<tr>
<td>Ozone</td>
<td>16.64 days</td>
<td>0.057 days</td>
</tr>
<tr>
<td>Isoprene</td>
<td>4.35 hours</td>
<td>0.170 hours</td>
</tr>
<tr>
<td>Nitric acid</td>
<td>58.86 hours</td>
<td>0.102 hours</td>
</tr>
<tr>
<td>Sulphate</td>
<td>4.40 days</td>
<td>0.010 days</td>
</tr>
<tr>
<td>Organic Carbon</td>
<td>6.20 days</td>
<td>0.082 days</td>
</tr>
</tbody>
</table>
Regionally, lifetimes respond both to the different biomass burning inventories and their vertical distribution used in the model. The largest differences (up to 100%) are calculated for the lifetimes of isoprene and OC (up to 80%) at the outflow of biomass burning hotspots. The difference in calculated lifetimes between biomass burning inventories is displayed in figure 3. ACCMIP being the inventory with the larger amounts of CO for the year, combined with the differences in spatial distribution with ECLIPSE, gives significantly different regional lifetimes for all pollutants.

![Cartoon of a map showing CO lifetime differences](image)

**Fig. 3.** Calculated percentage difference of tropospheric CO between base case (ECLIPSE) and ACCMIP emissions database. Blue areas are caused by higher ACCMIP emissions where red areas by higher ECLIPSE emissions.

### 4 Conclusions

The use of different emission datasets in the global model affects the calculated global distribution and levels of pollutants. Primary pollutant concentrations, with lifetimes of the order of a few days are mostly affected by differences in the emission inventories (OC, SO$_4^{2-}$), while concentrations of chemically produced pollutants (O$_3$) seem less sensitive. Calculated global tropospheric lifetimes of pollutants depend only weakly on the assumed biomass burning emission and vertical distribution. Regional lifetimes are highly affected by different inventories as well as by different height distribution with spatial differences resulting to the biggest regional lifetime differences.

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Remote sensing in meteorological forecasting

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The objective is to review existing satellite products for irrigation purposes relevant for the ENORASIS project. A host of international organizations developed and launched operational satellites that provide products of interest for irrigation planning. United States of America organizations are the National Aeronautics and Space Administration (NASA), the Defense Meteorological Satellite Program (DMSP), the Suomi National Polar-orbiting Partnership. The satellite missions of European organization for the Exploitation of Meteorological Satellites (EUMETSAT) with the Meteosat Second Generation (MSG) and the EUMETSAT Polar System (EPS) and the European Space Agency (ESA) operational earth observation missions. Several European/USA jointly missions such as TOPEX/Poseidon and Jason-1 and the Ocean Surface Topography Mission (OSTM) Jason-2 and the French space agency CNES with the SPOT satellite series. In our study we give an overview of each relevant product, together with information on the horizontal and temporal resolution, the data availability, the condition of observation (cloud-free, land-ocean), the term of use (license required), shortcomings and advantages. Access portals and information on the product formats are provided too.

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1 Introduction

The aim of this work is to review existing satellite products for irrigation. Satellite observation provides information on large area with spatial resolution from 1 up to 50 km and temporal resolution from 5 minutes up to a few days. Satellites measure radiances, so algorithms are used to process geophysical products. High resolution products at the 1 to 5 km scale are clearly required (Matthews et al. 2008) for irrigation. The satellite data of interest for the ENORASIS project will focus on the water cycle products, hydrology and meteorology disciplines.

2 Review of satellite missions for irrigation

This section presents current operational satellites relevant for the ENORASIS goals. The National Aeronautics and Space Administration (NASA) missions dedicated to the observation of the earth are:

- The Quick Scatterometer (QuickSCAT) mission was launched in June 1999.
- Aqua is part of the A-train satellites and it was launched on May 4, 2002. The satellite has different instruments such as the Atmospheric Infra-red Sounder (AIRS), the Advanced Microwave Scanning Radiometer-EOS (Earth Observing System) (AMSR-E), the Advanced Microwave Sounding Unit-A (AMSU-A), the Cloud and the Earth's Radiant Energy System (CERES) and the MODerate-Resolution Imaging Spectroradiometer (MODIS).
- Terra was launched on December 18, 1999. The instruments on board Terra are the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), CERES, the Multi-angle Imaging Spectroradiometer (MISR), MODIS and the Measurements of Pollution in the Troposphere (MOPITT).
- CloudSat is part of the A-train and was launched on April 28, 2006. CloudSat uses the Cloud Profiling Radar (CPR) sensor to slice the vertical structure of the clouds.
- The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) is part of the A-train and it was launched on April 28, 2006. CALIPSO uses the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) and the Imaging Infrared Radiometer (IIR) sensors to observe cloud properties.

The satellite missions of European organization for the Exploitation of Meteorological Satellites (EUMETSAT) are:

- The spin-stabilised Meteosat Second Generation (MSG) that images the full earth disk every 15 minutes.
- The EUMETSAT Polar System (EPS) is the polar orbiting operational meteorological satellite for the morning orbit with Meteorological-Operational (MetOp) satellites, the first of which was successfully launched on October 19, 2006. The sensors on-board MetOp are the Advanced Very High Resolution Radiometer (AVHRR), the Advanced Scatterometer (ASCAT), the Infrared Atmospheric Sounding Interferometer (IASI), the Advanced Microwave Sounding Unit A1 and A2 (AMSU-A), the Microwave Humidity Sounder (MHS) and the Global Navigation Satellite System Receiver for Atmospheric Sounding (GRAS).

EUMETSAT disseminates satellite data and products; the Satellite Application Facility (SAF) network dedicated to specialized development and processing centres. Some SAFs seem relevant for irrigation:

- SAF on Land Surface Analysis (LSA) develops, process and disseminates products based on MSG and MetOp data dedicated in particular to surface radiation budget and surface water balance.
- SAF Ocean and Sea Ice Satellite (OSI) process and disseminates products for comprehensive information on the ocean-atmosphere interface.
• SAF on Support to Operational Hydrology and Water Management (H-SAF) develops process and delivers products based on microwave and infrared satellite measurements. H-SAF focus on precipitation, soil moisture and snow cover products.

The European Space Agency (ESA) operational earth observation missions are:
• The Soil Moisture Ocean Salinity (SMOS) Earth Explorer mission dedicated in particular to the measurement of soil moisture for hydrology applications.
• The Environmental Satellite (ENVISAT). The sensors relevant for our study are the Advanced Along-Track Scanning Radiometer (AATSR), the Advanced Synthetic-Aperture Radar (ASAR), the Medium-Resolution Imaging Spectrometer (MERIS), the Microwave Radiometer (MWR) and the Radar Altimeter - 2 (RA-2). ENVISAT was launched on March 1, 2002 and it is operational.

3 Review of the satellite based products for irrigation

The products are presented by geophysical parameter because some products are derived from a multi-sensors approach. The geophysical parameters are derived from the level-1 satellite data and delivered in the so called level-2, level-3 or level-4 satellite product. The level-2 product is derived geophysical variables at the same resolution and location as level-1 source data. The level-3 product corresponds to gridded variables in derived spatial and/or temporal resolutions. The level-4 data consists in model output or results from analyses of lower-level data. It is not possible to present all the products which are relevant for irrigation, for this reason we highlight a few products.

3.1 Surface radiation budget parameters

Radiation data are very useful to calculate the solar energy at ground surface which is crucial for the evapotranspiration estimation. The LSA SAF Land Surface Temperature (LST) product is estimated from MSG /SEVIRI data. It provides LST field over Europe every 15 minutes. The product is operational. The product is at the SEVIRI spatial resolution 3x3km at sub-satellite point. Other products are Down-welling Surface Longwave Flux and Down-welling Surface Shortwave Flux.

3.2 Surface water balance parameters

Snow cover is very important for the snowmelt runoff calculation. Evapotranspiration which quantifies the water vapour flux from the ground surface (soil and canopy). Soil moisture data are useful for the calculation of evaporation and runoff.

3.3 Wind products

EUMETSAT wind products are derived from MSG /SEVIRI data by tracking the motion of clouds fields or humidity patterns. The height below the tropopause is determined with the infrared temperature and converted into pressure levels with European Centre for Medium-Range Weather Forecast (ECMWF) forecasts. Moreover wind product is derived from scatterometer measurements ASCAT on board MetOp. The following products are available: High Resolution Visible Wind, High Resolution Visible Winds, Ocean surface winds.
3.4 Cloud products

**Cloud mask**: the EUMETSAT CCloud Mask (CLM) is an image-based product at the MSG/SEVIRI full resolution (3x3km), which provides information on the presence of clouds. CLM is disseminated every 15 minutes at the GRIB2 format. The cloud mask is derived from MODIS/Aqua and Terra data. The products are operational at the spatial resolution of 1x1km and they provide 4 observations per day. The product is disseminated in HDF-EOS format. The product include quality assurance field.

This product will be soon derived from VIIRS/NPP data. The spatial resolution will be increased to 750m, with two measurements by day.

**Cloud parameters**: the EUMETSAT IASI level2 Cloud Parameters (CLP) product is derived from IASI level 1c, AMSU-A and MHS data. The product provides fractional cloud cover, cloud top temperature and pressure and cloud phase. The sampling is about 25km at nadir. The accuracy of the product is 10% for the fractional cloud cover, 2K for the top cloud temperature and 300m for the cloud top height. The product is operational and disseminated in BUFR format in near real-time on EUMETcast with a timeliness of 3 h. Moreover the product is delivered through the EUMETSAT DATA Centre in HDF5 format with a timeliness of 8-9 h. the product is delivered twice per day.

The cloud parameters product (cloud top pressure, cloud top temperature, cloud fraction, cloud phase) is derived from MODIS/Aqua and Terra data. The products are operational at the spatial resolution of 5x5km and they provide 4 observations per day. The product is disseminated in HDF format. The product cloud phase is available only during daytime, 2 measurements per day.

3.5 Precipitation products

Precipitation products can be used for the crop water management and crucial for the irrigation scheduling.

The EUMETSAT Multi-Sensor Precipitation Estimate (MPE) product is derived from MSG and SSM/I and SSMIS instruments on DMSP satellites. The product is delivered at MSG full pixel resolution in near real-time; it consists of the rain rate in mm/h. The product is disseminated every 15 minutes at the GRIB2 format. The product contains two quality indicators (standard deviation and correlation coefficient) calculated on 5x5 degrees of latitude and longitude box. They are based on comparison of rain rate calculated with Meteosat 8/9 IR channels and SSM/I water vapour channels. The quality indicators are used to identify region where precipitations can be used with confidence. This product is more accurate in case of convective precipitation than in frontal or orographic rainfall. This product accuracy is good for tropical and subtropical regions but it can be used with limitations at higher latitudes.

The H-SAF precipitation rate at ground by Geostationary Earth Orbiting InfraRed (IR) (MSG/SEVIRI) supported by Low Earth Orbiting microwave (DMSP/SSMIS, MetOp/MHS/AMSU-A and NOAA/MHS/AMS-A). The product is delivered at the MSG IR pixel size (average over Europe is about 8km) over the H-SAF area limited to latitude 25-67.5 North] and to longitude -25 West 45 East. The accuracy is better than 10 mm/h in 80% of the cases. This product is not applicable for low rate (more suitable for convective precipitation). The product is pre-operational and delivered in near real-time every 15 minutes in BUFR format via EUMETCast and via EUMETSAT Data Centre.
3.6 Atmospheric weather parameters

These products are useful to be assimilated in the regional atmospheric model. 

*Temperature, humidity and surface temperature:* The EUMETSAT IASI level2 Atmospheric Water Vapour and Surface Skin Temperature (TWT) product is derived from IASI level1c, AMSU-A and MHS data. The product provides vertical profiles of temperature and humidity on 90 pressure levels, and surface skin temperature. The sampling is about 25 km at nadir. The quality of the vertical profiles is strongly related to the cloud properties available in the IASI CLP product. The accuracy of the product is 1K for the temperature profile in the troposphere and 10% for the relative humidity profile. The product is operational and disseminated in BUFR format in near real-time on GTS (The World Meteorological Organisation’s Global Telecommunication System) or EUMETcast with a timeliness of 3 h. Moreover the product is delivered through the EUMETSAT DATA Centre in HDF5 format with a timeliness of 8-9 h. The product is delivered twice per day.

The temperature and humidity profiles are derived from MODIS/Aqua and Terra data. The product provides vertical profiles on 20 pressure levels. The product is operational at the spatial resolution of 5x5km and it provides 4 observations per day in cloud-free areas. The product is disseminated in HDF format.

3.7 Biogeophysical parameters

These products are used to depict the spatial and temporal change of the vegetation cover. They are useful to initiate and update the land use variable of atmospheric models.

3.8 Data Accessibility

All MODIS level 1 and Atmosphere data products are available to the public (at no charge) through the Level 1 and Atmosphere Archive and Distribution System (LAADS) (http://ladsweb.nascom.nasa.gov/data/).

Selected MODIS level 4 land data are available at Land Processes Distributed Active Archive Center (LP DAAC) Data Pool. Data are downloadable via direct FTP access and at no cost to the user (https://lpdaac.usgs.gov/get_data/data_pool). The operational data are not included in this Data Pool.

The NASA’s Earth Observing System Data and Information System (EOSDIS) provides access to near-real time products from the MODIS and AIRS instruments in less than 2.5 hours from observation by using the Land and Atmosphere Near-real time Capability for EOS (LANCE). Data are freely available after self-registration (http://earthdata.nasa.gov/data/nrt-data).

The MODIS snow cover data are available from the NSIDC Data Pool web server or by subscription for automated requests (http://nsidc.org/data/modis/order_data.html).

All data including near real-time METEOSAT, MetOp data and products delivered via EUMETCast, Direct Dissemination and FTP over the internet require a registration on the Earth Observation Portal (EO Portal http://www.eumetsat.int/Home/Main/DataAccess/EOPortal/index.htm?l=en). The EO Portal allows users access to, and manage, their subscriptions to data, products and services provided by EUMETSAT. EUMETCast is EUMETSAT’s primary dissemination mechanism for the near real-time delivery of satellite data and products generated by the EUMETSAT Application Ground Segment and SAFs.

For the delivery of products, the EUMETSAT Data Policy applies (http://www.eumetsat.int/Home/Main/AboutEUMETSAT/LegalInformation/SP_1228227333602?l=en). Data are subject to a set of licensing terms and conditions. The type of licence
required will depend upon the Data Usage and the set of data you wish to receive. These conditions may involve the payment of fees. Council may waive such fees on a case by case basis for specific applications.

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Impact of SRTM and Corine Land Cover data on meteorological parameters using WRF

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We evaluate the impact of the high resolution SRTM topography and Corine Land Cover data on simulated meteorological variables in WRF. We compare the results with the WRF simulation using the 30-arc seconds USGS Land Cover and topography, and with observations. We focus on north Italy for summer and winter 2008. The simulated average wind speeds are in general lower using the SRTM and Corine LC and agrees better with the observations; lower bias with Corine LC and SRTM. In fact the Corine LC shows a larger fraction of the ‘urban and built-up’ category than the USGS, leading to more friction/roughness in the domain, which lowers the surface wind speeds. During winter, WRF with SRTM and Corine LC calculates higher temperatures (up to ~1.0 °C) and R² values are higher. For the summer period the differences in average temperatures are larger up to 2.7 °C. The differences are related to the higher fraction of urban and built-up area in the Corine LC, which affect the sensible and latent heat fluxes. The probability of detection of the precipitation event and the Hansen-Kuipers score are on average 1% higher by WRF with SRTM and Corine than by WRF with 30arcs USGS

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1 Introduction

A common problem in air quality modelling is the underestimation of particulate matter (PM) simulated values by air chemistry transport models (ACTMs). Several model studies (De Meij et al. 2009 and Vautard et al. 2009), and coordinated modelling activities such as Citydelta [http://aqm.jrc.ec.europa.eu/citydelta/], showed that models in general underestimate observed PM concentrations over Europe. In De Meij et al. (2009) several reasons are given for the underestimation of PM concentrations, such as uncertainties in the estimation of gases and primary aerosols in the emission inventories, aerosol dynamics and meteorological factors. Meteorological input data is simulated by a meteorological model and serves as input for the air an ACTM. The ACTM requires a set of meteorological parameters to calculate transport, diffusion, chemistry and formation and removal mechanisms of gas and aerosol pollutants. Several studies have shown the importance of topography and meteorology on simulated gas and aerosol concentrations (Minguzzi et al. 2005). The City Delta exercise showed that simulated PM concentrations are underestimated by the ACTMs for Milan (Italy), especially for winter time episodes. The Po Valley is characterized by very low wind speeds and frequent weak circulation conditions. These stagnant meteorological conditions are difficult to simulate by prognostic and diagnostic models over complex areas (Minguzzi et al. 2005 and De Meij et al. 2009), which lead to the underestimation of simulated PM concentrations. The accuracy of land-use classifications in meteorological modelling affects some meteorological parameters such as wind fields and temperature near the surface (Lee et al. 2010). A good estimate of meteorological variables in the meteorological datasets is therefore crucial for calculating gas and aerosol impacts on air quality and evaluating coherent reduction strategies.

In this study, we investigate the impact of the high resolution Shuttle Radar Topography Mission (SRTM) 90m topography data (Farr et al. 2007) together with the Corine Land Cover 2006 (Büttner et al. 2002.) at 100x100m resolution on the simulated wind, temperature and precipitation profiles by WRF. We compare the simulated meteorological parameters with the results of the WRF simulation using the standard 30-arc seconds USGS Land Cover and topography and with observations of the ARPA network.

2 Data and Methodology

The WRF model is used over a part of the Po Valley area (north Italy) to study the impact of high SRTM topography and Corine Land Cover on the simulated meteorological variables wind speed, precipitation and temperature at 2 meters. WRF operates on the 5x5 km and 1x1km resolution domains (two-way nested). The 5x5km domain covers North Italy, Switzerland, eastern part of France and 1x1km domain the Lombardy region in North Italy. Four simulations were performed with no nudging to the observations of the meteorological stations. The first simulation uses the SRTM and Corine Land Cover data for the period January – February 2008. The second simulation uses the standard USGS 30-arc seconds land-use data (~1x1km) and topography data for the same period. The third and fourth simulations are for the period July – August 2008. We compare the results with observations of the Regional Agencies for Environment Protection monitoring network in Lombardy (www.arpalombardia.it). A spin-up time of 4 days is applied in order to initialize the model. WRF use meteorological initial conditions and lateral boundary conditions from 6 hours analyses from the National Centers for Environmental Protection (NCEP) Climate Forecast System Reanalysis (CFSR), which is provided on ~0.5x0.5 (pressure) and ~0.205x0.204 (surface) degree resolution.
3 Results

3.1 Wind speed

Clear differences in the average simulated wind speeds at 10m height between WRF with SRTM and Corine LC (WRF_CLCW) and WRF with USGS (WRF_30sW) are observed outside the city of Milan (Fig. 1). Large areas in WRF_CLCW, which are classified as urban areas in the Corine Land Cover data (not shown), show lower wind speeds (on average between 0.1 and 0.4m/s lower) than WRF_30sW. The differences in average wind speeds for July – August are similar (not shown) as for the winter period (lower by WRF_CLCS).

![Fig. 1. Average wind speed (m/s) simulated by WRF_CLCW (left) and WRF_30sW (right) for the period January – February 2008.](image)

Comparing the simulated wind speeds with observations (Table 1) shows that the wind speeds are in general overestimated (less by WRF_CLC). The biases for the simulation with the WRF_CLC are lower for the both periods (January - February and July – August) than the simulation with the 30-arc seconds USGS.

<table>
<thead>
<tr>
<th>Wind speed</th>
<th>WRF_CLC</th>
<th>WRF_30sW</th>
<th>WRF_CLC</th>
<th>WRF_30sW</th>
<th>WRF_CLC</th>
<th>WRF_30sW</th>
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<tr>
<td></td>
<td>BIAS</td>
<td>RMSE</td>
<td>BIAS</td>
<td>RMSE</td>
<td>STDERR</td>
<td>STDERR</td>
<td>R²</td>
<td>R²</td>
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<tr>
<td>Winter</td>
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<td>1.30</td>
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<tr>
<td>Summer</td>
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<td>1.82</td>
<td>1.98</td>
<td>1.43</td>
<td>0.08</td>
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</tr>
</tbody>
</table>

3.2 Temperature

Clear differences are found in the average simulated 2m temperature between WRF_CLCW and WRF_30sW outside the city of Milan (Fig. 2). In the areas for which the USGS data set does not register urban and built-up areas, the differences between WRF_CLCW and WRF_30sW vary between ~0.2 and ~1.0 degrees Celsius (°C) and ~1.2 °C for Milan.

![Fig. 2. Average 2m temperatures (degrees Celsius) simulated by WRF_CLCW (left) and WRF_30sW (right) for the period January – February 2008. The white pixel in right panel represents the maximum value of 8.6 degrees Celsius.](image)

To understand better the differences in simulated 2m temperatures between WRF_CLCW and WRF_30sW we analyze in Fig. 3 and 4 the upward sensible (SH) and latent heat (LH) fluxes.
Higher LH fluxes lead to lower temperatures near the surface and higher SH fluxes lead to higher surface temperatures and higher PBL heights (Fraedrich et al., 1999). The SH fluxes by WRF_CLCW are in general higher for a large area in the domain than by WRF_30sW. The higher values of SH fluxes in WRF_CLCW correspond to the location of the urban built-up area in the Corine Land Cover.

![Fig. 3. Mean sensible heat flux (W/m²) between January – February 2008 by WRF_CLCW (c) and WRF_30sW.](image)

In Fig. 4, the mean LH fluxes between January–February by WRF_CLCW and WRF_30sW are presented. The differences in LH fluxes are clearly visible between WRF_CLCW and WRF_30sW. Higher LH fluxes by WRF_30sW result in lower surface temperatures as shown in Fig. 2. For the summer period the differences in average temperatures are larger up to 2.7 °C. Similar differences in SH and LH fluxes between WRF_CLCW and WRF_30sW are found for the summer period (not shown).

![Fig. 4. Mean latent heat flux (W/m²) between January – February 2008 by WRF_CLCW (c) and WRF_30sW.](image)

### 3.3 Precipitation

The probability of detection of the precipitation event is on average 1% higher by WRF_CLCW. The frequency bias for the threshold values 0.5mm and 1.0mm are for both the simulations larger than 1, indicating an overestimation of the numbers of precipitation events. The Hansen-Kuipers score (model’s ability to correctly time both the precipitation events and to avoid the false alarms) is in general 1% higher for WRF_CLCW for all the threshold values.

<table>
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<tr>
<th>Threshold value in mm</th>
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<th>0.5</th>
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<th>1.0</th>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WRF_CLCW</td>
<td>1.15</td>
<td>1.14</td>
<td>1.19</td>
<td>1.18</td>
<td>1.35</td>
<td>1.35</td>
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<td>WRF_30s</td>
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<td>1.57</td>
<td>1.57</td>
<td>1.26</td>
<td>1.31</td>
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<tr>
<td>Frequency bias average</td>
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<td>0.68</td>
<td>0.68</td>
<td>0.68</td>
<td>0.60</td>
<td>0.59</td>
<td>0.43</td>
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</tr>
<tr>
<td>Hansen Kuiper score average</td>
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<td>0.73</td>
<td>0.72</td>
<td>0.72</td>
<td>0.65</td>
<td>0.64</td>
<td>0.48</td>
<td>0.47</td>
<td>0.28</td>
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</tr>
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</table>

Table 2. Average Frequency bias, Hansen Kuiper score and Probability of Detection of precipitation based on 17 stations by WRF with Corine Land Cover (WRF_CLC) and the simulation with 30-arc seconds USGS Land Cover (WRF_30s) for January – February 2008.
4 Conclusions

Our analysis indicates that between January and February 2008 lower average wind speeds are simulated by WRF_CLC than by WRF_30s. The reason for this is that the urban and built-up land cover in the Corine LC is ~17 times larger than in 30-arc seconds USGS. A higher fraction of urban and built-up land cover results in more friction/roughness in the domain, which lowers the surface wind speeds. Comparing the wind speeds with observations shows that the biases for WRF_CLC are lower for the both periods than for WRF_30s. Clear differences are found in simulated 2m temperatures between the two simulations outside the city of Milan for the both periods. The reason for this is that the higher fraction of urban and built-up area in the Corine LC impacts the simulated SH and LH heat fluxes. WRF_CLC simulates in general higher SH fluxes for a large area in the domain (corresponding to the location of the urban built-up area) than WRF_30s. The LH fluxes are higher by WRF_30s, which lowers the surface temperatures. Maximum temperatures are in good agreement with the observations for both the simulations. The POD of the precipitation event is on average 1% higher by WRF_CLC. The FBI for the threshold values 0.5mm and 1.0mm are for both the simulations larger than 1, indicating that the simulations overestimate the number of precipitation events for these thresholds. The HK score is in general 1% higher for WRF_CLC for all the threshold values. Both simulations overestimate by a factor ~1.28 the total amount of observed precipitation. Our analysis clearly shows that using high resolution topography and, in particular, land-use improves the results of calculating wind speeds, temperature and precipitation on 1x1km. Therefore, ACTMs will strongly benefit from the use of the high resolution SRTM and Corine LC data, especially with regard to reducing the bias between observed and simulated aerosol (precursor) concentrations. Besides this, environmental sustainable related projects (e.g. ENORASIS; http://www.enorasis.eu/) for which meteorological models are used for optimizing irrigation management by farmers, will benefit from higher precision precipitation, wind speed and temperature fields by the meteorological models.

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References

Study of climate change impacts on tourism in Messenia using a regional climate model

Douvis K., Kapsomenakis I., Zanis P., Konsta D., Zerefos C.S.

The regional climate model RegCM4 was used to study climate change and the respective impacts at the area of Messenia, in southwestern Peloponnesse. The model was used to subscale the results of the earth system model MPI-ESM initially to a resolution of 50 km and subsequently to 13.3 km. This study is part of Program XENIOS which focuses on the impacts of climate change on tourism using a synergistic and multidisciplinary approach. Emphasis is given on the change of climatic parameters that affect tourism, such as cloudiness and solar radiation. The combination of temperature rise and cloudiness reduction suggests that the touristic season may spread out into the transitional seasons. At the same time the higher temperatures projected for the future may cause the outdoors environment to become unattractive, downgrading the tourism product for the current peak of the touristic season. Also the reduction of precipitation throughout the year may cause a negative effect to the local flora and, combined with the temperature rise, to increase the risk of wildfires.

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1 Introduction

The main tools used for climate change projections are global climate models, i.e. complex computer programs that describe the atmospheric motion and conditions. In the latest years they are named Earth System Models (ESMs) as they have evolved in complexity by incorporating several other components that describe the earth system: the oceans, the land surface, land and sea ice, carbon cycle, aerosols and chemistry, land and ocean biology. ESM simulations are extremely demanding in computational resources, especially in high resolution. This leads to rather low resolution global simulations, as well as to the development of Regional Climate Models (RCMs) for the downscaling of the ESM results in limited area domains.

Climate change simulation results are used in the process of decision making. In order to be suitable for use by decision makers, the climate projections need to be converted into projections of the impacts in specific sectors, i.e. human health, energy resources, agriculture, water resources, tourism and other economic sectors.

The tourism sector is a particularly important economic sector for Greece, including Messenia. The quality of the tourism product is in turn very sensitive to the quality and attractiveness of the external environment which depends heavily on local climate. In the present study an RCM is used to produce a climate change projection in order to assess the impacts of climate change to the tourism industry of Messenia, in the south-western Peloponnese. It is part of XENIOS Project which focuses in the area of Messenia, Greece. XENIOS Project studies a wide range of geophysical phenomena (climatic, geological, hydrological, ecological) with a synergistic approach and with a scope to study their effects on tourism which is one of the most important local products.

2 Data and Methodology

The Regional Climate Model RegCM4 (Giorgi et al. 2012) was used for the simulation of climate change until the end of the 21st century. More specifically, the results of MPI-ESM (Giorgetta et al. 2013) were downscaled from 1.875° (≈ 200 km) to 50 km (Lowres) and subsequently to 13.3 km (Hires). Fig. 1 presents the elevation in the three simulations. The resolution of each simulation can be deduced by the size of the grid points. The simulation periods are 1980-1999 (REF) and 2080-2099 (FUT) according to the RCP8.5 scenario (van Vuuren et al. 2011).

Prior to the simulation, the model performance was evaluated against observations from ground stations gridded data, soundings and satellites. Twelve months of re-analysis data were downscaled using the same domain configuration for 11 different model set-ups. Key climatological parameters were compared to the observations in order to choose the optimum model set-up. Focus was given to the simulation of clouds as it is a climatic parameter of high importance for the touristic product. After the optimization of the model for Lowres, the
procedure was repeated for Hires in order to select the optimum set-up out of 7 different configurations. For Lowres convection was described by the MIT convection scheme (Emanuel and Zivkovic-Rothman 1999) over ocean grid points and by the Grell convection scheme (Grell 1993) with the the Arakawa-Schubert closure (Grell et al. 1994) over land. For Hires the MIT convection scheme was used with an increased specific humidity threshold for the initiation of convection (elcrit=0.01, default=0.0011). Fig. 2 presents part of the procedure for Hires. The monthly variability of mean cloud fraction in Messenia (yellow square in the map on the right) is compared to the observations separately for the land (left) and ocean (center) grid points. The selected set up (blue curves) performs best at reproducing the observations (red curves), especially over sea and during the wet period of the year.

Fig. 2. The comparison of mean monthly cloud fractional cover time series over Messenia produced by the 7 simulations that were tested for the Hires calibration with satellite observations. The horizontal axes run from December 2006 to November 2007. The observational time series (red) were derived from the Meteosat data with a resolution of 0.05º x 0.05º, higher than the model grid. The results of the selected set-up are blue and the results of the 6 rejected set-ups are black. Left: The time-series over land, center: the time-series over sea, right: the land-sea mask of the model in the area of Peloponnese, the grid points that were included in the calculations are in the yellow frame.

3 Results

Fig. 3 presents the change in mean temperature for each individual season between the future period and the reference period. Temperatures rise in all seasons with a minimum of 2.5 to 3°C in winter and a maximum of 4 to 5°C in summer. The temperature increase is higher in the interior of the Peloponnese and milder near the coast, except in winter when it is higher in the north-east.

Fig. 3. The change in seasonal temperature between FUT (2080-2099, CRP8.5) and REF (1980-1999). Left column: winter and spring, right column: summer and autumn.
Fig. 4. Same as in Fig. 3, but for the percentage change in seasonal precipitation.

Fig. 5. Same as in Fig. 4, but for the percentage change in seasonal cloud fractional cover.

Fig. 4 presents the percentage change in precipitation for each individual season between the future period and the reference period. Overall precipitation decreases. The decrease is mostly prominent (over 30%) in spring and in winter except along the eastern and north-eastern coastline. In autumn the decrease is mostly under 20%. In summer mixed signals are observed, decrease prevails but given that summer precipitation is limited this corresponds to slight precipitation height changes. In terms of precipitation height (not shown) the decrease is most prominent in the winter, especially in the western and south-western Peloponnese, in most of which it exceeds 2 mm/day.

Fig. 5 presents the percentage change in cloud fractional cover for each season. A reduction is projected for all seasons with similar results for winter, spring and autumn: reduction of 15-25% in most of Peloponnese, including Messenia. In summer the reduction is much higher, over 30% in most of Messenia. However, in absolute values the reduction is smallest in the summer as the mean cloud cover is very small (not shown).

Fig. 6 presents the range of daily maximum and of daily minimum temperature at 2m for the 12 months of the year for a coastal grid point near the center of Messenia which is shown in the inset at the top left. The summer temperature rise will cause this season to become less hospitable, with often overwhelming maximum temperatures and with a weakened relieving effect of the minimum temperature. On the contrary, winter cold will be less severe based on the findings of mean temperature. The transient months are projected to move away from summer and towards the winter. For example the months of September and May in the reference period resemble more to the months of August and June respectively in the future period in terms of maximum and minimum temperatures. Similar description applies to all the land grid points in the area of Messenia.
Fig. 6. The range of daily maximum temperature and of daily minimum temperature in FUT (2080-2099, red) and in REF (1980-1999, blue) for the grid point shown in the inset, top left. The dots correspond to the mean monthly extreme temperatures. Each arrow corresponds to one standard deviation of the total daily values of the respective month, therefore the range denoted by both arrows of each dot corresponds roughly to 68% of the variability.

4 Conclusions

The results of a climate simulation by MPI-ESM were downscaled to 13.3 km using RegCM4 in order to study the consequences of climate change to the tourism sector of Messenia by the end of the 21st century.

The most prominent feature of the projected climate change is the rise in temperature. It will cause the summer season to become too warm and unattractive to tourists. On the other hand, the warming of transitional seasons will make them more attractive, especially in combination with the warming of the sea waters. This means that the tourism demand will seize to be mostly concentrated in the present peak season and it will be spread more evenly throughout the year, especially in the transitional months but also in the winter. Aside from the temperature rise this effect will be enhanced by the decrease of precipitation and cloudiness in the transitional seasons and winter. Precipitation is perceived by tourists as an inconvenience as it obstructs them from enjoying the outdoors environment, while sunshine is considered to be a significant attraction. One more reason is that the cost of air-conditioning for the warm season is expected to increase dramatically.

Another important consideration, not only for the tourism sector, is the issue of water resources, including availability and quality. The reduced precipitation and cloudiness and the increased temperature will cause a shortage of water. Planned management of water resources is considered necessary, including the acquisition and distribution of fresh water, as well as the management of water demand for agriculture and other anthropogenic needs, i.e. the choice of low-water demanding crops and the construction of facilities. The water shortage will also challenge the conservation of non-anthropogenic environment which is an important asset for the tourism industry. Natural flora and fauna are expected to suffer a strong stress due to lack of water and desertification will be a possibility that should be addressed. Fire hazard will increase dramatically and measures for fire security must be taken in advance, in order to increase not only the capability to put out fires but also in order to manage the forests in order to make them less prone to mega-fires.

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References


Preliminary retrieval of water vapor column from direct solar irradiance spectral measurements with a CCD system

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The retrieval of water vapor column using direct solar irradiance spectral measurements with the Phaethon system which covers the spectral range 300-1000 nm is investigated. Data acquired in the period 2006-2008 are used to determine the water vapor transmittance at two spectral bands located near the upper spectral limit of the spectrograph centered at around 915 nm and 945 nm respectively. The extraterrestrial solar spectrum required for the retrieval was determined with a modified Langley extrapolation approach. The water vapor transmittance was converted to columnar water vapor by means of radiative transfer model calculations. Preliminary results are presented, and compared with data from a collocated CIMEL sun photometer.

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1 Introduction

Water vapor is a key component of the Earth’s atmosphere and its importance in the climate system is undisputedly immense. It is involved in photochemical processes and in the atmospheric energy transport, while, as one of the most important greenhouse gases, it affects atmospheric opacity in the infrared part both of solar and Earth’s surface radiation (IPCC 2013). According to climate models’ predictions, water vapor is expected to represent the largest positive feedback in global warming (Held and Soden 2000). It is also the main source of OH production in the lower stratosphere and upper troposphere and, thus, affects the ozone depletion and global radiation budget (Scientific Assessment of Ozone Depletion 2010). Moreover, water vapor contributes indirectly to radiative forcing by affecting the formation and development of clouds and the aerosol optical and microphysical properties. For all the above reasons, water vapor is the subject of ongoing scientific research and various methods and techniques have been developed for its observation and retrieval. Its atmospheric spatial and temporal distribution is characterized by strong variations. Hence, the development of reliable methods for the real time monitoring and measuring of water vapor content in the atmosphere is of great importance.

Column water vapor (CWV) is defined as the vertical integral of water vapor amount from the ground to the top of the atmosphere. Studies that indicate the connection between the CWV and the transmission of radiation in the near infrared water vapor absorption bands date back to the early 20th century (Fowle 1912, 1913). This relationship between the CWV and the transmission of radiation is well known qualitatively, but it has proved difficult to quantify. Earlier papers rely on the empirical approach proposed by Fowle (Volz 1974). This method is based on a fitting of the data to collocated CWV measurements, usually radiosonde or microwave radiometer measurements. Several studies have assumed a square root dependence of transmittance on CWV (Volz 1974), although overall a wide range of empirical water vapor exponents have been proposed. Using the modified Langley approach (Schmid et al. 2001), CWV can be calculated by means of a radiative transfer model, without the assumption of a standard exponent or the need of data of another sort for the calibration.

In this study, we make a first attempt to retrieve CWV using data from a CCD spectrometer. We apply the modified Langley technique to determine the solar spectrum at the top of the atmosphere. The coefficients of the exponential relationship that converts the water vapor transmittance to CWV were calculated by means of the radiative transfer model libRadtran (Mayer and Kylling 2005). The molecular absorption files used as input in libRadtran simulations were produced by ARTS (Atmospheric Radiative Transfer Simulator), a software package for long wavelength radiative transfer simulations (Buehler et al. 2004, Eriksson et al. 2011). The details of the approach applied are given in the Methodology section. Results from the CCD measurements are displayed and compared with data from a collocated CIMEL sun photometer and nearby radiosonde data.

2 Data and Methodology

Calibrated direct solar irradiance spectral measurements were used for the water vapor retrieval. These measurements have been performed in the period from the last half of 2006 to late 2008 with the prototype MAX-DOAS (Multi Axis Differential Optical Absorption Spectroscopy) system Phaethon, developed at the Laboratory of Atmospheric Physics, AUTH, in Thessaloniki. In Greek mythology, Phaethon was the demigod child of the Sun-god Helios. The prototype Phaethon system consists of a Zeiss CCD spectrograph operating in the spectral range 310-1000nm. Detailed technical description and characterization of the system are presented in Kouremeti et al. (2008). The monitoring site is located at the roof of the Physics Department, at the city centre and ~60 m above sea level. Validation of the CCD measurements has been performed during the Stratospheric Climate Links with Emphasis on the Upper Troposphere and Lower Stratosphere (SCOUT-O3) campaign held at Thessaloniki
from 12 to 24 July 2006. Overall, the available data cover 75 days. From them, measurements recorded under cloudy sky conditions were excluded. For the comparison with the collocated CIMEL sun photometer only 30 days of data were used, due to gaps in the datasets of the two instruments. This dataset covers mostly the months June - November. For the water vapor retrieval two different spectral bands were used, located near the upper spectral limit of the spectrograph centered at around 915 nm (910-920 nm) and 945 nm (936-955 nm). These two spectral bands are sub-regions of the water vapor absorption band known with the Greek letters (ρ, σ, τ). This absorption band has been extensively used for the water vapor retrieval from sun photometer measurements.

Generally, the attenuation of the direct solar radiation penetrating the Earth’s atmosphere can be described by the monochromatic Beer-Lambert-Bouguer law:

$$ V = V_0(\lambda)\exp[-m\tau(\lambda)] $$

(1)

where $V_0(\lambda)$ is the instrument measurement corrected for the mean Sun-Earth distance, $V_0(\lambda)$ is the signal that the instrument would measure at the top of the atmosphere (calibration constant), $\tau$ is the total atmospheric spectral optical depth and $m$ is the relative optical air mass. In the case of strong wavelength-dependent absorption such as the water vapor absorption lines in the near infrared spectrum, where, due to saturation, further solar radiation propagation through the earth’s atmosphere can lead only to a weaker absorption in the pressure broadened line wings, the dependence of extinction on the absorber amount is no longer linear. Thus, water vapor transmittance $T_w$ is related with some power of the CWV according to the equation:

$$ T_w(\lambda) = \exp\left[-a\left(m_u\right)^b\right] $$

(2)

where $m_w$ is the water vapor optical air mass, $u$ is the CWV and $a$ and $b$ are constants that depend on wavelength position and pressure, temperature and water vapor vertical distribution in the atmosphere. The product $(m_wu)$ represents the slant-path water vapor amount. Assuming that the only absorbers in the spectral region used here are H$_2$O and O$_3$, (1) can be written as:

$$ V(\lambda) = V_0(\lambda)\exp\left[-\left(m_R\tau_R(\lambda) + m_\sigma\tau_\sigma(\lambda) + m_\omega\tau_\omega(\lambda)\right)\right]T_w(\lambda) $$

(3)

where subscripts $a$, $R$, $\sigma$, $\omega$, and $O_3$ refer to aerosol extinction, Rayleigh scattering by air molecules and O$_3$ absorption respectively.

The modified Langley approach is based on (3) upon taking the logarithm:

$$ \ln V(\lambda) + \left[m_R\tau_R(\lambda) + m_\sigma\tau_\sigma(\lambda) + m_\omega\tau_\omega(\lambda)\right] = \ln V_0(\lambda) - a\left(mu\right)^b $$

(4)

The extraterrestrial spectrum is determined from the ordinate intercept of a least-squares fit by plotting the left side of (4) versus $m^b$ for every pixel of the spectrometer within the desirable spectral range. For the modified Langley plots construction, early morning or late evening periods when CWV remains constant are preferred. In this paper we used evening measurements performed on January 16$^{th}$ 2007 and November 20$^{th}$ 2008. During these measurements the solar zenith angle ranged between 60° and 90° and the CWV and the aerosol optical depth (AOD) remained relatively constant. The AOD is calculated according to Kouremeti et al. (2008). The AOD in the water vapor absorption band is derived by fitting the formula $\tau=\beta\lambda^a$ to the AOD values of adjacent wavelengths to the water vapor absorption band. The Rayleigh optical depth is calculated according to Hansen and Travis (1974). For the O$_3$ optical depth calculations, the column measured by the collocated Brewer spectroradiometer and the absorption cross sections by Bogumil have been used (Bogumil et al., 2000). The optical air masses for aerosol extinction, Rayleigh scattering by air molecules and H$_2$O and O$_3$ absorption have been calculated separately using the formula described by Guenther (2001).

Coefficients $a$ and $b$ were estimated from (2) using simulated water vapor transmittance data produced over a wide range of slant-path water vapor amounts with the radiative transfer model libRadtran-1.7. An exponential fit was applied between $T_w$ and $(m_wu)$ for every pixel of the CCD spectrograph located in the two spectral bands. The model simulations were done line-by-line and the high resolution (less than ~0.01nm) molecular absorption optical depth
files used were obtained from ARTS-2.0. For the ARTS simulations, the HITRAN-04 molecular absorption database (Rothman et al., 2005) was used and the water vapor continuum absorption was also taken into account. The HITRAN-04 database was chosen because the stable version of ARTS-2.0 cannot read the later ones. Once the $V_o(\lambda)$ values were obtained, the CWV was derived by rearranging the terms in (4).

3 Results

Being situated alongside the northerly part of the Thermaicos Gulf, Thessaloniki enjoys meteorological characteristics of continental and Mediterranean climates, with mild winters and hot summers with rather humid nights. The amount of water vapor in the atmosphere follows the atmospheric temperature changes. Thus, the quite significant seasonal temperature differences experienced in Thessaloniki indicate important annual variation in CWV. The two and a half years dataset for CWV acquired by the Phaethon system is in good agreement with that, demonstrating an annual pattern characterized by higher values during summer and lower values during winter time. The highest recorded CWV values exceed 3.5 cm, while the lowest are below 0.5 cm.

Fig. 1 shows CWV data collected on July 18, 2006 and November 20, 2008 by the Phaethon system and the collocated CIMEL sun photometer, as well as from radiosonde measurements at Thessaloniki airport at 12:00 UTC. November 20, 2008 is characterized by low water vapor concentration in the atmosphere, while the warmer July 18, 2006 shows moderate to high amounts of atmospheric water vapor. It should be noted that the variation in the CWV with time on November 20, 2008 is small. Thus, it was a good day for the determination of the ordinate intercept ($V_o$) in (4). Generally, CWV obtained by Phaethon follows quite closely the daily variations. The CWV retrieved from measurements in the 945 nm band is in better agreement with CIMEL measurements, with variances $\leq$~15%. The retrieval in the narrower 915 nm band has both positive and negative biases of up to 30% in some cases. The fact that for both spectral bands the deviations from CIMEL occur at the same periods in the day, implies problems in the absolute signal of Phaethon which may be caused by drifts in the sun tracking system. The less accurate retrieval of CWV in the 915 nm band is probably due to the weak water vapor absorption signal in this region. Comparison with the radiosonde measurements is difficult, because they are only launched once during daytime. Moreover, the air column sampled by radiosondes is rarely the same with the path of radiation measured by a sun pointing system. However, the two data points are generally in good agreement with both the CIMEL and Phaethon CWV.

Scatter-plots of CWV determined by Phaethon in both spectral bands versus the CIMEL sun-photometer data are shown in figure 2. For the 915 nm band (left panel) there is appreciable noise, which has not been explained yet. In contrast, the agreement in the 945 nm band is very good ($R^2$~0.96). In both bands Phaethon data captures very well the variations in CCW but
there is still a negative bias of about 10%. The bias could arise from deviations in the pointing system of Phaethon which affects the absolute level of irradiance, or from instabilities of the system in the long term. Finally, optimization of the methodology with respect to the removal of aerosol effects and the determination of the extraterrestrial irradiance are expected to further improve the results.

4 Conclusions

Direct solar irradiance spectral measurements acquired with a CCD spectrograph were used to retrieve CWV in two spectral bands around 915 nm and 945 nm. The CWV data derived from the latter showed good agreement with data from a collocated CIMEL sun-photometer following closely the diurnal variability with a small offset. For the 915nm band the agreement is weaker, probably due to the weak water vapor absorption signal in this band. Ongoing investigation aims at improving the retrieval methodology, as well as the hardware performance.

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Preliminary analysis of long-term variability of upper tropospheric humidity in the northern mid-latitudes

Eleftheratos K., Gierens K., Shi L., Kapsomenakis I., Zerefos C. S.

We use 30 years of intercalibrated brightness temperature data from the High-Resolution Infrared Radiation Sounder (HIRS) onboard the NOAA series of satellites to produce a 30 year data set of upper tropospheric humidity with respect to ice (UTHi). The upper tropospheric humidity (a mean relative humidity in the upper troposphere roughly between 300 and 500 hPa) is derived from the measured brightness temperatures in HIRS channels 12 and 6 using the formula proposed by Jackson and Bates (2001). We have produced daily files of UTHi for each NOAA satellite that carries the HIRS instrument, from which we have calculated monthly means in 2.5 × 2.5 degrees resolution for the northern mid-latitudes (30°–70° N). We present a preliminary analysis of climatology and long-term variability of UTHi in the past three decades over the northern mid-latitudes.

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The geographic climate information system Geoclima


Geoclima is an integrated web-based Geographic Information System (GIS) allowing the user to manage, analyze and visualize the information which is directly or indirectly related to climate and its future projections in Greece. The system was developed by first collecting, preprocessing and producing climate and environmental related data, then mapping climate data and creating thematic web map services, implementing a geographic database, and finally developing the integrated GIS. The final product is an interactive open access web GIS application through which users are able to analyze and visualize the climate information. This paper provides an overview of the research efforts to develop the system and demonstrates the results.

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1 Introduction

The collection, management and analysis of climate data is a time consuming process demanding important human resources. Therefore, decision making and research in climate change issues are usually based on the analysis of limited climate datasets. Moreover, there is a need for a modern system of management, analysis and visualization of all the available climate information, irrespective of their type and source, in order to let the user focus exclusively on the use of data rather than on their collection and management. In addition, the study of climate changes and their impacts requires a multi-dimensional approach which is only possible by using the abilities offered by a Geographical Information System (GIS). Although there are some web GIS applications available worldwide (e.g. http://www.bom.gov.au/climate/averages/maps.shtml, http://www.climatewizard.org/), none of them integrates historic climate data and future projections while their majority simply present climate maps without providing tools for analysis.

This paper presents the Geoclima, an integrated GIS allowing the user to manage, analyze and visualize the information which is directly or indirectly related to climate and its future projections in Greece. The system is based on conventional in-situ and satellite measurements, climate model simulations, geographic and socio-economic data related to climate change. The final product is an interactive open access GIS web application through which users are able to analyze and visualize the climate information (http://www.geoclima.eu).

2 Data and methodology

The geographic database of the system Geoclima comprises:
- climatic data from 80 weather stations of the Hellenic National Meteorological Service (27 parameters, 1955 – 2010),
- satellite data (precipitation, land surface temperature, vegetation index, cloudiness, instability, 1998 – 2010),
- socio-economic data (15 parameters, 1951 – 2001), and
- geographical and topographical data derived by a Digital Elevation Model (DEM).

Data were first processed and analyzed before importing them into the system database. This includes:
- data quality assessment and control to exclude extreme and unrealistic values in the climate data,
- missing data imputation based on a spatiotemporal method that takes into account the data of the time series itself in combination with the data of the timeseries of the nearby stations,
- homogeneity test to detect abrupt changes in the time series which are the result of no-climate influences (changes in instruments, observing practices and the station site) using the Alexanderson test (Alexanderson, 1986). Inhomogeneous time series were excluded from further analysis.
- standardization of data in a form suitable for input in the database.

The system was developed in five steps: a) data time series were statistically analyzed and underwent a trend analysis, b) future climate projections were assessed based on existing regional climate model (RCM) simulations for Europe and a supplementary transient high resolution (10 km x 10 km) simulation for Greece over the period 1961-2100 using RegCM3, c) climate data was mapped and thematic web map services were created, d) a geographic database was implemented, managing all descriptive and geospatial data that was collected or produced, and e) the integrated GIS was developed.
3 Results

3.1 Statistical and trend analysis of climate data

Data time series were first statistically analyzed to compute statistical parameters (mean values, standard deviations, extreme values and percentiles) for a 30-year period (1975-2004) at monthly, seasonal and annual time scales. Then a trend analysis was implemented to find positive or negative trends based on the least squared method and detect the starting year of possible climatic discontinuities or changes using the Mann-Kendall test (Sneyers 1990).

3.2 Regional future climate projections

An assessment of future climate change and variability in Greece is provided for a number of meteorological parameters based on regional climate model simulations carried out under the European programs RUDENCE (http://prudence.dmi.dk) and ENSEMBLES (http://ensemblesr3.dmi.dk) as well as on a high resolution regional climate simulation (10 x 10 km$^2$) with RegCM3 for Greece for the A2, A1B and B2 IPCC (Intergovernmental Panel of Climate Change) emission scenarios (Katragkou et al. 2014).

![Fig. 1.](image1.png)

Specifically, from the analysis of the regional climate simulations the following fields were produced for each database:

- **PRUDENCE database (50 x 50 km$^2$ resolution):** Fields of differences between 2071-2100 and 1961-1990 were produced for the variables T2m (temperature at 2 m), Tmin (minimum temperature at 2 m), Tmax (maximum temperature at 2 m) and Prec (precipitation) for the emission scenarios A2 (ensemble of 9 RCMs) and B2 (ensemble 5 RCMs) for the 4 seasons and the whole year (a total of 40 fields).

- **ENSEMBLES database (25 x 25 km$^2$ resolution):** Fields of differences for 2071-2100 and 2021-2050 relevant to 1961-1990 were produced for the variables T2m, Tmin, Tmax and Prec, for the emission scenarios A1B (ensemble of 5 RCMs driven by the general circulation model ECHAM5 r3), for 4 seasons and the year (a total of 40 fields).

- **High resolution simulation for Greece (10 km x 10 km resolution) with RegCM3:** Fields of differences for 2071-2100 and 2021-2050 relevant to 1961-1990 were produced for the emission scenario A1B for the variables T2m, Tmin, Tmax, Prec as well as 5 extreme indices on yearly basis (Warm days Tmin>20$^\circ$C, Hot days Tmax>35$^\circ$C, Night frosts (days) Tmin<0$^\circ$C, Dry spell days, Growing season) (for 4 seasons and the year a total of 50 fields).

Indicatively, the high resolution simulation with RegCM3 for Greece in Figure 1a indicates an increase in warm days with Tmin>20$^\circ$C between 2021-2050 and 1961-1990 ranging from 10 days at the North of Greece up to 40 days at South.
3.3 Spatialization of climate data

Spatialization of data aims to provide climate information for any place, even at places where no observations exist, and map the data using spatial interpolation methods. One deterministic (inversed distance weighted) and two probabilistic (ordinary kriging and multiple linear regression) methods were used in the analysis after testing ten different interpolation methods on a test sample. Annual, seasonal and monthly normals for 27 climate parameters obtained from 73 weather stations distributed evenly over Greece were used in the analysis along with a set of topographical and geographical parameters extracted from a DEM. The validity of the three interpolation models was checked through cross-validation error statistics against an independent test subset of station data. Best performance was obtained in most cases with the multiple regression model using as an input several topographical and geographical parameters (Fig. 1b).

3.4 The geographic database

In order to store and manage all data collected or produced in the previous steps, either alphanumeric or geospatial, a homogeneous geographic database (Rigaux et al. 2002) was implemented. This choice provides data integrity and consistency checking, concurrent access by multiple users and comprehensive data analysis.

The design of the geographic database, besides the uniform manipulation of all different variables, had to fulfill two critical requirements: (a) avoidance of database structure modification in case of new data introduction, and (b) provision of complex information reports for any user-specified geographic area. In this way both the sustainability of the project (since maintenance costs are reduced) and the maximum utilization of retained data from end-users are ensured.

To fulfill these requirements, different database tables were used for variable names and their category, variable instances (per period and season), variable values, and variable values geographic extent. Additionally, stored Structured Query Language (SQL) procedures were created to dynamically produce complex reports for any geographic point specified by end-users. To form unified geographic datasets (layers), needed for the creation of the web services, database views were implemented, joining together geospatial and alphanumeric data.

The database was developed on Microsoft SQL Server and ESRI Spatial Database Engine. Over 18,000 data files were incorporated in 32 database tables, occupying 25 gigabytes of disk space.

3.5 The web GIS application

The Geoclima is an interactive webGIS application that allows users to find, visualize and analyze spatial climatic and other related data over a background map. It is based on ESRI ArcGIS Server architecture (Fig. 2) and has been developed using the ArcGIS API for Microsoft Silverlight.

Fig. 2. The webGIS architecture.
The webGIS is accessible to end-users through a Web Server. Any spatial related request is transferred to the GIS server which responds according to the request. For example, a request for spatial data visualization will produce a png file which will be displayed in the WEB application, while a feature query request will produce an xml response file which will also be displayed in the WEB application using an appropriate User Interface (UI).

Fig. 3. The User Interface of the Geoclima WEB GIS application.

The GIS Server provides access to a number of Representational State Transfer (REST) map services that have been created in order to display and query the data managed in the geographic database. Each service includes a number of layers regarding a climatic or other variable, for a specific period of time. Map services are relaying on the views implemented into the geographic database. Their cartographic design was based on the equal intervals classification method, using the ESRI ArcMap software.

The Geoclima application is designed to provide easy access to all datasets incorporated into the geographic database (climatic datasets, climatic model datasets, satellite climatic datasets, social-economic datasets) (Fig. 3). The users can easily find, select and visualize data for different climatic or other variables and get information about them using simple to use but advanced data mining tools (climatic reports). Additionally, the webGIS offers more spatial related tools for map navigation, background map selection, layer ordering and transparency, feature info, Query, table view, measuring and red line overlays.

4 Conclusions

Geoclima is an innovative information technology application, serving as a tool for the study of the climate and climate change providing combined information related to the climate regime and variability with high spatial resolutionin Greece. It can be used by government entities and the wide public sector which are responsible for decision making and strategic planning in environmental protection and climate change impact assessment, adaptation and mitigation, by nongovernmental organizations acting in the field of environmental protection, in all levels of education as a interactive training tool in climate and climate changes issues, in the private sector whose activities are affected by climate, by research institutions as well as by anyone interested in being informed on the climate state.

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References

Analysis of Mediterranean extreme rainfall events in the presence of cyclones using observations from the HyMeX SOP in October 2012

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The international project HyMeX aims at the understanding of the hydrological cycle of the Mediterranean region. The first Special Observations Period (SOP) of the project took place during the Autumn of 2012, when two extreme rainfall events were documented to be associated with intense cyclones. Our analysis aims at the understanding of the convection processes during these two events using the AMSU-B passive radiometer, which informs about scattering by clouds, the ZEUS observational network, which detects lightning impacts in the region, as also a plethora of ground meteorological stations. All observations work in a complementary way in order to pin point the cells of deep convection in a temporal and spatial detail. In order to associate these rainfall patterns with the dynamics of cyclones, we compare the observations with the ERA-Interim reanalyses. Results show the spatial organization of convection in function of the cyclones dynamical characteristics, namely the formation of fronts and distribution of upper-level potential vorticity.

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1 Introduction

The Mediterranean basin is located in a transitional zone between the dry and arid region of
North Africa and the mid-latitudes of northern Europe. The region is characterized by the
Mediterranean Sea and the high surrounding mountain chains, such as the Alps and the Atlas.
One of the most prominent features of the local weather systems is the Mediterranean
cyclones. Cyclones in the region present a large variety in size and life-time, but typically of
weaker intensity than the strong extra-tropical cyclones occurring over the oceans (Campa
and Wernli, 2012). The most intense Mediterranean cyclones take place during winter and
autumn and usually present Sea Level Pressures (SLP) of the order of 1000 hPa; in rare
occasions SLP might reach values as low as 970-980 hPa (Trigo et al. 2002; Campa and
Wernli, 2012).

Mediterranean cyclones are highly associated with high impact weather (e.g. Kotroni et al.
2006), provoking extreme rainfall and windstorms. Although the most intense cyclones are
favored by large scale meteorological conditions such as Potential Vorticity (PV) streamers
(Flaounas et al. 2014), open questions still exist on the organization of convection during their
mature stage. This paper presents initial results of the analysis of two case studies of intense
cyclogenesis in the leeward side of the Alps. The leeward side of the Alps is known to be one
of the favorite location of Mediterranean cyclogenesis (Trigo et al. 2002; Campins et al.
2011), associated with intense systems which might present tropical characteristics
(McTaggart-Cowan et al. 2010). Both cases examined here caused heavy rainfall in autumn of
2012, during the special observations period (SOP) of the international Hydrological cycle in
the Mediterranean Experiment (HyMeX; Drobinski et al. 2014).

In this short paper we present preliminary results of our work based first on a detailed
description of the meteorological conditions under which the two cyclonic systems
developed, as well as of the characteristics of the associated convection.

2 Data and Methodology

The two investigated cyclogenesis events occurred during the period of 26/10/2012 –
01/11/2012. The atmospheric state during this period is taken by the European Center for
Medium range Weather Forecasting (ECMWF) analysis with horizontal resolution of
0.25°x0.25°, while daily rainfall estimations are taken by the TRMM Multi-Satellite
Precipitation Analysis (TMPA-RT): 3B42RT.

In order to determine deep convective cells we use lightning observations from the ZEUS
detection system (Kotroni and Lagouvardos, 2008) and observations from the Advanced
Microwave Sounding Unit (AMSU), which measures the Brightness Temperature (BT) in
several channels. The AMSU observations are taken from three satellites, scanning the
Mediterranean region twice per day. The BT is interpolated in a 0.2°x0.2° grid determining
deep convection as areas of difference of at least 8 K between channels three (183±1 GHz)
and five (183±7 GHz). Funatsu et al. (2007) showed that such a diagnostic depicts rainfall of
at least 10mm per three hours.

3 Results

Figure 1 shows the two cyclone tracks, as also their central value of minimum SLP. The first
cyclogenesis event took place over the Atlantic Ocean where the cyclone reached its deepest
pressure values on 20 October 2012. The following days, the cyclone moved progressively
over the Mediterranean Sea where it re-intensified reaching its secondary pressure minimum
at the leeward side of the Alps (~970 hPa) on 27 October. The second cyclone was tracked as
a pressure perturbation, moving from the western coast of Spain towards the Mediterranean
basin. The cyclone intensified rapidly over the Mediterranean Sea reaching its minimum
pressure also at the leeward side of the Alps.
Fig. 1. (top) Tracks of the two analyzed cyclones (bottom) Time series of the sea level pressure evolution of the two cyclones. The first (second) cyclone trajectory and time series are denoted in black (red) color. Circles denote the position or SLP at 00:00 UTC of each day.

During the investigated period both cyclones produced large amounts of rainfall over the western Mediterranean Sea. Figure 2 shows for the periods 27/10 - 28/10 and 31/10 - 1/11, the total daily rainfall as estimated by TMPA-RT, the regions of deep convection (as detected by the AMSU diagnostic) and finally the regions of intense lightning activity (as observed by ZEUS). Results show equally strong rainfall peaks of more than 40mm for both events extending over the center of the Mediterranean basin. As the cyclone moves towards the east, the rainfall peaks also migrate over the eastern Mediterranean. Focusing on the lightning occurrences and the AMSU diagnostic, two different patterns are observed. For the first event most part of heavy rainfall is collocated with both the AMSU diagnostic on deep convection and the areas of intense lightning activity. On the other hand, on the 31/10, when the second cyclone reaches its minimum pressure, deep convection and lightning seem to be restricted in small areas and rather far from the cyclone center. In Flaounas et al (2014) it was shown that most rainfall takes place close to the center of Mediterranean cyclones, due to increased conditional instability. Indeed, for both cases (27/10 & 31/10), the cyclones centers present strong rainfall at the proximity of their centers, but observations show no deep convection for the second event. Consequently, both cyclones produced heavy rainfall during their passage over the Mediterranean basin, but without doubt the two systems are qualitatively distinct by their themodynamical and possibly dynamical structure.

Fig. 2. Total daily rainfall (grey shading), areas of lightning activity (red contours) and areas of deep convection (green contours) for the days of 27/10, 28/10, 31/10 and 1/11.
In order to investigate more in depth the dynamical profile of the two events, Fig. 3 presents the PV and wind speed at 300 hPa and the geopotential height at 500 hPa, for the days of 27/10, 28/10, 31/10 and 1/11 (at 12:00 UTC). The first event is characterized by a distinctive PV streamer (at 0°E and 45°N, on 27/10) which moves towards the east and deepens over the Alps on 28/10, i.e. one day after the cyclone presented its lowest SLP (October 27 18UTC). Such a PV streamer has been shown in a composite analysis (Flaounas et al. 2014) to provoke cyclogenesis over the Mediterranean region through the release of baroclinic instability. The streamer wraps up cyclonically due to the strong horizontal shear between the Subtropical jet (blowing along 30°N) and the descending branch of the Polar jet (at 0°E on 28/10). Such a baroclinic life cycle of a cyclonic wrapping of the PV streamer has been shown by Thorncroft et al. (1993) to be associated with deep cyclones. The second cyclone is provoked by a weaker streamer of less than 3 PVU, being also located over the Alps on 31/10. In fact, it is the conditions over Northern Europe that differentiate the evolution of these systems.

Indeed, the synoptic conditions during the period of 31/10 – 1/11 are characterized by a strong cyclone developing over the UK. From 31/10 to 1/11, a strong PV streamer is extending over Europe with values exceeding 10 PVU at 300 hPa. This streamer provokes the development of a deep and intense cyclone over the North Sea. Such an extended and deep atmospheric PV tongue at the upper troposphere completely dominates cyclogenesis over the North Sea and also has a strong impact on SLP over the whole European continent. As a result, the second Mediterranean cyclone gets rapidly weakened being abruptly absorbed by the stronger northern cyclone (Fig. 3, bottom). Furthermore, at 12 UTC of October 3, the cyclone center was located under the PV streamer suggesting the ending of its mature stage and the beginning of its decaying phase (Flaounas et al. 2014).

4 Prospects

In this paper we presented the preliminary analysis on the dynamics of two deep cyclones over the Mediterranean Sea. Both systems produced heavy rainfall exceeding 40 mm over the central and the eastern Mediterranean. Nevertheless, only one cyclone was associated with deep convection, as revealed by both the AMSU diagnostic and the observed lightning activity. During both cyclogenesis events over the Mediterranean Sea a PV streamer was present but under different synoptic meteorological conditions. In contrast with the first cyclone occurring on 27/10/2012, the cyclogenesis of a strong extra-tropical system over the North Sea restricted the development of the second cyclone on 31/10 that we examine here.

This is an ongoing research and here we presented our preliminary results on the description of the meteorological conditions and on the convective profile of the two cyclones. Our research is concentrated to the link between the meteorological conditions
during the development of the two cyclonic systems with their observed deep convection cells. Particular attention is given to key circulation features leading to extreme rainfall, namely the Warm Conveyor Belts (WCBs). The WCBs have been identified as slantwise ascending air parcels over the extra-tropical cyclones' warm front. It is interesting that in the Mediterranean region, the WCBs have been shown to provoke almost 60% to 80% of the total extreme rainfall events, depending on the areas (Pfahl et al. 2013). Our next step is to further investigate the meteorological conditions leading to extreme rainfall, using the WCBs as a dynamical key feature for explaining intense convective movements of air masses during the development of baroclinic instability.

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References

Air pollution from airborne particulate matter during wintertime in two Greek cities

Florou K., Pikridas M., Kaltsonoudis C., Papanastasiou D. K., Louvaris E., Gkatzelis G., Pandis S. N.

Local and regional air pollution sources were characterized for two major Greek cities (Athens and Patras) during wintertime campaigns conducted in 2012 and 2013. A major objective of both campaigns was to quantify the impact of particulate matter (PM) emissions from residential wood burning which has dramatically increased, since 2010, as a result of the Greek economy crisis. State-of-the-art instrumentation was employed, in both campaigns, to monitor PM concentration, characterize its chemical composition and identify pollution sources. High PM$_1$ (particle diameter < 1 μm) concentrations were observed during both campaigns, often exceeding 50 μg m$^{-3}$ during nighttime. In both cities, PM$_1$ consisted of mainly organics (60-80%), black carbon (5-20%) and inorganic salts (around 20%). Positive matrix factorization analysis of the Aerosol Mass Spectrometer measurements showed that more than half (50-60%) of the organic aerosol was due to biomass burning, while the remaining organics originated from traffic, cooking and long-distance transport. The contribution of residential wood burning was even higher during the nighttime peak concentration periods.

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1 Introduction

Air pollution and climate change are significant environmental challenges that the world is currently facing. Atmospheric particulate matter (PM) contributes to air pollution in urban areas, has an impact on human health and affects regional and global climate. Fine particles, PM$_{2.5}$ (aerosols with diameters <2.5 μm), are directly linked with cardiovascular and respiratory health problems even leading to premature death (Dockery et al. 1993). Moreover, aerosols affect the global energy balance directly, by scattering and absorbing solar radiation, and indirectly, by influencing cloud formation, properties, and lifetimes (IPCC, 2007). Air pollution has been traditionally treated as a local problem, yet there has been increasing evidence of the contribution of regional sources (Lelieveld et al. 2002, Pikridas et al. 2013).

In Greece, an increase of air pollution due to high PM emissions has been observed in major cities, during wintertime. These air pollution episodes have been attributed to residential wood burning. Other sources, like traffic have been proposed as causes of these problems and the contributions of each source to the problem are yet to be elucidated. In this study, results from two intensive wintertime field campaigns, conducted in Patras and Athens (two of the largest Greek cities), are presented with a focus on fine PM composition and sources. The contributions of the various local and regional PM sources in both cities are estimated and the impact of increased residential wood burning on local air quality is discussed.

2 Data and Methodology

Measurements were conducted in the campus of Technological Educational Institute of Patras, the third biggest city of Greece with 300,000 inhabitants, from February 26 to March 5, 2012(38°13'N 21°44'E). The site was located in a medium density residential area with a lot of two-three story buildings, 3 km southeast of the city center and far from any industrial activity. Athens, the largest Greek city with 5,000,000 inhabitants, is located 220 km east of Patras. A second and more extensive campaign was conducted a year later in the center of Athens from January 10 till February 9, 2013. Measurements took place at the National Observatory premises at Thiseio (37°58′30″N 23°43′00″E, 100 m above sea level) in collaboration with NCSR Demokritos, the University of Crete, the University of the Aegean and the National Observatory of Athens. This is located 1.5 km southwest of downtown, northwest of the Acropolis archeological site and does not have nearby roads.

A High Resolution Time-of-Flight Aerosol Mass Spectrometer (HR-ToF-AMS) was used in both campaigns to monitor the aerosol mass size distributions of the major non-refractory PM$_1$ components, a Scanning Mobility Particle Sizer, (SMPS) to measure the number distribution of PM$_1$, a Multiangle Absorption Photometer (MAAP) to measure the PM$_{2.5}$ absorption and to estimate the Black Carbon (BC) concentration and a Tandem Element Oscillating Microbalance (1405-DF TEOM) used for monitoring PM$_{2.5}$ mass concentration.

In both sites, PM$_1$ consisted mainly of organic matter during nighttime. In order to identify its origin, source apportionment was conducted using Positive Matrix Factorization (PMF). PMF separates the mixed spectra of organics (obtained by the AMS) into a combination of time-depended factors (sources) (Ulbrich et al. 2009, Paateroand Tapper1994, Lanz et al. 2007).

3 Results

The one hour averaged mass concentrations (in μg m$^{-3}$) of the major PM$_1$ components during the Patras campaign in winter 2012 are shown in Fig. 1. The major component of PM$_1$ was organic matter which increased dramatically reaching levels up to 100μg m$^{-3}$ during the evening. The organic aerosol concentration also increased during morning rush hour but the
corresponding concentrations were less than 20 μg m\(^{-3}\). BC closely followed the trend of organic aerosol with maximum BC mass concentration of approximately 8 μg m\(^{-3}\) during nighttime and 4 μg m\(^{-3}\) during rush hour. Nitrates followed a similar trend but sulphate concentrations had smaller fluctuations during the campaign, indicating a different source origin.

![Fig. 1. Mass concentration time series (hourly averaged) for the major PM\(_1\) components during the Patras campaign in the winter of 2012.](image)

The mass concentration for the major PM\(_1\) components during the Athens campaign in winter 2013 is shown in Fig. 2. Once more, the major component of PM\(_1\) was organic matter (OM) which had frequent nighttime (after 18:00, UTC+2) peaks (up to 40 μg m\(^{-3}\)). During most of the days the PM\(_1\) mass was lower than 20 μg m\(^{-3}\) due to frequent rain events and strong winds. During the nighttime the BC mass concentration maximized was as high as 15 μg m\(^{-3}\) while the corresponding morning rush hour maxima were up to 8 μg m\(^{-3}\).

The diurnal variation of PM\(_1\), OM and BC for both cities is shown in Fig. 3. In both sites the diurnal profile of PM\(_1\) has two peaks during the day, the first one in the morning which coincides with the rush hour traffic and the second one in the evening (after 16:00 in Patras and after 17:00 in Athens, UTC+2). The evening peak for Athens is 3 hours later than in Patras. In Patras, the daily average PM\(_1\) concentration was 27 μg m\(^{-3}\), while in Athens 10 μg m\(^{-3}\). The higher concentrations in Patras were due to the lower temperatures and lower rainfall during that period compared to the Athens campaign. The location of the Patras site in the suburbs of the city in an area with a lot of biomass burning compared to the rather isolated sampling site in the center of Athens probably contributed to the observed concentration differences. In Patras, OM and BC followed closely each other and the PM\(_1\) mass.

![Fig. 2. Mass concentration time series for the major PM\(_1\) components during Athens campaign, in winter 2013.](image)
During both campaigns four factors were identified in the PMF analysis: biomass burning organic aerosol (BBOA), oxygenated organic aerosol (OOA), cooking organic aerosol (COA), and hydrocarbon-like organic aerosol (HOA). BBOA, which is due to biomass burning, comprised 50% of the total PM1 OA followed by the OOA factor (responsible for 15-25% of the total PM1 OA). OOA represents the chemically aged OA and is mostly due to long range transport from other areas. These results are consistent with long term measurements in Patras that indicated transported pollution as a major PM source throughout the year (Pikridas et al. 2013). The two last factors were COA, which is related to cooking and its concentration peaks during mealtimes, and HOA which is associated with hydrocarbons in vehicle exhaust emissions and is attributed mainly to traffic. The source apportionment results are summarized in Fig. 4.

4 Conclusions

During both winter periods organic compounds accounted for more than 60% of the PM1 concentration, followed by sulfate ions and black carbon. The OM concentration increased in both cities during the evening hours (after 5 pm LST, UTC+2) and peaked at around 8 pm in Patras and 11 pm (LST, UTC+2) in Athens. The average concentration of OM in Patras was 20 μg m⁻³ with an hourly maximum of 75 μg m⁻³. The concentration of BC in Patras was also high, showing an average value of 2 μg m⁻³ and maximum 8 μg m⁻³. During the Athens campaign the average mass of OM and BC were 6 and 2 μg m⁻³, while their maxima were 75 and 15 μg m⁻³ respectively. Positive matrix factorization analysis showed that 50-60%
of the total PM$_1$ organic aerosol was derived from biomass burning while the rest originated from traffic, cooking and long-distance transport. The high BC and organic concentrations during winter nighttime were mainly the result of wood burning.

Acknowledgments: This research was co-financed by the European Union (European Social Fund - ESF) and national funds through the Operational Programme «Education and Lifelong Learning» of the National Strategic Reference Framework (NSRF) - Research Funded Project: THALES. Investing in knowledge of the society, through the European Social Fund. Title - Identify sources and physicochemical properties of fine and very fine suspended particles of atmospheric aerosols that affect the climate of Greece."

References


Space-time and kinematic features of hailstorms in Northern and Central Greece

Foris D., Vetsos I., Spanos S., Foris V.

In this study, radar recorded data of storms that affected the areas of application of the Greek National Hail Suppression Program during hail seasons 2012 and 2013 were examined. Some of these storms were seeded with AgI in order to suppress hail, while some of them produced a confirmed hailfall. The spatial and temporal stormy activity was investigated, as well as kinematic characteristics in relation to physical features of the storms. An attempt was also made towards relating hailfall with the above features. Several parameters appear to be related to hail, the best among them being the VIL of storms (Vertically Integrated Liquid: an estimate of total mass of precipitation in clouds).

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1 Introduction

The Greek National Hail Suppression Program (GNHSP) is applied in two project areas, one in Northern Greece (A1) and another in Central Greece (A3) during each hail season from April to September. Storms are tracked by two C-band radars, one located at Filypio, Thessaloniki, detecting storms in A1 and another at Liopraso, Trikala, detecting storms in A3. From all the storms recorded, only those that affected the project areas were examined, that is those developed or decayed inside the areas and those that crossed or skimmed the areas. Hailfalls were confirmed using a hailpad network installed in A1 and by agronomists.

2 Data and Methodology

2.1 Data

A total of 500 storms were recorded during 2012 and 2013, 360 in A1 (165 on 2012 and 195 on 2013) and 140 in A3 (75 on 2012 and 65 on 2013). These occurred on 95 days. Storm data consist of storm date, time of first and last detection of the 30 dBZ reflectivity contour (leading to lifetime), starting and ending areas, distance traveled, direction of motion, storm type, maximum reflectivity (above -5°C level), maximum echo top, height of the 45-dBZ contour and VIL of storm (Greene and Clark 1972). All these data were recorded with the aid of radar recording system TITAN (Dixon and Wiener 1993). Seeded and non-seeded storms were identified, as well as whether or not storms produced hail on ground.

2.2 Methodology

First of all, the storms that produced a confirmed hailfall were identified with the aid of TITAN. Then, storms with reflectivity less than 45 dBZ and tops less than 6 km were filtered out (20 storms and 5 days were thus excluded). Storms were also classified in three categories, namely singlecell, multicell and supercell type (Browning 1977). Thus, the record of each storm comprises the following fields: month, time of initiation, lifetime, distance traveled, average speed, direction of motion, type, maximum reflectivity, maximum top, height of 45-dBZ contour, VIL, seeded/non-seeded, hail/no-hail.

The results are presented for each area separately, since they often show their climatic difference. Monthly and daily distributions of storms are followed by preferred areas of initiation, decay and direction of movement with respect to project areas. Next, distance covered, lifetime, speed and direction of motion are examined in relation to storm type, seeding and hail on ground. Finally, physical features of storms that produced hail are compared with those that did not.

3 Results

The assessment of convective activity is accomplished by the monthly distribution of storm days and of individual storms (Fig.1). A well-defined maximum of storm days is found in A1 during May, while for A3 May and June have a similar occurrence. The number of storms is more pronounced in A3 during May and June, while storm frequencies are more evenly distributed in A1 from May to August. This constitutes an indication for the formation mechanism: thermal heating is prevailing for storm initiation in A3, while for A1 the dynamic
synoptic trigger plays also a key role. Several storms may be generated on a storm day: in A1 one and in A3 1-2 storms per day are more frequent (Fig. 2).

The distribution of storm initiation times and storms' duration are presented in Fig. 3. Its maximum occurs clearly on maximum heating hours, a fact that is more evident in A3. Very few storms are triggered on early morning, while nighttime activity can't be ignored. A more detailed monthly distribution of these times reveals subtle differences: the pronounced maximum at class 12-15 UTC, reflecting the thermal effect, holds for all months in A3, but only until June in A1. The maximum for the second half of hail season is shifted later (15-18 UTC). This has to do with the length of the day. For the same part of the season, storms arise also during the night (they develop particularly over warm sea).

Fig. 1. Monthly distribution of storm days (left) and individual storms (right) for the two areas.

Fig. 2. Distribution of the absolute number of storms per day for the two areas.

Fig. 3. Daily distribution of storm initiation times in three-hour intervals starting at the time indicated on x-axis (left) and storms' duration (right).

Frequencies of initial and final locations of storms relative to project areas are depicted in Fig. 4. The majority of storms initiates and decays inside them, the percentages being more than 50% for A1 and 48% for A3. North and west of A1 and north, west and south of A3 are also "source" regions, while "sinks" are preferably found east of both areas. Areas of initial and final location of storms are designated as 1 (inside), 2 (north), 3 (west), 4 (south) and 5 (east) relative to project areas. Relative percentages of motion appear in Fig. 4 (below), where the interior of circles represent storms that start and end inside (1→1). Right-pointing arrows represent trajectories 1→5, 3→1 and 3→5, left-pointing 5→1, downward 1→4 and 2→1 and upward 4→1, 4→5 and 1→2. In both areas storms usually develop and weaken inside. Eastward motion in A1 and eastward and northward in A3 are also preferred directions.
Multicells constitute the commonest type (69% in A1, 75% in A3), followed by singlecells (31% and 20% respectively), while supercells are just a few (0.3% and 5%). The relative number of multicells increases in A3 during June and July and in A1 during June, August and September, otherwise it is comparable to that of singlecells. Hail is produced by 17% of singlecells and 20% of multicells, independently of area. There is no statistically significant difference in these two proportions ($\chi^2$ homogeneity test). Hail is also a result of seeded (30%) and non-seeded (12%) storms. This difference in hail-production rate is statistically significant at 0.05 level. Stratification shows that seeding is more efficient to reflectivities lower than 60 dBZ.

Figure 5 gives the distribution of speeds, which is rather similar in the two areas, the average speeds being 23.8 and 22.8 km/h in A1 and A3 respectively. Only non-stationary storms are considered in this analysis. The 11.4% of the cases for A1 and 15.8% for A3 are thus excluded, as they travelled less than 10 km. Average distances travelled and lifetimes are higher in A3 compared to those in A1 (42.1 vs. 35.4 km and 109 vs. 97.3 min respectively). Seeded and non-seeded storms exhibit similar speeds (20.4 and 22.3 km/h) and the same holds for hailers and non-hailers (20.4 and 21.6 km/h respectively). Distance, lifetime and speed though, depend highly on storm type: they increase from singlecells to multicells and finally to supercells, a fact common in the two areas, as shown in Table 1.

![Wind Roses](image_url)

**Fig. 5.** Distribution of storm speeds in classes of 10 km/h for the two project areas.

**Table 1.** Variation of distance traveled, lifetime and speed with storm type.

<table>
<thead>
<tr>
<th>Storm Type</th>
<th>Distance (km)</th>
<th>Lifetime (min)</th>
<th>Speed (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Singlecells</td>
<td>22.5</td>
<td>69.6</td>
<td>19.5</td>
</tr>
<tr>
<td>Multicells</td>
<td>40.6</td>
<td>109.3</td>
<td>21.9</td>
</tr>
<tr>
<td>Supercells</td>
<td>149.0</td>
<td>275.1</td>
<td>31.3</td>
</tr>
</tbody>
</table>

Figure 6 presents wind roses for A1 and A3 (direction towards which storms move). A general eastward ($045-135^\circ$) direction of motion is observed (48.6% in A1, 45.2% in A3).
Moreover, a significant percentage 27.7% in A1 is south moving (135-225°), followed by 10.7% of southwest moving ones (225-255°).

Fig. 6. Direction of motion towards which storms move (rose diagrams) for the two areas.

Finally, average physical features of hailers are compared with those of non-hailers for the two areas. The results are presented in Table 2, which gives the respective values for hailers and non-hailers and their relative percent difference D (positive values of D indicate higher values of hailers).

<table>
<thead>
<tr>
<th></th>
<th>Area 1</th>
<th>Area 2</th>
<th>D (%)</th>
<th>Area 3</th>
<th>Area 4</th>
<th>D (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lifetime (min)</td>
<td>121.0</td>
<td>91.6</td>
<td>24.3</td>
<td>159.0</td>
<td>94.3</td>
<td>40.7</td>
</tr>
<tr>
<td>Distance (km)</td>
<td>42.1</td>
<td>33.8</td>
<td>19.7</td>
<td>71.1</td>
<td>33.5</td>
<td>52.9</td>
</tr>
<tr>
<td>Speed (km/h)</td>
<td>18.7</td>
<td>22.1</td>
<td>-18.2</td>
<td>24.3</td>
<td>20.2</td>
<td>16.5</td>
</tr>
<tr>
<td>Reflectivity (dBZ)</td>
<td>59.6</td>
<td>54.4</td>
<td>8.7</td>
<td>62.0</td>
<td>55.2</td>
<td>10.9</td>
</tr>
<tr>
<td>Top (km)</td>
<td>10.3</td>
<td>9.2</td>
<td>10.7</td>
<td>11.3</td>
<td>9.2</td>
<td>18.6</td>
</tr>
<tr>
<td>45dBZ height (km)</td>
<td>8.3</td>
<td>6.8</td>
<td>18.1</td>
<td>9.3</td>
<td>6.9</td>
<td>25.8</td>
</tr>
<tr>
<td>VIL (kg/m²)</td>
<td>72.7</td>
<td>36.1</td>
<td>50.3</td>
<td>83.2</td>
<td>41.0</td>
<td>50.7</td>
</tr>
</tbody>
</table>

It is observed that several parameters exhibit a strong relation to hail production. Among them, VIL values of hailers are in both areas double compared to non-hailers.

4 Conclusions

From the study above the following conclusions are drawn:

4. Convective activity is higher in May and June, as a result of thermal heating.
5. Maximum heating hours are the favorite time of storm initiation. Nighttime activity though can't be ignored, especially during July and August.
6. Storms develop and decay preferably inside project areas, their commonest direction of motion being from west to east.
7. Singlecells and multicells produce hail at a comparable rate.
8. Lifetimes and distances traveled are higher in A3, but speeds are similar.
9. VIL seems to be the best hail identifier among physical features of storms.

References

A climatic study at a vulnerable touristic region of Southwestern Greece – Observations and simulations

Founda D., Giannakopoulos C., Karali A., Zerefos C.S.

In the framework of the XENIOS project (http://www.xenios-net.gr/en/), Messinia, one of the most popular touristic destinations of Greece, was selected to assess the impacts of climate change on tourism in vulnerable areas. Historical observations were used to detect mean climatic features at this region as well as climatic variability and trends. A significant increase of the maximum air temperature was detected after mid 1970’s in accordance with the general trend for the eastern Mediterranean. This increase approximates 1°C/decade at the continental sites. The annual precipitation amount does not reveal any statistically significant change over the studied period. However, the annual number of rainy days was found to decrease by 4 days/decade, in contrast to the increasing trend in the annual number of heavy rain days. A set of Regional Climate Models from EU projects ENSEMBLES (www.ensembles-eu.org) and CIRCE (www.circeproject.eu) was also validated using observational data at Messinia. The use of an ‘average’ model improved the performance of individual models for all climatic indices. The ‘average’ model simulated successfully temperature and precipitation indices in the area, such as total precipitation and number of days above certain thresholds and hence can be used for future climate change projections.

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1 Introduction

Climate change is a global phenomenon but its effects concern local scales and have a direct impact on local economies. One of the economic activities which is particularly affected by weather and climate is tourism. The tourism industry is very important for local economies, providing employment and generating income. In Greece, tourism industry is a main pillar of the country’s economy corresponding to a high proportion (> 20%) of employment. Nevertheless, this industry is interlinked with climate change in various and different ways. It is imperative to reduce vulnerability (related to exposure/sensitivity and adaptive capacity) of touristic areas and implement measures of adaptation to climate change. First, vulnerable areas that face with problems must be recognized.

As regards climate change in the country, recent studies report a general warming over the past three decades, characterized by large spatial and seasonal variability (e.g. Feidas et al. 2004, Philandras et al. 2008). According to these studies, warming is more important and statistically significant during the warm season of the year, while in winter some areas present a cooling trend and others a warming trend (the latter not statistically significant). Moreover, extreme events and particularly heat waves have increased in terms of frequency, intensity and duration and are expected to be more frequent in the future (Founda and Giannakopoulos 2009).

Assessing vulnerability of tourism industry to climate change in Greece will allow mitigation and adaptation measures. In the framework of the XENIOS project (http://www.xenios-net.gr/en/), Messinia was selected to assess the impacts of climate change on tourism in vulnerable areas. A climatic study for Messinia was conducted, aiming at the detection of climatic changes in the area from long term observations, while a set of Regional Climate Models was validated to allow their application for future projections at Messinia.

2 Data and Methodology

Historic weather data from the network of meteorological stations of the Hellenic National Meteorological Service (HNMS) at Messinia, covering a period of at least three decades were used to demonstrate the spatial and temporal climate variability and detect possible significant trends. The stations of Methoni (coastal), Kalamata (airport) and Diavolitsi (continental) were used for the analysis. A number of climatic indices for air temperature and precipitation (concerning average and extreme values) as defined by the Expert Team of Climate Change, Detection and Monitoring Indices (ETCCDMI) was also calculated from daily historic data. Air temperature indices include daily maximum (Tmax) and minimum (Tmin) temperature, while extreme temperature indicators are based on percentiles and absolute temperature threshold values (e.g. number of days/nights with temperature above/below certain threshold values indicating summer days/nights or tropical days/nights or frost days etc). As regards precipitation, total precipitation amount, number of rainy days (>1mm) and number of days with light, moderate, heavy and extreme precipitation were also calculated.

Historic climatic data at Messinia for the control period 1975-2004 were also used for the validation of Regional Climate Models (RCMs) to be applied in the area for future projections. A set of RCMs simulations was carried out in the framework of the European Projects ENSEMBLES (www.ensembles-eu.org) and CIRCE (www.circeproject.eu) was used, at 25 Km horizontal resolution. Observations were compared with simulations of each RCM but also with an ‘average’ model produced by averaging the simulations of the individual models. In addition, daily reanalysis data (E-Ob) developed for Europe by Haylock et al. (2008) in the framework of the ENSEMBLES Project were also compared to observations and simulations for the control period.
3 Results

3.1 Air temperature variability

As regards the temporal variability of the air temperature at Messinia, the analysis of the historical records revealed significant positive trends in the summer maximum and minimum temperatures since mid 1970s at all stations, but lack of any significant trend in winter temperature.

Figure 1 displays the interannual variability of the daily maximum temperature in summer (June to August) at the coastal station of Methoni, at the west side of Messinia, from 1956 to 2010. A cooling from 1956 to 1975 is observed, followed by a clear warming from 1975 onwards. The overall long-term trend is positive and statistically significant (at 0.05 confidence level) according to the Mann Kendall test, amounting to +0.2 °C/decade. However, the trend for the period after mid 1970’s is much larger, amounting to +0.6 °C, and statistically significant at 0.01 confidence level. Warming trends in summer were also found at Kalamata station, while an outstanding positive trend in the summer maximum temperature, amounting to +0.9 °C/decade after mid 1970’s, was observed at the continental station of Diavolitsi (not shown). The findings for Messinia are in full agreement qualitatively and quantitatively with the findings at other parts of Central and Southern Greece, for instance Athens, where a pronounced warming in the summer maximum temperature has been observed during the last three decades (Philandras et al. 2008, Founda 2011).

The frequency of cold extremes at Messinia is very low. It was calculated that the frequency of days/year with Tmin<0 °C is less than 1% at the coast (Methoni) but reaches up to 5% at other sites (e.g. Kalamata). The lowest temperature ever recorded at Methoni was -5.6 °C (14/02/2004). Hot extremes are more important for the area of Messinia as they can have a great impact on a number of sectors. The highest temperature ever recorded at Methoni was 41 °C, however, the values of 43 °C or even 45 °C have been recorded at nearby stations of the area.

The frequency of summer days (Tmax>25 °C)/year is very high, amounting to 30-40% of the total days of the year, while the number of consecutive summer days per year was found to be on average 73 at Methoni and 107 at the station of Kalamata. As regards the frequency of occurrence of tropical days (Tmax>30 °C) from 1956 to 2010 at Methoni, a statistically significant increase (at 0.01 confidence level) in the number of tropical days/year is detected after mid 1970’s, amounting to 6 days/decade.
3.2 Precipitation variability

The analysis of the interannual variability of precipitation at Messinia suggested the lack of any significant long term trend, as regards the total rainfall amounts. Nevertheless, as regards the number of rainy days/year, the analysis revealed an ongoing decreasing trend, particularly pronounced at Methoni station. Figure 2 displays the interannual variability of the number of rainy days (daily rainfall >1mm) at Methoni for the period 1956-2010. The observed negative trend is equal to approximately 2.5 days/decade. It is worthy however to note that, the trend becomes much larger (approximately 4 days/decade) when rainy days are assigned as days with rainfall amount >0mm. Despite the decrease in the number of rainy days/year, a positive trend in the number of days/year with heavy rain (30mm/day) was observed at all stations.

3.3 Validation of RCMS

Figure 3 shows the intra annual variability (average monthly values) of the maximum air temperature at Methoni from simulations, observations and E-Obs. All models reproduce successfully the intra annual variability of the maximum and minimum air temperature, however with different scores. The accuracy of each model was sensitive to the particular climatic index (better performance was found in the maximum than minimum temperature) but also to the particular features of each site (coastal or continental). The performance of the ‘average’ model was much better, as it compensated overestimations or underestimations of individual models. However, even the ‘average model’ has a cold bias which ranges from 0.50°C in January to 1.90°C in May. An excellent agreement between observations and E-Obs is also found.

The inter annual variability and trends of Tmax at Methoni from observations was found to agree very well with E-Obs (for instance, +0.60°C and +0.7°C/decade in summer from observations and E-Obs respectively for summer), however, the simulated trend from the ‘average model’, though positive, was smaller by approximately 50%.

As regards extreme indices, the average model and E-Obs simulated successfully the upper percentiles (90th and 95th) of the maximum and minimum air temperatures at all stations, however, the model overestimated the number of very hot days (Tmax> 30°C and 35°C) at coastal stations and underestimated it at continental stations.

Figure 4 shows the mean monthly precipitation amounts at Methoni for the control period from observational data, ‘average’ model and E-Obs. E-Obs are in full agreement with observations, while the average model reproduces satisfactorily the precipitation amount for each month except for November and December, where an underestimation of almost 30% is found. The performance of all models was found to be quite successful in terms of the number...
of rainy days/year as well as the number of days corresponding to all categories of precipitation (light, moderate, heavy and extreme).

4 Conclusions

A climatic study for Messinia was conducted, to assess exposure and vulnerability to climate change effects that could have an impact on tourism activities in this area. A significant warming in the summer maximum air temperature after mid 1970’s was detected, in accordance to the findings in other areas of Greece. Warming is more pronounced at continental sites, accompanied with increased frequency of very hot (tropical) days.

A decrease in the number of rainy days/year is also detected, which in combination with hotter conditions could stress tourism activity at Messinia.

The comparison of RCMs output with observations and E-Obs for the control period 1975-2004, showed satisfactory performance of the ‘average’ model for almost all examined climatic indices except for the frequency of very hot days which was very sensitive to the location and characteristics of the stations site and mean precipitation amounts of November and December. In general, the use of an ‘average’ model improved the performance of individual models and can be used for future climate projections at Messinia.

Acknowledgments This work has been financed by the EU (ERDF) and Greek national funds through the Operational Program “Competitiveness and Entrepreneurship” of the National Strategic Reference Framework (NSRF) Research Funding Program COOPERATION 2009 (no 09COP-31-867, project title XENIOS). We thank the Hellenic National Meteorological Service for providing climatic data.

References

Long term variability of visibility in Athens - The urban influence

Founda D., Kazadzis S.

Visibility is related to the visual air quality and constitutes an important component of the climate and landscape of an area. Anthropogenic and natural atmospheric emissions, but also meteorological conditions are the main factors that control visibility. This study investigates the long term variability and trends of the visibility at the urban environment of Athens and its correlation with several meteorological parameters. Historical visibility observations of more than 80 years (1931-2012) conducted at the National Observatory of Athens were used. The analysis was performed for the two sub periods before and after 1970 in order to better highlight the urbanization influence on the visibility of Athens. The trend analysis over the long term period indicated a pronounced deterioration of the visibility in the city, equal to 3.3 Km/decade in summer and 2.3Km/decade in winter. Higher correlation coefficients between visibility and meteorological parameters before 1970, possibly indicate that meteorological conditions were the primary factor determining the optical air quality at the time, in contrast to the more recent decades with higher concentrations of air pollutants. In addition, satellite derived aerosol optical depth retrievals over Athens since 2000, have been compared and analyzed in order to verify our findings.

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1 Introduction

Visibility is an important part of the urban environment and has a direct impact on human health, telecommunication and transportation. Visibility is affected by the prevailing meteorological conditions such as the air humidity, precipitation, wind speed etc. However, aerosols play a dominant role in visibility and investigation of long-term trends in air quality has increasingly used visibility statistics as a surrogate for air pollution data (Pusheng et al. 2011).

Under clear sky conditions, visual optical quality is mainly determined from the concentration of the aerosols in the atmosphere. Absorption and scattering of sunlight from air pollutants and atmospheric aerosols constitute a major factor that reduces visibility in urban areas. The visibility deterioration is perhaps the most directly perceptible impact of the air pollution (Seinfeld and Pandis 2006) while atmospheric turbidity constitutes a main feature of the urban landscape.

Wang et al. (2009) report a reverse march of the visibility on a global scale from 1973 to 2007. A decreasing trend is detected until mid 1980’s, which is attributed to increased aerosols concentrations, followed by an increasing trend but only at certain regions, like Europe, consistent with reported European ‘brightening’. Numerous studies underline the pronounced degradation of visibility in developing areas, like Asia. Tsai et al. (2003) report a decrease of the mean annual visibility in South Taiwan from 20Km to 8 Km within a 4 decades period. Very low visibility values (< 8Km at a frequency of 25%) are also observed at the Pearl River Delta (China), which are attributed to high concentrations of PM10 (Wan et al. 2011). Ghim et al. (2006) found a decrease of 4Km/decade in the visibility in South Korea, despite the observed simultaneous decrease of the relative humidity levels. There are also reports on increasing trends of visibility in certain areas, like England, which was partly attributed to changes in the use of fuels and oil crisis during the early 1970’s (Doyle and Dorling 2002).

Although the landscape of Attika is traditionally connected with blue, clear sky and good conditions of visibility, very few studies focus on multi annual changes of visibility in Athens. Carapiperis and Karapiperis (1952) report on the correlation between the visibility and the blue color of the Attika sky, while Kanelopoulou (1979) reports a pronounced decrease of the visibility in Athens after the 1950’s. The present study updates research on the visibility in Athens until 2012.

2 Data and Methodology

The study of the visibility in Athens was based on the historical archives of the National Observatory of Athens. Daily observations of visibility towards the land (corresponding to the centre of the city) and thesea at 14:00 LST (LST= GMT+ 2hrs), conducted on the Hill of Nymphs at Thission site in the center of the city from 1931 to 2012 were used. An empirical scale has been used for the observations of the visibility at NOA, as recommended by the World Meteorological Organization (WMO) (Table 1). Visibility is defined as the greatest distance at which a predefined object can be seen and recognized with naked eye. This introduces an uncertainty in the visibility observations which are influenced by the subjectivity of the observers (or changes in the predefined objects). It is assumed however, that the performance of observations by different observers could have a compensating effect and an overall reduction of biases.

Monthly, seasonal and annual average values of visibility were derived from the daily observations at 14:00 LST. The warm and dry period of the year (May-September) and the cold and wet period (October – April) were studied separately in the analysis. Long term meteorological data at Thission site over the period 1931-2012 were also acquired from the historical archives of NOA.
Table 1: The empirical scale used for visibility observations at NOA and corresponding distances.

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<tr>
<th>Visibility degrees</th>
<th>1</th>
<th>2</th>
<th>3</th>
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3 Results

3.1 Intra-annual and inter-annual variability of visibility- Trends

Figure 1 illustrates the intra-annual variability of the mean visibility towards land for two 40-years sub periods, namely 1931-1971 and 1972-2102. Although urbanization of Athens intensified after World War II, the construction rate peaked during the 1970’s, therefore the period after the early 1970’s has been considered to represent a period with well established urban effects in the city.

According to Fig. 1, the visibility is higher (up to 2 degrees of the empirical scale) during the first sub period over the whole year. A seasonal variability is also discerned during the first period, with higher values of visibility in summer and lower in winter. This indicates the direct relationship of the visibility with meteorological conditions during this period. The maximum of the visibility is observed in August, (when Etesian winds prevail in Eastern Greece) and the minimum in March for both periods. Seasonality of visibility is much less evident during the second period, indicating a weakening of the influence of meteorological conditions and possibly a dominating effect of air pollution. According to recent research for Athens, coarse aerosols exhibit seasonality too, with higher values in summer and transitional seasons (Lianou et al. 2011). Regarding the values of the visibility towards the sea, they were found slightly lower compared to the visibility towards land, while maxima were found in June for both sub-periods.

Figure 2 depicts the inter-annual variability of the visibility in Athens from 1931-1971 and 1972-2012 along with trends from a linear regression analysis, averaged over the warm and dry periods of the year (Fig. 2-left panel) and the cold and humid periods (Fig. 2-right panel). Visibility values are shown using both the degree and the kilometric scale. Extreme declines are observed (from ~30Km in 1930’s to less than 10Km after 1990’s) during the warm period of the year.

The long term decrease of the visibility for the entire period studied amounts to 3.3 Km/decade (p<0.001) during the warm season. The most striking decrease is observed during the decade 1946-1955, a period with increasing urbanization in Athens. This drop is remarkable during both the warm and cold season of the year and equals 2Km/year reflecting
the urban influence on visibility. An ongoing deterioration of visibility from the 1950’s to the present is also obvious in Figure 2. However, during the last decade there is a tendency of stabilization, possibly related to reduced atmospheric aerosols concentrations. This development is due to a series of measures that had been taken during the 1990s concerning many aspects of the city activities. Such measures were the improvement of fuel quality (total ban of leaded fuel), the usage in the industry of crude oil with low sulphur content, the renewal of the fleet with vehicles using anti pollution technology, etc. In order to explore the aerosol load levels for the last decade, we have calculated monthly averages of aerosol optical depth (at 550 nm) retrieved from Terra/MODIS satellite for Athens area and using a 50x50Km daily satellite overpass (e.g. Ichoku et al. 2002). Results (not shown) showed a significant (-15%) decrease from 2000 up to 2010 and a further decrease of 8% for the 2012-2013 period. The deterioration of visibility during the cold and wet season is evident and amounts to 2.3 Km/decade (p<0.001) over the entire period studied (Fig. 2).

A similar behaviour was found for the visibility towards the sea, but with lower rates of decrease, equal to 2.6 and 1.6 Km/decade for the warm and cold seasons respectively. Figure 3 illustrates the frequency of occurrence of visibility degrees towards the land over the two sub periods. It is noteworthy that for the first period, visibility exceeded 10 Km for 70% of the cases and 20 Km for more than 25% of the cases, while for the second period, only 30% of the cases correspond to visibility greater to 10 Km and just 6% to visibility greater to 20Km. Focusing on the last decade, visibility exceeds 10 Km only at a percentage of 15%.

3.2 Correlation between visibility and meteorological variables

The correlation of visibility over the whole period under study with certain meteorological variables such air humidity, cloudness and wind speed has been also investigated. Visibility was found to be negatively correlated with relative humidity and cloudiness and positively correlated with wind speed. The correlation coefficient of visibility with cloudiness was equal to –0.27 (p<0.05) for both periods, 1931-1971 and 1972-2012. During the first period, the average visibility corresponding to total cloud cover > 75% was found to be lower by 7 Km compared to conditions of total cloud cover <25%, while for the second period, the respective decrease of visibility was 2 Km.

Regarding the correlation between visibility and relative humidity, the correlation coefficient was found to decrease gradually (with respect to its absolute value) during the whole period studied, with average values of –0.39 and –0.26 (p<0.05) for the first and second sub period respectively. This decrease possibly suggeststhe weakening of the meteorological influence on the determination of the visibility in Athens, compared to the influence of air pollution. On the contrary, the impact of the wind speed on the visibility values is more important during the recent decades, as high wind speeds are related to low concentrations of air pollutants. The correlation coefficient between the wind speed and visibility increased progressively during the whole period studied and was found to double (from 0.15 to 0.29, p<0.05) during the period 1972-2012.
4 Conclusions

The analysis of the observations of visibility in Athens for the period 1931-2012 revealed a dramatic deterioration of the visual air quality in the city. The decrease of the visibility towards the centre of the city amounts to 3.3 Km/decade during the warm season of the year. It was estimated that visibility exceeded 10Km at a percentage of approximately 70% before 1970, while during last decade this percentage drops to 15%. The correlation between visibility and meteorological conditions was found to be stronger for the period before 1970.

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References


Multi-annual changes in the occurrence of prevailing cloud types in Athens

Founda D., Nastos P.T., Skordara E., Pierros F.

Cloud forcing is fundamental for the determination of the water and energy budget on the earth. Clouds have a direct effect on the precipitation amounts and the surface air temperature. In addition to the total cloud cover, various types of clouds contribute differently to the energy budget between the earth and the atmosphere. The high, thin clouds are highly transparent to short wave radiation but they absorb the outgoing long wave radiation, and thus have a warming effect as they enhance atmospheric greenhouse effect. In contrast to high clouds, low clouds have a net cooling effect on the earth surface. The frequency of occurrence of the prevailing cloud types over Athens was calculated, based on the reports of the National Observatory of Athens (NOA) at 08.00, 14.00 and 20.00 LST, over the last 60 years. Intra-annual, inter-annual and seasonal variability and trends over the studied period were investigated. Various cloud types were classified in families according to their height (high/middle/low) but also to their form (cumuliform, stratiform etc). The analysis revealed pronounced changes in the occurrence of certain types of clouds. A dominant outcome of the analysis is the increased frequency of high clouds occurrence during summer.

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1 Introduction

Clouds have a large effect on climate which, in addition to their horizontal coverage, is strongly dependent on their form, height and content (water droplets or ice crystals). Additionally, cloud feedbacks introduce uncertainties in atmospheric modeling and contribute to the large diversities between climatic models.

It is thus essential to examine variations in individual cloud types, rather than just total cloud cover (Warren et al. 2007). Low clouds reduce on average the net radiative heating and contribute to cooling of surface air temperature. For example, an increase in low clouds by about 5% over the eastern United States, caused by warmer sea surface temperatures in the tropical Pacific, is responsible for the observed cooling of 0.1°C per decade during the last 50 years (NASA, 2001). High clouds (e.g. cirrus) can enhance the net radiative heating if they are optically thin enough or reduce it, if they are thicker (Jin et al. 1996).

Intense urbanization has possibly increased the frequency of occurrence of convective (cumuliform) clouds due to the heating and strong convection induced by artificial concrete surfaces. Matuszko (2002) reports a significant positive trend in the occurrence of convective clouds over Crakow during the past century and a significant decrease in the occurrence of stratiform clouds, possibly related to the urbanization of the area.

The expansion of the aviation globally and the increased emissions of aerosols has been linked by many researchers with the increased frequency of high-level clouds (e.g. Minnis et al. 2004, Milewska 2008). Milewska (2008) reports a prominent increase in cirrus clouds occurrence in Canada after mid 1970’s (possibly caused by a simultaneous increase of air traffic) and remarkable decrease/increase in the occurrence of stratus/cumulus. These changes were related to relevant changes in the maximum and minimum surface air temperature. A decline in the stratiform clouds has been also reported by Sakellariou et al (1993) over Athens during 1959-1988.

The present study investigates the multi annual variability and trends of different cloud genera in the highly urbanized area of Athens for the long period 1953-2012. It is noted that Athens has undergone significant climatic changes during last decades, manifested mainly through the prominent increase in both maximum and minimum daily surface air temperature (Founda 2011). These changes are attributed to both regional warming and urbanization (Founda et al. 2013). It is expected that the study of the temporal variations of different cloud genera in Athens, will contribute to the better understanding and interpretation of climatic changes in the area.

2 Data and Methodology

The analysis was based on the daily observations of cloudiness at 08:00, 14:00 and 20:00 LST (LST=GMT+2hrs) conducted at the National Observatory of Athens (38°58.3 N, 23°43' E) in the center of Athens. The period from 1953 to 2012 was selected for the analysis. The daily reports of cloudiness at NOA include the amount of total cloud cover as well as the different cloud genera that appear in the sky. It is expected that cloudiness reports suffer from some kind of subjectivity - mainly related to the experience of each observer- however, the management of such possibility is quite difficult, especially when long periods are treated.

Although different cloud genera coexist in the sky, one genus usually prevails. In our analysis we estimated the frequency of occurrence of the ‘prevailing’ cloud type for each observation over the studied period, which is the cloud type with the largest horizontal extent in the sky. Main cloud genera were classified in families according to their height or form. Cumulus (Cu), Stratocumulus (Sc), Stratus (St) and Cumulonimbus (Cb) are assigned as Low level clouds, Alto cumulus (Ac), Altostratus (As) and Nimbostratus are assigned as Middle level clouds and Cirrus (Ci), Cirrocumulus (Cc) and Cirrostratus (Cs) as High level clouds accordingly. Moreover, St, Sc, Ns and As are classified as stratiform or layered clouds, while Cb, Cu as convective clouds. NoCl indicates the cases with no clouds reports.
3 Results

3.1 Frequency of prevalence of cloud genera - Intra annual variability

Figure 1 shows the frequency of prevalence of each cloud genus over the entire studied period. A percentage of 18% corresponds to NoCl reports. The frequency of Low/Middle and High clouds as prevailing clouds in the sky were estimated equal to 36%/23% and 22% respectively, indicating that Low clouds prevail more frequently in the sky. Convective clouds (Cu, Cb) were found to have prevailed on 23%, but this percentage rises to 50% if genera of limited convection (Sc, Ac) are also included. Layered (stratiform) clouds at all levels (St, Sc, Ns, As) have prevailed on 23% as well, with higher frequency in Sc occurrence.

Figure 2 displays the intra annual variability of the frequency of occurrence of each genus over the studied period. As expected, the frequency of NoCl is maximum during summer. Stratiform clouds at all levels (Ns, Sc, As but also Cs) reveal minima in summer and maxima in winter, in contrast to convective clouds (Cu) that exhibit higher occurrence of prevalence in summer. As regards diurnal variations (not shown), low clouds (mainly Cu) prevailed more frequently at noon (52%), middle clouds in the evening and high clouds preferably in the morning.

Fig. 1. Frequency of prevalence of each cloud type over the period 1953-2012.

Fig. 2. Intra annual variability of the frequency of prevalence of each cloud type over the period 1953-2012.

3.2 Temporal variability and trends of cloud types

In addition to the prevalence of different cloud types over the entire studied period, it is interesting to investigate if and how prevalence has undergone significant changes over time. To this end, the frequencies of occurrence of cloud types for each decade from 1953-2012 were calculated.

The inter-decadal variability of the frequency of prevalence of Low, Middle and High clouds over the 60-yrs period are shown in Figure 3. The prevalence of low clouds is
constant all over the decades, with increased frequency during last decade. A remarkable decrease in the occurrence of Middle clouds during the last two decades is observed. This decrease is observed during all seasons but is marked in summer (not shown).

A progressive increase in the occurrence of High clouds is discerned from early 1950’s onwards, with markedly higher frequency in the decade 1993-2002. Actually, prevalence of high clouds during the second half of the studied period is almost double its value during the first half. The increasing trend at high levels has been shown to be caused by an outstanding increase in both cirrus and cirrostratus occurrence. Nevertheless, cirrus occurrence has declined recently while cirrostratus keeps increasing. It was also calculated that the increase in the occurrence of high clouds stands all over the year, but is more significant in summer. In addition to this, decreasing trends in the occurrence of middle level clouds are mainly due to a considerable decrease during summer after early 1990’s. The NoCl cases are almost constant all over the decades except for 1993-2002 with lower frequencies.

An additional analysis focused on the inter annual variability of groups of cloud types according to their form. Occurrence of stratiform clouds at different levels (St, Sc, Ns, As) exhibit a statistically significant negative trend over the studied period, which was found to be constant all over the year (Fig. 4). The long term decrease of the annual occurrence of stratiform clouds occurrence is approximately 20% (mainly from the combination of Sc and Ns). This is in full agreement with the results reported in other studies (e.g. Matuszko 2002, Milewska 2008).

As regards the temporal variability of convective clouds (Cu, Cb) occurrence, this was found to be strongly dependent on the season. In particular, the prevalence of convective clouds exhibited decreasing trend during the warm and dry period of the year (May-October) and increasing trend in the cold and wet period (November-April). This is clearly illustrated in Figure 5 which displays the temporal evolution of the occurrence of convective clouds in December and July over the period 1953-2012.
4 Conclusions

The long term observations of cloudiness at the National Observatory of Athens, including reports of cloud types, enabled the study of the frequencies of prevalence of certain cloud categories as well as the investigation of possible changes and trends over time. Some important results of the study can be summarized as follows:

- Low clouds tend to prevail more frequently in the sky all over the year.
- The occurrence of Stratiform clouds reveals minima in summer and maxima in winter, while the opposite is true for the convective clouds occurrence.
- A significant increase in the prevalence of High clouds is observed after early 1990’s accompanied with a significant decrease in the occurrence of Middle clouds.
- Stratiform clouds at all levels exhibit a decreasing trend since early 1950’s.
- The changes in the prevalence of convective clouds reveal marked differentiations depending on the season. Convective clouds exhibit increasing trends in winter and decreasing trends in summer.

Our findings concerning changes in Stratiform and High clouds occurrence are qualitatively in agreement with the findings elsewhere (e.g. Canada, United States, Poland etc). Future research will focus on the linkage between cloudiness changes (as regards total cloud cover and types) and changes in the regime of surface air temperature and precipitation in the area of interest.

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Organic aerosol concentration and composition over Europe

Fountoukis C., Megaritis A.G., Skyllakou S., Charalampidis P.E, Pilinis C., Pandis S.N.

A detailed three-dimensional regional chemical transport model (PMCAMx) was applied over Europe focusing on the formation and chemical transformation of organic matter. Three periods representative of different seasons were simulated, corresponding to intensive field campaigns. An extensive set of AMS measurements was used to evaluate the model and, using factor analysis results, gain more insight into the sources and transformations of organic aerosol (OA). Overall, the agreement between predictions and measurements for OA concentration is encouraging with the model reproducing two thirds of the data (daily average mass concentrations) within a factor of two. Oxygenated OA (OOA) is predicted to contribute 93% to total OA during May, 87% during winter and 96% during autumn with the rest consisting of fresh primary OA (POA). Predicted OOA concentrations compare well with the observed OOA values for all periods with an average fractional error of 0.53 and a bias equal to -0.07 (mean error = 0.9 μg m⁻³, mean bias = -0.2 μg m⁻³). The model systematically underpredicts fresh POA in most sites during late spring and autumn (mean bias up to -0.8 μg m⁻³). Based on results from a source apportionment algorithm running in parallel with PMCAMx, most of the POA originates from biomass burning (fires and residential wood combustion) and therefore biomass burning OA is most likely underestimated in the emission inventory. The model performs well at all sites when the PMF-estimated low volatility OOA is compared against the OA with C* ≤ 0.1 μg m⁻³ and semivolatile OOA against the OA with C* > 0.1 μg m⁻³ respectively.
1 Introduction

Organic aerosol (OA) is a significant component (20 – 90%) of atmospheric fine particulate matter and thus strongly affects the physicochemical properties of aerosols. Despite its importance, OA remains today the least understood component of the atmospheric aerosol system. OA has hundreds of sources, both anthropogenic and natural, while it can undergo complex atmospheric chemical and physical processing. The description of these emissions and processes in Chemical Transport Models (CTMs) is not a trivial task.

The Aerosol Mass Spectrometer (AMS) is used to measure the size-resolved mass concentration and total mass spectrum of organic aerosols with high time resolution. Information about processes or sources contributing to the OA levels can be provided by the Positive Matrix Factorization (PMF) method, the multi-linear engine (ME-2) or custom principal component analysis of the AMS measurements. These methods allow a deconvolution of the OA into different types based on their different temporal and mass spectral signatures. Two major components often resolved by the analysis of the AMS measurements are hydrocarbon-like organic aerosol (HOA) and oxygenated organic aerosol (OOA). HOA represents fresh POA from fossil fuel combustion while OOA is OA of secondary nature. Often, factor analysis can further classify OOA into a more oxygenated low-volatility OOA component (LV-OOA) and a less oxygenated semi-volatile OOA part (SV-OOA). Biomass burning OA (BBOA), marine-related OA (MOA) and cooking OA (COA) are other classes that the factor analysis may identify.

The factor analysis of AMS measurements can allow more in-depth evaluation of CTMs and further constrain the corresponding uncertain parameters. However, to date such model-measurement comparison studies on a regional scale are rare. In this work we apply PMCAMx (Fountoukis et al. 2011; 2013) over Europe during 3 periods, representative of different seasons, and use an extensive set of AMS measurements to evaluate the model. Using factor analysis data, we attempt to gain more insight into the formation and evolution of OA, as well as to identify strengths and limitations of the current OA modeling framework.

2 OA simulation in PMCAMx

The OA treatment in PMCAMx is based on the Volatility Basis Set (VBS) approach (Donahue et al. 2006). This version treats all organic species (primary and secondary) as chemically reactive. Primary OA in PMCAMx is assumed to be semivolatile with nine surrogate POA species used, corresponding to nine effective saturation concentrations ranging from 10^{-2} to 10^{6} μg m^{-3} (at 298 K) in logarithmically spaced bins. POA is simulated in the model as “fresh” (unoxidized) POA (fPOA) and oxidized POA (OPOA). The SOA is described using four volatility bins (1, 10^2, 10^3 μg m^{-3}) and its module incorporates NOx-dependent SOA yields.

Chemical aging is modeled through gas-phase oxidation of organic compounds assuming a gas-phase OH reaction with a rate constant of k=1×10^{-11} cm^3 molec^{-1} s^{-1} for anthropogenic SOA and k=4×10^{-11} cm^3 molec^{-1} s^{-1} for the primary OA and the IVOCs. Each reaction is assumed to effectively decrease the volatility of the compound by one order of magnitude.

3 OA predictions over Europe

Figure 1 shows the PMCAMx predicted average ground level concentration of PM_{10} OA during each simulation period. Overall, the domain-average contribution of OA concentration to total PM_{10} mass is similar (ranges from 31 to 33%) during the three simulation periods. However, the absolute concentration levels and spatial distribution are quite different. During May the model predicts elevated concentrations (up to 6 μg m^{-3}) in a large area covering the
UK, northern France, Belgium, the Netherlands and northwestern Germany while in central and southern Europe the model predicts lower concentrations (~ 2 μg m⁻³). During winter the situation is different with the model predicting high OA values at urban and heavily industrialized areas (up to 15 μg m⁻³), a result of the strong influence of primary emissions. The largest (on average) OA concentrations are predicted for the autumn period with a peak monthly average of 5.7 μg m⁻³ in the Po Valley in Italy. Contrary to the late spring period, OA predictions during September/October are relatively low in central and Northern Europe (1 - 2 μg m⁻³), a result of northwesterly winds prevailing in the last two weeks of the simulation period.

**Fig. 1.** Ground-level concentration predictions of PMi OA (μg m⁻³) averaged over the entire simulation period for (a) 1 – 29 May 2008, (b) 25 February – 24 March 2009, and (c) 15 September – 17 October 2008.

### 4 Comparison with field data

Figure 2 shows an overall comparison of modeled versus measured values for the two components, HOA and OOA. The AMS HOA component is typically associated with primary fossil fuel combustion organic matter and thus we compare it with the POA in the model. The oxygenated OA AMS component is compared against the sum of aSOA, bSOA and OPOA.

Overall, the average AMS HOA is higher than the POA concentrations (by roughly 0.4 μg m⁻³). However, the discrepancies vary considerably depending on the site and period. During winter PMCAMx underpredicts HOA in Barcelona and Chilbolton and overpredicts in Cabauw, Hyytiälä and Helsinki. During the fall there is systematic HOA underprediction in almost all sites. During the May period, the model correctly predicts very low concentrations of POA (less than 0.3 μg m⁻³) in Melpitz and Finokalia throughout the month while in Mace Head it underpredicts HOA with a mean error of -0.25 μg m⁻³. In Cabauw the model predicts an average concentration of 0.6 μg m⁻³ compared to a 1 μg m⁻³ of HOA estimated during the May period. Overall, the model performance is better during the late spring period with a mean error of 0.26 μg m⁻³ while the mean bias and error is always less than 1 μg m⁻³ during all three periods (with the exception of Barcelona).

The agreement between predictions and observations is better for OOA with the model reproducing 83% of the data within a factor of 2 during May, 55% during winter and 68% during the autumn period while the average fractional error and bias are 0.53 and -0.07, respectively (mean error = 0.9 μg m⁻³, mean bias = -0.2 μg m⁻³).

The error for HOA concentrations is most likely an indication of errors in the emissions rates of OA and/or errors in their assumed volatility distribution. Although most previous studies have considered OPOA as OOA it has been argued that not all OPOA is oxidized enough to be assigned to the OOA mass fraction by factor analysis. It has been suggested that if some OPOA was measured as part of HOA, the CTM bias would be reduced. In our case, if 50% of simulated OPOA is considered as fPOA, the model bias for HOA is reduced (mean error = 0.6 μg m⁻³, mean bias = -0.08 μg m⁻³ compared to mean error = 0.7 μg m⁻³ and mean bias = -0.4 μg m⁻³), but the average model performance for OOA deteriorates (fractional error and bias are 0.6 and -0.24 compared to 0.54 and -0.08 in the base case). Errors in the emissions inventory are likely to be the source of bias for HOA as well as the uncertain
distribution of OA emissions in the low volatility bins which can strongly influence the initial partitioning between the gas and the aerosol phase and thus the predicted POA concentrations.

Figure 3 shows a comparison of estimated LV-OOA and SV-OOA by factor analysis against predicted concentrations in Finokalia during the late spring period.

Predictions shown include OA transported from outside the domain plus the first 3 volatility bins (with C* of $10^{-2}$, $10^{-1}$ and 1 μg m$^{-3}$) for the LV-OOA comparison, and OOA with C* from 1 to $10^2$ μg m$^{-3}$ for the SV-OOA comparison. A number of different combinations were tested for all datasets. Statistically the model performs the best in all sites for both LV-OOA and SV-OOA when LV-OOA is compared against the OA with C* ≤$10^{-1}$ μg m$^{-3}$ and SV-OOA against the OA with C* > $10^{-1}$ μg m$^{-3}$ respectively. However, this model performance should not be overinterpreted, as these results are sensitive to the combination of boundary conditions used and the assumed volatility distribution. Furthermore, the 2-D VBS scheme tracking both the volatility and oxidation state could be more helpful for such a comparison, as in some sites the two OOA components analyzed by factor analysis may differ in the extent of oxidation but show similarities in volatility.

Finally, the agreement between predictions and measurements for the rest of the PM1 species (e.g. sulfate, nitrate, etc.) concentrations (not shown here) was also encouraging.

5 Conclusions

A three-dimensional regional chemical transport model was applied over Europe focusing on the formation and chemical transformation of organic matter. Three periods were simulated corresponding to intensive measurement campaigns at various sites in Europe, and the model predictions are compared against factor analysis AMS data. The overall agreement between
predictions and measurements for total fine OA mass is encouraging with the model reproducing the majority (more than 63%) of the data points within a factor of two. Interestingly, the model performance fluctuates substantially among the three periods, showing the lowest error (FERROR=0.35) during spring and the highest during the winter period (FERROR=0.68). On average, the predicted oxygenated OA contributes 93% to total OA during May, 87% during winter and 96% during autumn with the rest comprising fresh primary OA. Biogenic secondary OA is predicted to be the dominant oxygenated OA component with a contribution of ~40-60% to total oxygenated OA in all three periods. Predicted oxygenated OA concentrations compare well with the AMS measured values for all periods. The model performs well in all sites when the measured low-volatility oxygenated OA is compared against the OA with saturation concentration C* ≤10^{-1} μg m^{-3} and the semi-volatile oxygenated OA against the OA with C* > 10^{-1} μg m^{-3} respectively. The error for hydrocarbon-like OA concentrations (mean error = 0.7 μg m^{-3}, mean bias = -0.4 μg m^{-3}) is most likely an indication of errors in the emissions rates of primary OA. The model systematically underpredicts fresh primary OA in most sites during late spring and autumn with a mean bias up to -0.8 μg m^{-3} (fractional bias up to -0.95). The largest part of primary OA concentrations and emissions in continental Europe originates from biomass burning (fires and residential wood combustion).

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Long-term trends and climatology of spectral surface UV irradiance at Thessaloniki, Greece

Fountoulakis I., Bais A.F., Fragkos K., Meleti C., Zempila M.M., Kouremeti N., Tourpali K.

The effects of solar UV radiation on biosphere are of great importance. Thus, accurate measurements and extensive studies of the variability and the long term changes of UV radiation reaching the earth's surface are required. In this study the long term changes of the noon spectral global (direct + diffuse) UV irradiance for the wavelengths 305, 324 and 350 nm, as well as for the erythemal irradiance are investigated for the period 1993 – 2012, from measurements with a double-monochromator Brewer spectroradiometer operating in Thessaloniki, Greece. Furthermore, a climatology of these radiation quantities is constructed for the same period. Prior to analysis, all data were quality controlled and re-evaluated. For the noon UV Index, the calculated linear trends are +3.9% per decade for clear skies and +3% per decade for all-sky conditions. The greatest increases in clear-sky UV irradiance were found for spring and summer, while for all skies, significant increases have been found only for summer. The UV irradiance trends are attributed to changes in ozone, clouds and aerosols that have occurred during the period of study over the area.

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1 Introduction

Long records of spectral UV irradiance in conjunction with accurate and detailed data for aerosol, ozone and clouds are essential for better understanding the complex interaction between solar UV radiation and these factors (Bernhard et al. 2007, Meleti et al. 2009). Additionally, the great role of solar UV radiation for humans and ecosystems makes imperative the need for its continuous monitoring (Kazantzidis et al. 2009, Siani et al. 2013, Zepp et al. 2011). In many European sites the gradual decrease of aerosol load and cloud cover are the dominant factors that lead to continuing UV decline despite the general recovery of the stratospheric ozone layer (Fitzka et al. 2012, Smedley et al. 2012, Zerefos et al. 2012). Thessaloniki is an urban location where aerosol load declines during the last two decades (Meleti et al. 2009; Koukouli et al. 2010; Bais et al. 2012). The long term trends and the climatology of the noon values presented in this study may be considered representative for the corresponding values integrated over the day, as most of solar UV energy reaching the earth’s surface is distributed around the noon hours (Seckmeyer et al. 2008). Erythemal irradiance trends and climatology, calculated from the same dataset, are also presented due to its great importance for the human health.

2 Data and Methodology

At Thessaloniki, continuous measurements of the spectral UV irradiance are conducted for more than two decades with two Brewer spectrophotometers which are located at the Laboratory of Atmospheric Physics of the Aristotle University of Thessaloniki (latitude 40.63° N, longitude 22.96° E, altitude 60m a.s.l.). Both instruments are calibrated on regular basis, and the entire dataset has been quality controlled and re-evaluated. The uncertainty of the final data is estimated to less than 5%. The data used in this study are spectral UV measurements performed by the double monochromator Brewer MKIII spectroradiometer (with serial number 086) during the period 1993-2012. More information about the instrumentation and the calibration procedures can be found in Garane et al. (2006). The irradiance at each of the wavelengths examined is the average irradiance in the 2 nm wide spectral band centered at this wavelength.

To detect problems and discontinuities in the dataset, comparisons for short periods were performed with data derived from Brewer MKII, a NILU-UV multifilter radiometer, a UVA and a UVB broadband radiometer, and total solar radiation pyranometer. When feasible, the erroneous data were corrected, otherwise they were rejected. The noon irradiance is calculated as the mean of all measurements within one hour before and one hour after the exact local noon time. Thereby the value assigned to noon irradiance is slightly underestimated, but the uncertainty is reduced as adequate measurements are considered to calculate trends and the climatology.

The erythemal irradiance is derived as the integral of the spectrum produced by the instrument, extended to 400 nm using the SHICrivm algorithm (Slaper et al. 1995), and weighted with the CIE action spectrum (Mckinlay and Diffey, 1987). The UV Index (UVI) is calculated by multiplying the erythemal irradiance (in mW m⁻²) by 40. For the calculation of trends, all data were deseasonalised by removing the calculated monthly climatological mean. Then the monthly means are calculated and a least-squares linear fit is applied to derive the trend. Generally, the trend in solar UV irradiance is non-linear, but this is a rather realistic approximation within some uncertainty limits. At latitudes similar to Thessaloniki’s no abrupt signals from the ozone depletion and recovery have been observed, and the reduction of aerosols at this location has taken place gradually during the last 20 years. For the determination of the trend’s statistical significance the Mann Kendall test is used.
3 Results

3.1 Trends of the noon spectral irradiance

In figure 1, the seasonal changes for clear-sky and all-sky noon irradiance are presented. Additionally to the total ozone column (TOC), the aerosol optical depth (AOD), the aerosol optical properties and the clouds, the seasonal variation of noon solar zenith angle (SZA) is also affecting the calculated seasonal trends of the noon irradiance. Large SZAs may enhance the effect of all the above factors due to the increased optical path through the atmosphere.

The derived trends for the period 1993-2012 are generally positive for all wavelengths and all seasons. Positive trends for irradiance at 305 nm, statistically significant at the 95% level, were derived only for summer, reaching 0.5% per year for clear skies and 1.15% per year for all skies. Model simulations confirm that the clear skies trend is entirely attributable to the decline in AOD in conjunction with the absence of any statistically significant ozone trend that would counteract this result. The doubled trend for the all-sky irradiance is probably due to a downward trend in the cloud attenuation during summer (Bais et al. 2012).

![Fig. 1. Seasonal changes for (a) clear-sky irradiance, (b) all-sky irradiance. Error bars represent the standard error at the 95% confidence level.](image)

The trends in irradiance at 324 nm and 350 nm are similar, despite the small differences caused by changes in the TOC which have a small, but non-zero, effect at 324 nm. While the AOD decline is greater in summer, the trends in spring are similar or slightly larger than in summer. This might be attributed to the larger solar zenith angles in spring which lead to enhanced attenuation and/or the different seasonal characteristics of aerosols (AOD, size, species). In spring, the trends for these wavelengths under clear skies exceed 0.5% per year. Similar to 305 nm, for all skies, the positive trends are larger in summer than in spring due to less attenuation by clouds. In winter and autumn, there is no noticeable difference between the clear-sky and the all-sky trends for all wavelengths. For 324 nm, the calculated clear-sky changes are statistically significant at the 95% level at all seasons. The same occurs for 350 nm, except autumn when the changes are significant at the 90% level. Finally, the trends at these wavelengths under all skies are significant at the 95% level only for summer and autumn.

![Fig. 2. (a) Clear-sky and (b) all-sky anomalies and long term trends for the noon UV index.](image)

In fig. 2, the anomalies (departures from the long term monthly mean) and the trend for the clear-sky and the all-sky UV index is presented. The trends are respectively $0.27 \pm 0.14\%$ per year and $0.21 \pm 0.22\%$ per year, both statistically significant at the 95% confidence level. The observed increases are mainly driven by AOD decreases, while the small difference between clear-sky and all-sky trends, within the uncertainty intervals, is probably due to reduction in the cloud attenuation.
3.2 Climatology

Fig. 3. Climatology for (a) 305 nm, (b) 324 nm, (c) 350 nm and (d) erythemal irradiance. The blue line represents the all sky climatology and the red line represents the clear sky climatology. The corresponding shaded areas represent the 95% confidence intervals.

In fig. 3, the climatological annual variation of daily irradiance at 305, 324 and 350 nm and of the erythemal irradiance at local noon is shown for clear-sky and all sky conditions. The irradiance at 305 nm under clear skies is stronger during the second half of the year, because higher TOC in spring than in autumn. For 324 and 350 nm AOD is the main factor that determines the amount of clear-sky solar irradiance that reaches the surface at Thessaloniki. The effect of higher AOD values during late spring and summer is not as clear as that of ozone at lower wavelengths, since aerosols mainly redistribute the scattered radiance, so that at the end only a small fraction is lost by upward back-scattering. The annual variation of the attenuation by clouds is similar for all wavelengths in the UV region. The enhanced cloud cover during March – June compared to the cloud cover during July – October leads to enhanced all-sky irradiance during the first half of the year. The pattern of the UV Index climatological values is generally closer to the 305 nm irradiance pattern. The clear sky climatological UV Index ranges from about 7.5 to about 8.5 during June and July, while in December the UV index ranges around 1.5.

4 Summary and conclusions

The irradiance at 305 nm and the UVI under clear sky and all skies are lower during the first half of the year due to the greater TOC and cloud cover, compared to the second half of the year. The interannual variation of cloud cover affects the 324 nm and the 350 nm irradiance in the same way that it affects lower wavelengths. As a result of the more frequent occurrence of clouds in June than in July, the all sky maximum climatological values of all the studied quantities are calculated for July while the corresponding maximum climatological clear sky values are calculated for June.

Statistically significant upward trends of the clear sky irradiance, which are mainly driven by AOD changes, were calculated for spring and summer. For all sky conditions the spring trends are not statistically significant while the summer trends are greater. This result indicates that the interannual variations in the occurrence and the type of clouds are changing in a way that blocks a greater part of UV irradiance during spring and allows to a greater portion of it to reach the ground during summer. The overall result is the enhancement of the noon UV solar irradiance during the period 1993 – 2012 at Thessaloniki. The all sky trends are generally lower. The UVI at Thessaloniki is increasing by 2.7% per decade under clear sky and by 2.1% per decade under all sky conditions. The greatest part of this increase is due to the respective strong increase of the UVB irradiance in summer, indicating that overexposure to the sun may be achieved in shorter time intervals than twenty years ago. Thus the continuation of the solar UV radiation monitoring and the information of the public remain very important.
References


Variability of a thirty-year record of total ozone derived from a Brewer spectrophotometer at Thessaloniki and the SBUV version 8.6

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A single monochromator Brewer MKII spectrophotometer operates in Thessaloniki, (40.5°N, 22.9°E), continuously since March 1982 measuring the Total Ozone Column (TOC) from direct solar radiation measurements. The data availability of the Brewer at Thessaloniki is fairly good for the entire period, exceeding 70% for the majority of the years. In this study we present a comparison of thirty years of TOC measurements derived from the Brewer with Version 8.6 of the dataset derived from the satellite instrument SBUV. Moreover, we examine the whole dataset for the frequency of extreme (high and low) values, based on elements of the extreme value theory and we present preliminary results from the ground-based data. The agreement of daily mean TOC between ground-based and satellite overpass data is within ±5%, while the agreement becomes better (±2%) for monthly mean values. From a total of 7971 daily mean TOC measurements, 961 (~12%) extreme-low and 1199 (~15%) extreme-high events have been identified. Removing those extreme events from the time series results in smoother year-to-year variability.

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1 Introduction

After the discovery of the Antarctic ozone hole in the mid 80’s, the successful implementation of the Montreal Protocol followed, which has led to a decrease in the ozone depletion substances (WMO 2011) that had dominated ozone loss in the recent past (Shepherd and Jonsson 2008). However, other processes, mostly linked to human induced climate change, such as CO2-induced cooling of the upper and middle stratosphere that leads to increases in ozone due to slower gas-phase ozone-loss cycles and the acceleration of the Brewer-Dobson circulation or changes in transport, are likely to play a more important role in the evolution of ozone through the 21st century (Eyring et al. 2010). Thus, the continuous monitoring of the total ozone column (TOC) levels from satellite and ground-based instruments are of great importance for the determination of the evolution of past and future levels of the ozone layer and the better understanding of the processes (dynamical and chemical) that regulate its abundance.

The interest for the extreme events in TOC was always high in the scientific community. In the past, the identification of extreme events was mainly accomplished by investigating the deviations from a standard mean value. However, a recent study showed that the frequency distribution of the TOC cannot be adequately described by the normal distribution, and elements from the extreme value theory (EVT) are more appropriate for this purpose, especially for the determination of the threshold values above (below) which an event is characterized as high (low) extreme (Rieder et al. 2010a).

In the current study we present a comparison of thirty years of TOC measurements over Thessaloniki conducted with a Brewer spectrophotometer with the satellite data from the BUV and SBUV instruments. Moreover, following the methodology of Rieder et al. (2010a), we examine the evolution of the extreme high and low TOC events, in the framework of the EVT.

2 Data and Methodology

A single monochromator spectrophotometer type Brewer MKII (SN 005, hereafter B005) is operating in Thessaloniki (40.5°N, 22.9°E) since March 1982. The calculation of TOC is based on direct-sun (DS) spectral radiance data at four wavelengths in the range 310-320 nm. The retrieval (Kerr et al. 1981) is based on a relationship using a linear combination of differential absorption (Bass & Paur, 1985) and Rayleigh scattering coefficients. B005 is the first commercial Brewer deployed worldwide, thus Thessaloniki has one of the longest Brewer TOC data sets and provides a series suitable for investigation of long-term changes. In this study we used mean daily data from B005 for a 30-year period spanning from March 1982 to February 2012.

Recently, data from a series of nine Solar Backscatter Ultraviolet (SBUV and SBUV/2) instruments have been reprocessed to create a coherent ozone time series (SBUV v8.6) covering the periods 1970-1972 and 1979-2012 (McPeters et al. 2013). This dataset covers the whole period of B005 operation, allowing for direct comparison of the two datasets. Overpass TOC values for Thessaloniki from the SBUV v8.6 have been retrieved from the NASA/TOMS database (ftp://toms.gsfc.nasa.gov/pub/sbuv/MERGED/).

For the determination of the high and low TOC extreme events, we followed a methodology similar to that suggested by Rieder et al. (2010a) for Arosa. This analysis is based on fitting the Generalized Pareto Distribution (GPD) to the distribution tails of the ozone data on a monthly basis and has been used for the analysis of extreme events of high/low TOC for five additional European stations (Rieder et al. 2011). The GPD of a specific variable x (TOC in our case) is defined by three parameters: the threshold value u, the scale parameter σ and the shape parameter ξ (details about the GPD can be found in Coles, 2001). To account for the autocorrelation, a de-clustering procedure (Davison and Smith, 1990) was applied in order to identify clusters of extremes. From each cluster, only the
maximum or minimum values were used in the analysis. The number of cases exceeding a series of thresholds is plotted as a function of the threshold values and a likely threshold is assumed when the plot starts behaving linearly. Then, the scale and shape parameters as function of threshold are plotted and the smallest threshold is selected above which these parameters are roughly constant. For all possible thresholds the GPD fit is applied on the observations above each threshold. The final threshold selection is based on the best agreement between the observations and modeled values from GPD, using the diagnostic tools that are detailed in Rieder et al. (2010a).

3 Results

For the thirty-year period of B005 operation in Thessaloniki, the data availability is fairly good, on average 70%, with less data (50 - 60% availability) in the first 6 years of its non-automated operation. For the same period, the data availability for the SBUV is very high, close to 95%. The long-term mean TOC for Thessaloniki is estimated to 328.1 DU from B005 and to 324.9 DU (323.8 DU for the common days) from the SBUV, a difference of about 1%. In Fig. 1 (left panel) we present the daily climatological values for both datasets, for the common days. The annual cycle of total ozone over Thessaloniki as well as the corresponding range of its variability are well captured by both datasets, with B005 values to be a little higher for the majority of the days. The correlation is high ($R^2 = 0.982$). In Fig. 1 (right panel) the monthly differences between B005 and SBUV are shown, for the thirty-year period. In this analysis we calculated the mean monthly TOC values using only the common daily TOC values in both datasets. In general, there is quite good agreement between the two datasets with the differences ranging between ±2%, with differences close to zero in the mid-1990s and more negative in the 1980s. On average, there is an underestimation on the SBUV TOC, with a mean difference for the overall period of -1.35%. These findings are consistent with the results from comparisons of the SBUV measurements with the network of Dobson/Brewer spectrophotometers (Labow et al. 2013). When we extend the comparison in daily mean values the agreement remains good, but with differences within ±5%. Using the Brewer dataset, the monthly threshold for high/low TOC extremes were estimated, as described in section 2. The analysis was performed with the POT package (Ribatet 2007), in the statistical computing environment R. The monthly threshold values were interpolated so as to estimate the daily thresholds. In Fig. 2 we present the long-term mean monthly values of TOC from B005 and the thresholds for each day of the year. TOC values higher than the red dashed line in Fig. 2 are characterized as extreme high events and those below the green dashed line of Fig. 2 as extreme low events.

![Fig. 1. Left panel: Climatological annual cycle of the TOC over Thessaloniki from B005 (blue dots) and SBUV (green crosses). The dashed lines are ±2σ envelopes from the daily means, for B005 (blue) and SBUV (green). Right panel: Monthly TOC percentage differences between B005 and SBUV for the periods 1982-2012.](image-url)

In Fig. 3 (left panel) the annual evolution of the extremes (high and low) events of TOC over Thessaloniki is shown for the thirty-year operation of B005. It is clear that until the early 90’s
the extreme events are dominated from high TOC events, while after 1992 there is an increase in the occurrence of extreme low events and a relative reduction (statistically significant at the 95% level) in the extreme high events, for about one decade. Since 2000 a stabilization in the occurrence of extreme low events is evident, with a slight reduction, possibly connected with the successful implementation of the Montreal Protocol. For the same decade (2000-2010), the frequency of the extreme high TOC events seems to have a small increasing tendency. The findings of this analysis are in good agreement with the results for Arosa (Rieder et al. 2010b).

![Fig. 2. Low (green dashed line) and high (red dashed line) threshold values for extreme high and low total ozone and monthly means of total ozone (crosses) over Thessaloniki.](image)

In Fig. 3 (right panel) is shown the annual average TOC over Thessaloniki from all observations (blue line), as well as annual averages derived from the series after excluding the high, low, and both types of events. Obviously, the removal of the extreme events in the calculation of annual mean values removes a large part of the year to year variations, suggesting that the greatest fraction of year to year variability can be attributed to the occurrence of extreme events.

The influence of the extreme low events on the annual mean TOC values can be as high as ~18 DU (Fig. 3, right panel, magenta dashed line), while the extreme high events have lower impact that doesn’t exceed 12 DU (Fig. 3, right panel, orange dashed line).

![Fig. 3. Left panel: Annual evolution of the frequency of the extreme TOC low events (light blue area) and extreme high events (blue area). The abbreviation GTO stands for Grouped Total ozone Observations. Right panel: Annual mean values of TOC over Thessaloniki for the period 1982-2011: all observations (blue), extremes removed (red), low extreme events removed (orange dashed) and high extreme events removed (magenta dashed).](image)

**4 Conclusions**

We compared thirty years of total ozone column measurements over Thessaloniki conducted with a Brewer spectrophotometer, with Version 8.6 total ozone column dataset from the
satellite instrument SBUV. The overall agreement of the two datasets is very good for the entire period with a mean difference of 1.35%. This underestimation of the SBUV is within the range reported for other mid-latitude stations.

Moreover, we present preliminary results from the analysis of extreme (high and low) events of TOC from the Brewer data. The annual evolution of the low extreme events show a reduction tendency in the last years (about 5.5%/decade for the period 1996-2011, statistically significant at the 88% level), in agreement with other similar studies (Rieder et al. 2010b; 2011). A more detailed investigation of the evolution of these events with respect to “fingerprints” of atmospheric dynamics (e.g., effects of ENSO, NAO, etc.) and chemistry (e.g., effect of volcanos and ozone depleting substances) requires comparison of the frequency of the extremes with proxies describing these effects and it is beyond the aim of the current study. A large part of the year to year variability of the annual mean TOC values can be attributed to the occurrence of the extreme events.

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References


Von Kármán Cloud Vortex Street over the Aegean Sea

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One of the most impressive cloud formation that can be observed in satellite images is the von Kármán Vortex Streets, which consist of two roughly parallel lines of spiral eddies that alternate their direction of rotation. This structure is usually created when a cloud street of marine stratocumulus is disturbed by an obstacle, such as an island with high mountains, resulting in a cloud pattern of repeating swirling vortices downwind of the air flow on the lee side of the island. Many areas worldwide can cause such vortex streets and over the Atlantic Ocean, the most known are the lee of the Madeira and Canary Islands. This exquisite cloud formation can also be seen in satellite images over Greece at the northeast part of the Aegean Archipelago on the lee side of the mountainous island of Samothraki, usually during the cold season of the year. In this study is presented the favorable weather conditions under which this phenomenon can occur and is examined the factors of wind and atmospheric stability contributing to the formation of the von Kármán Vortex Streets on December 30, 2007.

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1 Introduction

The von Kármán Vortex Street (vKVS) is an impressive phenomenon in fluid dynamics consisting of two roughly parallel lines of spiral eddies that alternate their direction of rotation. This fascinating pattern that can be observed both in laboratory and nature, is generated behind an obstacle when the obstacle interrupts the flow motion. This formation is named after the engineer Theodore von Kármán (1881–1963) who first showed that the only stable arrangement of the flow behind a body is these anti-symmetrical vortices.

In the atmosphere, a fluid in constant motion, vortices can be formed at all scales, but the visualization of the flow as large scale eddies captured by satellite images is a unique phenomenon to be observed. The atmospheric vKVS can be identified within a board field of marine stratocumulus cloud sheets on the lee of mountainous islands. This analog appearance of the atmospheric vKVS is also referred as atmospheric or island wake and is defined as the region of turbulence immediately to the rear of a solid body in motion relative to a fluid (Glossary of Meteorology).

Fig. 1. Atmospheric von Kármán Vortex Streets on May 22, 2013 in the Pacific Ocean behind Isla Socorro (1,130 m high). (Aqua/MODIS Satellite, Image © NASA).

Worldwide there are many islands that can trigger atmospheric wakes, some of which are the Canary Islands, Madeira Island, Cape Verde Islands, Aleutian Islands, Guadalupe Island, Cheju Island and Socorro Island.

What is not known is that atmospheric vortex streets are generated on the lee of Samothaki Island, a mountainous island at the northeast Aegean Sea, in Greece. These cloud vortices are observed within cloud bands of marine stratocumulus, normally in the cold season of the year, when a strong anticyclone is established over Balkan Peninsula.

This study in section 2 reviews the basic theory. Focusing in Greece, section 3 analyzes the favorable weather conditions for marine stratocumulus and vKVS to occur, while section 4 examines the case study of atmospheric vKVS in the wake of Samothaki Island on December 30, 2007. Finally, section 5 summarizes the conclusions but mostly, since to the authors’ best knowledge no previous research paper dealt with this topic, the important features for further studies are discussed.

2 Theoretical Analysis

According to the Glossary of Meteorology a vortex street (also Kármán vortex street, vortex trail, vortex train) is defined as two parallel rows of alternately placed vortices along the wake of an obstacle in a fluid of moderate Reynolds number.

In fluid dynamics, the Reynolds number expresses the ratio of inertial to viscous forces and indicates the transition from the laminar to the turbulent flow. Around a bluff body, the Reynolds number (Re) is defined as $Re=Ud/v$, where $U$ is the flow velocity upstream of the body, $d$ is the horizontal scale of the body (diameter) and $v$ the kinematic viscosity of the fluid.
A von Kármán Vortex Street is a typical example of the instability in the flow conditions and is observed in the wake of the cylinder when the flow reaches a critical Reynolds number value. For the Madeira and Canary Islands calculated values of the Reynolds number ranged from 150 to 210 (Zimmerman 1969).

Concerning the geometry of the vortex pattern, two dimensionless measurements are used to describe its stability. In particular these properties are the aspect ratio $= h/a$ and the dimensionless width ratio $= h/d$, where $a$ is the distance between two consecutive vortices of the same row, $h$ is the distance between the two rows of the vortices and $d$ is the diameter of the object.

Since the theory of von Kármán and Rubach (1912) with the aspect ratio value of 0.28, several studies have been done in laboratory and nature. Research papers for atmospheric vortex streets yield aspect ratio values for Madeira 0.43 (Chopra and Hubert 1965), for Cheju Island 0.33 (Tsuchiya 1969) and 0.50 (Jensen and Agee 1978) respectively and for the Aleutian Islands 0.38–0.60 (Thomson et al. 1977). Young and Zawislak (2006) analyzed 30 individual atmospheric vKVS events and, after statistic tests, calculated mean values of aspect ratio 0.42 and, for the less studied, dimensionless width ratio 1.61 respectively.

Regarding the favorable synoptic situation, the atmospheric vKVS pattern can be recognized in areas of cloud streets of marine stratocumulus normally in cold season during cold air outbreaks from inland over relatively warm sea. As the cold air leaves the land it is modified by vertical transfer of heat and moisture from the underlying water surface, triggering vertical convection and eventually the formation of clouds bands which frequently organized into streets, roughly parallel to the wind direction (www.eumetrain.org). When a mountainous island interrupts this flow then, under certain conditions, the vortices are formed. The necessary conditions for this formation require a strong low-level temperature inversion with the island causing the wake to be high enough to penetrate this capping and a wind force ranging from 5 to 15 m/s (smaller speed do not favor the generation while higher speed do not guarantee the maintenance of the eddies). After the eddies are formed, then they are shed from alternating edges of the island downwind of the main flow.

Cloud Streets can be detected in satellite imagery in Visible and HiresVIS channels. In Infrared and WaterVapor channels the cloud streets cannot be easily identified because the convection is limited to the lower levels of the troposphere.

3 Marine Stratocumulus over Aegean Sea and the Samothraki’s wake

Frequently, during the cold season of the year over Aegean Sea streets of marine stratocumulus oriented parallel to the wind flow can be observed from the satellite images (a recent example, not shown, is on December 11, 2013). These cloud bands are the main characteristics of the so-called northeast weather type, a pattern that occurs after a cold air outbreak associated with a trough disruption on the eastern flank of a blocking high established over western Europe. At the surface the dominate element is an anticyclone over the northern part of the Balkan Peninsula and its combination with the low pressure system, usually over the central Mediterranean Sea, results in strong northeast winds over Greece. This circulation transferring cold and dry air mass from Russia and Ukraine over the warmer waters of the Aegean Sea triggers the mechanism for the formation of the marine stratocumulus.

The occurrence of marine stratocumulus over the Aegean Sea evidences the prevalence of strong and, very often, gale force north winds at this area. Herodotus, the ancient Greek historian reports a representative incident of these conditions over the Aegean Sea. In particular, when the Athenians claimed from the Pelasgians, citizens of Lemnos Island which is located at the northeast part of the Aegean Sea, their country, the latter in reply said “whenever by north wind in one day trip a ship arrives from your land Attica at ours, then we will give it up to you” because the Pelasgians knew that this was impossible since Attica lies far to the south of Lemnos (Herodotus, 6.139-140).
The Aegean Sea, due to its morphology, is referred as Archipelago and Samothaki, the highest of this group of islands, is located at its northeast part. In cold season of the year under the suitable environment for the marine stratocumulus to occur, as the northeast wind current enters the Aegean Sea the Mountain Saos (highest peak Feggari 1,611 m) stands as a perpendicular barrier to the aforementioned flow. Then the wake and the atmospheric vKVS can be generated downwind on the lee of this steep island and an example of this circulation is presented in the next section.

4 A case study of Samothraki’s Vortex Streets

The satellite image in Figure 2 is an instance of well developed atmospheric vKVS in the Samothraki’s wake on December 30, 2007. The counter rotating eddies can be easily identified, while streets of marine stratocumulus are evident over the central Aegean Sea aligned parallel to the north-northeast direction.

The synoptic weather analysis of the closest time to the satellite image satisfies all the required conditions for the vortices configuration. Briefly, at the 500 hPa isobaric chart, a cut-off low and a cold air mass associated with the occurrence of a cold outbreak a couple of days ago are present over Russia, while at mean sea level the 1030 hPa anticyclone established over Balkans is combined with the low pressure system over the Gulf of Sirte causing the northeast winds over Greece (Fig. 3, left). The sounding analysis of Thessaloniki upper-air station (about 230 km west of Samothraki) reveals a temperature inversion of 3.5°C with the top of this layer at 1,557 m, height lower than this of Mt. Saos (Fig. 3, right). Northeast surface wind approximately 10 knots reported by the nearest synoptic meteorological station of Lemnos (WMO-16650, about 65 km southwest of the lee of Samothraki).

Concerning the vortex geometry, the distance parameters of the pattern were measured directly from satellite image. For this case, the calculated values of the aspect ratio and the dimensionless width ratio are 0.36 and 1.66 respectively; findings in agreement with the results of referred in section 2 other studies.
Fig. 3. (left) 500 hPa isobaric chart at 00.00 UTC on December 30, 2007 (black lines: geopotential height step 6 gpdam, white lines: MSL isobars step 5 hPa, colored palette: 500-1000 thickness (Global Forecast System, © www.wetter3.de) and (right) Tephigram of Thessaloniki at 00.00 UTC on December 30, 2007 (© University of Wyoming).

5 Conclusions

This study dealt with the analog of von Kármán Vortex Streets in the atmosphere and their development behind islands and specifically the lee of the mountainous Samothraki Island, in northeast Aegean Sea. After a brief description of the formation of the marine stratocumulus cloud streets over the Aegean Sea, it was presented the Samothraki’s wake, the turbulent area behind this steep island where the von Kármán Vortex Streets are observed. Finally for the case of the vortex pattern on December 30, 2007, the synoptic weather condition was analyzed and the geometric characteristics of this configuration were calculated.

As it was previously stated, this is probably the first scientific research concerning the atmospheric vortex streets generated by Samothraki Island. This initial approach raised questions about the size, the frequency of the formation and the duration of each pair of eddies, in additional with the dimensions of the wake and the required space for the development and the shedding of the vortices. Therefore it is necessary for more cases to be detected and, for enlighten this phenomenon, for more studies to be carried out.

Acknowledgments we wish to thank Professor Emeritus N. Prezerakos for his valuable suggestions and our colleague P. Giannopoulos for providing us with some useful information.

References

Herodotus, Histories, 6, 139–140.
Molecular insights in cold stress tolerance of durum wheat cultivars

Fragogeorgi G., Chronopoulou-Sereli K., Tsiros J.

Freezing and chilling temperatures have damaging effects on plant growth and survival. Proline (Pro) has an important role in cold stress tolerance of plants, since elevated levels of Pro in plant tissues are associated with cold tolerance. In the present study, we examined the expression patterns of two cDNAs encoding Δ1-pyrroline-5-carboxylate synthetase (P5CS1, P5CS2), a key enzyme in Pro synthesis, in a cold susceptible and a cold tolerant durum wheat cultivar. Quantitative polymerase chain reaction (qPCR) analysis revealed that TdP5CS1 expression reached its maximum value at 6 h after plants' exposure to 4°C in the roots and after 12 h in the shoots of the cold tolerant cultivar. On the other hand, in the cold sensitive cultivar the TdP5CS2 transcripts were barely detected in roots throughout the experiment, but strongly accumulated at 24 h in shoots. These results suggest that both P5CS genes are over-expressed under cold stress conditions, yet an earlier and higher response was observed in the cold-tolerant cultivar.

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1 Introduction

Low temperature is one of the key limiting factors that affect plant distribution, growth, development, production and survival. Many plants accumulate organic osmolytes or compatible solutes in response to the resulting osmotic stress, so to maintain cell turgor and therefore the driving gradient for water uptake. Proline (Pro), comprises a proteinogenic amino acid, essential for primary metabolism in plants during various stress conditions. Several studies have demonstrated that the manipulation of genes involved in Pro biosynthesis improves plant tolerance to drought and salinity in a number of crops (Zhu et al. 2005).

In higher plants, Pro biosynthesis may proceed either via glutamate (Glu) or ornithine (Orn). The pathway via ornithine is not important for Pro synthesis during osmotic stress (Delauney and Verma 1993). The first two steps of Pro biosynthesis from Glu are catalyzed by a bifunctional enzyme, P5CS, which is the rate-limiting enzyme in the pathway. The expression patterns of different P5CS genes in plants have been studied in various stress conditions including cold stress. In rice, Arabidopsis, common bean and jatropha expression of the P5CS was induced by cold, while changes in transcript levels of P5CS were not always correlated with changes in the levels of Pro (Hur et al. 2004, Kaplan et al. 2007, Chen et al. 2009, Zhuang et al. 2011).

In this study, we investigated the molecular regulation of Pro biosynthesis in a cold resistant and susceptible durum wheat cultivar, under cold stress conditions.

2 Data and Methodology

2.1. Plant material

The main commercial durum wheat cultivars, Rusticano and Grazia, cultivated in Greece were used in the present study. The cvs Rusticano and Grazia are considered as drought and semi – drought tolerant, respectively.

2.2. Plant growth under stress treatments

Seeds of cvs Rusticano and Grazia were surface-sterilized for 5 min in NaClO, rinsed with sterile distilled H₂O and allowed to germinate in darkness at 22°C, for 5 days. For cold-stress treatment, the seedlings were transferred to a hydroponic aerated system consisted of plastic tanks containing sterile distilled H₂O and allowed to grow at 4°C or 22°C (control treatment) with a photoperiod of 12 h.

2.3. Morphological measurements

Ten day-old seedlings grown under the aforementioned cold stress conditions were sampled to record the length and dry weight of roots and shoots. The dry weight was measured after oven-drying the samples at 60°C for 72 h. The experiment was repeated three times with 10 and 5 seedlings per replication for length and dry weight recordings, respectively.
2.4. RNA Isolation and cDNA synthesis

Root and shoot tissues were sampled (5 seedlings per treatment per replication) at different time points up to 72 h after stress treatment, quickly frozen in liquid nitrogen and subsequently used for total RNA extraction. Total RNA was isolated according to Brusslan and Tobin (1992) and was quantified by spectrophotometry and agarose gel electrophoresis. The RNA samples were treated with DNase I (Promega, Madison, WI, U.S.A.) at 37°C for 45 min, to eliminate traces of contaminating genomic DNA. First-strand cDNA was synthesized using SuperScript II and following the manufacturer’s procedure (Invitrogen, Paisley, U.K.).

2.5. qPCR P5SC1 and P5CS2 expression

Quantitative polymerase chain reaction reactions were performed by using SYBR Green master mix (Applied Biosystems), genes’ specific primers at a final concentration of 0.2 μM each and 1 μl of the cDNA as template in a Stratagene Mx3005P™ thermocycler. Primers used for quantitative polymerase chain reaction reaction analysis are listed in Table 1. The tubulin gene (TdTUB) was used as an internal standard to normalize small differences in cDNA template amounts. Quantitative polymerase chain reactions were performed on three biological repeats.

Table 1. Primers used for quantitative polymerase chain reaction.

<table>
<thead>
<tr>
<th>Name</th>
<th>Forward Primer</th>
<th>Reverse Primer</th>
</tr>
</thead>
<tbody>
<tr>
<td>TdP5CS1</td>
<td>5’-CGTATACATGCACGTGAACCTG-3’</td>
<td>5’-CCCTTCCCCTCGTAAGAGCCATC-3’</td>
</tr>
<tr>
<td>TdP5CS2</td>
<td>5’-TGCACCCCTCAGAATTGGTTGA-3’</td>
<td>5’-TGTGTGTGCACCTCCATAACGA-3’</td>
</tr>
<tr>
<td>TdTUB</td>
<td>5’-GCCCAACATACACACACCTCA-3’</td>
<td>5’-GAAGCCTGTACGGATGAAATGA-3’</td>
</tr>
</tbody>
</table>

3 Results

3.1 Cold stress effect on seedling growth

Length and dry weight of roots and shoots were significantly reduced in both cultivars after 5 days of exposure to low temperature, compared to the control treatment (P<0.05; Table 2). Nevertheless, the length and dry weight of roots and shoots were reduced less in cv Rusticano than Grazia.

Table 2. Effect of low temperature (4°C) on root length (RL), shoot length (SL), root dry weight (RDW) and shoot dry weight (SDW) of the two durum wheat cultivars. The cultivars were exposed to cold-stress treatment for 5 days and results are expressed as percentage of the RL, SL, RDW and SDW of the cold-stressed seedlings over the non-treated. (n=120 for RL and SL, n=60 for RDW and SDW). Values followed by different letters in each column are statistically different according to Tukey’s multiple range test (P<0.05).

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Temperature (°C)</th>
<th>RL (%)</th>
<th>SL (%)</th>
<th>RDW (%)</th>
<th>SDW (%)</th>
<th>Ratio of RDW/SDW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rusticano</td>
<td>4</td>
<td>78.35±0.25a</td>
<td>57.94±0.025a</td>
<td>66.41±0.01a</td>
<td>63.57±0.02a</td>
<td>1.04±0.00</td>
</tr>
<tr>
<td>Grazia</td>
<td></td>
<td>68.97±0.033b</td>
<td>41.72±0.018b</td>
<td>49.64±0.025b</td>
<td>49.37±0.015b</td>
<td>1.00±0.00</td>
</tr>
</tbody>
</table>
3.2 TdP5CS1 and TdP5CS2 expression under cold stress conditions

The transcription levels of TdP5CS1 and TdP5CS2 were recorded in cold stress treated T. durum root and shoot tissues at different time points (Fig. 1 and 2).

Our results revealed that cold stress (4°C) caused rapid induction of TdP5CS1 expression up to 9.25-fold at 6 h after treatment in roots of cv Rusticano, followed by a significant reduction. In roots of cv Grazia the TdP5CS1 transcripts were initially detected at 6 h after cold stress and reached the highest level at 12 h, being 7.3 times higher than control (Fig. 1A). TdP5CS1 mRNA levels, in shoots, reached a maximum after 12 h at 4°C in cv Rusticano and after 24 h in cv Grazia (Fig. 1B). In addition, the expression levels of the gene in the cold treated plants were lower than control at all-time points after 24 h of the cold treatment, in both tissues and cultivars.

![Fig. 1. Analysis of P5CS1 transcript levels in roots (A) and shoots (B) of durum wheat seedlings, exposed at 4°C. Transcript levels of P5CS1 were normalized to the expression of TUB, and expressed relative to normalized transcript levels in control seedlings. Columns with different letters at the same time point are statistically different (P<0.05).](image)

As it is shown in Figure 2A and B, TdP5SC2 transcripts were detected in roots and shoots of both cultivars at 4°C. Nevertheless, the expression of the TdP5SC2 was slightly increased in roots, but greatly induced in the shoots of the cold treated plants. The expression of the TdP5SC2, in roots of cv Rusticano, was up-regulated at the early stages of the cold treatment, whereas TdP5SC2 in shoots, showed significant increase in expression after 12 h at 4°C in cv Rusticano and after 24 h in cv Grazia (Fig. 2B).

Overall, the results presented in this study indicate that TdP5CS1 and TdP5SC2 in Glu pathway may function synergistically in durum wheat. Interestingly, the expression of TdP5SC2 was higher than TdP5CS1 in shoots, while the opposite observation was made in roots. In addition, the up-regulation of TdP5CS1 and TdP5SC2 in shoots was higher than
In both cultivars, the expression of TdP5CS1 and TdP5SC2 in non-treated plants was at the same level.

**Fig. 2.** Analysis of P5CS2 transcript levels in roots (A) and shoots (B) of durum wheat seedlings, exposed at 4°C. Transcript levels of P5CS2 were normalized to the expression of TUB, and expressed relative to normalized transcript levels in control seedlings. Columns with different letters at the same time point are statistically different (P<0.05).

4 Conclusions

Our results showed that the tolerance of cv Rusticano to cold stress, is underlined by the smaller decrease of root growth as well as by the higher root/shoot ratio compared to cv Grazia.

Quantitative polymerase chain reaction analysis revealed that TdP5CS1 and TdP5SC2 were expressed at higher levels in the roots of cv Rusticano than Grazia as early as 6 and 12 h after cold-stress treatment, respectively. According to our best knowledge this is the first published study on the effect of cold stress on P5CS expression between a cold resistant and sensitive cultivar. Our results are in agreement with the results of Igarashi et al. (1997) who observed that P5CS mRNA level was higher in the salt-tolerant cultivars than in sensitive ones. Therefore, we conclude that:

1. Both TdP5CS1 and TdP5CS2 are stress inducible genes
2. Earlier and higher response, of the TdP5CS genes, to cold stress treatment was observed in the cold-tolerant cv Rusticano as compared to cv Grazia.
References

Climate and climate change analysis for the island of Korcula, Croatia

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In the framework of international project CC-WateS, Blato catchment on the island of Korcula at middle Croatian Adriatic coast is selected as karstic aquifer test bed. Air temperature and precipitation are analysed as basic input parameters used in hydrological calculations for water supply estimates. Analyses of present climate (1961-1990) contain intra-annual variability and extremes and their temporal variations during 1951-2009 period on monthly, seasonal and annual scale for meteorological stations within the catchment. In the second part, climate is analysed in simulations of three regional climate models. Comparison of simulations of present climate with these three models, local observations and time series from E-OBS database points to a need for bias correction. In this sense, statistical bias correction has been applied to all model simulations when compared to E-OBS values. Since there are differences present between E-OBS and local observations, further simple adjustment is developed. Climate change defined as a difference between future climate (2021-2050 and 2071-2100) and present climate (1961-1990) in all three models points towards temperature increase. Trend in precipitation amount points to higher variability in sense of sign and amount of change which also depends on model and season.

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1 Introduction

The observed global and regional warming is also present along the eastern Adriatic coast (Branković et al. 2013), which shows a tendency towards drier conditions that is a common feature for the broader European part of the Mediterranean. The fact that precipitation change is highly variable regionally increased the need for more accurate regional and local precipitation change analysis to improve the analysis of impacts. The results of analyses in air temperature and precipitation variability and trend in present and future climates within CC-WaterS project is aimed to be the input meteorological data for hydrological calculations of water balance needed for estimates and projections of water supply at three test locations at the eastern Adriatic coast.

The climate of the observed catchment Blato on the island of Korčula is determined by the mid-latitude circulation dominantly modified by the sea, and the high orography of the Dinaric Alps and to a lesser extent by its elevation, relief configuration, soil type, etc. It is under the influence of the subtropical high pressure zone during summer, which brings dry and warm weather. During cold part of the year the area is within the zone of the main western winds of moderate latitudes, where the exchange of cyclones and anticyclones is present. The sea with its large thermal capacity moderates air temperature extremes, cooling effect in summer and decreasing cold in winter.

2 Data and Methodology

The local climate conditions are described by the Vela Luka data from the reference period 1961-1990. Seasonality is described in terms of annual cycle of the mean monthly values, and their interannual variability by standard deviations for air temperature and coefficient of variation for precipitation. Extremes in annual and seasonal averages are discussed after their percentiles calculated from the empirical cumulative distribution function (CDF).

Linear trends have been estimated for the annual and seasonal data series in the period 1951-2009. They have been tested for significance by the non-parametric Mann-Kendall rank test (Gilbert 1987). For the series showing the significant trend, a progressive analysis of the time series was performed in order to determine the beginning of this phenomenon. The short-term fluctuations were eliminated by the weighted 11-year binomial moving average filter.

Present and future climate simulations using three limited area models are analyzed. The models are Aladin (Bubnova et al. 1995), Promes (Castro et al. 1993) and RegCM3 (Pal et al. 2007). For 2m temperature and precipitation, time series for each model were considered and for present climate they are compared with local observations and with the E-OBS data (Haylock et al. 2008). There are three types of model data in this framework: 1) regional climate model (RCM) output: regridded to E-OBS grid (Jones 1999); 2) RCMcorr: bias corrected model output by E-OBS data (Déqué 2007, Formayer and Haas 2010); 3) RCMcorr_adj: further adjusted model time-series due to differences between E-OBS data and local observations.

3 Results

3.1 Air temperature and precipitation 1961-1990

Mean annual air temperature cycle at Vela Luka area has maritime characteristics with the warmer autumn than spring (mean difference 2.4°C). The winters (DJF) are mild (8.2°C) and the summers (JJA) are moderate (23.3°C). The warmest months are July (24.4°C) and August (23.8°C) and the coldest is January (6.7°C). According to the standard deviation values, interannual variability is low (0.8°C to 1.5°C) due to the strong influence of the sea. July is
the least likely to change its thermal character and November is the most unstable month. In the annual percentile cycle, the differences between the mean daily air temperatures of percentiles 98 and 2 are the greatest in November (5.6°C) and February (5.4°C) and the smallest in July (2.7°C).

The island of Korcula has the maritime type of annual precipitation cycle with the lowest amounts occurring during the warm half-year (April to September). In JJA falls only 13% of the annual precipitation while the monthly minimum appears in July (23 mm). The cold period (October to March) receives 68% of the annual total with monthly maximum in November (110 mm). Certain years can experience a significant deviation in monthly amounts. There are years when months with normally abundant precipitation in autumn and winter, have amounts less than 10 mm. In summer months it can occur that very poor or no rain falls, or on the other hand that average monthly amount is exceeded more times. Coefficient of variation indicates these high interannual variations in mean monthly precipitations, which are higher than 61%.

In Vela Luka the values of monthly precipitation percentiles and their deviation from median show high values especially from October to March. Monthly precipitation amounts which will be exceeded once in 50 years (percentile 98) show the greatest deviation from median in January (209 mm). The highest values of seasonal precipitation percentiles have winter and autumn. Their differences decrease for higher percentile values. Annual precipitation amounts of over 1078 mm can be expected once in ten years, and annual precipitation amounts of over 1154 mm once in 50 years.

Extremely dry seasons can be supposed to be those with precipitation amounts lower than percentile 2. Their annual course follows those of mean precipitation, having the lowest percentile 2 value in summer (33 mm) and the highest one in autumn (121 mm). Extremely dry months are expected to be with precipitation amounts less than 11 mm (percentile 2) for all months except November for which percentile 2 value amounts 37 mm. In July, August and October there may be no precipitation.

According to the average regime of water balance components, the area of middle Adriatic islands suffers from the permanent shortage of water. Precipitation deficit is high and long-lasting from April to October. The runoff appears only occasionally in the years with exceptional rainy events in winter months. Only about 5% of annual precipitation runs off only during the cold part of the year (November to March).

Precipitation spatial distribution is strongly modified by orography. According to mean annual isohyetal map for Croatia (1961-1990) (Zaninovic et al. 2008) the lowest amounts of 700 to 900 mm fall at the western part of the island of Korcula, the most part has 900-1250 mm at up to 400 m asl and on the hilly summits annual precipitation could be 1250-1500 mm.

### 3.2 Trends in temperature and precipitation 1951-2009

During the period 1951-2009 mean annual temperature anomalies in 1950s and 1960s are mainly positive, during the next two decades they show large interannual variability and negative departures prevail from 1961-1990. Since the mid 1990s warm period is present. Such fluctuations resulted with no trend in the observed 59-year period. Within recent shorter periods by the end of the first decade of the 21st century, air temperature trend is amplified. Annual air temperature tendencies show an increase of 0.3 °C/10yrs for 49-year period (1961-2009), 0.4 °C/10yrs for 39-year period (1971-2009) and 0.5 °C/10yrs for 29-year period (1981-2009). The last two trends are statistically significant. The consequence of such temperature fluctuations is that, out of ten warmest years since the middle of the 20th century, 5 of them were recorded before 1961 and 4 of them in the first decade of the 21st century.

Interannual variability is large in all mean seasonal air temperatures. Despite that, their trends are statistically significant, but they are not in the same direction. Winter (DJF) and autumn (SON) show decreasing tendency, and opposite to this, mean spring (MAM) and summer (JJA) air temperatures have negative trends. Negative trend begins in 1973,
becoming significant in 1990 for winter (DJF), and for autumn in 1973, statistically significant since 1990. Positive trend begins for spring in 2006 becoming significant at the end of the observed period in 2009, and for summer in 1998, significant since 2007.

During the period 1951-2009 there is a decreasing tendency of annual precipitation over the island of Korcula. The contribution mainly comes from the declining winter precipitation totals, as well as in the minor extent from decreasing autumn amounts. The progressive trend test for annual amounts indicates at the beginning of the negative trend in 1982, becoming significant in 1997, and for winter negative trend begins also in 1982, but significant in 1991.

### 3.3 Simulations of regional climate models

Fig. 3 shows comparison of RCMcorr with local observations and E-OBS data. The time period considered is 1951-2000 for both corrected model results and observations. E-OBS and model data are for the point that is located approximately 50 km to the north from the meteorological station Vela Luka, because of the finite E-OBS spatial resolution and data availability. In terms of annual cycle (Fig. 3. a and b) there is an almost exact match between all the graphs for temperature annual cycle. For precipitation annual cycle, there is an overlapping from May to August, but in other months E-OBS and RCMcorr underestimate local observations. In terms of variability (Figs. 3.c and d), all datasets show generally similar behaviour. Although standard deviation of local precipitation seems to be higher than that of the other data, for coefficient of variation there is a better agreement among all datasets.

For extreme values, models behave in similar way. Promes and Aladin are approaching closely to the maximum precipitation amounts in local observations. For this test bed, the EOBS and RCMcorr temperatures are comparable to local observations, but no similarity was found for precipitation. This discrepancy entails a requirement of further adjustment to the available model data.

Adjustment differences are applied to RCMcorr time series in order to create RCMcorr_adj. For each month, they represent the mean difference between each model and local observation during 1961-1990. This is not a standardized adjustment procedure and it is based on the recommendations made during the CC-WaterS TW3.3. The amplitude of adjustment differences is comparable among different models. After applying adjustment, temperature annual cycle is almost unaffected. However, for precipitation annual cycle of the models considered, a shift towards local observations can be seen.

Variability of both temperature and precipitation is not changed. After adjustment, there are no important changes for time series of mean annual temperature and there are improvements in case of precipitation. For maximum precipitation amounts a somewhat higher improvement can be seen when compared to that in minimum precipitation amounts.

The simulations of future climate are done under IPCC SRES A1B scenario (Nakicenovic et al. 2000). Temperature trends for all time series are statistically significant. However, changes in precipitation amounts and trends are more variable than for temperature and even differ in the sign. On the annual time scale there is a large negative, statistically significant, trend simulated by Aladin.

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**Fig. 1.** The Blato catchment: annual cycle a) mean monthly temperature, b) monthly precipitation amount; standard deviation c) mean monthly temperature, d) monthly precipitation amount (full lines) and coefficient of variation (dashed lines); time series e) mean annual temperature, f) annual precipitation amount; CDFs g) mean annual temperature, h) annual precipitation amount. Model time series are RCMcorr.
4 Conclusions

The combined influence of observed meteorological parameters, air temperature and precipitation, affects water balance components. The detected increase in air temperature in warm season causes an increase in evapotranspiration. Together with a decreasing tendency in precipitation, the precipitation deficit is expected to become larger in the warm season. In the cold part of the year runoff and the filling of aquifers could be reduced due to negative precipitation trend.

The analysis for this test bed shows that local observations and EOBS follow each other closely. The largest differences in precipitation are during winter and autumn. The annual precipitation curves of standard deviation and CDF indicate that local precipitation is more variable than EOBS precipitation.

Comparison of raw (uncorrected) model results (RCM) with local observations and EOBS data for the time period 1951-2000 indicates for annual cycles of temperature and precipitation a spread among models. The Aladin time series follows the annual cycle and monthly standard deviations of local observed precipitation closely. For annual means of temperature and its CDF, all models are clearly separated from EOBS and local observations. At the beginning of the 21st century Promes has the highest temperature increase when compared to the reference period. By the end of the 21st century, Aladin and RegCM3 have similar amplitude of the changes in temperature means. On annual time scales, changes in precipitation at the beginning of the 21st century are not to be expected. However, according to the Aladin model, a decrease in precipitation amount becomes important when comparing reference period and middle of the 21st century.

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References

On the aerosol-cloud relations over Eastern Mediterranean


In this work, the aerosol-cloud relations over the region of Eastern Mediterranean at the high spatial resolution of 0.1 degrees (~10 km) are investigated. For the scopes of this research, a 13-year gridded dataset with several aerosol and cloud related parameters has been compiled using level-2 single pixel measurements from MODIS TERRA and MODIS AQUA satellite sensors. The aerosol gridded dataset has been successfully validated against ground-based observations from 12 AERONET sites, while a more sophisticated gridding method has been followed in the case of cloud data. The high resolution of the dataset allows for the investigation of local phenomena. By combining MODIS data with data from the Earth Probe TOMS and OMI satellite sensors, meteorological data from the ERA-interim reanalysis and data from the GOCART chemical-aerosol-transport model and the MACC reanalysis, the relative contribution of different aerosol types to the total aerosol optical depth (AOD\textsubscript{550}) has been quantified. Using these results, we calculate the relations of AOD\textsubscript{550} with the cloud effective particle radius, the cloud droplet number concentration, the cloud cover and the cloud water path for different types of aerosols. In this short paper, we present a case study on the AOD\textsubscript{550}-Total cloud cover relations for spring (March-April-May).

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1 Introduction

For more than a decade, satellite observations from MODIS have been used in numerous studies in combination with observations from other satellite and ground-based instruments, as well as model simulations to quantify the optical properties and the direct radiative impact of different aerosol types at a global, as well as regional scale. On the other hand, a significant number of studies incorporate MODIS observations and model simulations to assess the effect of aerosols on clouds and by extension on the radiative balance in the Earth-Atmosphere system and precipitation (aerosol indirect effects). The vast majority of these studies is based on coarse resolution 1-degree level-3 gridded data. Within the framework of QUADIEEMS (QUantifying the Aerosol Direct and Indirect Effect over eastern Mediterranean) project we combine high resolution level-2 MODIS data with data from various satellites, reanalysis projects and global models to quantify the aerosol direct and indirect radiative effect at a spatial resolution of 0.1 degrees (~10 km) over Eastern Mediterranean.

The core method used in the project was originally proposed by Quaas et al. (2008) and revisited by Bellouin et al. (2013). This method may be used with an algorithm, originally suggested by Bellouin et al. (2008), that combines aerosol optical depth (AOD) and fine-mode ratio (FMR) at 550 nm from MODIS, aerosol index (AI) from TOMS and surface wind speed over oceans from SSM/I to estimate the relative contribution of marine, dust and anthropogenic (fossil fuel and biomass burning) aerosols to the total AOD$_{550}$ on a daily basis. However, this is possible over oceans only, since the FMR product is not considered reliable over land. Alternatively, over land they used regional anthropogenic fractions derived from five global models from the AEROCOM project. A similar approach was used in Bellouin et al. (2013) with data from MACC aerosol reanalysis. The relative contribution of different types of aerosols is then used in the satellite-based parameterizations proposed by Quaas et al. (2008) allowing for the quantification of the aerosol direct and indirect radiative effect per aerosol type. Within QUADIEEMS, we apply the same method at a high spatial resolution, combining data from 5 satellite sensors with data from the ERA-interim reanalysis, data from the GOCART model and the MACC reanalysis.

Within the Quaas et al. (2008) parameterizations the first aerosol indirect effect is expressed through the cloud droplet number concentration (CDNC)-AOD$_{550}$ slope while the second indirect effect could be expressed through the relation of total cloud cover (TCC) and cloud liquid water path (LWP) with AOD$_{550}$. So, it becomes obvious that the calculation of these slopes is crucial for the quantification of the aerosol indirect effects. In this paper, we present selected results from the validation of the joint aerosol-cloud 0.1 degree gridded dataset we compiled for the region of Eastern Mediterranean [30°N-45°N, 17.5°E-37.5°E], the quantification of the relative contribution of different aerosol types to the total AOD$_{550}$ and finally part of the research that we did on the relations of AOD$_{550}$ with cloud effective particle radius (CEPR), CDNC, TCC and the LWP for different types of aerosols and clouds. Specifically, since the effect of aerosols on the microphysical properties of clouds over Eastern Mediterranean is a very delicate issue which cannot be discussed adequately in a short paper like this, we preferred to present here some results for the TCC-AOD$_{550}$ relations.

2 Data and Methodology

First, we defined a 0.1°x0.1° grid covering the region of Eastern Mediterranean which is interpreted into 30,000 grid cells. Only level-2 (C051) single pixel AOD$_{550}$ measurements (~10 km at nadir) with a quality flag of 3 were used to ensure the high quality of the data. The original MODIS pixels are attributed at a specific grid cell if their center falls within a 25x25 km$^2$ square window around the grid cell. This means that pixels with centers outside the 0.1°x0.1° grid cells are counted as belonging to the cell and some of the original pixels are shared between successive grid cells; however, this does not affect the representativeness of
the dataset over each grid cell. These pixels are afterwards used for the calculation of daily averages on a grid cell basis (see Georgoulas and Kourtidis 2012). A grid cell of 0.1° (~10 km) is as big as the centre of a large Mediterranean city like Thessaloniki, Northern Greece (~1 million inhabitants). We repeated the same method increasing the gridding window to 50, 75 and 100 km and we found that the 25 km window we used is the best compromise between accuracy and spatial discrimination. The 0.1-degree gridded AOD$_{550}$ data were validated against data from 12 AERONET stations in the region. Both MODIS TERRA and AQUA overestimate AOD$_{550}$ compared to AERONET with the correlation coefficient (R) being greater than 0.75. MODIS TERRA shows a better agreement with the AERONET data with a slope of ~1 (see Fig. 1).

For the MODIS cloud data a more sophisticated gridding method was followed. Each original daytime (C051) MODIS single pixel (~5 km at nadir for clouds) was divided into 25 (~1 km) sub-pixels with each one carrying its parent value. Then a sub-pixel was attributed to a 0.1x0.1 degree grid cell if this was centered within the grid cell and the data were averaged on a daily basis. This method has the advantage of taking into account the contribution of each original pixel covering part of a grid cell and does not leave gaps between successive grid cells.

Then we used the aerosol gridded dataset to quantify the relative contribution of different aerosol types to the total AOD$_{550}$ (marine, dust, anthropogenic and fine-mode natural). Over the ocean, we used the Bellouin et al. (2008) method combining AOD$_{550}$ and FMR$_{550}$ data from MODIS with wind speed (ws) data from ERA-interim reanalysis, AI data from Earth Probe TOMS and OMI AURA (see Fig. 2). All the datasets were re-gridded using bilinear interpolation to a 0.1x0.1 degree spatial resolution to match the MODIS data.

Over the ocean, three different types of aerosols are assumed to dominate: marine, dust and anthropogenic. Over land, we used AOD$_{550}$ data from the global chemical-aerosol-transport model GOCART (2000-2007) and the MACC reanalysis (2003-2012) for different aerosol types to calculate the dust and non-dust AOD$_{550}$ following a method similar to the one presented in Bellouin et al. (2013). In order to produce a homogeneous dataset for the period 2000-2012 we scaled the GOCART observations for the period 1/2000-12/2002 taking into account the relation between GOCART and MACC for the common period 2003-2007 on a seasonal basis for 1-degree grid cells. Finally, the homogenized data were re-gridded using bilinear interpolation to match the a 0.1x0.1 degree MODIS data. Then the MODIS dust component was calculated by scaling the MODIS data according to the dust component of GOCART-MACC. The remaining non-dust component was multiplied by a predefined anthropogenic factor from (Bellouin et al. 2013) to calculate the anthropogenic component of the total AOD$_{550}$. The remainder was afterwards attributed to fine-mode natural aerosols.
The relative contribution of different aerosol types was used to discriminate days with marine, dust and anthropogenic dominating aerosols. The aerosol-cloud relations were then examined for different aerosol types and different cloud types (mixed-ice-liquid) on a seasonal basis. Except from the maps we produced with the \( \ln(\text{cloud parameter})/\ln(\text{AOD}_{550}) \) slopes we also examined the relations between \( \text{AOD}_{550} \) and cloud optical properties by averaging the cloud properties for 0.01 \( \text{AOD}_{550} \) bins. Only \( \text{AOD}_{550} \) values less than 0.6 are used in order to ensure that dust was not falsely interpreted as clouds.

### 3 Results

We present below a case study on the \( \text{AOD}_{550} \)-TCC relations for spring (March-April-May). In Figure 3, the relative contribution of each aerosol type to the total \( \text{AOD}_{550} \) is presented. Over the ocean, 51.95% of the \( \text{AOD}_{550} \) is due to marine aerosols, 27.34 due to dust particles and 20.71% due to anthropogenic aerosols. Over land, 15.25% of the total \( \text{AOD}_{550} \) is attributed to fine-mode natural aerosols, 33.69% to dust and 51.06% to anthropogenic aerosols. Our results highlight the heavy dust load over the region during Spring, with the dust \( \text{AOD}_{550} \) fraction being very close over land and ocean. April is the month with the highest dust percentage over the ocean due to episodic intrusions from the Sahara Desert.

![Fig. 3. Relative contribution of different aerosol types to the total \( \text{AOD}_{550} \) over the ocean (left) and land (right).](image)

In Fig. 4, we give a sample from the analysis we have done within QUADIEEMS. The relations of \( \text{AOD}_{550} \) with the cloud fraction of liquid and ice clouds can be seen here for cases that a specific aerosol type dominates. We observe that when anthropogenic and dust particles dominate the slope between LCF and \( \text{AOD}_{550} \) is rather low for \( \text{AOD}_{550} \) values less than 0.1-0.2, becoming higher as \( \text{AOD}_{550} \) increases. In the case of marine aerosol dominance, the slope is higher for \( \text{AOD}_{550} \) values lower than 0.1-0.2. In the case of ice clouds, the ICF-\( \text{AOD}_{550} \) slopes are very low compared to the LCF-\( \text{AOD}_{550} \) ones for the total of the aerosol types. In all cases, the LCF and ICF is higher when marine aerosols dominate.
4 Conclusions

In this short paper, we present selected results from an ongoing scientific project that deals with the aerosol-cloud-radiation relations over the region of Eastern Mediterranean. For the scopes of the project, high resolution level-2 MODIS data are combined with data from other satellites, reanalysis projects and global models in order to produce a high resolution 0.1-degree (~10 km) gridded dataset with all the parameters needed in order to quantify the aerosol radiative effect. It is shown here that the high resolution gridded AOD\textsubscript{550} data from MODIS agree well with ground-based data from the AERONET. The relative contribution of different types of aerosols is also presented for land and oceanic regions within Eastern Mediterranean. Over the ocean, 51.95\% of the total AOD\textsubscript{550} may be attributed to marine aerosols, 27.34 to dust and 20.71\% to anthropogenic aerosols. Over land, 15.25\% of the total AOD\textsubscript{550} is due to fine-mode natural aerosols, 33.69\% due to dust and 51.06\% due to anthropogenic aerosols. The investigation of the LCF-AOD\textsubscript{550} and ICF-AOD\textsubscript{550} relations reveals that in the case of anthropogenic and dust particle dominance the slope between LCF and AOD\textsubscript{550} is rather low for AOD\textsubscript{550} less than 0.1-0.2. In the case of marine aerosol dominance, the slope is higher for AOD\textsubscript{550} lower than 0.1-0.2. The ICF-AOD\textsubscript{550}slopes are very low compared to the LCF-AOD\textsubscript{550} slopes, while the LCF and ICF is higher when marine aerosols dominate.

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References

Visibility records and trends since 1956, as a proxy of decadal changes in aerosol loads (SW Greece, Messenia)

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This study investigates visibility records in Methoni - Peloponnese (SW Greece) during the last 6 decades, based on routine, non-automated observations. The motivation for this study has been to examine how visibility trends and variability can be used as a proxy for changes related to the local/regional climatic parameters or to atmospheric aerosol loadings, the latter due to anthropogenic activities or other natural sources. For this purpose relative humidity and AOD data were considered. The analysis showed high reduction visibility rates from mid 50s to late 70s, followed by a stabilization since around 2000, while an increase in visibility after 2008 could be attributed to the economic crisis and the subsequent reduction in anthropogenic activities/ emissions. A trajectory analysis for the whole period allowed the estimation of the relative source contribution, indicating RH as the main controlling factor.

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1 Introduction

Visibility in the unpolluted atmosphere is restricted by Rayleigh scattering, the curvature of the earth’s surface and natural aerosols (e.g. water drops, dust, forest fires, volcanoes, sea spray, vegetation emissions). These sources cannot be easily amenable to control, however, their impacts must be considered in studies of visibility impairment. In the Mediterranean region, humidity and dust aerosol from arid areas in N. Africa are expected to be the main controlling factors of visibility. Moreover, anthropogenic aerosols during the last decades may also have posed an effect on visibility, taking into account that Eastern Mediterranean has been well identified as a crossroad of air masses carrying numerous and various aerosols types (Lelieveld et al. 2002).

The scope for this study is to examine the trends and the variability of visibility in the Methoni area (Peloponnese, SW Greece) as related to meteorological parameters and aerosol loading information.

2 Data and Methodology

Visibility records in the area of Methoni - Peloponnese (SW Greece) since the mid-50s (1956-2013) are used in this study. The records are based on routine, non-automated observations taking place at the Hellenic National Meteorological Service (HNMS) station. In particular, one observation every three hours was conducted during the whole period (on an annual basis full coverage until 2001, ~70% since then), from which monthly and annual averages were calculated (the records were decoded to provide visibility in km and annual averages were corrected for data gaps). Mean daily values of relative humidity (RH %) were also used from the HNMS station in Methoni (40 m a.s.l.). For a long term time series of AOD we extrapolated the NOAA/AVHRR 4D climatology of AOD for the Mediterranean Sea by Nabat et al. (2013; their figure 13), while since 2000 we deployed MODIS AOD over the area of study.

We also performed an extensive analysis of air-mass origin and meteorological history during transport. For this purpose we calculated 10 day back trajectories at 10, 100, 500 and 1000 m above sea level. A trajectory was calculated every 3 hours through the studied period. The model used was HYSPLIT4 (Draxier and Hess 1998) applied on NCEP/NCAR reanalysis data archive. The model provides, besides latitude and longitude pairs for all endpoints, meteorological information such as relative humidity and temperature. The trajectories were subsequently used to study the potential contribution from different source regions of air with low visibility (<10km) and air with high visibility (>25km). Also other transport characteristics were investigated in detail.

3 Results and Discussion

3.1 Long term trends in visibility

Visibility on an annual basis (Fig. 1) shows an abrupt reduction from mid 50s to late 70s, from about 26-28 km down to 17-18 km. Since then the reduction rate slowed down considerably and only during the last years (2008-2012) an increasing branch is observed. According to Vrekoussis et al. (2013) this period coincides with a significant acceleration in the reduction of emissions in Greece due to the ongoing economic recession.

Visibility until the mid 70s seems to be driven by changes in RH. In particular, despite the overall trend, two characteristic peaks in RH in 1962-1963 and 1967-1970 are well reflected
on visibility that shows considerable drop. After the mid-70s the RH appears stable and so does the visibility, while a new hump during 1997-2002 in the RH is again reproduced by visibility before the gap in the series. For the main period of available AOD data, no signal of aerosol impacts on visibility is easily recognizable. However, it should be noted that in Nabat et al. (2013), different datasets (satellite and models) show great variability both in terms of absolute values and long term trends, thus making safe conclusions difficult to be drawn. The spatial representativity of these data compared to the point observation and specific direction recording at Methoni, should also be taken into account. AOD as revealed from the MODIS data for a grid including the Methoni station, decreases since late 90s, while its last period decrease (since 2008) coincides with a significant increase in visibility despite the concurrent spike in RH too.

![Fig. 1](image1.png)

**Fig. 1.** Inter-annual variability of visibility (black), RH (blue) and AOD (MODIS: light green, NOAA/AVHRR-Nabat et al. 2013: dark green).

To follow the long term visibility changes on a seasonal basis, we produced the monthly cycles of visibility per decade (Fig. 2). In the first two decades clearer conditions are found during summer and fall. The biggest change is observed during the 70s when visibility in spring and summer showed a rapid decrease, probably following the industrialization in the extended area (the nearby Megalopoli lignite power plant began its production in 1971) and the appearance of photochemical smog, especially in nearby urban centers (e.g. Athens) and during summer time. Thence visibility further deteriorated and showed up no distinct seasonality.

![Fig. 2](image2.png)

**Fig. 2.** Seasonal cycle of visibility (at 9:00 UTC) per decade.

### 3.2 Role of source area and transport characteristics

The visibility observations used in this study are not automated and are quantified based on known distance to reference points. This means that the visibility observations typically are discrete and unevenly spaced. The current dataset thus includes 16 “type” values between 0.8
and 30km. In order to make the data more accessible it was arranged into five visibility bins (0.8-8km, 10km, 15km, 20km and 25-30km). In this section we study the transport characteristics associated with observations that sorts under the highest and lowest visibility bin, respectively.

Figure 3a shows the likelihood that air originating from any grid is associated with observations of visibility that is less than 10km (i.e. visibility bin 0.8-8km). Figure 3b in turn shows the average transport height over the different grids at which an air parcel associated with the lowest visibility bin resides.

![Fig 3. a) Likelihood function for different source regions to contribute with visibility <10km. The figure shows the number of times a grid has been associated with the criteria of visibility <10km normalized by the total amount of times air has resided over the grid. b) Average altitude over the grid cell during transport of air associated with visibility <10km.](image)

It is clear, from Fig. 3a, that the regions that most likely are associated with observations of poor visibility generally is located south of Methoni, and notably southern Mediterranean region as well as north Africa. Surprisingly, neither Western nor Eastern Europe seem to be associated with a high likelihood of bringing air that is associated with low visibility to Methoni, suggesting other sources and/or mechanisms than anthropogenic emissions alone are needed to result in poor visibility. A low visibility source sector seen in NE Europe could probably be related to long range transport of industrial pollutants. As can be seen in figure 3b, the observations of low visibility is further more associated with low level transport over the Mediterranean ocean. This suggests either that strong sources of particles do exist in either the Mediterranean itself or northern Africa in the form of e.g. desert dust. Although this at least partly could explain the observed features, the role of relative humidity is likely of bigger importance. High relative humidity significantly causes soluble particles to grow, thereby enhancing their light scattering ability. The fact that the air is transported from hotter regions to (relatively) cooler regions during low level transport over open water strengthen the hypothesis that RH, in fact, is the most dominating controlling factor for poor visibility. Another contributing factor is also the fact that sea salt is highly hygroscopic which further enhances the attenuation of light.

The opposite relation is true for the largest visibility bin (25-30km). Observations in this visibility range are typically associated with a northerly, subsiding airflow, bringing drier air to the receptor. This again highlights the strong control RH excerpts on the visibility in the Mediterranean region.

A first attempt to investigate the separate effects of RH and AOD on visibility is shown in Fig. 4. Humidity and AOD during the common period 2000-2013 were averaged for different visibility bins. In both cases, the decrease in visibility is due to the combined increase in both RH (in the range from 55% to almost 80%) and AOD (in the range from 0.05 to over 0.3).
4 Conclusions

The current study revealed high reduction visibility rates at Methoni station (SW Peloponnese), from the mid 50s to late 70s. Until the mid 70s, visibility seems to be driven by changes in RH reproducing characteristic peaks during specific periods. After the mid-70s, both time series showed some trend of stabilization. On a seasonal basis, the biggest change was observed during spring and summer in the 70s, probably following the industrialization in the extended area. The specific impact of AOD on visibility at this coastal site was proven a challenging task, however, binning of data revealed important relations. Moreover, an increase in visibility after 2008 could probably be attributed to the economic crisis and the subsequent reduction in anthropogenic activities/emissions. Finally, the trajectory analysis showed that the source regions of air masses associated with poor visibility are generally located south of Methoni and at low altitudes demonstrating the direct effects of dust from N. Africa, water vapor from the Mediterranean and/or combination of both (including hygroscopic particle growing processes).

Overall, further analysis is required, in conjunction with observations from more sites so that the conclusions draw are safer, more representative for the whole area and the decomposition of RH-AOD becomes feasible.

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References


Climatic conditions of the delta of the Pinios River (Thessaly, Greece), based on in situ meteorological measurements

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The microclimatic conditions of the deltaic plain of the Pinios River are studied, within the framework of the THALES-DAPHNE research project. Three meteorological stations were installed at Stomio, Palaiopyrgos and Mesagkala and the recorded time series were intercompared to monitor meteorological conditions and their variation in the deltaic plain. Climatic data for the area were obtained from the analysis of multi-year data from two monitoring stations at Karitsa (1978-1996) and Pyrgetos (1960-1993) and of ERA-interim data. During 2013 the Stomio area received more rain than the Palaiopyrgos area by 9-54%, with the exception of July and August, when Palaiopyrgos received 85% and 593% more rain respectively. Both areas received significantly less precipitation (from -28% to -96%) than the multi-year mean monthly values of Karitsa and Pyrgetos, with the exception of February (+32-95%) and July (+110-300%). Air temperature at Palaiopyrgos was 1-2 °C higher than at Stomio during the winter months and about equal during the rest of the year. Both areas are slightly warmer (7-14%) than Karitsa during the summer and much warmer during the winter (57-69%). The above differences are attributed to the effects of orography and vegetation on the microclimate of each installation area.

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1 Introduction and study area

River deltas are among the most sensitive coastal ecosystems, characterized by immense biological diversity and conflicting human activities (e.g. agricultural, touristic). Changes in climatic conditions and weather patterns could affect both agriculture and tourism on local and regional scale (Becken 2010, Matzarakis and Nastos 2011). Furthermore, coastal ecosystems, such as river deltas, are very sensitive to temperature and rainfall changes, which could affect important ecological processes and species interactions. The trends and variability of the air temperature for the wider area of Greece and for several time periods have been studied in recent studies (e.g. Nastos and Matzarakis 2008, Philandras et al. 2008; Nastos et al. 2011). Research on precipitation over Greece has been carried out on local and regional scale (e.g. Feidas et al. 2007, Nastos and Zerefos 2008).

A significant part of the Thales-DAPHNE project of the University of Athens is to expand the current knowledge of the local climatic conditions in the area of the Pinios River delta, by monitoring and analysing the temporal variability of important meteorological parameters, and to assist stakeholders in planning necessary interventions and in developing compatible rural and touristic activities.

The delta of Pinios River is located on the western coast of south Thermaikos Gulf (Fig. 1). The deltaic plain (approximately 69 km²) extends between the Lower Mount Olympus to the N and Mount Ossa to the S, has elevations up to 10 m and is under "Special Protection" according to the Directive 79/409/EEC, NATURA 2000 (GR1420002).

![Fig. 1. Location map of the study area showing the Pinios River delta, the locations of the weather stations and the ECMWF ERA-Interim grid used in this study.](image)

The delta is generally considered to have a “Mediterranean” type climate, even though its central area is closer to the “continental” type with less rainfall and larger seasonal variations of air temperature (Foutrakis et al. 2007). Mean annual precipitation ranges from 400 mm near the delta to nearly 1600 mm in the surrounding mountainous area. Mean annual temperature is about 17°C (Gaki-Papanastassiou et al. 2010).

The objective of this work is to analyze the climatic regime of the Pinios River delta based on the ERA-interim reanalysis dataset (ECMWF) and on long-term ground-based observations and to present the preliminary results of the study of the micro-meteorological conditions of the deltaic plain, based on in situ observations.
2 Data and Methodology

Climatic data over the deltaic plain of Pinios for the period 1979-2013 were obtained from the ERA-interim reanalysis dataset (ECMWF). These data consist of 6-hourly estimates of mean sea level pressure, temperature at 2m, zonal and meridional wind vectors, with a grid analysis of 0.125°x0.125°. Historical data from the Pyrgetos rainfall gauge station (altitude: 34 m) and the Karitsa weather station (altitude: 380 m), covering the periods 1960-1993 (Pyrgetos) and 1978-1996 (Karitsa) (Panagopoulos et al. 2001) were used for the investigation of recent climate trends.

In order to study the micro-meteorological conditions of the deltaic plain, two meteorological stations (Davis Vantage Pro2 Plus) were installed at Stomio (in June 2011) and Palaiopyrgos (in January 2013) (see Fig. 1), at altitudes of 9 and 6.5 m respectively, to record the barometric pressure, air temperature, relative humidity, rainfall, wind speed and direction, solar radiation and UV radiation. In November 2013 a third weather station was installed close to the shoreline at Mesagkala to monitor wind speed and direction, barometric pressure, air temperature and relative humidity. The time series for each parameter, recorded at 5 min intervals by the three weather stations, were used to examine the annual variability and to investigate the cross-correlations between the datasets. The same analyses were performed on the data from the Pyrgetos and Karitsa stations in order to extract climatological information for the general area of the Pinios river delta.

For the ERA-interim dataset, the four points of the grid nearest to the weather stations were used to compute the weighted distance average value of each parameter at the location of each weather station. The resulting time series were converted to monthly mean values and were used for the extraction of information on the climatic conditions in the delta area over the past 35 years.

3 Results

3.1 Climatic characteristics of the delta area

According to the analysis of the ERA-interim data set, during the last 35 years the mean monthly air temperatures range from 6°C (in January) to 26°C (in July). Stomio appears to be consistently warmer (1-2°C) than Palaiopyrgos (Fig. 2a,c), with the higher differences occurring during the colder months (October to March). Mean monthly wind speeds range from 2.2 to 3.7 m/s with the highest speeds occurring in February and December and the lowest in July and August (Fig. 2b). Mean monthly wind speeds at Stomio are consistently higher (12–20%) than at Palaiopyrgos, with the difference increasing as the wind speed increases (Fig. 2d). The above differences are attributed to the fact that Stomio is located close to the sea and to the influence of the nearby mountainous region of Ossa.

From the analysis of the rainfall data, recorded by the Pyrgetos and Karitsa stations, it is concluded that the area of Karitsa receives significantly more rainfall than the area of Pyrgetos. During the summer months both areas receive approximately the same amount of rain, but from October to April the amount of rainfall at Karitsa is almost double the amount recorded at Pyrgetos (Table 1).
3.2 Current conditions and trends

Recent micro-meteorological data (2011-2013) show that Palaiopyrgos is slightly warmer (1-2°C) than Stomio during November, January and February (Fig. 3a, c). Both Stomio and Palaiopyrgos have received significantly less rainfall (from -28% to -96%) than the climatic monthly means of Karitsa and Pyrgotos. However, five severe storms (February and July 2013 at Palaiopyrgos and February, May, November and December 2012 and February 2013 at Stomio) have resulted in monthly precipitation higher than the corresponding climatic means. Year 2012 was exceptionally wet. In 2013 Stomio received approximately twice the amount of rainfall of Palaiopyrgos (see Table 1 and Fig. 3b,d). Monthly rainfall values at Stomio were 1.5 to 3.6 times higher than the corresponding values at Palaiopyrgos with the exception of April and June, when values were similar, and July, when the severe storm that hit the area of the delta produced 5.5 times more precipitation at Palaiopyrgos than at Stomio (Table 1).

From April to December the mean monthly wind speeds at Stomio were slightly higher than the wind speeds at Palaiopyrgos, whereas they were approximately equal during the rest of the year (Fig. 3e, f). During the two months of operation of the weather station at Mesagkala (November and December 2013), mean monthly wind speeds at Mesagkala were approximately three times the wind speeds at Stomio and Palaiopyrgos (Fig. 3e). This is attributed to the sea breeze that minimizes calm periods, but it has to be seen if this trend persists throughout the year.
Fig. 3. Comparison of recent (2011-2013) mean monthly temperature, precipitation and wind speeds data from the Stomio, Palaiopyrgos and Mesagkala weather stations.

4 Conclusions

The preliminary results reveal micro-meteorological anomalies within the Pinios river delta, which can be attributed to the effects of the local orography and to the distance from the shoreline. Thus, Stomio shows higher temperatures and wind speeds than Palaiopyrgos, both in climatic means and in recent data, while recent data from both stations show higher temperatures and lower precipitation, compared to the climatic means for the region.

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References


Forecast errors of Rossby waveguides

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The significance of upper level Rossby wave trains (RWTs) for weather forecasting has long been recognized. More recently Langland et al. (2002) found that RWTs originating over Western Pacific may play an important role for the middle and long range predictability of high impact weather events over North America and beyond. Dirren et al. (2003) analyzed forecast errors from PV perspective and they found that errors are concentrated along the wave guide of RWTs due to amplitude or phase errors of RWTs. However, our knowledge of the factors limiting the predictability of RWTs and the forecast skill of numerical weather prediction systems with respect to RWTs is still limited. Our research is focused on the forecast errors of spatially localized areas of high PV gradients which act as waveguides for the RWTs (Schwierz et al.2004). An object based spatial forecast verification tool has been developed which compares form, amplitude and location characteristics of waveguide objects in the analysis and in the forecast. As input ECMWF analysis and deterministic forecast data of ECMWF’s Integrated Forecast System (http://www.ecmwf.int/research/ifsdocs/) was used. A short climatology of forecast errors is presented for the period 01/2008-12/2010 for short and medium range forecast lead times (1 day-10 days). This climatology is used to derive error statistics as a function of season and location and to identify time periods where large errors occur.

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Synoptic, dynamic and thermodynamic characteristics of snowfall events in the area of Thessaloniki

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An attempt is being made to study the synoptic situations which cause snowfall in the Thessaloniki area. Weather charts are used for the snowfall day and the day before the snowfall event, for various isobaric levels - from the surface to 300 hPa - for the period 1980-2011. Additional data information is retrieved from radiosondes of the Regional Meteorological Center of Macedonia in Thessaloniki. Emphasis is given to the height of the freezing level, the 500-1000 hPa thickness and parameters related to the relative humidity. The snow producing synoptic situations are studied and classified in order to identify the most favorable ones. The results are further analyzed from the thermodynamic and dynamic point of view. It is believed that the concluded results will initiate further studies and provide a valuable and useful tool to forecasting skills.

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1 Introduction

Snowfall is a phenomenon which affects the most areas of human activity, and is one of the biggest risks to the smooth running of people’s daily activities, mainly related to transport. The first Greek scientist who studies the snowfalls in Greece was Eginitis at 1907. Since then, many scientists have studied the phenomenon of snowfall. Lioki-Livada-Tselepidaki (1979) made an effort to study thoroughly the phenomenon of snowfall over Greece. In the area of Thessaloniki, the snowfall was first studied by Livadas and Stergiou (1975). In this study, the synoptic evolution of surface and middle troposphere barotropic systems which cause snowfall in Thessaloniki is studied.

2 Data and Methodology

To study the synoptic evolution of the barotropic systems which cause snowfall in Thessaloniki, data from the Hellenic Meteorological Service are used. Initially observations which give past or/and present weather snow conditions were chosen and their specific dates were used for this study. It must be clarified that during the selection of the snowfall dates, the criterion was that at least one of the eight synoptic observations of a day, reports snow for present (ww=70 to 79) or/and past (w=7) weather, independently of whether the snow remains lying on the ground or whether it melts. The examined period for the snowfall cases is 1980-2011. To study the selected dates, weather charts are used for the snowfall day and the day before, for the isobaric levels between surface and 300hPa.

3 Results

From the examination of the synoptic conditions related to the snowfall dates in Thessaloniki, it is found that the most favorable ones and common situations could be classified into the following four synoptic types, in hierarchical order: the North-West flow (NW), the High-Low diffluent block, the South-West (SW) flow and the Omega Block (OME). These synoptic conditions were firstly introduced by Karacostas et al. (1992) and have been used by many scientists. In order to further analyze these four synoptic situations, a representative snowfall event (case study) is chosen for each type and the weather charts at 500hPa, M.S.L pressure and 500-1000hPa thickness are developed for the snowfall event (that is, day D) and D-1.

The first presented case study is a NW synoptic condition and corresponds to the snowfall event occurred on the 2nd and 3rd March of 1996 between 1500UTC and 0000UTC. On D-1 day (Fig.1a), at the 500hPa chart, a long wave ridge is dominating the area of interest, preserving the circulation almost unchanged. As a function of time, the encountered geopotential heights fall over Greece, mostly due to the positive vorticity advection and the cold air advection in the inflow area of the trough. It is worth noticing the initial location of the trough (Scandinavian area) and the prevailing strong NW winds. The cold air advection is also noticeable through the evolution of 500-1000hPa thickness charts (Fig.1b, 2b), showing the cold air mass existed over north Greece, becoming even colder. On D day (Fig. 2a), the ridge over Western Europe has moved eastward, while from the 500-1000hPa thickness chart (Fig. 2b) the cold air mass has reached Greece.
Fig. 1. (a) Geopotential height at 500 hPa (black contours) and temperature valid at 1200 UTC 1 March 1996. (b) Mean sea level pressure (white contour) and 500-1000 hPa thickness chart.

Fig. 2. (a) Geopotential height at 500 hPa (black contours) and temperature valid at 1200 UTC 2 March 1996. (b) Mean sea level pressure (white contour) and 500-1000 hPa thickness chart.

The next case study is a synoptic situation type known as High-Low (H-L). This is another type of blocking situation, somehow different from the one characterized as Omega Block. The snowfall event occurred on the 3rd of January 1993 between 0600 UTC and 1800 UTC. On the 500 hPa chart (Fig. 3a) for the D-1, the trough is located in west Europe and moved towards Greece. At the same time, the 500 hPa geopotential heights start falling over Greece, due to the fact that the cold air advection is approaching to the area of interest. This is also depicted at the 500-1000 hPa thickness charts (Fig. 3b, 4b). On the M.S.P charts (Fig. 3b, 4b), a strong anticyclone is located over north Europe and as it moved southwards, it became much stronger. On D day (Fig. 4a), the trough at the 500 hPa chart is located in the area of southwest Italy, while on the M.S.P chart the low pressure system is located further eastwards, over the Ionian Sea. The thickness values between 500-1000 hPa (Fig. 4b) are becoming smaller, due to the cold air advection.

Fig. 3. (a) Geopotential height at 500 hPa (black contours) and temperature valid at 0600 UTC 2 January 1996. (b) Mean sea level pressure (white contours) and 500-1000 hPa thickness chart.
The next synoptic situation is characterized as SW flow. The snowfall event occurred on 24 and 25 of December 1986, between 2100UTC and 1800UTC of the next day. On the 500hPa chart, during the D-1 (Fig.5a), a trough is located over north Europe. On the M.S.P chart (Fig.5b), a strong anticyclone is located in southwest Europe, while at the same time, south of Italy, in the Mediterranean Sea, a low pressure system developed and moved northeastwards. On D day, at the 500hPa chart (Fig.6a), the trough has moved south over the area of Italy, while on the M.S.P chart (Fig.6b) the low pressure system is located over Greece. On the 500-1000hPa thickness chart (Fig.6b), the cold air mass has already reached the Greek area and produced snowfall.

The last synoptic situation is characterized as Omega Block. The snowfall event took place on 26 and 27 of December 1996 between 1800UTC and 1800UTC of the next day. The synoptic situation on D-1 (Fig.7a) is characterized by the development of a cold core low over the
North Atlantic Ocean, causing a strong southerly flow close to the western European coasts. This flow contributes to the development of an amplified ridge, being located over northwest Europe. As a result, a trough has been developed at the eastern flank of this ridge. From the 500-1000 hPa thickness chart (Fig.7b), the cold air mass has not reached the Greek area, yet. On D day, at the 500 hPa chart (Fig.8a), the trough has been deepened further, due to the positive vorticity advection and the cold air advection at the entrance zone of the trough, forming thus a strong low pressure system. From the 500-1000 hPa thickness chart (Fig.8b) become obvious the approach of the cold air mass, which finally reaches the Greek area. On the M.S.L chart (Fig.8b), the center of the anticyclone has moved southwest in accordance with the movement of low pressure system, which is located in southern Aegean.

![Fig. 7.](image1.png)  
(a) Geopotential height at 500 hPa (black contours) and temperature valid at 0000 UTC 26 December 1996. (b) Mean sea level pressure (white contours) and 500-1000 hPa thickness chart.

![Fig. 8.](image2.png)  
(a) Geopotential height at 500 hPa (black contours) and temperature valid at 0000 UTC 27 December 1996. (b) Mean sea level pressure (white contours) and 500-1000 hPa thickness chart.

4 Conclusions

The snow producing synoptic conditions over the area of Thessaloniki are identified, classified and studied for the period 1980-2011. Four types were resulted to be the most favorable ones for snowfall formation in Thessaloniki. These are, in hierarchical order: (a) the North-West flow (NW), (b) the High-Low diffluent block, (c) the South-West (SW) flow and (d) the Omega Block (OME). The synoptic and dynamic characteristics of four representative (for the synoptic conditions) case studies are presented. The cold air advection at the base of the upper level trough and the positive vorticity advection at the 500 hPa isobaric level seem to play a very important role. It is believed that the concluded results will initiate further studies and could provide a valuable and useful tool to forecasting procedures.

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Quantifying the importance of the Mediterranean Sea as a moisture source for extreme precipitation and flooding episodes

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In this study a sophisticated Lagrangian model and ERA interim data were used to quantify the importance of the contribution of the moisture coming from the Mediterranean to the total precipitation in surrounding continental areas. To do this, we compare 1x1 degree grid precipitation when moisture comes from the Mediterranean Sea with the total precipitation taken from the Global precipitation Climatology Program (GPCP). The analysis was illustrated with the example of year 2000 and the big October 2000 Piemonte flooding.

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1 Introduction

The moisture transport from the oceanic sources to the continents is the bridge between evaporation in the ocean and precipitation over the continents and its detailed study can provide a better understanding of the observed changes and a physical support to the results of the projections for future climates (Gimeno et al. 2012). In previous studies (Gimeno et al. 2010, 2013), we used a 3D Lagrangian approach to identify whether continental regions are affected by precipitation originating from specific oceanic regions. It was found that the Mediterranean Sea makes a significant contribution to the precipitation over the Iberian Peninsula and to the European countries through short and medium range transport and local storms. The role of the Mediterranean as a moisture source for North Africa and specifically for the Saharan region is also remarkable (Nieto et al. 2006). In this study, we quantify the importance of the contribution of the Mediterranean to the total precipitation in continental surrounding areas by comparing precipitation when moisture comes from the Mediterranean Sea with the total precipitation taken from the Global precipitation Climatology Program (GPCP). The analysis is illustrated with the example of the full year 2000 and then also restricted to extreme precipitation occurred during one of the most significant flooding episodes, the big October 2000 Piemonte flooding.

2 Data and Methodology

To identify the sinks for the moisture evaporated from the Mediterranean Sea, the method developed by Stohl and James (2004) was used. This approach is based on the Lagrangian particle dispersion model FLEXPART v9.0 (Stohl et al. 2005). The ERA-Interim reanalysis of the European Centre for Medium-Range Weather Forecasts (Dee et al. 2011) was used to run the Lagrangian FLEXPART model.

The FLEXPART model is a three-dimensional Lagrangian particle dispersion model initially used to study pollution dispersion and now widely used in moisture transport by analyzing the trajectories and changing properties of moisture in air parcels (Stohl and James 2004, Stohl et al. 2005). The analysis of moisture transport between source and sink areas is done by dividing the atmosphere homogeneously into a large number of air parcels (particles), which are transported using the three-dimensional wind field (in this case provided by ERA-interim).

The FLEXPART model can be run either forwards or backwards in time. In this study, we used the forward mode, where the particles are “released” from a source (in this case the full Mediterranean Basin) and concentrations are determined downwind on a grid. We track approximately 2.0 million ‘particles’ (the highest limit allowed by the model). The net rate of change of water vapour of an air parcel along a trajectory can be expressed as: \( e - p = m \frac{dq}{dt} \), where \((e - p)\) is the increase or decrease in moisture along the trajectory according to the changes in \((q)\) with time \((t)\) for an air parcel of mass \(m\). By adding \((e - p)\) for all the particles in the vertical atmospheric column over an area, we can obtain the surface freshwater flux \((E - P)\), \(E\) being the evaporation rate per unit area, and \(P\) the precipitation rate per unit area.

Data were retrieved every 6 hours (00, 06, 12 and 18 UTC) and the sum of these four values constitutes the daily value used in this study. Positions of each particle along its trajectory and changes in specific humidity \((q)\) were recorded for 10 days (the average residence time of water vapour in the atmosphere (Numaguti 1999). In order to derive the Lagrangian estimation of evaporation minus precipitation, the \((E - P)\) values were integrated over each 1”x1” column over the gridded area.

As we are interested in precipitation associated with moisture transported from the Mediterranean only negative values of \(E - P\) (when precipitation exceeds evaporation) were recorded and used in the analysis. So for each grid point it is possible to know the daily precipitation (if any) whose moisture origin is the Mediterranean Sea. It is important to notice that this value is not a real value of precipitation because the method is not able to completely
separate precipitation from evaporation. We have supposed that when \( E \) is lower than \( P \), \( E-P \) value could be assigned to precipitation. Although this is only an estimate to precipitation, the approach is good enough to compare precipitation associated with a moisture source among different sink regions. In our study, this value will be called \( P_{i,j,med} \) to indicate the precipitation in a grid point associated with moisture coming from the Mediterranean.

Total precipitation for each grid point \( (P_{i,j}) \) can be estimated from the Global Precipitation Climatology Project (GPCP) dataset which uses data from rain gauge stations, satellite data and sounding observations to estimate daily rainfall on a 1x1-degree grid (Huffman et al. 2001).

By dividing \( P_{i,j,med} \) by \( P_{i,j} \) we obtained a daily index of the contribution of the Mediterranean Sea to the daily precipitation in each grid point.

### 3 Results

As an example of these results we show values for the year 2000, so figure 1 shows the annual precipitation from GPCP data \( (P_{i,j}) \), the contribution of the Mediterranean Sea to precipitation from FLEXPART simulations \( (P_{i,j,med}) \) and the ratio between the contribution of the Mediterranean Sea to precipitation from FLEXPART simulations and precipitation from GPCP data \( (P_{i,j,med} / P_{i,j}) \).

![Fig. 1. Analysis of the contribution of the Mediterranean Sea (MED) to the 2000 annual precipitation. (Left) Total precipitation for each grid point \( (P_{i,j}) \) from the GPCP (units mm/day). (Center) Precipitation associated to moisture coming from MED \( (P_{i,j,med}) \) (units mm/day). (Right) Accumulated daily ratio of the contribution of the Mediterranean Sea to the daily precipitation in each grid point \( (P_{i,j,med} / P_{i,j}) \) (scaled by a factor of \( 10^3 \)).](image)

From a visual inspection of figure 1, it is possible to observe those areas where the annual precipitation was the highest (in red fig.1a) (the NW Atlantic coasts), where the Mediterranean Sea has a higher contribution (in red fig 1b) (an area centered over the Ligurian Sea and extending to the Alps) and those areas where the Mediterranean Sea provides moisture for precipitation relative to the total precipitation at a rate higher than for the rest of the Mediterranean region (in red fig 1c). These last areas are the following four: the surrounding areas of the Ligurian Sea with implication for the Northwest of Italy, an area centered on the Ionian Sea and extending to the South Adriatic coasts of Italy, a big continental area in the North of Africa from Tunisia to Egypt, and a continental area over Romania and Hungary. On the other hand, the contribution of moisture coming from the Mediterranean Sea to the total precipitation over the Atlantic coasts of Europe was the lowest. The big extended area over the North Africa is due to the small GPCP precipitation and the other areas could be grouped in a continental tongue with SE-NW orientation originating from the Mediterranean coast.

These results for the year 2000 could be influenced by a single severe episode, the very well known “Piemonte flooding”, during October 2000. The event occurred from 13 to 15 October 2000 when extreme rainfall amounts were measured in the Alpine region. There was a maximum in these 3 day sum of precipitation of 706 mm in the upper Po valley which resulted in a flood during the following days. A detailed analysis of the situation can be read in Pinto et al. (2013) but in summary precipitation was induced by an extratropical cyclone.
which took most of the moisture from a previous tropical storm (named Leslie). An analysis of the integrated moisture flux for the three-day period and previous periods (figure 2) shows a change in the moisture flow reaching the region. During the three days period a very intense flow over the Mediterranean to the Piemonte area was evident.

**Fig. 2.** Integrated flux of moisture [kg/(m s)] shown as vectors and module (contours) for the period from 7 to 15 October 2000) of extreme precipitations over the Piemonte region (Italy). a-c) for the 3-days mean, d) for the previous day of the flood.

This strong moisture advection from the Western and Central Mediterranean into the area affected by flooding, suggests that the contribution of the moisture coming from the Mediterranean to the precipitation in this area during the whole 2000 could be due mostly to this single event. Figure 3 shows precipitation from GPCP data ($P_{ij}$) and the contribution of the Mediterranean Sea to precipitation from FLEXPART simulations ($P_{ij,med}$) for the period 9-15 October 2000. This pattern of $P_{ij}$ is clearly different from the average 2000 pattern as a whole, but the pattern of $P_{ij,med}$ matches $P_{ij}$ pattern which confirms the influence of a single event in the global influence of the Mediterranean over the surrounding areas precipitation.

**Fig. 3.** Analysis of the contribution of the Mediterranean Sea (MED) to the case study of extreme flood occurred during 9-15 October 2000. (Left) Total precipitation for each grid point ($P_{ij}$) from the GPCP (units mm/day). (Right) Precipitation associated to moisture coming from the MED ($P_{ij,med}$) (units mm/day)
4 Conclusions

By means of a sample figure for the year 2000, we have shown the ability of a new approach to quantify the importance of the contribution of the Mediterranean to the total precipitation in continental surrounding areas and the potential to study the relative contribution of the moisture coming from the Mediterranean Sea to extreme precipitation and flooding episodes.

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Was the Sahara dust transport towards Greece exceptionally frequent and persistent during the spring 2013?


The Mediterranean basin is a crossroad where different aerosol types converge (e.g. anthropogenic, maritime and mineral dust). Dust particles mainly originating from North Africa deserts are transported according to prevailing synoptic conditions, resulting thus in a distinct seasonality. Eastern Mediterranean, including the broader Greek area undergoes dust intrusions frequently in spring resulting in high atmospheric dust loads in the region. However, during spring 2013 dust transport over Greece seems to have exhibited a clear persistence with dust episodes being frequent. In this work, in order to investigate whether the spring of 2013 was exceptional in this aspect or not, data of aerosol optical properties such as Aerosol Optical Depth at 870 nm (AOD_{870}), Ångström parameter (\(\alpha_{440-870}\)) from FORTH- and NOA-AERONET (Aerosol Robotic Network) stations in Crete and Athens respectively, are used. The estimated values for the study season are compared with the available data of previous years, namely 2003-2012 for Crete and 2008-2012 for Athens. Complementary, daily values of AOD_{550} and \(\alpha_{550-865}\) derived from MODIS (MODerate resolution Imaging Spectroradiometer) database are also considered. Finally, the associated synoptic conditions over Mediterranean are analyzed to examine the persistence of dust flow.

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1 Introduction

Aerosols, both anthropogenic and natural, are considered as one of the drivers of climate changes and despite the improvements in estimates of aerosol effects, they continue to contribute the largest uncertainty to the total radiative forcing estimate (Myhre et al. 2013). The Mediterranean basin is an area where various aerosol types such as urban and industrial, desert dust, biomass burning and marine coexist, and having relatively high aerosol load affect the regional radiative budget (Papadimas et al. 2012). Desert dust is advected over the Mediterranean mainly from Sahara desert through synoptic-scale systems. Mineral particles are present in the atmosphere above the Mediterranean during most of the year (Papayannis et al. 2008). However, their transport usually occurs as dust events associated with increased concentrations, with a marked seasonal behavior modulated by the prevailing meteorological conditions (Moulin et al. 1998). This seasonality is summarized as follows: during spring and even earlier in late winter, synoptic conditions route dust transport towards the eastern Mediterranean, in summer dust activity moves mainly in the western part of the basin and in autumn dust is mostly transported to the central Mediterranean. Specifically, the Eastern Mediterranean including the broader Greek area, experiences dust events with a high frequency and intensity in spring (Gkikas et al. 2013) with loadings that change from year to year.

In this work, we investigate whether the spring of 2013 was exceptional regarding the dust activity over Greece or not. For this purpose, data of aerosol optical depth (AOD\textsubscript{870}) and Ångström parameter ($\alpha\textsubscript{440-870}$) from Crete (FORTH) and Athens (NOA) AERONET stations (Holben et al. 2001) are used. Additionally, AOD\textsubscript{550} and $\alpha\textsubscript{550-865}$ derived from MODIS-Aqua database are employed. The selected optical properties provide the necessary information about the aerosol load (AOD) and the size of the suspended particles ($\alpha$). Finally, the persistence of dust flow is examined based on geopotential height data at 1000 and 700 hPa taken from the NCEP/NCAR Reanalysis data base.

2 Data and Methodology

In the present study, Level 1.5 (cloud-screened) daily values of AOD\textsubscript{870} and $\alpha\textsubscript{440-870}$ from FORTH- and NOA-AERONET stations for the period 2003–2013 and 2008–2013, respectively, are used. Note that Level 2 (quality-assured) data for the year 2013 are not yet released from AERONET for the study period. Based on the available data, for each AERONET station a day for which AOD\textsubscript{870} value is greater than or equal to the limit of the 95% of all AOD\textsubscript{870} values distribution and simultaneously the $\alpha\textsubscript{440-870}$ is less than or equal to the limit of the 5% of all $\alpha\textsubscript{440-870}$ values distribution, is considered as a dusty day. For the FORTH station, the AOD\textsubscript{870} 95% limit is found to be equal to 0.36, the $\alpha\textsubscript{440-870}$ 5% limit is 0.20 and the defined dusty days are 85, while for the NOA station, these limits are 0.28 and 0.35, respectively and the dusty days are 35. To obtain full spatial coverage daily satellite measurements of AOD\textsubscript{550} and $\alpha\textsubscript{550-865}$ have been taken by the MODIS-Aqua database (Collection 051, Level 3, 1°x1° spatial resolution), for the spring months over the period 2003–2013.

In addition, the main atmospheric circulation associated with the dust transport days, during the study period, is examined. For this purpose, monthly mean maps (15°N to 60°N and 20°W to 40°E) of 1000 and 700 hPa geopotential heights (Z1000 and Z700 respectively) for the spring months of 2013 and the 30-year period 1984–2013 as well, are produced based on data from the NCEP/NCAR Reanalysis database. Subsequently, the circulation anomaly patterns of the 2013 spring monthly mean maps, with respect to the corresponding climatology of the 1984–2013 period, are drawn.
3 Results

3.1 Timeseries of dusty days and the respective AOD\(_{870}\) and \(\alpha_{440-870}\) values

In Figs. 1a and 1b it is shown that the number of dusty days, during the spring months of 2013, is relatively high, especially during March for Crete and May for Athens. The number of dusty days of spring 2013 is the second highest for Crete and the highest, along with that of spring 2010, for Athens. Note that in Athens there are missing data for spring 2011. The timeseries of the monthly mean values of AOD\(_{870}\) and \(\alpha_{440-870}\), given here only for the dusty days in Crete (Fig. 1c) show that AOD\(_{870}/\alpha_{440-870}\) is relatively high/low during the spring months of 2013, especially in March. On the other hand in Athens, although the highest/lowest AOD\(_{870}/\alpha_{440-870}\) mean monthly values are found in April 2009 and May 2010 (Fig. 1d), they refer to only one and two dusty days respectively, meaning that the dust transport towards Athens was intense but not so frequent. The 6 dusty days during May 2013 imply persistence of dust transport.

Therefore, the spring of 2013, along with the spring seasons of 2004, 2008 and 2010, can be characterized as particularly dusty concerning the dust load and the persistence of dust transport over Crete but for Athens only regarding the occurrence of dust intrusions. This is attributed to the possible differentiations of the dust transport pathways towards these two areas.

![Fig. 1. Number of dusty days for the spring months (line) and spring season (bars), at AERONET FORTH (a) and NOA (b) stations. Timeseries of AOD\(_{870}\) and \(\alpha_{440-870}\) monthly mean values computed only for the dusty days, of spring months at AERONET FORTH (c) and NOA (d) stations.](image)

3.2 The dust in spring of 2013 as seen from satellites

The spatial characteristics of aerosol load during dust transport are variable and therefore can only be captured by satellite measurements due to their complete spatial coverage. The anomalies of AOD\(_{550}\) and \(\alpha_{550-865}\) (expressed in percent values) are given for each spring month of 2013 in Fig. 2. These anomalies express the deviation of spring values of 2013 from the corresponding climatological values (2003-2013).

According to the geographical distributions of March, there is an apparent increase of AOD\(_{550}\) values by up to 80%, reaching 0.7 in absolute terms, and a decrease of \(\alpha_{550-865}\) values by 35%, dropping down to 0.5, in the maritime parts southern of Crete. In April, the dust transport activity is more intense over the Gulf of Gabès. More specifically, the AOD\(_{550}\) values
are increased by up to 45% of the mean value (0.4) while negative anomalies, as high as 22%, are found for α550-865. In May, the dust transport activity is stronger over the central parts of the Mediterranean Sea. This is supported by the increase of AODs (from 0.4 to 0.65, 63%) and the reduction of the α values (from 0.7 to 0.4, -43%).

![Image](image-url)

**Fig. 2.** Monthly mean maps of the anomalies between the 2013 year and the 11-year period 2003-2013 for the AOD550 (1st column) and α550-865 (2nd column) level.

### 3.3 Atmospheric circulation anomalies during the spring of 2013

The Z700 and Z1000 anomalies patterns for March 2013 (Fig. 3) show negative anomalies over Europe and especially over its western parts and the western Mediterranean. This indicates more frequent and/or even deeper than usual mid-latitude low pressure systems, resulting in the enhancement of the meridional wind component at the low troposphere over Eastern Europe and the Eastern Mediterranean. Under these conditions dust transport over these areas becomes more pronounced. This is in line with the positive AOD550 and negative α550-865 anomalies shown in Fig. 2. On the contrary, in April 2013 positive anomalies dominate over the central and eastern parts of the Mediterranean both at the 700 and 1000 hPa level, due to the persistence of the Siberian anticyclone resulting in northern flow which is unfavorable for dust transport over the study area, consistent with the rather small number of dusty days (Fig. 1b, d) in Greece during this month. In May 2013, at both 700 hPa level and surface, the negative anomalies over Western and Central Europe induce a stronger south-southwesterly flow, which explains the significantly increased dust aerosol loads over the central Mediterranean Sea (Fig. 2). The identified atmospheric circulation patterns during spring 2013 are in excellent agreement with the results from the satellite retrievals but also from surface AERONET measurements which puts confidence on the findings of both of them.
Fig. 3. Monthly mean maps of the anomalies between the 2013 year and the 30-year period 1984-2013 for the geopotential height of 700 hPa (1st column) and 1000 hPa (2nd column) level.

4 Conclusions

The synergy of ground-based (AERONET) and satellite data (MODIS) showed that spring of 2013 has been among the most exceptional seasons regarding the frequency and intensity of dust transport from Africa to the eastern Mediterranean, especially in March and May, while, according to MODIS observations, in April the transport activity has moved westward. Based on analyzed reanalysis geopotential height data, the intensification of dust advection over Greece in spring 2013 has been favoured by the deepening of low pressure systems over the western or central Europe, and/or the rise of frequency of cyclones occurrence in the western Mediterranean.

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Combining synoptic scale weather typing and satellite based surface solar radiation monitoring for the assessment of the extremes of solar radiation accumulation

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Weather pattern variability and persistence have the potential to strongly influence accumulations of surface solar radiation over periods of days to weeks. Such variability can have important impacts on electricity markets and on agricultural production when it coincides with critical crop growth phases. Examples of such effects will be presented, based on analyses of satellite-derived measurements and on NWP modeling to support the decision making for a number of applications ranging from farming activities to energy production and commodity trading.

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Verification of operational weather forecasting systems on the planetary boundary layer (PBL)

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In the verification field it is particularly important the exploitation of any kind of existing, controlled and homogenous set of surface and near surface observations. This becomes even more crucial in the Planetary Boundary Layer (PBL) where usually very limited dataset are available and observation concerning fluxes, radiation and soil characteristics are rarely available. In the EUMETNET framework of SRNWP programme an action took place in the last year with the aim to collect organize and control specialized observations in the PBL from selected stations all over Europe. In this paper the particular characteristics of these available observations are briefly described and their use in verification activities, through the verification system VERSUS, is presented. A general overview of the performance of the Italian and Greek implementations of COSMO model, as compared to the observed parameters, mainly surface fluxes and radiation, is discussed as well as specific case studies and applications of the conditional verification technique.

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1 Introduction

In these last years the increase of horizontal and vertical resolution of numerical atmospheric model has been dramatic. Global models are actually in the range of 10km mesh size and many more than 100 vertical levels, while limited area models have usually a grid space up to 1-2km and 40-50 vertical levels. The increment of resolutions has mainly the goal to achieve a better representation of the real topography and to resolve explicitly physical processes that otherwise would be of the sub-scale kind and would need a specific treatment (parameterization) of the correspondent equations. For this reason, usually, the increment of levels has mainly an impact on the planetary boundary layer (PBL) where turbulence, convection, fluxes of heat and moisture and radiation play all together, combined and separately, a major role. The improvement in the representation of PBL processes is of course, or can be, evident from the assessment of the general quality the forecast and from there the quality of forecasted fluxes or radiations balances can be inferred, having a look to the quality of 2mT forecast for example. At the same time the direct verification of such parameters is extremely important for modellers in the effort to focus the attention to the source of the physical process and not to one of the effect, which can be partially or even misleadingly representative. Unfortunately this kind of information, organized as extensive dataset, are not usually available, while in the verification field it is particularly important the exploitation of any kind of existing, controlled and homogenous set of surface and near surface observations. Clearly, due the peculiarity of the processes, becomes even more crucial in the PBL, where usually observation concerning fluxes, radiation and soil characteristics are rarely available.

Nevertheless in the EUMETNET framework of SRNWP programme, an action took place in the last years with the aim to collect, organize and control specialized observations in the PBL from selected stations all over Europe (Fig. 1). Data have been collected in a standard ASCII format from 2006 to 2012 set, even if not complete, and made available to EUMETNET community for scientific purposes. These data have been used in this study to compare COSMO model to some of the available observations in the PBL, from some selected stations, and in particular: long and short wave radiation (upward and downward components) (LW and SW), latent and sensible heat flux (LHF and SHF).
The chosen stations are Cabauw, Lindenberg, Fauga-Muzac, Payerne, Debrecen and S.Pietro Capofiume, for the completeness of their datasets and because all of them are included in the model domain. Datasets have been made available on the COSMO Consortium website to the scientific community.

2 Methodology of Comparison

For this paper the complete dataset 2011-2012 for both observations and forecasts has been used and compare with different methodologies. As forecasts parameters were given as an average from the reference time of the model run, a homogenising pre-processing phase with the observation was performed and hourly datasets created. The comparison between model output and observations has been carried out mainly through long term time series and daily cycle mainly. This choice has been adopted in order to be able to compare, from a more general point of view, the ability of the model to reproduce the parameters behaviour without paying attention to statistical score values. The plots have been initially calculated over a stratification including all the set of stations described in the previous paragraph and afterwards some consideration focusing on the Italian station of S. Pietro Capofiume will be shown. In this last part also some peculiar situations connected also to the usual weather parameters, like 2m temperature and total cloud cover, will be shown and discussed in the
perspective of a conditional verification technique. In the following Table 1 the association between the observations used and the model outputs is shown:

Table 1. association of observations and model output. Radiation observation balances have been calculated as they are not available from the datasets. All parameters in W/m².

<table>
<thead>
<tr>
<th>OBS data</th>
<th>FCS data</th>
</tr>
</thead>
<tbody>
<tr>
<td>RSWD: incoming solar radiation</td>
<td>ASWDIR_S: Average direct downward SW rad Surface</td>
</tr>
<tr>
<td>RSWU: reflected solar radiation</td>
<td>ASWDIR_S: Average diffuse downward SW rad Surface</td>
</tr>
<tr>
<td>(RSWD-U balance)</td>
<td>AveragedBalance of SW</td>
</tr>
<tr>
<td>RLWD: incoming thermal radiation</td>
<td>ALWD_S: Average downward LW radiation at the surface</td>
</tr>
<tr>
<td>RLUW: outgoing thermal radiation</td>
<td>ALWU_S: Average upward LW radiation at the surface</td>
</tr>
<tr>
<td>(RLWD-U balance)</td>
<td>AveragedBalance of LW</td>
</tr>
<tr>
<td>HS: sensible heat flux</td>
<td>ASHFL_S: averaged sensible heat flux</td>
</tr>
<tr>
<td>LE: latent heat flux</td>
<td>ALHFL_S: averaged latent heat flux</td>
</tr>
</tbody>
</table>

All the results shown in the present paper, the calculations and the graphs have been produced using the unified system for verification developed and adopted by the COSMO consortium as the standard tool for models and observations comparison, VERSUS (VERification System Unified Survey).

3 Results

It is useful, for the understanding of the physical processes in the PBL, to summarize, in Fig. 2, the annual radiation and heat balance of the Earth.

Fig. 2. The mean annual radiation and heat balance of the Earth (Houghton et al 1996).

Fig. 3 shows the daily cycles of long and short wave radiation and the LHF and SHF averaged on the period 2011-2012 for all the stations considered. The long period daily cycle is able to filter out seasonality and asse the general quality of the model. It is evident the general accordance between the model output and the observation, where the model overpredicts the LW upward radiation and the maxima of SHF (overestimated during the day and underestimated early morning and evening) and LHF (underestimated during the day) precede the observation.
Focusing the attention on S. Pietro Capofiume station and comparing the previous parameters with daily cycles of 2mT (Fig. 4) and total cloud cover (Fig. 5), some others interesting considerations arise.

The typical COSMO model tendency to overestimate the 2mT during night and early morning is reflected also in the overestimation of negative (downward) flux of SH, taking in account that the SHF can be seen as proportional to \((T_{\text{surf}} - T_{\text{atm}})\) if 2mT is considered representative of \(T_{\text{atm}}\). The light underestimation of 2mT during the day is less evident and the correspondent overestimation of positive flux (upward) could be due mainly to the surface heating produced by solar radiation (not present during the night). The connection between LW radiation and total cloud cover shown in figure 5 is even more interesting. The overestimation of TCC in the daily cycle results clear also in the light underestimation of SW radiation during the central part of the day, while the higher amount of upward LW radiation compared with observation seems to be in contrast with this conclusion, as the presence of clouds, especially during the night, should result in a LW radiation balance closer to zero than the one showed below. Actually (see Fig. 6) also 2011-2012 winter scatter plots show an evident overestimation of the upward component of LW radiation balance, especially during the night (Step 24).
Under the reliable hypothesis of a several number of days with high amount of cloud cover and in connection with the daily cycles of TCC shown in Fig. 5, the conclusion can be only that COSMO model predicts less thick clouds and/or less amount of low and medium clouds, able to maintain the LW radiation balance close to zero during the winter nights.

Another very interesting example, in the perspective of the application of conditional verification to these special observations in order to discover connection between physical processes and weather parameters behaviour, is shown in Fig. 7.

Here in the time series of LW radiation balance it is shown and highlighted the period from 10/01/2011 to 20/01/2011. It is evident the mismatch between the observed LW radiation balance, that is almost zero, and the predicted one that has clear fluctuations of quite high magnitude. In this situation the examination of TCC time series and daily cycle is revealing of the problem. The model predicted a complete wrong amount of cloud cover in those days, even up to 90-100% of error and the correspondent daily cycle shows the gap between forecast and observation. In this situation the whole predicted atmospheric column will be affected by the error and other parameters, not shown here, will present similar deficiency.

4 Conclusions

The exploitation of controlled and homogenous set of surface and near surface observations is fundamental in any verification process in the framework of NWP. This is even more crucial
when the field of application of such activity is the PBL and the effort is to explore directly the sources of the physical processes. The availability of datasets like the one used here gives to the verificators and the modellers the possibility to check directly some specific model outputs and to cross-check them in connection with the usual weather parameters, also using the conditional verification techniques. In this paper has been briefly shown how COSMO model perform generally well predicting LW and SW radiation balance and fluxes, with some exception, especially for LW radiation. It has been also explained how also the different aggregations of results can be revealing of the reason of model drawback, like the contemporary use of time series, daily cycle and scatter plots. The overprediction of negative sensible heat flux has an impact also on the prediction of 2mT, mainly during the night and the early morning, while the shift of maximum in latent heat flux should be better investigated connected with dew point and specific humidity prediction. The model tends to steadily overpredict the upward LW radiation for both the complete station stratification and S. Pietro Capofiume, with almost the same behaviour. It has been shown how in two specific situations this can be due to different reason: the wrong representation of TCC in terms of percentage and/or in terms of cloud layer thickness. Finally the use of conditional verification technique should be applied in order to find connection between specific significant thresholds, for which these fields become more significant, and the usual weather parameters.

References

NO$_2$ measurements over Athens using the MAX-DOAS technique


Measurements using the MAX-DOAS (Multi Axis Differential Optical Absorption Spectroscopy) technique were carried out for the first time at the urban environment of Athens. In this work, NO$_2$ slant column (SC) densities were retrieved and analyzed for the period October 2012-March 2013, at eight different azimuth angles and eight elevation angles. The results provide an overview of the horizontal distribution of NO$_2$ over Athens, associated with different pollution sources, as well as the main temporal characteristics. Comparing the MAX-DOAS values to in-situ measurements, an evaluation of the MAX-DOAS ability to reproduce spatial patterns of the existing air quality network was attempted.


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1 Introduction

It has been shown that over 50% of NOx (NO₂ + NO) emissions in Athens are due to traffic (Markakis et al. 2010), with industry (in the West-Southwest of Athens) and the Piraeus port (South) following (Kassomenos et al. 1995, Kalabokas et al. 1999).

Several studies about tropospheric NO₂ levels in Athens have been published, based either on in-situ measurements (e.g. Ziomas et al. 1998) or on remote sensing technique measurements, like active DOAS (e.g. Kalabokas et al. 2008). In this study, the use of a MAX-DOAS system provided for the first time the advantage of measurements at multiple viewing directions, scanning horizontally and vertically the atmosphere over the urban area of Athens. Measurements at low elevation angles relative to the horizon have great sensitivity to the concentrations of trace species close to the surface, since the greater part of the optical path is in the lower troposphere (Hönninger et al. 2004, Wittrock et al. 2004).

In this work, MAX-DOAS measurements over Athens are presented for the time period from October 2012 until March 2013.

2 Data and Methodology

The MAX-DOAS instrument is installed at the premises of the National Observatory of Athens in Penteli (30.050N, 23.860E, 500 m a.s.l) in the Northeast of Athens and is part of the BREDOM network (Bremian DOAS network for atmospheric measurements). It has been continuously operating since October 2012, performing measurements at eight different azimuth angles (Table 1) and eight elevation angles (-1ο, 0 ο, +1ο, +2ο, +4ο, +8ο, +15ο and +30ο). A clear unobstructed view is available towards all directions. The duration of one cycle through all the directions is about 15 minutes.

Table 1. Azimuth angles (aza) and corresponding viewing directions of MAX-DOAS in Athens. The 0ο azimuthal angle corresponds to the direction towards the South. Positive directions are spread from South to West.

<table>
<thead>
<tr>
<th>aza (°)</th>
<th>Symbol</th>
<th>Viewing direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>-60</td>
<td>W</td>
<td>Pikermi (remote)</td>
</tr>
<tr>
<td>-30</td>
<td>A</td>
<td>Airport</td>
</tr>
<tr>
<td>40</td>
<td>R</td>
<td>Ag Paraskevi (suburban)</td>
</tr>
<tr>
<td>52.5</td>
<td>S</td>
<td>Centre (urban traffic)</td>
</tr>
<tr>
<td>65</td>
<td>T</td>
<td>Piraeus (urban-port)</td>
</tr>
<tr>
<td>77.5</td>
<td>U</td>
<td>Olympic Stadium (suburban)</td>
</tr>
<tr>
<td>100</td>
<td>V</td>
<td>Lykovrysi, Liosia (urban background)</td>
</tr>
<tr>
<td>140</td>
<td>B</td>
<td>Parnitha (remote)</td>
</tr>
</tbody>
</table>

The measured spectra are analyzed using the DOAS technique (Platt and Stutz 2008), which is based on the Beer-Lambert law. The logarithm of the ratio of the observed to a reference spectrum, i.e. the optical thickness, is separated into a high and a low-frequency component. The high frequency part corresponds to the absorption by trace gas molecules and the low to attenuation by scattering processes in the atmosphere and the low-frequency part of the absorption. The so-called differential slant column density (SC) is then determined by fitting laboratory cross-sections, along with a polynomial which accounts for the low-frequency component. The concentration of NO₂ as a function of altitude could be calculated by a profiling algorithm, but here the analysis is limited to the SCs. The zenith measurement of each scan is used as the reference spectrum. Hence, the retrieved NO₂ differential slant columns are not absolute, but the difference between zenith sky and observed spectrum at lower elevation. As a result, the stratospheric NO₂ amount is removed from the lower elevation spectrum. In this work, SC densities are used mainly to estimate the spatial distribution of NO₂ by varying the azimuthal angle.

Hourly data of NO₂ concentration from 11 ground-based stations of the National Network for Atmospheric Pollution (EDPAR) were used for comparison reasons.
3 Results

The correlation coefficients between the eight azimuthal directions for +1° and +30° elevation angles were calculated in order to investigate the spatial homogeneity of the SC NO2 measurements in the layer near the surface and in higher layer. As expected, there is a greater degree of correlation between neighboring directions. The measurements at +30° elevation are characterized by higher correlation coefficients since at higher elevations the measurements are less sensitive to the lower troposphere and to the boundary layer (Wittrock et al. 2004, Hönniger et al. 2004, Platt and Stutz 2008). The 52.5°(S) direction, which is characterized by the highest measured values of NO2, is representative of the polluted city area. The -60°(W) direction is representative of suburban area.

The time series of daily SC NO2 densities for suburban (W) and polluted (S) areas are presented in Figure 1. The differences between suburban and polluted area are more apparent at low elevation angles: at +1° elevation the SC NO2 densities in polluted areas are higher than in suburban by an average of 71%, while for +8° and +30° elevations the percentage is 21% and almost zero, respectively. The enhanced values of SC NO2 at lower elevation angles are due to the longer light path within the boundary layer (e.g. Wittrock et al. 2004, Hönniger et al. 2004, Leigh et al. 2007, Platt & Stutz, 2008).

![Fig. 1. Daily SC NO2 density values for three elevation angles (blue, green and red lines represent +1°, +8° and +30° elevation angles, respectively) for suburban (left panel) and polluted (right panel) areas.](image)

3.1 Diurnal variation and weekend effect

The diurnal cycles of SC NO2 densities at +1° elevation angle, separated for weekdays and weekends are presented in Fig. 2. In all cases, a morning and an evening maximum is observed. The morning maximum is due to the increased NOx emissions from traffic (rush hour). Later in the day, photochemical processes lead to NO2 dissociation (Boersma et al. 2008). In the evening, the photochemical processes are decelerated while NOx is still being emitted, producing the second maximum of the day. In remote areas, the two maxima are not so clear during weekends. It is important that the MAX-DOAS method identified the NO2 diurnal cycle over Athens and reproduced its main characteristics in agreement with other studies (e.g. Menut et al. 2012).
Fig. 2. Diurnal cycles of \( SC_{NO_2} \) density at +1° elevation angle, all azimuth directions. The blue and red lines represent the weekdays and the weekends, respectively.

In all directions, higher values are observed during weekdays due to higher traffic emissions. This is in agreement with results reported in other studies for the Athens area (e.g. Kanakidou et al. 2011). The \( SC_{NO_2} \) values during weekends are 25% to 49% lower than during weekdays, on a monthly basis. The difference does not depend on the characterization of the area (suburban or polluted).

3.2 Comparison to in-situ NO\(_2\) measurements

In order to validate the range and the horizontal distribution of the MAX-DOAS measurements, the \( SC_{NO_2} \) measurements are compared to in-situ NO\(_2\) measurements. The comparison is carried out using daily data at the +1° elevation angle (representative of the lower troposphere). It should be mentioned that since the MAX-DOAS is performing measurements at a height of 500 m, data are not representative of the surface concentration, unless the boundary layer is well mixed. Correlation coefficients were calculated for the MAX-DOAS measurements and the ground-based stations located close to each viewing axis. The best correlation is found at 140° azimuth angle (labeled as “B”) due to the temporal homogeneity of the slant column, characteristic of the suburban environment. The respective scatterplot along this viewing direction and along the “T” direction (urban) are shown in Figure 3. The average value for the full period is \( 0.50 \times 10^{17} \) molec/cm\(^2\) for the remote (B) and \( 0.75 \times 10^{17} \) molec/cm\(^2\) for the polluted (S) region. The bad correlation for the polluted case is attributed to the fact that the MAX-DOAS measurements are probably more biased from the closest part of the path, which represents suburban conditions.

Moreover, the closer the ground-based station is located to the MAX-DOAS, the better correlation is found. For example, the scatterplots along the “V” viewing direction for two stations are shown in Fig. 4. The results are consistent with the generally accepted theory that MAX-DOAS has better sensitivity to trace gases which are closer to the instrument (Platt & Stutz, 2008).

![Fig. 3. Scatter plots between \( SC_{NO_2} \) densities and in-situ concentration measurements of NO\(_2\) for suburban (a) and polluted (b) areas.](image-url)
4 Conclusions

Slant column (SC) NO$_2$ densities have been retrieved from six months of ground-based MAX-DOAS measurements in Athens. Low elevation measurements over polluted areas are 14 times higher than the measurements at the +30° elevation. The corresponding maximum ratio for the view to the remote area is 7.5.

A pronounced diurnal cycle is observed with a morning maximum during the traffic rush hour and a secondary evening maximum. During weekends, the NO$_2$ levels are decreased in the range of 25% to 49%.

Best correlation ($r=0.76$) between the MAX-DOAS and in-situ measurements is found in suburban areas, due to greater homogeneity regarding NO$_2$ emissions in these areas. Finally, the closer the ground based station is to the MAX-DOAS location, the better correlation is calculated.

Acknowledgments The authors wish to thank the National Network for Atmospheric Pollution (EDPAR) for providing data from ground based stations. The current work was financed in the frame of the project THESPIA of the action KRIPI of GSRT. The project is financed by Greece and the European Regional Development Fund of the EU in the frame of NSRF and the O.P. Competitiveness and Entrepreneurship and the Regional Operational Program of Attica.

References


Fig. 4. Scatter plots between SC$_{NO2}$ densities at 100° azimuth angle and NO$_2$ concentrations at (a) Lykovrysi (8 km) and (b) Liosia (16 km).
SOLID – a European FP7 Project towards the First European Comprehensive Solar Irradiance Data Exploitation


Although variations of solar irradiance are the most important natural factor in the terrestrial climate and the time dependent spectral solar irradiance is a crucial input to any climate modelling, there is still large uncertainty on the spectral and total solar irradiance changes on yearly, decadal and longer time scales. As observations of irradiance data exist in numerous disperse data sets, it is important to analyse and merge the complete set of European irradiance data, archiving also data from non-European missions.

A collaborative effort unifying all European solar space experiments and European teams specialized in multi-wavelength solar image processing, irradiance modelling and reconstruction has started; results are used to bridge gaps in time and wavelength coverage of the observations. This allows reduction of uncertainties in the irradiance time series - an important requirement by the climate community - and construction of uniform data sets of modelled and observed solar irradiance from the beginning of the space era to the present including proper error and uncertainty estimates. Climate research needs these data sets and therefore, the primary benefit is for the climate community. The team realizes a wide international synergy in solar physics complemented by members from the climate community, who accompany their research work with wide dissemination activities.


The SOLID project webpage (http://projects.pmodwrc.ch/solid/) provides more details, access to the database with first results and useful links on future meetings and relevant publications.

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Migratory anticyclones affecting the Mediterranean: climatological characteristics and links with modes of atmospheric variability

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A comprehensive climatology of migratory anticyclones affecting the Mediterranean was generated by the University of Melbourne finding and tracking algorithm, applied to 34 years (1979–2012) of ERA-Interim mean sea level pressure dataset. The tracks and the statistical properties of the migratory systems revealed the major anticyclonic routes affecting the Mediterranean. Variations of system density and genesis maxima are evident throughout the year and can be attributed to the seasonal variability of the major anticyclonic systems that are involved in this region. Further, the interannual variations of the system density and depth are found to be strongly correlated with the major Northern Hemisphere modes of atmospheric variability.

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1 Introduction

Although anticyclonic activity can be regarded as equally important as cyclonic for determining surface climate conditions, climatological studies on anticyclones are few. High-pressure systems are also associated with important weather phenomena, while they act to determine climatic variability.

The Mediterranean basin and southern Europe are affected by extensive cyclonic activity (Maheras et al. 2001). They are also influenced by semi-permanent large scale anticyclones, the Azores anticyclone in the west during summer and the cold Siberian anticyclone in the northeast during winter. The Mediterranean is also affected by moving anticyclones generated over Scandinavia, Atlantic Ocean or North Africa (Makrogiannis and Giles 1980) and by local anticyclogenesis (Godev 1971).

Climatological studies for transient anticyclones based on objective methods have been performed in the Southern Hemisphere (SH) e.g. by Jones and Simmonds (1994) and Pezza et al. (2007) and in the Northern Hemisphere (NH) by Ioannidou and Yau (2008). Especially for the Mediterranean, several studies have attempted to depict the characteristics of the cyclonic tracks by employing objective tracking methods (e.g. Trigo et al. 1999; Flocas et al. 2010), however, there are no studies that describe the characteristics of anticyclonic systems in the Mediterranean employing objective tracking methods. The tracks of migratory anticyclonic systems in the eastern Mediterranean and south-eastern European region have been studied by Makrogiannis and Giles (1980) and Katsoulis et al. (1998) both on the basis of daily surface synoptic charts.

In this study, a new and updated climatology of the aspects of migratory anticyclones affecting the Mediterranean region is presented, employing for the first time an objective identification and tracking scheme and at the same time a link with the modes of atmospheric variability is provided.

2 Data and tracking algorithm

For the present study, the mean sea level pressure (MSLP) global reanalysis datasets from the ERA-Interim Project have been used for the period from 1979 to present, with a 1.5°x1.5° longitude/latitude resolution. The examined domain includes the greater area around the Mediterranean basin, extending from 10°W to 40°E and from 25°N to 50°N, though the implementation of the finding and tracking procedure was made for the entire NH in order to retain the continuity of the tracks at the boundaries.

The anticyclone identification and tracking was performed with the algorithm developed at the Melbourne University (MS algorithm; see Murray and Simmonds 1991). More details about the finding and tracking procedure can be also found in Simmonds et al. (1999), Pinto et al. (2005) and Kouroutzoglou et al. (2011). The algorithm is employed for the first time for anticyclones in this region, thus, its robustness and reliability in efficiently capturing the individual characteristics of the anticyclonic tracks in the Mediterranean were checked and verified. The control parameters of the MS algorithm were modified, in order to better capture the individual characteristics of anticyclones in a closed basin with complex topography, such as the Mediterranean. Finally, only systems tracked at five or more consecutive analysis time steps (i.e. track duration >1 day) were retained, in order to exclude short-lived systems and to enable the calculation of time derivatives of the velocity and pressure tendency. From the ensemble of the retained anticyclonic tracks (i.e. with duration >1 day), every track entering the Mediterranean region for at least one analysis time step was considered as Mediterranean track.
3 Size, motion and intra-annual variations of anticyclonic tracks

From the total population of the tracks affecting the Mediterranean (i.e. the tracks with at least one step in the examined region) two more populations were created: a) the tracks generated in the examined region, constituting the 75% of the total population and b) the tracks that spent their entire lifecycle in the examined region, constituting the 46% of the total population.

Regarding the motion of the systems, the majority of the tracks exhibit a mean 6-hr displacement of 200-250km/6h (Fig. 1). This value is in accordance with the mean propagation velocity proposed by Leighton (1994) and Katsoulis et al. (1998). From the frequency distribution it can be seen that the 0.02% and 0.04% of the tracks, respectively, have mean 6-hr displacement less than 20km/6h (that corresponds to the 10th percentile), indicating that this study is confined to the population of migratory systems.

It can be also noted that the average mean 6-hr displacement of the total population is larger compared to the population spending the entire lifecycle in the examined area (difference statistically significant at 95%). This shows that the anticyclonic systems move slower when passing over the Mediterranean in relation to the Atlantic and North Europe as a result of the relief of the region.

For the total population of anticyclones that affect the Mediterranean (Fig. 2), it can be seen that regardless of their lifespan, the initial radius is greater than the radius at the time of dissipation, but the longer-lived anticyclones have greater maximum radius, exceeding the 8 deg.lat for anticyclones lasting more than 13 days. Moreover, the negative skewness of the curves indicates that the rate at which the radius decreases after its maximum exceeds the rate of increase during the growth phase.

The frequencies of anticyclonic tracks having at least one step (~200 tracks per year) and generated (~150 tracks per year) in the Mediterranean show that the majority of the tracks generate within the examined area (not shown). This ratio is greater than 0.7 for all months, reaching peak values from May to July and lower values from August to November (not shown). Moreover, there is no pronounced intra-annual preference for anticyclones, suggesting that anticyclonic tracks affect the Mediterranean throughout the year, though higher frequencies occur in January, June and December and lower during autumn.
4 Seasonal mean fields

The spatial variations of the anticyclonic occurrence are described by the mean seasonal system density (Fig. 3). In winter, the anticyclonic activity is confined in the continental region along the Mediterranean coast, complying with the fact that the warmer sea during this season prevents the generation and the persistence of anticyclonic systems (Katsoulis et al. 1998). The northern Mediterranean acts also as anticyclogenetic area, since the frequent passage of cold fronts and frontal depressions in winter favours the generation of anticyclones behind the cold front. The peaks of system density over the Iberian Peninsula and the northern African coast follow the extensions of the subtropical ridge (Katsoulis et al. 1998). A remarkable winter maximum is found over the Balkans, in accordance with Makrogiannis and Giles (1980), likely due to the extensions of winter cold persistent anticyclones of northern Europe and the Siberian high (Prezerakos 1985). From spring to summer, the number of anticyclones tends to increase over the sea, following the progressive cooling of the sea compared to the adjacent land. A notable peak over the Black Sea during spring (not shown) reflects the gradual establishment of the Pakistan low over the Middle East (Bitan and Saaroni 1992). In summer, system density maxima are also found over North Africa. In autumn, a reduction in system density is apparent over the entire area. The areas of maximum system density also constitute centres of anticyclogenesis with similar seasonal characteristics (not shown).

Fig. 3. System density for winter (left) and summer (right).

5 Interannual variability

The interannual variability of synoptic systems can be attributed to natural low frequency variability. For this purpose, the correlation on seasonal basis between indices of NH teleconnection patterns (NAO, EA, EA/WR, EMP, Scandinavian, Polar Eurasian) and the statistical properties of anticyclones (system density and depth) have been analysed. To verify our results, the composite anomalies of the statistical properties for positive and negative phase years of the patterns have been also calculated (not shown).

The prominent effect of winter NAO on anticyclonic activity is shown in Fig. 4. The spatial distribution of the correlation between winter NAO and system density (Fig. 4, left) shows that statistically significant positive correlations are located at the zone between 40°N and 50°N, while negative correlations predominate above and below this zone. The increase in anticyclonic density over the Atlantic and the northern Mediterranean barrier for the positive NAO phase can be attributed to the northward shift of the North Atlantic storm track, associated with this phase (Hurrell 1995); i.e. the storms follow a more northern route allowing anticyclonic activity to increase. Similar behaviour is revealed for system depth (Fig. 4, right). The maximum effect of NAO depth is located over north-eastern Europe, while a significant negative correlation is found over the central Mediterranean region.

Fig. 4. Spatial distribution of correlation coefficients between winter NAO index and system density (left) and depth (right).
6 Conclusions

A comprehensive climatology of migratory anticyclones affecting the Mediterranean, generated by the University of Melbourne finding and tracking algorithm, was applied to 34 years (1979–2012) of ERA-Interim MSLP. It was found that the majority of the tracks are generated in the examined area. The mean displacement is about 220km/6h, while the mean radius is 5.5 deg.lat that increases for longer-lived systems. The statistical properties of the tracks revealed two major anticyclonic routes. The anticyclones prefer to move on paths parallel either to the northern (from the Iberian towards the Balkan Peninsula) or to the southern (North Africa coast) Mediterranean barriers. A transition of the system density and anticyclogenesis maxima is evident throughout the year from solely continental in winter and autumn to more maritime environments in spring and summer, while the frequency increases over the northern route in winter and over the southern route in summer. The interannual variations of the system density and depth are strongly correlated with the NH modes of atmospheric variability, while the effect of NAO is more prominent as it determines the Atlantic storm track and thus, the behaviour of synoptic systems of the European and Mediterranean areas.

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Spectral characteristics of the basic meteorological parameters in the Marine Atmospheric Boundary Layer

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The aim of this work is the study of the spectral characteristics of the basic meteorological parameters in the surface marine Atmospheric Boundary Layer. The analyzed data are based on in-situ instrumentation measurements, performed during summer 2003, in the frame of CBLAST-Low project, at Nantucket Island, MA, USA. A 20 m mast equipped with sonic anemometer and a fast hygrometer, was used to calculate fluxes of momentum, sensible heat and latent heat, using the eddy correlation method. Spectra and co-spectra of the basic meteorological parameters (u, v, w, T and q) were also calculated and analyzed. Results showed that the slope values of spectra and co-spectra at the inertial sub-range are close to the expected theoretical ones, although there is a certain deviation between theory and observations. As the atmospheric stability and wind decrease and the drag coefficient and friction velocity increase, the spectra slopes become steeper, meaning that turbulence dissipates faster than expected.

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1 Introduction

Spectra of wind components, temperature and humidity in the Atmospheric Boundary Layer (ABL) are widely used in boundary layer studies. According to Kansas (1968) and Minnesota (1970) experiments and following Kolmogorov similarity theory, spectra and co-spectra of the atmospheric parameters exhibit a -5/3 and -7/3 slope respectively in the inertial sub-range and they are related with the atmospheric stability and the surface roughness (Kaimal and Finnigan, 1994). These spectral characteristics are also reproduced for measurements close to the shoreline (Helmis et al. 1987) or within the surface marine ABL (MABL) (Warner 1973, Smith and Chandler 1987, Smith and Anderson 1984). Recent studies provide though evidence that similarity theory exhibit deviations in the turbulent surface ABL and by extension to the surface MABL, which are probably related to the large persistent eddies that modify the shape of the spectra (McNaughton and Laubach 2000, Högström et al. 2002, Li et al. 2007, Smedman et al. 2007). Similar results are observed in the co-spectra of momentum, heat and humidity transport when compared to the Kansas equivalent co-spectra (Andreas 1987, Smeets et al. 2000, McNaughton and Laubach 2000). This work aims to study the MABL’s spectral characteristics, to evaluate possible deviations from the theoretical values and to examine any possible relation between the spectral/co-spectral slope values in the inertial sub-range and parameters’ characteristics such as, stability parameter z/L, friction velocity u*, drag coefficient C_D and wind speed.

2 Data and Methodology

2.1 Data

The data for this analysis were collected during the Coupled Boundary Layers Air-Sea Transfer Experiment in Low Winds (CBLAST-Low) between July 30 and August 26, 2003, at the SW coastal area of Nantucket Island. A 20-m tall mast was installed at a distance of 94 m from the waterfront, equipped at two levels (10 and 20 m) with sonic anemometers and fast hygrometer at 20 m, for three dimensional wind components, temperature and water vapor concentration measurements at a sampling frequency of 20 Hz. Measurements of the wind speed and direction, temperature and relative humidity, with a sampling frequency of 1 Hz were also carried out from the same mast at three levels (5, 10 and 20 m). It was clarified that the wind sector from 200° to 250° corresponds to a pure MABL (Katsouvas et al. 2007). Since an internal boundary layer (IBL) was developed due to flow over land, data from 10 m level was excluded and data concerning MABL (20-m level) was carefully separated, through a detailed examination of the measured momentum, heat fluxes and the stability parameter. More details on the experimental site and the instrumentation are given by Helmis et al. (2013).

The raw data of ABL parameters (u, v, w, T and q) are separated in 10 minute successive segments, then they were quality controlled where any spikes due to instrumental noise are detected and eliminated. Then, the 3-D wind data is tilt corrected using the planar fit method (Wilzscak et al. 2001). Finally the time series of all parameters are generated for the 28 day experimental period.

2.2 Methodology

The tilt corrected 10 minute records of the wind components u, v and w are adjusted to the mean wind coordinate system and by using Reynolds averaging, each parameter is separated into a mean and a fluctuating part (u', v', w', T' and q') which was used for the spectral analysis and for the estimation of stability parameter (z/L) and drag coefficient (C_D). The 10
minute records are characterized as MABL records when the mean wind direction is between 200° and 250° and the record is considered statistically stationary following the criteria according to Mahrt et al. (1996). Based on the above, 618 in total 10 minute records, satisfied the MABL criteria for stationarity. The MO length scale is given by $L = \frac{u_*^2 \partial}{gk \theta}$, where $u_*$ is the friction velocity given by $u_* = \left( \bar{u}^2 + \bar{v}^2 \right)^{1/4}$, $\theta$ is the potential temperature, $g$ is the gravitational acceleration and $k$ is the Von Karman constant and over-bars denote mean quantities time averaged. For the drag coefficient the following equation is used: $C_D = \frac{u_*^2}{U_{hor}}$, where the mean horizontal wind $\bar{U}$ is given by $\bar{U} = \left( \bar{u}^2 + \bar{v}^2 \right)^{1/2}$. Spectra and co-spectra of every 10 min record are estimated using a 1024 (2¹⁰) Fast Fourier Transform (FFT) and the power spectral density is calculated. The slope of the estimated spectra and co-spectra is calculated by linearly fitting a line on the curve of each spectrum or co-spectrum in the range of frequencies 0.5-5 Hz, which was selected as the range where the inertial sub-range is expected to be, since the lowest inertial frequency is $f_i \propto \frac{2U}{z}$ where $z$ is 20 m and $\bar{U}$ the mean wind (Kaimal and Finnigan 1994).

3 Results

This section presents results for the slope values of $u'$, $v'$, $w'$, $T'$ and $q'$ spectra, as well as the slope values for $\bar{u}'w'$, $\bar{u}'T'$, $w'T''$ fluxes and $T'q'$ co-spectra. Figure 1 shows 2 examples, one for $w'$ and one for $T'$ spectrum. Although at a first glance the slope in the inertial sub-range, plotted as solid red line on the $w$ spectrum and as a solid cyan line on the $T'$ spectrum, seems to compare well with the -5/3 slope suggested by similarity theory (solid black line on both panels), the overall results demonstrate clearly deviations from the theory.

![Figure 1](image1.png)

Table 1 shows a summary of the mean spectral and co-spectral slope values per parameter for all MABL records as well as the deviations from the theoretical slope values. The deviations are calculated as the ratio of the difference between the mean spectral slope and the theoretical one (-5/3 or -7/3), divided by the latter value. It seems that the MABL mean slopes are generally steeper for all spectra, compared to the theoretical ones, suggesting that in the MABL surface layer, the turbulence dissipates faster than it does according to the similarity theory. The deviations are larger in the case of the co-spectral slopes, while they are smaller for the spectral slopes. The range of deviations is from 9% (very good agreement between theory and observations) to 40% (fairly good agreement). Flatter spectral slopes have been previously observed by MacNaughton and Laubach (2000) where they observed $v$ spectra that do not obey to -5/3 power but to -1.3 power law and they attributed the difference to the mean wind calculation, as during the experiment unsteady wind resulted in changing wind direction and thus the $v$ spectrum was a “hubrid of normal $u$ and $v$ spectra”. Also, Wyngaard and Zhang (1985) attributed spectral attenuation that affects the shape of the spectra to shadowing effects in the sonic anemometer sensors.
Table 1. Mean spectral and co-spectral slope values and correlation coefficient between slope values (MABL only records) and MABL stability parameter $z/L$ and drag coefficient $C_D$

<table>
<thead>
<tr>
<th>Parameters and theoretical slope values</th>
<th>MABL10 minute records</th>
<th>$R^2$ between slope values and MABL parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean Slope</td>
<td>Deviation</td>
</tr>
<tr>
<td>$u'$ (-5/3)</td>
<td>-1.38±0.13</td>
<td>17.20%</td>
</tr>
<tr>
<td>$v'$ (-5/3)</td>
<td>-1.50±0.10</td>
<td>10%</td>
</tr>
<tr>
<td>$w'$ (-5/3)</td>
<td>-1.52±0.14</td>
<td>8.80%</td>
</tr>
<tr>
<td>$T'$ (-5/3)</td>
<td>-1.43±0.21</td>
<td>14.20%</td>
</tr>
<tr>
<td>$q'$ (-5/3)</td>
<td>-1.44±0.37</td>
<td>13.60%</td>
</tr>
<tr>
<td>$u'w'$ (-7/3)</td>
<td>-1.40±0.20</td>
<td>40.00%</td>
</tr>
<tr>
<td>$u'T'$ (-7/3)</td>
<td>-1.37±0.23</td>
<td>41.29%</td>
</tr>
<tr>
<td>$w'T'$ (-7/3)</td>
<td>-1.37±0.23</td>
<td>41.29%</td>
</tr>
<tr>
<td>$T'q'$ (-5/3)</td>
<td>-1.46±0.30</td>
<td>12.40%</td>
</tr>
</tbody>
</table>

$R^2$ is the correlation coefficient estimated with 95% confidence interval

Figure 2 gives two scatter plots between the vertical velocity spectral slope, the friction velocity $u_*$ and the drag coefficient $C_D$. It shows that for lower values of friction velocity, the spectrum slope becomes flatter (lower absolute values), meaning that the turbulence dissipates slower than it does according to the theory. The same characteristics were revealed from the scatter diagram between vertical velocity spectral slope and drag coefficient, although a more intense decrease of slope values is given for low values of drag coefficient. Figure 3 shows two scatter plots between the vertical velocity spectral slope, the stability parameter $z/L$ and the mean wind speed. It is clear that as the atmospheric stability and/or the wind speed decreases, the slope generally becomes steeper, meaning that the turbulence dissipates faster than according to the theory. The characteristics which were shown for the vertical wind component were revealed also for the other two wind components and to a lower degree for the temperature and humidity.

![Fig. 2. Left: scatter plot of vertical velocity spectral slope and friction velocity $u_*$. Right: scatter plot of vertical velocity spectral slope and drag coefficient $C_D$.](image1)

![Fig. 3. Left: scatter plot between the vertical velocity spectral slope and the stability parameter. Right: scatter plot between the vertical velocity spectral slope and the mean wind speed.](image2)

The last two columns of Table 1 show the correlation coefficients that emerge from the scatter plots for all cases. The correlation is much better between the spectral slope values and the
MABL parameters for the velocity components than the corresponding ones for temperature or humidity. On the other hand all the relevant estimations from the co-spectra (transfer of momentum, heat and cross-correlation between temperature-humidity) reveal high values of correlation with the MABL stability parameter and drag coefficient.

4 Concluding remarks

1. At all cases of MABL spectra and co-spectra, the slope values in the inertial sub-range are lower (flatter spectral slope) than the expected theoretical values.
2. The deviations of the MABL co-spectral slope values from the theoretical values are larger than those of the spectral slopes.
3. The atmospheric stability and drag coefficient are better correlated with the spectral and co-spectral slopes in the inertial sub-range of frequencies.
4. The slope of the spectra and co-spectra is steeper under unstable atmospheric conditions, meaning that the turbulence in the MABL dissipates faster than expected. The same stands for the cases with lower wind speed where the mechanical production of turbulent kinetic energy is much lower. On the other hand for lower values of friction velocity (lower values of vertical momentum transport) the spectrum slope becomes flatter, meaning that the turbulence dissipates slower than it does according to the similarity theory. It is worth mentioning that although this study is based only on pure MABL data, deviations of the spectral slope from the theoretical value could be connected to fetch effects.

Acknowledgments This work was supported by the special account for Research Grants of the University of Athens (grant 10812) and the Office of Naval Research (ONR)

References

A Study of Nitrogen Oxides, PM$_{2.5}$, and PM$_{2.5}$-bound Polycyclic Aromatic Hydrocarbons in the Ambient Air of Heraklion city

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Levels, seasonal and spatial variation of NO$_x$, PM$_{2.5}$ and thirty-five polycyclic aromatic hydrocarbons (PAHs) were studied in archived 14-day PM$_{2.5}$ samples collected in the broader area of Heraklion (Island of Crete, Greece). For comparison purposes, additional samples were collected at the background Finokalia station and a semi-rural site. The arithmetic mean of PM$_{2.5}$ concentration and its range, in the urban environment, were 16.47 (±3.05) μg/m$^3$ and 12.33-22.39 μg/m$^3$, respectively. Urban NO$_x$ concentration levels ranged from 9.12 to 26.03 μg/m$^3$. The arithmetic mean concentration of NO$_2$ was 11.32 (±5.24) μg/m$^3$ and 5.09 (±2.77) μg/m$^3$ for NO. The corresponding ΣPAHs concentration, at the urban site, was 0.635 (±0.258) ng/m$^3$. The ΣPAHs at the semirural site and the background station were 0.590 ng/m$^3$ and 0.035 ng/m$^3$ respectively. The most abundant PAH members, in the urban sites, were benzo[ghi]perylene (0.134±0.064 ng/m$^3$), benzo[b]fluoranthene (BbF) (0.091±0.039 ng/m$^3$), benzo[e]pyrene (0.068±0.030 ng/m$^3$) and indenopyrene (IP) (0.086±0.049 ng/m$^3$). The total benzo[a]pyrene (BaP) mean exposure equivalent (BaP$_{eq}$) was 0.057 ng/m$^3$. The mean percentage contribution, to ΣBaP$_{eq}$ for BaP, BbF and IP were 46%, 16% and 15% respectively. Site location and seasonality determined the BaP$_{eq}$ percentage distribution. Significant correlation was determined between ΣPAHs, NO$_2$ (r 0.639 and p<0.001) and NO$_x$ (0.664v and p<0.001). In addition, Principal Component Analyses associated with PAH diagnostic concentration ratios, revealed that gasoline and diesel vehicles’ emissions were the major sources for PM$_{2.5}$-bounded PAHs in Heraklion urban area.

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1 Introduction

Polycyclic aromatic hydrocarbons (PAH), a group of carcinogenic and mutagenic pollutants, are by-products of incomplete combustion of organic matter, and therefore ubiquitously present in the ambient air, soil and water (Ravindra et al. 2008). The presence of PAHs in the atmosphere, especially in densely populated areas, is significantly affected by anthropogenic emissions, such as automobile exhaust, fossil fuel combustion, biomass burning, cigarette smoking, and industrial activities (Robinson et al. 2006). Combustion characteristics and the atmospheric decay of PAHs (Galarneau 2008), influence the relative compound distribution of PAHs in the atmosphere.

High levels in particulate matter, especially in particles smaller than 2.5 µm in diameter (PM$_{2.5}$), have been associated with adverse health effects and mortality in studies covering more than 150 cities. Both acute and chronic exposure to high levels of PM$_{2.5}$ has been associated with increased mortality rates and hospital visits, as well as cardiopulmonary disease, heart attacks, decreased lung function, and asthma (Park et al. 2013). Recently, a European epidemiological study, implemented between 2009-2012, (ESCAPE; http://www.escapeproject.eu), aimed to investigate long-term effects on human health of exposure to air pollution in Europe. This study has revealed direct association between inhaled particulate matter and low birth weight (Pedersen et al. 2013). Other studies have shown a statistically significant association, between risk for lung cancer and PM$_{10}$ (hazard ratio 1.22 per 10 µg/m$^3$), or PM$_{2.5}$ (hazard ratio 1.18 per 5 µg/m$^3$) (Raaschou-Nielsen et al. 2013).

The presence of toxic compounds in PM$_{2.5}$, especially PAHs, could further enhance the effects on human health. For the general population, the main exposure routes are inhalation of polluted air or cigarette smoke and ingestion of food, contaminated with PAHs (Li et al. 2009). In addition, fossil fuel combustion processes result in the oxidation of nitrogen compounds and therefore the formation of nitrogen oxides. Nitrogen oxides mainly consist of nitric oxide (NO) and nitrogen dioxide (NO$_2$) and mainly emitted as NO in the ambient air (WHO, 2006). In 1996, specific limit values and alert thresholds considering NO, NO$_2$ and other pollutants have been established by the European Commission Directive (EC, 1996), which was substituted by the Directive 2008/50/EC (EC, 2008). Since then, European Union aims to enforce the legislation, regarding the levels of air pollutants, on the basis of epidemiological studies (Cyrys et al. 2012). Nitrogen oxides are often used as indicators associated with urban traffic containing fine and coarse particles.

The main objective of the present work (a satellite ESCAPE study) was to investigate the occurrence of particulate PAHs species associated with fine particulate matter (PM$_{2.5}$) observed in the urban atmosphere. PM$_{2.5}$ concentrations and their content in PAHs were concurrently measured. Emission sources of PAHs were evaluated by using diagnostic ratios, alongside with reliable statistical tools, and their correlation with other air pollutants such as nitrogen oxides.

2 Sites of measurements and methods

A sampling campaign was conducted in 10 sites, during 2009, located in the greater area of Heraklion city and selected on the basis of specific criteria (Eeftens et al. 2012), and categorized in 2 major groups, urban background and street sites. For each site, three samples were collected for 3 seasons (spring, summer and fall), in two periods per season (n=30) and 14-days duration (15 min/2 h) per period. All urban samples were collected using Harvard Impactors (Air Diagnostics and Engineering Inc., Naples, Maine, USA), designed to collect PM$_{2.5}$ at low flow rates of 10 L/min. Additional samples were collected between October and November 2010, at the Finokalia station (finokalia.chemistry.uoc.gr) and on the roof of Chemistry Department, University of Crete in Voutes Campus (semi-rural site), respectively.
In both sites, high volume air samplers (General Metal Works) were used (continuous air flow 450 L/min for 68 h). The location of sampling sites is indicated in Fig. 1.

Pre-cleaned Andersen 37mm, 2μm pore size, Teflon filters (PALL Life Science) were used on Harvard Impactors and Glass Fibre Filters (GFF, Pall Life Sciences) on high volume samplers for particulate matter sampling. Preceding sampling, GFF were heated in 420 °C for 3h, wrapped in aluminium foil and stored until use. After sampling, all filters were pre- and post-weighted, using a 5-digit analytical balance located in a room with standard temperature and humidity conditions in order to obtain PM$_{2.5}$ concentrations and stored in -20 °C, until analysis.

The filters were spiked with a mixture of perdeuterated PAHs ($d_{10}$-Phenanthrene, $d_{10}$-Pyrene and $d_{12}$-Perylene) and the extraction of PAHs was carried out using an Accelerated Solvent Extraction system (ASE 300, Dionex). The clean-up procedure is described in detail elsewhere (Mandalakis et al. 2004). Gas Chromatography-Mass Spectrometry (GC-MS) analysis of PAHs was carried according to Tsapakis and Stephanou (2005).

### 3 Results

#### 3.1 PM2.5 in the ambient air of Heraklion.

Fine particle concentrations in Heraklion (median values) ranged from 13.91(±1.37) µg/m$^3$ (in autumn) to 18.38 (±3.84) µg/m$^3$ (in spring). In Finokalia, the measured concentration PM$_{2.5}$ was 11.15 µg/m$^3$, while in the semi-rural site was 14.93 µg/m$^3$. The similar PM$_{2.5}$ levels observed, regardless of site classification, might indicate common sources and removal processes, such as particulate matter re-suspension, diffusion and other particle formation mechanisms (Saliba et al. 2010). Also, a similar seasonal trend between the urban traffic and background sites was observed, with higher concentrations (average values) in spring (18.10 µg/m$^3$ and 18.25 µg/m$^3$ respectively), lower in summer (17.03 µg/m$^3$ and 16.91 µg/m$^3$ respectively), and even lower in autumn (14.84 µg/m$^3$ and 13.71 µg/m$^3$ respectively). This variability is due to several causes associated with a wide range of meteorological conditions (e.g. increased wind speed levels in summer could lead to dust re-suspension, possible atmospheric circulation dominated by the sea breeze phenomenon in summer, probable bulged African dust events in spring, lower mixing layer height and lower air temperatures in spring, compared to summer and autumn ones).

Our observed PM$_{2.5}$ concentrations were below the annual average health National Ambient Air Quality Standard (12 µg/m$^3$) and have not exceeded the corresponding daily average standards established by the USEPA (35 µg/m$^3$; EPA 2013) and the European Commission (25 µg/m$^3$, EC 2008) (Fig. 2).
3.2 PM$_{2.5}$-bound PAH occurrence.

The average ΣPAHs concentration in the urban area was 0.635 (±0.258) ng/m$^3$ (range 0.159-1.210 ng/m$^3$). The highest molecular weight PAH members dominated the concentration distribution pattern. In Finokalia and the semi-rural site the corresponding ΣPAHs concentrations were 0.035 and 0.590 ng/m$^3$, respectively. Urban traffic sites had relatively higher ΣPAHs concentrations due to stronger influence of PAH sources (Park et al. 2002). ΣPAHs concentration varied inversely with temperature. Lower mean concentrations were observed in summer (0.416 ng/m$^3$) than in autumn (0.780 ng/m$^3$) and spring (0.714 ng/m$^3$). This seasonal trend in the current study is consistent with findings in other studies (Li et al. 2009). Several factors may contribute to this trend, from which two of the most important is that high atmospheric temperature can affect the distribution of PAHs between gas and particle phase and result in a relatively larger portion of PAHs partitioning to the gas phase (Tsapakis and Stephanou 2005) and increased atmospheric dispersion, resulting from higher mixing height, could lead to lower air pollutant levels in ambient air during summer (Hong et al. 2007). The influence of meteorological conditions on the distribution of PAHs, is shown in Table 1.

Table 1. Pearson correlation between several meteorological conditions [Temperature (T), Relative Humidity (RH), Wind Speed (WS) and Atmospheric Pressure (AP)].

<table>
<thead>
<tr>
<th></th>
<th>ΣPAH</th>
<th>T</th>
<th>RH</th>
<th>WS</th>
<th>AP</th>
</tr>
</thead>
<tbody>
<tr>
<td>ΣPAH</td>
<td>1</td>
<td>-0.474</td>
<td>0.491</td>
<td>-0.225</td>
<td>0.644</td>
</tr>
</tbody>
</table>

Moderate negative linear relationship with temperature was observed (-0.474, p<0.004). Under high temperature and strong solar radiation, the degradation rate of PAHs is usually faster (Gu et al. 2010). Moderate positive correlation between the PAHs concentrations and relative humidity is also observed (0.491, p<0.003). The absorption of PAHs in the gas phase can be suppressed, with increasing relative humidity (Tsapakis and Stephanou 2005). Moderate and statistically significant correlation between ΣPAHs and atmospheric pressure (AP) was found. Low temperatures, combined with high levels of AP, may reduce vertical mixing and entrap contaminants near the surface (Li et al. 2009). Because some PAH members are considered carcinogenic or mutagenic, including BaA, BbF, BaP, Py and DBA, regulatory standards have been proposed (WHO, 2006). The limit of 1 ng/m$^3$ BaP$_{eq}$, as recommended by WHO (Bari et al. 2010), was not exceeded in any sampling interval during all sampling seasons.
3.3 Source identification of PAHs.

Diagnostic ratios for PAHs are convenient tools for identifying potential emission sources of PAHs and they can be used to investigate PAH origins or as an indication of PAH photochemical degradation.

Table 3. Diagnostic ratios of PM$_{2.5}$-bound PAHs in Heraklion.

<table>
<thead>
<tr>
<th>PAH Ratio</th>
<th>Mean (standard deviation)</th>
<th>Estimation</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>ΣMe-Phe/Phe</td>
<td>0.44(0.19)</td>
<td>&lt;1 Gasoline vehicles</td>
<td>Tsapakis and Stephanou (2005)</td>
</tr>
<tr>
<td>Fluo/202</td>
<td>0.54(0.03)</td>
<td>&lt;0.5 Gasoline engines</td>
<td>Ravindra et al. (2008)</td>
</tr>
<tr>
<td>BaA/228</td>
<td>0.74(0.06)</td>
<td>&gt;0.35 Combustion sources</td>
<td>Soclo et al. (2000)</td>
</tr>
<tr>
<td>BeP/(BeP+BaP)</td>
<td>0.73(0.03)</td>
<td>&gt;0.5 Aging of air samples</td>
<td>Tsapakis et al. (2002)</td>
</tr>
<tr>
<td>IP/BghiP</td>
<td>0.57(0.12)</td>
<td>0.33+0.06 Vehicle emissions</td>
<td>Dickhut et al. (2000)</td>
</tr>
</tbody>
</table>

The diagnostic ratios, calculated using the estimated concentration of PAHs for each source, indicated that combustion of gasoline, diesel, and other fuels using in transportation were the major source of these PAHs (Table 3).

In addition, to the diagnostic ratios, Principal Component Analysis (PCA) simplifies the interpretation of complex systems and transforms the original set of variables into a smaller set of linear combinations that accounts for most of the variance of the original set and variables with similar characteristics are grouped into factors. These factors can be interpreted either as an emission source, or a chemical interaction. However, many of these factors indicate more than one possible cause. Six principal factors appeared to have eigen value >1, but only one of them could be associated with possible emission sources of PAHs, which explained approximately 49% of the data variance. PAHs with high loading factor were Phe, Fluo, Py (indicators of gasoline emissions) and BbF, BkF, BaP and BghiP (tracers of diesel vehicles) (Guo et al. 2003).

3.4 Nitrogen Oxides in Heraklion ambient air.

In this study, measurements of nitrogen oxide concentrations were conducted in parallel with PM$_{2.5}$ samplings, at the same intervals, using OGAWA passive air samplers (Cyrys et al. 2012). Average NO$_x$ concentrations for urban traffic areas ranged from 15.83 to 26.03 μg/m$^3$, and for urban background areas from 9.12 to 20.10 μg/m$^3$. A seasonal variation was found in NO levels (higher concentrations in spring, lower in summer and autumn, 5.82 μg/m$^3$, 4.41μg/m$^3$ and 5.04 μg/m$^3$, respectively). The same seasonal pattern was observed for NO$_2$ (spring 15.58 μg/m$^3$, autumn 10.31 μg/m$^3$, and summer 8.06 μg/m$^3$), along with PAHs, as mentioned above. The same pattern was observed also and in other areas (Tham et al. 2008). Significant correlation was determined between ΣPAHs, NO$_2$ (r 0.639 and p<0.001) and NO$_x$ (0.664v and p<0.001).

4 Conclusions

In this study, levels and seasonal trends of PM$_{2.5}$, 35 particle-bound PAHs and nitrogen oxides at ten sites in the greater Heraklion area were measured. A tendency for similar PM$_{2.5}$ levels was observed, regardless of site classification, which may indicate common sources and
removal processes. Relatively higher ΣPAH concentrations were found in most of the urban traffic sites, compared to urban background sites. A strong seasonal ΣPAH pattern was observed, as lower concentrations were found in summer, since lower temperatures could affect PAH distribution between gas and particle phase. In addition, statistically significant negative correlation was found between ΣPAH and temperature, while ΣPAH was positively correlated with ambient relative humidity and atmospheric pressure levels. The total carcinogenic potency, as estimated by total ΣBaP eq was significantly lower that the proposed threshold, which was not exceeded in any sampling interval. The average NO2 concentration in Heraklion was higher in spring and autumn and lower in summer. The same seasonal pattern was also found for NO, with substantially lower concentration levels compared to NO2.

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The use of WRF with data assimilation technique for daily weather forecast on smaller scale within the ENORASIS framework

Jakobs H.

In the frame of ENORASIS, a WRF ensemble data assimilation system has been developed to bring together information from satellite precipitation data, data assimilation techniques, ensemble forecasting and cloud-resolving models to dynamically downscale precipitation data. The system runs with a multiple domain nested configuration that covers Europe at a resolution of 32km, with the smallest domains having a resolution of 2 km. The proposed process transfers the quantitative information about the uncertainty of the rainfall forecast to the hydrological model and, thus, to the irrigation management system. One part of the ensemble system is the use of the WRF data assimilation tool to improve the initial state of the forecast by more recent measurements from different sources: Surface observations, balloon data, wind profiler data, aircraft reports, radar observations, and satellite observations. These data are provided by the Global Data Assimilation System (GDAS) from NCEP and are available in near real time.

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1 Introduction

One major task within the 7 framework project ENORASIS (ENvironmental Optimization of Irrigation Management with the Combined Use and Integration of High Precision Satellite Data, Advanced Modeling, Process Control and Business Innovation) is the development of Analysis Tools (Meteorological Analysis, Hydrologic Analysis) in order to set up the Weather Research and Forecasting (WRF) model with a multiple domain nested configuration, with the smallest domain having a resolution of 2 km. Initial and lateral boundary condition will be provided by a coarse-resolution global model. The configuration of meteorological analysis tool is the setup of an ensemble prediction system with perturbations in the physics options (i.e. microphysics, surface physics, physics of the planetary boundary layer (PBL)) and perturbations of the initial state. Thus an Ensemble Data-Assimilator will generate optimal initial states for the WRF model to produce improved ensemble rainfall forecasts.

2 Data and Methodology

The ENORASIS WRF ensemble system runs with a multiple domain nested configuration that covers Europe at a resolution of 32 km, with the smallest domains having a resolution of 2 km for the pilot stations in four different climate regimes (North Central Europe- Poland, South Central Europe- Serbia, continental Mediterranean- Turkey and island Mediterranean- Cyprus). The ensemble system consists of three different model runs with one data assimilation approach (Ens 3). The other two ensemble members vary by perturbations in the physical option (Ens 1 and Ens2). The assimilation approach uses the Weather Research and Forecasting Model's Community Variational/Ensemble Data Assimilation System (WRFDA, Barker et al. 2012) in order to reach the optimal initial state with newest observational information of all kinds: Surface observations, balloon data, wind profiler data, aircraft reports, radar observations, and satellite observations. The ensemble system starts every day with initial state of the 12 UTC data.

2.1 Data

The main problem to run the assimilation system WRFDA in the forecast mode is to get free available data in near real time for the initial state. Therefore the observational data from the Global Data Assimilation System (GDAS) from NCEP are used to run WRFDA. Besides station observations they include the following relevant satellite data:

- AQUA-AIRS-E processed radiances
- GOES Satellite-derived wind reports
- SSMI Wind Speed
- SSMI Atmospheric Water Vapor
- SSMI Cloud Liquid Water
- SSMI Rain Rate
- GOES GPS Integrated Precipitable Water

The data are ready for download at around 18:30 UTC

2.2 Methodology

The WRFDA system was developed during the last decade (Barker et al. 2004; Skamarock et al. 2008; Huang et al. 2009). The system has the advantage of being built directly within the WRF software framework, thus providing a direct interface to other components of the WRF modeling system.
The approach which is used in the WRFDA system is the 3 dimensional variational (3D Var) algorithm (Barker et al. 2004). In general terms, VAR systems may be categorized as those data assimilation systems which provide an analysis $x^a$ via the minimization of a prescribed cost function $J(x)$.

$$J(x) = J^b + J^o$$
$$= \frac{1}{2}(x - x^b)^T B^{-1} (x - x^b)$$
$$+ \frac{1}{2} (y - y^o)^T (E + F)^{-1} (y - y^o)$$

The analysis $x = x^a$ represents the a posteriori maximum likelihood (minimum variance) estimate of the true state of the atmosphere given two sources of data: the background (previous forecast) $x^b$ and observations $y^o$ (Lorenc 1986). The analysis fit to this data is weighted by estimates of their errors $B, E$ and $F$ and are the background, observation (instrumental), and representiveness error covariance matrices, respectively. Representiveness error is an estimate of inaccuracies introduced in the observation operator $H$ used to transform the gridpoint analysis $x$ to observation space $y = H(x)$. This error will be resolution dependent and may also include a contribution from approximations in $H$. Thus with the observations $y^o$, summarized in chapter 2.1 the analysis vector $x$ is calculated for the initial state.

Three ensemble runs were performed every day. The runs differ mainly in selecting different physical processes (Ens1 and Ens2) and using 3D Var for setting the initial conditions. Table 1 demonstrates the different options for the model runs.

**Table 1. Physical and assimilation options for the ENORASIS Forecast Ensemble.**

<table>
<thead>
<tr>
<th>Ens1</th>
<th>Microphysics</th>
<th>Surface Physics</th>
<th>PBL Physics</th>
<th>3D Var Initial conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Thompson graupel</td>
<td>Noah Land-Surface</td>
<td>Mellor-Yamada-Janjic</td>
<td>no</td>
</tr>
<tr>
<td></td>
<td>scheme</td>
<td>Model</td>
<td>(Eta) TKE scheme</td>
<td></td>
</tr>
<tr>
<td>Ens2</td>
<td>WSM 6-class graupel</td>
<td>Thermal Diffusion</td>
<td>YSU scheme</td>
<td>no</td>
</tr>
<tr>
<td></td>
<td>scheme</td>
<td>scheme</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ens3</td>
<td>Thompson graupel</td>
<td>Noah Land-Surface</td>
<td>Mellor-Yamada-Janjic</td>
<td>yes</td>
</tr>
<tr>
<td></td>
<td>scheme</td>
<td>Model</td>
<td>(Eta) TKE scheme</td>
<td></td>
</tr>
</tbody>
</table>

The Ensemble starts every day with 12 UTC data and is run for the consecutive 3.5 days (e.g. Start at 01.06.2013 12 UTC, End 05.06.2014 00 UTC). The Ensemble Forecast Episode is operated within the crop season from 01. April 2013 to 31. October 2013.

### 3 Results

As mentioned, within the ENORASIS project 4 Pilot areas were selected in different climate zones. Since the precipitation forecast in one major issue for irrigation plans, the results for the Pilot area in Poland are shown.

#### 3.1 Maximum Temperature

One important variable besides precipitation is the forecasted maximum temperature for the selected pilot area. Fig. 1 shows the maximum temperature for the pilot Poland exemplarily for the month of June 2013.

As seen from Fig. 1, the simulated temperature is most sensitive to the choice of physical options (Ens1 and Ens 3 compared to Ens2). The Ens2 run predict slightly higher
temperatures compared to Ens1 and Ens3 and the observations (Obs). Table 2 summarizes the main statistical parameters for the whole episode (April – October 2013).

**Table 2.** Statistical values for the maximum temperature in the pilot Poland area during the crop season in 2013.

<table>
<thead>
<tr>
<th></th>
<th>Mean value(°C)</th>
<th>Root Mean Square Error (RMS)</th>
<th>Correlation Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ens1</td>
<td>20.24</td>
<td>2.46</td>
<td>0.88</td>
</tr>
<tr>
<td>Ens2</td>
<td>21.05</td>
<td>1.75</td>
<td>0.94</td>
</tr>
<tr>
<td>Ens3</td>
<td>20.33</td>
<td>1.80</td>
<td>0.95</td>
</tr>
<tr>
<td>Obs</td>
<td>20.50</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

There are no significant differences between the different ensemble runs, but as seen in Fig. 1 for June, the Ens2 run has a slight over prediction of the maximum temperature, but the best error analysis (RMS). The Ens3 run has the best performance, when looking at the bias and correlation. Thus the data assimilation procedure that optimize the initial condition has some improvements on the forecast results.

**3.2 Precipitation**

The target within this project is the performance of the precipitation prediction during the forecast episode. The results for precipitation are also shown for the pilot Poland area. Fig. 2 shows the precipitation forecast also for the month of June 2013.

As seen in Figure 2, the differences in the ensemble runs are much higher that regarding the maximum temperature. Generally all forecasts are higher than the observed precipitation, but the major precipitation events are well predicted.

Table 3 summarizes the statistical scores for the whole forecast episode. Besides the mean values some threat scores are displayed to emphasize the performance of the members of the Ensemble. The selected threat score \( TS \) above a certain threshold is defined as follows: \( TS = \frac{Correct}{(Forecast + Observed - Correct)} \) For a perfect forecast, Correct = Forecast = Observed to yield a TS of 1. The worst possible forecast, with Correct = 0, yields a TS of zero. For the whole episode the Ens3 simulation reaches highest scores. Thus optimizing the initial state by means of data assimilation has a significant positive impact on the performance of the prediction.
Fig. 2. Daily precipitation for June 2013 in the Poland Pilot area for the first day of the forecast.

Table 3. Statistical values for the precipitation in the pilot Poland area during the crop season in 2013.

<table>
<thead>
<tr>
<th></th>
<th>Mean value (mm)</th>
<th>Threat Score 5mm</th>
<th>Threat Score 1 mm</th>
<th>Threat Score 0.1 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ens1</td>
<td>3.38</td>
<td>0.61</td>
<td>0.74</td>
<td>0.71</td>
</tr>
<tr>
<td>Ens2</td>
<td>2.09</td>
<td>0.66</td>
<td>0.72</td>
<td>0.71</td>
</tr>
<tr>
<td>Ens3</td>
<td>3.22</td>
<td>0.66</td>
<td>0.77</td>
<td>0.78</td>
</tr>
<tr>
<td>Obs</td>
<td>1.84</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4 Conclusions

An ensemble forecast with 3 approaches was conducted for the ENORASIS framework. The effect of assimilated initial conditions using the WRFDA 3D Var approach was examined. The data assimilation has no severe effect on temperature forecast, but major differences occur in the precipitation forecast. It was found that the run with optimized initial conditions performs best over the whole simulation episode in 2013.

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References

Possible effects of aerosol changes on cloud physical properties

Kagkara C., Hatzianastassiou N., Gkikas A., Flossmann A.

In the present study, modifications of warm cloud properties induced by aerosol related changes are investigated by using the spectral DESCAM (DEtailed SCAvenging and Microphysics) model coupled to the dynamics of an ascending and entraining air parcel model. To this aim, observed changes of Cloud Condensation Nuclei (CCN) above specific Mediterranean areas characterized by different aerosol types, namely biomass burning, urban, desert dust and sea salt, with emphasis on the last one, were taken into account in DESCAM in order to simulate their effect on evolving properties of clouds forming on these CCN, in particular the cloud droplet number and mass density ($f_d$ and $g_w$). The CCN data were obtained from the NASA’s MODIS Aqua database. Very large changes of CCN and their cloud effects were considered during specific aerosol episodes in the Mediterranean basin. The results show that CCN changes not accompanied by temperature and humidity changes affect the cloud droplet number and air parcel updraft velocity but not the cloud water content.

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1 Introduction

Atmospheric aerosol particles despite their small dimensions and mass are very important for the Earth-atmosphere system; their impact on cloud properties and climate represent a great challenge for the atmospheric scientific community. Aerosol-cloud interactions (formerly known as aerosol indirect climate effects) involve the modification of cloud properties by changes in aerosol that act as cloud condensation nuclei (CCN) and ice nuclei (IN). Aerosol-cloud interactions can alter cloud and planetary albedo (first indirect effect) or increase cloud lifetime and thus enhance radiative forcing (second indirect effect). The second indirect effect has also implications for precipitation producing efficiency of clouds (colloidal stability, Stevens and Feingold 2009) which in turn changes cloud amount. Moreover, other effects of aerosols have also been proposed, for instance suppressing convection and modifying monsoonal circulations and the hydrological cycle at different world locations (e.g. Rosenfeld et al. 2008). Such effects can only be accurately modeled taking into account the various and complex aerosol cloud interactions (Flossmann 1998). Despite the progress in understanding and modeling aerosol-cloud interactions down to regional scales (e.g. Bangert et al. 2011) uncertainties still remain (Koren et al. 2010). Moreover, the effects of aerosols on cloud properties under special conditions characterized by massive transport of aerosol loadings, called henceforth aerosol episodes, have not been yet adequately studied.

The aim of the present study is to investigate the possible effects of aerosols on cloud properties during aerosol episodes, in particular the potential changes of cloud droplet number and water mass for clouds formed on enhanced CCN during days with transport of aerosol particles. The focus is on cases of warm clouds forming on the Mediterranean basin. This region is a world hot spot area in terms of current and future climate change, which makes the present work relevant, especially given the primary role of clouds and aerosols. The study is performed using a 0-D spectral scavenging and microphysics model (DESCAM) coupled to the dynamics of an ascending and entraining air-parcel model. The aerosol episodes are identified using an objective and dynamic algorithm based on a synergy of satellite data (Gkikas et al. 2008). Both DESCAM and the data used are described in section 2.

2 Model, Methodology and Data

2.1 Model and Methodology

The ascent of air parcels is simulated using the DESCAM model (Flossmann et al. 1985, 1994) which reproduces the evolution of interstitial aerosol and cloud spectra during the cycle of a cloud forming on different types of aerosol spectra e.g. maritime or continental. Both aerosol and droplet spectra are treated in a bin resolved form whereas their temporal evolution is computed taking into account various dynamical and microphysical processes. The model contains prognostic equations for 11 distribution functions for which details are given by Flossman (1994). The combination of the dynamics of the rising and entraining air parcel with the DESCAM module yields the dynamic, thermodynamic and microphysics every 2 s while the resulting cloud droplet and aerosol particle spectra were stored every 100 s.

The initial vertical profile for temperature and humidity for a medium sized cumulus cloud is the one used by Lee et al. (1980). The initial dry aerosol particle spectrum for the reference case (non episode day) is assumed to be of maritime, desert and urban type, depending on the type of aerosol episode taking place, and consists of a superposition of three log-normal distributions as proposed by Jaenicke (1988). In this study, results will be given for maritime aerosol only due to space limitations. The parameters were set equal to the typical marine air mass as given by Jaenicke (1988) but adjusted to match the total number of aerosols with that indicated by the satellite data (MODIS) for the day before the episode. The parameters are
summarized in Table 1. All particles were assumed to consist of 100% (NH₄)₂SO₄. The model parcel was launched at 900 mb (=1000 m) with an initial relative humidity of 99% and a vertical velocity of 1 m/s. For the aerosol episode day, the model initialization was similar except for the values of parameters (Table 1) that were adjusted to match the total aerosol number of the episode day based on satellite data. In this way, the formation of clouds on enhanced maritime aerosol spectra under episode conditions in the Mediterranean, and the cloud evolution, have been simulated with DESCAM and were compared with the cloud forming under non-episode conditions.

Table 1. Parameters for the maritime aerosol particle distribution for the air parcel dynamics during an aerosol episode day in the Mediterranean. The corresponding quantities under non-episode days are given in the parentheses. N is the total number of aerosol particles per cm³.

<table>
<thead>
<tr>
<th>Mode i</th>
<th>Total number nᵢ (cm⁻³)</th>
<th>Rᵢ (μm)</th>
<th>log(σᵢ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>293(133)</td>
<td>0.0039</td>
<td>0.657</td>
</tr>
<tr>
<td>2</td>
<td>116.6(66.6)</td>
<td>0.1330</td>
<td>0.210</td>
</tr>
<tr>
<td>3</td>
<td>12.56(3.06)</td>
<td>0.2922</td>
<td>0.396</td>
</tr>
</tbody>
</table>

Fig. 1. The greater Mediterranean basin and the location of occurrence of different types of aerosol episodes (maritime only are included in the present analysis).

2.2 Data

The total numbers of aerosols (CCN) during the non-episode and episode days were taken/derived from NASA’s MODIS satellite level 3 daily gridded atmospheric data. More specifically, CCN and AOD₅₅₀₅ nm data were obtained from MODIS Aqua and MODIS Terra databases respectively. The maritime sea-salt like episode that is simulated here took place in February 08 2004 in the oceanic location shown in Fig. 1. It should be noted that MODIS provides CCN above sea surfaces while above land aerosol optical depth (AOD) is only given; therefore AOD values during the episode days were converted to CCN required by the model using relationships between CCN and AOD over remote maritime regions proposed by Andreae (2009).
3 Results

An example of the evolution of cloud properties, namely total number and liquid water content of cloud droplets, along with the ascending air parcel velocity is given in Fig. 2. The figure displays the simulated properties obtained for clouds forming on aerosol particle spectra during a typical marine aerosol episode and a non-episode day. During the episode, in which the aerosol particle number is increased by 108% (cf. Table 1), the air parcel ascends initially with the same velocity with that during the non-episode day until about 2 km, where it subsequently develops higher velocities and reaches a slightly higher altitude. As expected, the initially formed cloud droplets are more numerous during the episode, by about 80 #/cm³, resulting thus in a more “polluted” cloud. However, during the evolution of polluted cloud cycle, this difference gradually reduces and gets almost identical to that of the reference (non-episode or -polluted) cloud at altitudes near 4 km. At the same time, the total liquid water content remains the same for the two clouds (episode and non-episode). This is because in the performed simulation the different populations of maritime aerosols share the same atmospheric humidity, which was kept unchanged in the model simulation. Of course, this may be not realistic since during an episode the atmospheric humidity, but also the temperature, profiles can be modified depending on the origin of the air mass which brings the enhanced aerosol population.

![Fig. 2. Evolution of: (a) air parcel velocity, (b) total cloud droplet number, and (c) cloud liquid water content, during a maritime aerosol episode (in red color) and non episode (black color) day.](image)

Additional information is given in Fig. 3, where the aerosol particle spectra of the two clouds, the “polluted” and the “non-polluted” (corresponding to episode and non-episode days), are compared during the cloud lifetime cycles (results are shown here every 300 s). This is just an example and similar information is obtained with the model for aerosol and droplet distributions, but cannot be given in this study because of space limitations. At the beginning of cloud cycles, a greater number of droplets form in the “polluted” cloud during the episode, but this is valid only for droplets with radius smaller than about 6 µm, while the droplets with larger sizes are less numerous than in the “non-polluted” cloud, yielding an overall slightly larger total number of droplets (N_d larger by about 80 #/cm³) as already suggested. Therefore, under maritime aerosol episode conditions, more and smaller droplets initially form than under non-episode conditions. Nevertheless, as the two clouds evolve, although the total number of droplets gradually decreases in both cases, the result is a just slightly different total droplet number at the end of cloud cycle (difference equal to about 2.5 #/cm³ at 1900 s). At the same time, the size of droplets is shifted to larger sizes during the evolution of clouds, which can be explained by condensational growth at the beginning of cloud cycle and collision and coalescence latter on, which also explains the drastic decrease of total number of droplets.
Fig. 3. Evolution of droplet number size distribution ($N_d$) of two clouds formed on maritime aerosol particles during an aerosol episode (long-dashed lines) and non episode (solid lines) day.

The comparison between the cloud droplet liquid water mass ($w_L$) for clouds forming on maritime aerosol episode and non-episode conditions (Fig. 4) does not indicate essential differences. Again, there is a shift of high $gw$ values to slightly smaller droplets, but the overall total water mass ($w_L$) is about equal in both cases. Note the existence of bi-modal droplet spectra after the middle of cloud lifetime (about 1000 s) in both cases, which is attributed to the formation of droplets larger than 20 µm which are able to lead to effective collision-coalescence resulting in the rapid formation of larger droplets. Towards the end of cloud cycles, the cloud water mass is almost entirely being contained in the larger droplets, in both cases, whereas despite the situation at 1300 s there are no differences at the end of cloud cycles.

Fig. 4. Evolution of droplet water mass size distribution ($g_w$) of two clouds formed on maritime aerosol particles during an aerosol episode (long-dashed lines) and non episode (solid lines) day.
4 Conclusions

The present analysis using a detailed cloud microphysics model has shown that aerosol number concentration changes during aerosol episodes in marine environments can significantly affect cloud droplet number spectra, especially at the beginning of the cloud cycle. However, the effect on cloud water content is minimal because of unchanged atmospheric temperature and humidity profiles assumed in the simulation. This work will be refined/extended in the future by:

1. Assuming more realistic atmospheric profiles of temperature and humidity, during both episode and non episode days, based on radiosonde data.
2. Implementing realistic vertical temperature/humidity profile changes during aerosol episodes, corresponding to the location and days of the identified aerosol episodes.
3. Evaluating basic microphysical parameters used in the simulations, such as aerosol or CCN number, using in-situ data from the Easter Mediterranean.
4. Performing similar simulations for other aerosol episode types (desert, urban).
5. Repeating the DESCAM simulations but coupled with a more sophisticated and realistic dynamic framework (e.g. 1-D or 2-D).
6. Taking into account the existence of ice in addition to the liquid phase in clouds.

References

Andreae MO (2009) Correlation between cloud condensation nuclei concentration and aerosol optical thickness in remote and polluted regions, Atmos. Chem. Phys. 9: 543–556
Effect of climate projections on the behavior and impacts of wildfires in Messenia, Greece

Kalabokidis K., Palaiologou P., Kostopoulou E., Zerefos C.S., Gerasopoulos E., Giannakopoulos C.

Climate change has the potential to affect many aspects of wildfires, while wildfire itself can accelerate phenomena such as environmental degradation and desertification. As a result, floods, microclimate alteration, environmental changes, destruction of infrastructures, economic losses and human causalities are some of the post-fire impacts. During the last decade, Peloponnesus in Greece experienced several large-scale wildfire events with unprecedented fire behavior and fire effects. In this study, thousands of wildfire events were simulated with the well-established Minimum Time Travelfire growth algorithm and resulted in spatial data that describe burn probabilities, potential fire spread and intensity in Messenia, Greece. Present and future climate projections were derived from simulations of the KNMI regional climate model RACMO2 with a horizontal resolution of 25x25 km, under the SRES A1B emission scenario for the 1961-2100 time period. Data regarding fuel moisture content, wind speed and direction were modified for the different projection time periods. Results were used to assess the vulnerability changes for certain values-at-risk of the natural and human-made environment; e.g. residential, agricultural and tourist infrastructures. Differences in wildfire risk in terms of burn probabilities and fire intensity were calculated for the different simulation time periods.

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1 Introduction

Changes in climate have the potential to significantly affect wildfire frequency, size and intensity, while higher fire risks, longer fire seasons and more severe fire effects are expected. Fire regimes in the Mediterranean are influenced by factors beyond those related directly to climatic conditions (e.g. socioeconomic, land use/land cover types, anthropogenic pressures and intensive human influences), but climate and weather conditions have a profound effect on fire occurrence over time. Different vegetation types are anticipated to have different responses to climate change in terms of fuel availability and flammability. Changes in fire regimes will impact the quantity and compactness of dead and live fuels, along with their composition and height. Furthermore, plant succession patterns are expected to alter if climate change favors exotic species to colonize burned areas. The removal of overstory vegetation and canopy cover will result in lower fuel moisture content and, thus, increased flammability. The large fires that occurred in the Mediterranean Basin in the last decade were related not only to extremely warm and dry weather (Founda and Giannakopoulos 2009), but also to positive anomalies in the previous wet season that promoted plant growth and fuel build-up (Trigo et al. 2006).

Agee (1997) originally raised the question about the relative importance of weather and fuel on fire behavior, creating the “weather hypothesis” and the “fuel hypothesis”. The weather hypothesis suggests that large, severe fires are driven by extreme weather events and intensely burn through forests regardless of the condition of their fuels; while on the contrary, the fuel hypothesis suggests that reduction of fuels limits fire severity. Forest fire behavior is complicated by the erratic and, often, weather-driven nature of these phenomena. Keeley and Fotheringham (2001) claim that catastrophic fires are less dependent on fuel and more dependent on the coincidence with severe weather. In this study, the weather hypothesis was tested by conducting fire behavior simulations for current and future climate conditions, to assess the degree of expected changes in wildfire frequency and intensity and the anticipated impact on several values-at-risk in the area of Messenia in Peloponnese.

2 Materials and Methods

To assess climatic change in the study area, daily output from the KNMI regional climate model (RCM) RACMO2 (Lenderink et al. 2003, van den Hurk et al. 2006, Van Ulft et al. 2008) was used. The KNMI RCM RACMO2 is forced with output from a transient run conducted with the ECHAM5 GCM, run on a spatial resolution of about 25x25 km under the SRES A1B emission scenario (Nakicenovic et al. 2000). The model provides five grid points over SE Peloponnese, three of which were used in this research. Simulations of present day (period 1961-1990) and distant future (period 2071-2100) with KNMI RCM RACMO2 were utilized including relative humidity (%), mean and maximum temperature (°C), wind speed (m/s) and the mean eastward (u) and mean northward wind components (v). The u and v components were used to calculate the wind direction, as derived from arctan (u/v), and averaged for 16 directions. Wind speed and direction were calculated at the height of 10 m a.g.l., while air temperature and relative humidity at 2 m a.s.l.

Fire behavior simulations were conducted by the command-line version of the Minimum Time Travel (MTT) algorithm (Finney 2002), called Randig, making it feasible to rapidly simulate thousands of fires that can then be used to generate burn probability maps. MTT results include a burn probability (BP) grid of the area, fire perimeter shapefiles, flame length probabilities, conditional flame length (CFL) and a fire list (text file with coordinates and area in ha of each fire). The MTT algorithm accepts weather parameter inputs in the form of scenarios that define the wind speed and direction (mph at 20 ft a.g.l.) and the dead and live fuel moisture content (FMC) for each fuel model and each scenario’s selection probability. To define these scenarios for Messenia, the daily wind speeds of each time period were sorted into three classes (0 to 2 m/s, 2 to 4 m/s and greater than 4 m/s) that are based on the model
wind data of the region during fire season. Then, the percentage of days that fall in each category over the total number of prediction days, as well as the wind direction frequency (%) per sector was calculated. The three most frequent wind direction sectors were used for each wind speed category, with their frequency being used for defining the selection probability of every scenario on MTT simulations. Eventually, each time period had nine weather scenarios (three wind speeds with three directions each), with the relevant FMC values for each wind speed category. To estimate FMC, the relative mean air temperature and relative humidity values from each wind scenario were incorporated into the BehavePlus software (Heinsch and Andrews 2010), using the “Fine Dead Fuel Moisture Tool”.

By using spatial data and information for values-at-risk, such as houses outside urban areas, agricultural infrastructures (corrals, residential storehouses, auxiliary buildings, etc.), hotels and land use/land cover (LULC) types, a vulnerability assessment analysis was conducted for each of them for the two time periods. The Randig results (BP and CFL) were displayed in scatter plots for each value-at-risk, indicating attributes that have the potential of facing frequent and intense fires. This analysis allowed the identification of important attributes with respect to high vulnerability (e.g. hotels, houses or LULC types).

3 Results and Discussion

Raster values of the BP and CFL files for the two time periods were subtracted (i.e. future minus present) to produce new raster files of BP (Figure 1-A) and CFL (Figure 1-B) differences. Positive values reveal an increase, while negative values reveal a decrease of the fire frequency and behavior in the future time period. Spatial results revealed that fire frequency and intensity are projected to increase under future climate change conditions (Figure 1). A low (from 0.0001 to 0.001), moderate (from 0.001 to 0.006) and high (more than 0.006) increase on future BP values was calculated on 55%, 25% and 15% of the total study area, respectively; with only a 5% decrease across the landscape. A low (from 0.01 to 0.2 m), moderate (from 0.2 to 0.5 m) and high (more than 0.5 m) increase on future CFL values was calculated on 25%, 28% and 9% of the total study area, respectively. A substantial decrease by 0.25 m was calculated on 37% of the landscape, located mainly in the coastal zones of Messenia.

The SE tip of the Messenia region (i.e. Mt. Taigetos and Mani areas) is expected to experience a large increase in BP vs. the current predicted conditions, ranging from 0.006 to 0.04; i.e. about 7% of total study area. The primary vegetation types of the area to carry the wildfires are conifer forests, evergreen shrublands and reforested agricultural areas. An increase of approximately 0.3 m in the CFL values was estimated for these areas. Another area with high BP increase is on the northern part (about 4% of total study area), covered with evergreen shrublands, oak woodlands and reforested agricultural areas with values ranging from 0.004 to 0.02. The area west of Koroni in the south (about 3% of total study area), mainly covered with evergreen shrublands, has also increased BP values as well as the area of Pilos on the west; both having a well developed touristic sector. CFL values in these two areas are also expected to have a large average increase of 0.5 m. The area east of the Aigaleo-Mali forest (central part of Messenia) also has increased BP values for the future time period. The coastal zone south from Kyparissia has increased CFL values of 0.4 m on the average, covered mainly by agricultural zones.
Fig. 1. Burn probability (A) and conditional flame length (B) differences of current and future time periods in Messenia, Greece

A clear trend for increased fire size exists in Figure 2, having higher frequency for fire sizes more than 500 ha. It is expected that the number of small forest fires (<10 ha) will be reduced in favor of larger fires. Current situation produced 30% of fire events greater than 500 ha, while future situation outputs had about 50%. Fire sizes of 1,000 ha were very rare for current situation (almost 5%), and increased to 15% for future conditions. Scatter plots of LULC types (Fig. 3) show that most values have an increase in vulnerability (a shift from lower far left to upper far right). Shrublands and mixed forest-shrublands have a CFL increase (almost 0.5 m), along with an increase in BP values. Sparse coastal pine forests have also a similar trend. A moderate increase in CFL values (almost 0.3 m) will happen in sparse shrublands, coastal pine, fir and sparse oak forests. Grasslands will have a large increase in BP values, with small changes in CFL. Most of the other vegetation types will have small increases in both CFL and BP values.

Fig. 2. Histograms of fire size vs. frequency of current and future time periods

Fig. 3. Vulnerability scatter plots of the two time periods for LULC types of Messenia

Values-at-risk in Figure 4 show that agricultural installations have a moderate percentage of attributes that portray increased vulnerability, with most of the rest attributes having BP and CFL values smaller than 0.01 and 1.5 m, respectively. Although most of the hotels seem
relatively less vulnerable, with lower BP and CFL values, extra attention must be given for those facilities with high expected vulnerability in the future. Hundreds of houses are also expected to increase their BP and CFL values, but the vast majority will remain under low threat status.

Fig. 4. Vulnerability scatter plots of the two time periods for agricultural installations, hotels and houses

4 Conclusions

Based on the results, wildfires with increasing frequency and intensity are expected to occur in the Messenia region towards the end part of the 21st century. Fire size is likely to have an increase that can substantially affect several values-at-risk. It is expected that vegetative fuel availability conditions for most of the LULC types studied will intensify over the next 50 years. Changes in vegetation composition, structure and arrangement lead to analogous modifications in fuel models used in the simulation procedure. Since weather patterns cannot be changed or modified directly by humans on a local or regional scale and during the time needed (weather hypothesis), the only option left for protecting societies and values-at-risk is by modifying vegetation and fuel patterns (fuel hypothesis) to reduce and control wildfire activity. This study’s outcomes emphasize the need for fuel treatment techniques aiming at reducing vegetation fuel accumulations, strategically implemented around areas and facilities that have high hazard and vulnerability.

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References


The use of ATR spectroscopy for the determination of functional groups in size segregated aerosol collected during a forest fire

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A method for determining the loadings of organic functional groups in size-segregated aerosol has been developed and applied to ambient samples. The method utilizes a ten-stage MOUDI impactor, equipped with PTFE (Millipore, 47 mm diameter, 0.2 μm pore size) impaction surfaces to sample. The aerosol samples are analyzed directly, without extraction, using Fourier Transform Attenuated Total Reflection (ATR) spectroscopy. The resulting spectra of aerosol size fractions are used to determine loadings of organic hydroxyl, primary amine, carboxylic acid, alkane and carbonyl groups, using calibration factors developed in model compound studies. This paper describes the data interpretation used to obtain these functional group loadings from the infrared spectra during a forest fire near the city of Patras. Comparison of the sum of the mass measured by the ATR technique and gravimetric mass indicates that this method can quantify on average 90% of the aerosol mass. This method bridges the gap between individual compound identification with Gas Chromatography-Mass Spectrometry (GC/MS) and total (Organic Carbon) OC obtained by thermal/optical methods and provides a nearly complete characterization of size-fractionated sub-micrometer aerosol mass. The functional group loadings, particularly the size distributions of organic compound classes, provide new insights into the composition of atmospheric aerosol.

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1 Introduction

Fine particulates are one of the biggest air pollution problems in world cities. The study of their chemical composition and size distribution can help identify the pollution sources and to evaluate this effect on health. The mixture of solid particles and liquid droplets found in the air is called “Particulate Matter”, PM$_{x}$ where $x$ refers to particulate matter having a diameter of $x$ μm or smaller in size. Some of the main sources of PM and especially of PM$_{2.5}$ include transportation, industrial processes, wood burning and other combustion sources. In the atmosphere these particles can be also formed by sulfur dioxide, nitrogen oxides and volatile organics after transformation in the air by chemical reactions (Mouli et al. 2003). Two kinds of analytical techniques are used to measure aerosols, namely the off-line and the on-line techniques. The off-line analysis include techniques such as gas, liquid, ion and paper chromatography, atomic emission spectroscopy, thermal desorption spectroscopy, laser microprobe mass spectrometry, X-ray photoelectron spectroscopy and particle-induced X-ray emission. On the other hand, the on-line techniques include differential mobility analysis, flame photometric detection and the semi-continuous ion-chromatographic analysis (Tobias et al., 2000; Ehara et al. 2000). Fourier Transformed Infrared spectroscopy (FTIR) has become one of the major analytical techniques. It is an attractive option, since it is a rapid, non-invasive and inexpensive method with high spectral signal-to-noise ratio and allows the detection of constituents present in very low concentrations.

In this work, we used the ATR technique based on total internal reflection, in an effort to provide functional group and bond information for the entire aerosol without sample manipulation beyond collection. We will focus on the characterization of aerosol emitted during a forest wildfire near the city of Patras in western Greece. Particles were collected utilizing a size-segregating 10-stage impactor (MOUDI, model 110) with PTFE substrates as impactation plates 5 km away from the wildfire. The source sampling and characterization is combined with other field measurements at the center of Patras, 20 km away from the forest burning during the first four days of the fire. Thus, 10 filters were collected from the impactor near fire (ICE location) the first day after the wildfire start and one filter per day from the center of Patras for the first four days after the wildfire start.

2 Data and Methodology

All spectra were recorded using an Alpha spectrometer (Bruker) operating in the infrared 500-4000 cm$^{-1}$ region. The instrument was fitted with a desiccated and sealed interferometer with a deuterated triglycerine sulfate (DTGS) detector. The instrument was equipped with an ATR accessory. Appropriate optics transfer the infrared radiation to a detachable ATR crystal made of ZnSe. The crystal was a parallel side plate with the upper surface exposed. The number of reflections at each surface of the crystal depends on the length and thickness of the crystal and the angle of incidence. The penetration depth is up to 5 micrometers. In general, the penetration depth is a function of the angle of incidence and of the refractive index. The force applied to the sample ensuring sampling reproducibility was fixed to 100 N. The spectral resolution for all measurements was fixed at 2 cm$^{-1}$. A background spectrum was recorded prior to any measurement using the atmospheric vapor correction. Furthermore, all spectra were subjected to a standardization procedure allowing quantitative estimations. Spectra were collected for each sample and transformed in absorbance units using the background spectrum of a blank filter. The surface of the ATR crystal was fully covered by the deposited filter. This condition is necessary when quantitative estimations are required. After each measurement, the ZnSe crystal was cleaned with spectroscopic grade isopropanol. The cleaned crystal was often checked spectrally to ensure that no residue sample from the previous measurement was retained on the crystal surface.

In this work we analyze PM collected with a size-segregating 10-stage impactor using a constant flow-rate of 30 Lmin$^{-1}$ for 24 hours. The stage cutoffs were 10, 5.6, 3.2, 1.8, 1.0,
0.56, 0.32, 0.18, 0.10 and 0.056 μm. We used PTFE filters (Millipore, 47mm diameter, 0.2 μm pore size) as impaction plates instead of more infrared transparent ZnSe substrates, which are expensive, brittle, highly toxic and would have to be made impractically thin. The sample was collected in the Institute of Chemical Engineering (ICE), 10 km outside Patras.

An SMPS (TSI 3034) was measuring the number concentration distribution of particulate matter during the period of 8 June – 26 July 2012 at the roof of the Literature and Art Hall at the center of Patras. Also an Ecotech Aurora 1000 single-wavelength integrating Nephelometer was used to measure th PM scattering.

PM$_{2.5}$ mass concentration was measured using a Partisol – FRM Model 2000 PM$_{2.5}$ Air Sampler, that operated continuously to collect 24-h samples for the duration of the study at the center of Patras. For each sampling day, one 47mm diameter Teflon filter was used for the collection of aerosol. Prior and after sampling the filters were conditioned for 24h and then weighted in a controlled environmental chamber maintained at a relative humidity of 35 ± 2% and a temperature of 22±2°C. Filters were weighted on a Sartorius ME5-F microbalance. Strips of Polonium were used to minimize the weighting errors induced by electrostatic charge. All collected filters were divided in half and extracted in an ultrasonic bath with 20 ml of nanopure water for 30 min for the determination of water soluble ions. The instruments used were two Metrohm 761 Compact ICs for anions and cations, respectively. For the analysis of anions a Metrosep A Supp5 column was used, with isocratic elution with 0.7 ml min$^{-1}$ of Na$_2$CO$_3$/NaHCO$_3$ as eluent. For the analysis of cations a Metrosep C4 column was used, under isocratic conditions with HNO$_3$/dipicolinic acid eluent and flow rate of 0.9 ml min$^{-1}$.

3 Results

The ATR spectra of size-segregated aerosol collected using the MOUDI impactor close to the wildfire during the first 24 hours and in the center of the city during the first four days after the wildfire start are shown in Fig. 1. The spectra are characterized by the spectral fingerprints of alkane groups (~2920 cm$^{-1}$), organic hydroxyl groups (~3350 cm$^{-1}$), carboxylic acids (~1720 and ~2800 cm$^{-1}$), primary amines (~1625 cm$^{-1}$) and carbonyl groups (1720 cm$^{-1}$). The assignment is in agreement with that of Kostenidou et al. (2013). It seems that the spectra of aerosols with size up to 2.5 μm are dominated by carboxylic acids and primary amines, while organic hydroxyl and carbonyl groups characterize the spectra of the coarse particles. On the other hand, the spectra from the center of the city, which correspond to total PM$_{2.5}$, are similar to that of the higher stages of the impactor in ICE.

![Fig. 1. (a) ATR spectra of aerosol collected using MOUDI impactor in ICE close to the wildfire on 18/7/2012 (b)ATR spectra of aerosol collected in the center of the city during the first four days after the wildfire start.](image-url)
Fig. 2 shows the ATR spectra of aerosol emitted from olive tree branches burning only, biomass burned in Mexico and the forest fire near the city of Patras. The biomass burning spectrum has higher organic hydroxyl group and lower carbonyl group concentration compared to that of olive tree branches burning. The spectrum of the forest wildfire exhibits an intermediate behavior between the other two cases. This is reasonable if we take into account the fact that the specific forest includes a significant number of olive trees. Differences in the alkane group spectral region are expected since the biomass burned in Mexico did not include olive trees.

The volume and the number time series from the SMPS in the center of the city exhibit unusual behavior for the specific period, which is attributed to the adjacent fire. The decay of the values after the first day is due to the increase of the wind velocity and change of the wind direction in the opposite direction.

![ATR spectra of aerosol emitted from olive tree burning, biomass burning and forest burning for comparison.](image)

The composition estimated based on the FTIR analysis is presented in Fig. 4 and indicates that the forest burning organic aerosol is composed of 1.4% alkane groups, 59.1% organic hydroxyl, 3.7% primary amines, 33.1% carboxylic acid and 2.8% carbonyl groups. The correspond values of olive tree organic aerosol are 48.7%, 28.1%, 9.7%, 10.3% and 3.2%, respectively (Kostenidou et al. 2013). The trend in olive tree is Alkanes>organic hydroxyls>carboxylic acids>primary amines>carbonyl groups, while in forest burning is organic hydroxyls>carboxylic acids>primary amines>carbonyl groups>alkanes. The ratio of alkane/hydroxyl is dependent on the ratio of wax-oil/cellulose for terrestrial plants.

![Volume and number time series for the four first days of the wildfire in the center of the city.](image)

From the chromatographic data we can estimate the acidity of the atmosphere of Patras in the time period of interest. The aerosol was close to neutral (close to the 1:1 line). The results are in a good agreement with the corresponding chromatographic ones supporting the use of the
ATR technique for the identification and/or quantification of organic groups on aerosols collected on PTFE filters.

Fig. 4. Acidity plot based on chromatographic and spectral data. Chemical composition percentages of the organic aerosol emitted by olive tree burning and forest wildfire.

4 Conclusions

A method for determining the loadings of organic functional groups in size segregated aerosol has been presented. The aerosol samples collected during a forest wildfire near the city of Patras are analyzed using ATR spectroscopy. The resulting PM spectra of tree branches burning, biomass burning in Mexico and forest burning in Greece exhibit clear differences. Complementary field measurements from the center of the city show the differences between the PM composition for a site affected by biomass burning and one that is not affected.

Acknowledgments

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References

Athens cloudiness index variability and correlation with main teleconnection indices

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The historical observations of cloudiness amount since 1900 from the archives of the National Observatory of Athens were used in order to investigate the inter-annual variability of cloudiness in Athens. Advanced spectral analysis applied in order to resolve climatic from random variability. Both the winter and the annual cloudiness time series were studied. The effect of the teleconnection indices (NAO, EA, EA/WR and SCAND) on the cloudiness climatic dynamics was also investigated. Results show that Athens cloudiness climatic variability is controlled by a strong non-linear term plus intermittent oscillatory modes (at 2.4 yrs, 4 yrs and 7.8 yrs). A discontinuity in the mean was also detected at about 1959–1961. The annual cloudiness found to be anti-correlated with the NAO index, while a more complex correlation regime found between winter cloudiness and NAO and an in-phase correlation with the SCAND index.

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1 Introduction

Clouds have a direct effect on dynamic and thermal processes of the climatic system as they control radiative balance on the earth. Percentage of total cloud cover and different types of clouds are related to precipitation and other climatic indices. Moreover, cloudiness has a dominant role in the feedback mechanisms and constitute a large source of uncertainty of climate models. It is thus essential to study variation and trends of cloudiness (amount and type) and enhance our understanding on this climatic variable. Recent studies report mixed spatial and temporal tendencies on cloudiness variability worldwide depending on the period and the database used (Zong et al. 2013). Other studies detect significant correlations between total cloud cover and large scale atmospheric anomalies (Chernokulsky et al. 2013). The present study examines the multi-year variability of total cloud cover in Athens since 1900 and explores its correlation with known teleconnection indices.

2 Data and Methodology

The daily cloudiness amount from the archives of the National Observatory of Athens (NOA) is used in this study in order to compose the annual and the winter total cloud cover time series, $TCC_A$ and $TCC_W$ respectively, since 1900. Cloudiness index is defined as the total cloud cover in octas. Cloud cover reports at NOA until February 1951 were available in tenths and thereinafter in octas. Cloudiness before February 1951 were thus reduced to octas. Homogeneity/discontinuity of both $TCC_A$ and $TCC_W$ series was tested through the SNHT (Standard Normal Homogeneity Test – Alexandersson, 1986), Buishand (1982), and Pettitt (1979) tests and long term, as well as partial linear trends, were computed. Following Ghil et al. (2002), the search of the variability modes in the $TCC_A$ and $TCC_W$ series was attempted using three spectral analysis methods, able to resolve the statistically significant non-linear and intermittent oscillatory terms (climatic signal) out of the random variability (noise) of the climatic system. The revised Multi-Taper method or MTM (Mann and Lees 1996), the Singular Spectrum Analysis method or SSA (Allen and Smith 1996) and the Continuous Wavelet Transform or CWT (Torrence & Compo 1998) were applied for an efficient resolution of the climatic signal from noise. Non-linear trends and the so-called “slow” components (T-EOFs associated with very low frequency oscillations and/or non-linear trends that reveal less than two zero crossings) are also resolved. In consequence, the Reconstructed Components (RCs) corresponding to the significant temporal empirical orthogonal functions (T-EOFs) was computed in order to recompose the estimated non-stochastic part of each series, that is, the climatic signal in Athens cloudiness variability.

3 Results

As can be seen in Fig.1, the annual $TCC_A$ series reveals a long term increase of cloudiness equal to 0.0103 yr$^{-1}$ (1.3% /decade). A similar positive trend equal to 0.0071 yr$^{-1}$ (0.9% /decade) is detected in the winter $TCC_W$ series ($p$-value < $10^{-4}$ for both series).

All the applied homogeneity tests detected the existence of a break point, at 1961 in the annual series (or at 1953 according to Pettitt’s test) and at 1959 in the winter series (or at 1961 according to SNHT), with $p$-values$<10^{-4}$. By considering that the observed time series does not suffer from inhomogeneities related with station relocations (as NOA station is permanently established at its present location in Athens, since 1890), or changes in the observational practices, it is estimated that the detected discontinuity is due to a climatic regime shift in cloudiness. Cloudiness reports worldwide usually suffer from some kind of subjectivity. A change in the observational practice of cloudiness at NOA is only reported in February 1951, when the scale of cloud cover changed from tenths to octas. Necessary reduction was performed to the data to account for this change. The shift in the cloudiness
index at NOA is detected later on and is not supported by any known artificial change according to metadata information. Similar increase of cloud cover around 1960’s is reported in other regions of Europe e.g. Spain (Sanchez Lorenzo et al 2012). Remarkably, the increase rate in the annual series $\mathcal{TCC}_A$ does not reveal any significant change across the regime shift, as it varies from 0.0071 yr$^{-1}$ prior 1961, to 0.0075 yr$^{-1}$ after 1961. However, in the winter series $\mathcal{TCC}_W$, the positive 0.0054 yr$^{-1}$ (p-value = 0.076) trend prior 1959, actually neutralizes after 1959, as it becomes equal to −0.0017 yr$^{-1}$ (p-value = 0.72). This change is also apparent in the non-linear trend RC-1 of the winter cloudiness series (depicted by the orange line in Fig.1). The MTM, SSA and Wavelet spectra of Athens annual and winter total cloud cover series are shown in Fig.2.

Fig. 1. The annual and the winter cloudiness index in Athens (blue and black lines respectively) along with the linear trends (dashed lines). The long term non-linear trends (RC-1) detected by the SSA and the MTM method, are also shown by orange and green lines, respectively. Finally, the gray vertical lines mark the position of the detected regime shift in the cloudiness, while the small orange arrows indicate the mean levels for each sub-period.

Fig. 2. (a) : The MTM (green line) and SSA (blue line) spectra of the annual series $\mathcal{TCC}_A$, with the 95% confidence level of the red noise estimation (indicated by the orange dashed lines for the MTM and by the 2.5th and 97.5th red noise percentiles for the SSA spectra). (b) : The Wavelet spectrum of the $\mathcal{TCC}_A$ series, with statistically significant regions indicated by heavy black lines. (c) & (d) : As in (a) & (b), but for the winter total cloud time series, $\mathcal{TCC}_W$.

Results show that both the $\mathcal{TCC}_A$ and $\mathcal{TCC}_W$ series are composed by:
(i) A strong long-term non-linear trend (depicted in Fig.1 by RC-1) that accounts for 57% of variability in $\mathcal{TCC}_A$ and 21% in $\mathcal{TCC}_W$, plus
(ii) An intermittent oscillatory term at 2.2–2.4 yrs, significant at the 95% confidence level. In the winter series two extra oscillatory terms are found, at 4.4–4.6 yrs and 7.5–7.8 yrs, but significant at a lower confidence level (90%).
The associated reconstructed components are depicted in Fig.3. Additional slow-trend T-EOFs with apparent periodicities at 43/53 yrs (accounting for 14% / 11% of variability) are detected in the annual/winter series by SSA alone.

![Fig. 3. (a) The 2.2 yrs SSA RC of the annual cloudiness series TCCa. (b) & (c): The 4.4 yrs MTM RCs and the 7.8 yrs SSA RC of the winter cloudiness series TCCw. (d) The period of maximum wavelet power of the 7–8 yrs oscillatory component (red line), along with the corresponding maximum power values (blue line, scale on the right).](image)

The Wavelets spectral counterparts of the aforementioned terms are depicted in Figs.2b,d. These spectra refer to the detrended series (by the RC-1 non-linear trend). As a consequence, the power and statistical significance of mid-scale terms at 7–8 yrs, are upgraded compared to MTM and SSA results. The lack of significant features in the 9–25 yrs range, becomes more apparent in the Wavelets spectra and distinguish two bands of variability modes in the annual/winter cloudiness: (a) The band of sub-decadal modes that includes the 2.2–2.4 yrs, 4.4–4.6 yrs and 7–8 yrs oscillatory terms, and (b) the band of interdecadal modes that includes all the detected slow oscillatory terms (with periodicities longer than 25 yrs) plus the non-linear trend RC-1.

The possible correlation of the Athens cloudiness variability with the main teleconnection patterns of anomalous pressure distribution, namely the North Atlantic Oscillation (NAO), the East Atlantic (EA), the East Atlantic / Western Russian (EA/WR) and the Scandinavia (SCAND), is searched by us using Squared Wavelet Coherence (or SWC; Grinsted et al. 2004). The regions of high local cross-correlation and the phase difference $\delta \phi$ between two oscillators are revealed in this way in the time-frequency space. The winter and annual values of the EA, EA/WR and SCAND indices adopted from NOAA Climate Prediction Center (www.cpc.ncep.noaa.gov), while the zonal averaged index NAOI, defined by Li and Wang (2003), adopted for NAO.

![Fig. 4. (a) Squared Wavelet Coherence between the annual $TCC_a$ and NAOI series. Arrows mark phase difference according to the following scale. $\rightarrow$ : 0°, $\downarrow$ : 90°, $\leftarrow$ : 180°, $\uparrow$ : 270°. Statistically significant correlation regions at the 95% confidence level, are also indicated by the black lines. (b) As in (a) but for the winter (DJF) cloudiness and SCAND series.](image)

NAO is well known to influence the precipitation, cloudiness and temperature anomaly variability patterns in Europe and the Mediterranean, by significantly affecting westerlies strength, the depression trajectories and activity over these areas (e.g. see Hurrel and van Loon 1997, Wanner et al. 2001, Lolis 2009). When NAO is in a positive mode, Southern Europe
and Mediterranean experiences lower than usual cloudiness and precipitation, while the opposite is valid when NAO is in a negative mode.

Results reveal an almost exact anti-correlation (180° phase difference) of TCCA and NAOI annual series (Fig. 4a) in various temporal scales. Significant (at the 0.05 level) intermittent anti-correlation is mainly detected at the short (2–3 yrs) and mid (6–10 yrs) scales, while a steady anti-correlation is detected across the entire observations interval (1900-2012) for the scales longer than 30 yrs. However, a low-correlation interval is observed between 1950 and 1975, that almost coincides with the 25-yrs period (early 1950s to mid-1970s) where NAO was at a persisting negative phase. Concerning the winter series, two different correlation epochs were found: One prior 1955, where a tendency of positive correlation is detected (0°≤δφ≤90°) in mid and short scales (2–8 yrs), and a second epoch after 1960 (almost at the regime shift time), where an anti-phase (negative) significant correlation progressively establishes in a broadening band of scales (not shown).

Apart from NAO, Athens cloudiness was found to be positively correlated with the SCAND index, although no steady phase relation was found in the annual series. However, the winter SCAND and TCCW series exhibit a nearly steady in-phase significant (at the 0.05 level) correlation in the periodicity scales shorter than about 14 yrs, after 1958 (Fig.4b). In the scales longer than 14–16 yrs, δφ increases rather suddenly from 0° to 90° along the entire observations interval, possibly indicating driving of a different climatic process.

Finally, apart from NAO and SCAND no other significant and phase consistent correlation was found to exist between Athens cloudiness and EA or EA/WR indices.

4 Conclusions

Athens cloudiness, as described by the total cloud cover time series of the period 1900-2012, reveals a significant variability, which in the long-scale is dominated by a positive trend of 0.0103 yr−1 (1.3% /decade). A climatic regime shift found about 1959~1961, split the series in two sub-periods, each one characterized by more moderate positive trends (0.0071–0.0075 yr−1). The winter series reveals a similar positive trend before 1960, which however seems eliminate after 1960.

Climatic signal detection spectral methods show that apart from the long-term positive trend, there are three more variability modes in Athens cloudiness: one oscillatory at 2.2–2.4 yrs (significant at the 95% confidence level) plus two similar modes at 4.4–4.6 yrs and 7.5–7.8 yrs (but significant at a lower confidence level, of 90%).

Athens cloudiness was found to be anti-correlated with NAO across the observations interval. However, a more complicated correlation regime is detected between NAO and winter cloudiness, where positive correlation prior 1955 changes to negative, after 1960. At about the same time, a significant positive correlation is established between winter cloudiness and the SCAND index.

References


Atmospheric ion observations related to new particle formation in the atmosphere of Eastern Mediterranean

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At the environmental research station of the University of Crete at Finokalia, atmospheric ions were monitored as part of the FRONT project. The mobility distributions of air ions in the range between 3.2 and 0.0013 cm$^2$V$^{-1}$s$^{-1}$ were monitored continuously with 5 min resolution using an Air Ion Spectrometer (AIS) and were then transformed to size distributions in the size range 0.8-42 nm. AIS provided supplementary data to the mobility sizer (SMPS) of the Finokalia station for diameters smaller than the detection limit of the SMPS (9nm) and thus, the evolution of nucleation phenomena could be observed from the initial steps. Despite the fact that the Finokalia station is located in an area where the intense photochemistry leads to the production of high concentrations of sulfuric acid, the necessary compound for triggering atmospheric nucleation, new particle formation at Finokalia has been found to be less frequent than in most other locations across Europe. The present study focuses on the conditions that either favour or suppress nucleation and, along with earlier observations provides, a data base in an area with few observations, regional importance and unique characteristics. One of the main characteristics discussed is the presence of negative ion clusters at night during periods that nucleation is favoured at Finokalia.

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1 Introduction

Air ions are divided with respect to their size to into small ions (d<1.6 nm) that are basically charged molecules or molecular clusters, and intermediate (>1.6 nm and <7.4 nm) and large ions (>7.4 nm), representing charged aerosol particles. Small air ions are always present in the atmosphere and their natural sources are mainly ionization by radon decay, gamma and cosmic radiation (Bazilevskaya et al. 2008). For the marine environment cosmic rays play the most important role. Intermediate ions appear only under certain circumstances such as precipitation occurrence, high wind velocities and new particle formation processes (Hõrrak et al. 1998). During new particle formation events intermediate ions are produced either directly or by attachment of pre-existing ions onto neutral newly formed particles. Although ion induced nucleation is now quite certain that is of limited importance in the troposphere (Hirsikko et al. 2011), the study of new particle formation events with the use of ion mobility spectrometers provides valuable information at the actual sizes that these processes are taking place and can provide also information on the chemistry of these events and eventually the potential role of ions. With the use of ion spectrometers it was possible to observe night-time nucleation (Junninen et al. 2008) and prove that the mechanisms for nucleation and the subsequent growth of atmospheric particles are different between day and night.

During EUCAARI project (Manninen et al. 2010), the Finokalia site was found to have the second lowest nucleation event frequency among 12 European sites (Pallas in the Arctic Circle was the least frequent). The fact that this site was the southernmost during the campaign, with obviously more intense photochemical activity, and nonetheless nucleation was observed less frequently especially during summer, was the motivation for the FRONT follow up project.

2 Data and Methodology

Measurements took place at the Finokalia environmental research station of the University of Crete which is located at a remote site on the north-eastern coast of the island of Crete, Greece (35° 20’N, 25° 40’E, 250 m asl). The nearest urban center is Heraklion with 170 000 inhabitants, 50 km west of Finokalia and only minor agricultural activities take place in the area. The climatology of the area is characterized by the existence of two distinct seasons equally distributed throughout the year, the dry season (from April to September) and the wet season (from October to April). Atmospheric composition over the Finokalia station is strongly affected by long-range transport processes, from the urban and industrial centers of Europe and Asia, the arid areas of Northern Africa and the Mediterranean Sea itself. The Finokalia station is a European supersite for aerosol research, part of the ACTRIS (Aerosols, Clouds, and Trace gases Research Infrastructure) Network.

The data presented were collected during two distinct periods as part of the EUCAARI (April 2008 – April 2009, Manninen et al. 2010) and FRONT (December 2012-December 2013) projects. The mobility distributions of air ions in the range between 3.2 and 0.0013 cm²V⁻¹s⁻¹ were monitored continuously using an Air Ion Spectrometer (AIS) and were then transformed to size distributions in the size range 0.8-42 nm. The number counting threshold was approximately 10 cm⁻³ and the uncertainties of the AIS measurements were ~10% for negative and positive ion concentrations and ~0.5 nm in size. The diameter of the AIS inlet tube was 35 mm and the sample flow rate was 60 lpm. Aerosol number size distributions at the Finokalia station were measured with a custom built, Scanning Mobility Particle Sizer (SMPS) in the size range 9-848 nm. Ozone concentrations were measured using a Thermo Electron 49C ozone monitor. All data were collected with a 5 min resolution.
3 Results

At the Finokalia station new particle formation has been found to be a reoccurring phenomenon as reported in earlier studies (Manninen et al. 2010, Kalivitis et al. 2012) and confirmed in FRONT project. A typical nucleation event is presented in Fig. 1 as recorded by the AIS and SMPS systems. It can be observed that the sum of number concentrations of ions for both polarities cannot explain the observed numbers of the nucleated particles. However, the AIS observations provide valuable information about the early stages of the nucleation process, the event is captured since the very beginning (ca 9 am) while the available SMPS detected the new particle just after noon. This is not a typical banana shaped event, since the particles did not survive enough to grow to the Aitken/accumulation mode diameters, probably due to their removal from the atmosphere via precipitation. By comparing the observations for the two polarities, the most striking difference is seen in the size range of 1.25 – 1.66 nm, the sizes representing the upper limit of the preexisting small ion pool. For the negative polarity an apparent growth is evident accompanied by a simultaneous increase in the ion concentration, which is not observed for the positive ions. A detailed description of such events and their dependence on meteorological parameters can be found in (Kalivitis et al. 2012). A strong anti-correlation was found with the preexisting particles coagulation sink and almost half of these events were associated with new particle formation in the following or preceding day. Recent advances in the research of secondary formation mechanisms (Ehn et al. 2014) led us to reexamine these events and look further in the possible role that they might hold. (Lehtipalo et al. 2011) showed that similar events in a Boreal environment site (Hyytiälä, SMEAR II station) are seen equally frequently for neutral particles, and that they have a clear connection to oxidized organic molecules. (Ehn et al. 2010) observed that nighttime negative ion spectrum in the same environment contains highly-oxygenated organic acids, possibly from the oxidation of monoterpenes and only recently the same group (Ehn et al. 2014) showed that chemistry driven by other than ·OH oxidants such as ozone and ·RO₂, result to the production of highly oxygenated extremely low-volatility organic compounds (ELVOC) that could condense irreversibly onto aerosol surfaces and help explain the observations of atmospheric nucleation processes.

Fig. 1. Nucleation event observed at Finokalia on 2 December 2012 as captured by AIS (left panels for negative and positive polarity) and SMPS (right panel)

A more careful look in the frequency of occurrence of these events showed that during periods that nucleation events were taking place, this night-time appearance of ions was systematic. An example of a period favoring nucleation at Finokalia in March 2013 is demonstrated in Fig. 2. During four days that increase of the small ion concentrations was observed, three nucleation events were recorded and the average ozone concentration was 44 ppbv.
Fig. 2. Days of consecutive nucleation days at the Finokalia station in March 2013 as captured by AIS (left). At the negative ions size distribution evolution, night-time humps at the upper sizes of the small ions mode (Dp<1.6nm) can be observed (bottom panel). At the right panel time evolution of ion cluster number concentration in the size range 1.25-1.66 nm and ozone concentration.

If indeed these ions correspond to ELVOC molecules, then the concentrations are comparable to the ones reported by (Ehn et al. 2010) at the SMEAR II station. At the Finokalia site, it has already been shown that oxygenated organic aerosols with O:C ratio reaching up to 0.8 are present (Hildebrandt et al. 2010), however further studies are needed to confirm the composition of these ions.

4 Conclusions

At the Finokalia environmental research station of the University of Crete continuous measurements of atmospheric ions and aerosol particles confirmed that new particle formation events are common in the Eastern Mediterranean troposphere. The use of ion spectrometers (AIS) has given us the chance to observe such events since the very early stages. As shown in an earlier study during night-time, ion clusters can be produced and they are frequently associated with day-time particle nucleation events. These ions may reflect the presence of ELVOC molecules that as recently has been proposed may play a critical role in the formation of SOA. We have demonstrated the presence of negative cluster ions during periods that nucleation is favoured that have been associated with oxygenated organics at other sites. The proposed oxidation schemes of monoterpenes via ozone and ·RO2 radicals at night leading to the formation of ELVOCs is highly possibly to take place at Finokalia, where average annual concentrations of ozone are 50 ppb.

Acknowledgments The research project is implemented within the framework of the Action «Supporting Postdoctoral Researchers» of the Operational Program "Education and Lifelong Learning" (Action’s Beneficiary: General Secretariat for Research and Technology), and is co-financed by the European Social Fund (ESF) and the Greek State. This research is supported by the Academy of Finland Center of Excellence program (project number 1118615).
References


Simultaneous gas and aerosol measurements at Santorini and Finokalia during Etesians

Kalkavouras P., Bezantakos S., Bossioli E., Stavroulas I., Kouvarakis G.N., Protonotariou A.P., Dandou A., Biskos G., Mihalopoulos N., Tombrou M.

The size distribution of aerosols and the chemical composition of airmasses during the Etesians (July, 2013) are examined by analyzing short-term ground level measurements at a remote, coastal site at Santorini and at the monitoring station of Finokalia, Crete. This combination of locations allows investigation of the history of the monitored air masses at Finokalia, as Santorini Island is located upstream of Finokalia, in the central Aegean Sea. Concentrations of gaseous pollutants (O$_3$, NO$_x$, SO$_2$), the number size distribution of fine and coarse aerosol particles with diameter from 10 to 500 nm for Santorini and from 10 to 800 nm for Finokalia (measured with an SMPS) and their chemical composition were measured. O$_3$ concentrations exhibit a very similar pattern at both stations, with values between 50 and 60 ppbv, when the wind speeds were higher, while they exceeded 90 ppbv at both stations, when the wind became lower. Preliminary results of the aerosol mass measured at Finokalia follow the temporal variation of gaseous species. The total number concentration of the particles was up to 7x10$^3$ at Finokalia and 1.4x10$^4$ particles cm$^{-3}$ at Santorini. Most often the particles were observed in the Aitken and accumulation mode, but on the beginning of the elevated O$_3$ and secondary aerosols concentrations, ambient particle number increased and new particle formation events have been observed at both locations.

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1 Introduction

During the Etesians, high concentrations of gaseous pollutants and aerosol particles are usually observed over the Aegean Sea (AS) as a result of the simultaneous contribution of local and distant sources and enhanced photochemical production (Kouvarakis et al. 2002, Salisbury et al. 2003, Kalabokas et al. 2008, Kanakidou et al. 2011). At the AS region, which is a relatively remote area, the concentrations are also characterized by high variability as a result of the large diversity of their sources and the different physicochemical processes they are involved in during their lifetime (Hallquist et al. 2009). During the recent Aegean-Game campaign, the airborne measured concentrations were substantially different between two Etesian days, despite the fact that their planetary boundary layer structures and in particular their wind flows at low altitudes, depicted very strong similarities (Tombrou et al. 2012, Bezantakos et al. 2013). An area with apparent concentration differences was over the maritime area between Crete and Cyclades, as it is also shown by Bossioli et al. (this conference).

To further understand the interconnection between the air masses passing through Cyclades and the Eastern Crete, the Santorini-Finokalia campaign was performed from 15 to 28 July 2013. During this campaign, continuous ground measurements of gaseous concentrations (i.e. O\textsubscript{3}, NO\textsubscript{x}), as well as the physical (i.e aerosol number size distribution) and chemical properties of the atmospheric particles, were measured.

2 Data and Methodology

Ground level measurements were conducted simultaneously at two remote coastal areas, from 15 to 28 July 2013: at Ag. Artemios on the island of Santorini (36° 26' N, 25° 26' E) and at the monitoring station of Finokalia on the island of Crete (35° 19' N, 25° 40' E). Ag. Artemios is located at an elevation of 153 m, while Finokalia on the top of a hill at 230m asl. Both measuring locations are far from any large city or anthropogenic sources. Both stations are facing the sea; Finokalia within a sector 270° to 90°, whereas the station on Santorini within a sector 340° to 120°. Finokalia monitoring station houses a suite of instruments for measuring the meteorological parameters, the concentrations of gaseous species, as well as the physical properties and chemical composition of atmospheric particles. The measurements at Santorini were performed only for this campaign and included: a Scanning Mobility Particle Sizer (SMPS) and an Optical Particle Counter (OPC) to measure the size distribution of the particles having diameter from 10 to 500nm and from 300nm to 20μm, respectively. Gas phase concentrations were also measured using standard gas analysers, a Thermo Electron (TE) photometric analyser for ozone (O\textsubscript{3}) and dual channel chemiluminescence analyser for nitrogen oxides (NO\textsubscript{x}) and sulfur dioxide (SO\textsubscript{2}).

Complementary to the measurements, we provide calculations of the flow patterns and the chemical composition of the atmosphere, by the on-line air quality model WRF-Chem (version 3.2). The numerical simulations were performed by applying triple nesting: a) the first domain covers the extended area of Europe (spatial resolution 0.5°×0.5°), b) the second nested domain covers the extended area of Greece and Italy (0.167°×0.167°) and c) the third is centered on the extended area of Greece (0.056°×0.056°). Simulations were performed from 12/7-29/7/2013. The chemical mechanisms considered are RADM2 for gaseous chemistry and the MADE (inorganic)/SORGAM (organic) approach for aerosols. MADE/SORGAM in WRF-Chem uses the modal approach (nuclei, accumulation, coarse). The EMEP database was used for anthropogenic emissions for Europe (first and second domains) while for Greece (third domain) a national emission inventory was used. Natural (biogenic and sea-salt) emissions are on-line calculated within WRF-Chem model.
3 Results

3.1 Atmospheric conditions

During almost the whole period of the campaign, the measured winds exhibited a northern direction, with speeds exceeding 10ms$^{-1}$ at Santorini airport during the day, which are representative of Etesians (Brody and Nestor 1985, Kotroni et al. 2001). From this campaign, two distinct periods (A, B) with different characteristics, were detected. In period A (22 and 23 July) the measured wind speeds reached up to 13ms$^{-1}$ (in Santorini) with $O_3$ concentrations ranging between 50 and 60ppbv at both stations, while in period B (25-27 July) the wind speeds were about 10ms$^{-1}$ at the same station, with $O_3$ concentrations exceeding 70ppbv. In this particular study, the results are presented for days 23 and 26 July, representative for periods A and B.

Indicatively, Figure 1 shows the simulated spatial distributions of $O_3$ concentration together with the wind fields at 101m asl, for both days. On 23 July, the wind speeds are high over the northern and central AS (>11m s$^{-1}$) and decelerate over the southeastern AS, but they remain strong (>8m s$^{-1}$) with northwest direction, forming the characteristic 'ring-shape' of the Etesian flow around Turkey (Tyrlis 2013). On 26 July, the wind flow becomes northwestern over the north AS, northern over central AS and northwestern over the southern AS, while the wind speed increases gradually from north to south ranging from 4 (around Lemnos) to 8-12m s$^{-1}$ over the southeastern AS. This wind flow seems to form a weak Etesian pattern confined at the southeastern AS, due to the moving of the mean sea level pressure gradient towards southeast. For both days, the analysis of the omega fields shows subsidence that provides favorable conditions for stratospheric intrusion. In particular, for day 26 the subsidence reaches values up to 8Pa min$^{-1}$, over the western part of Greece.

3.2 Gaseous Concentrations

The temporal evolution of the measured and simulated $O_3$ concentrations at both stations is presented in Figure 2. There is a similar trend between the observations at the two stations. Until 24 July the $O_3$ concentrations range between 30 and 64ppbv at Santorini and between 46 and 71ppbv at Finokalia. On 23 July, both stations exhibit low $O_3$ concentrations due to the higher wind speeds (Fig. 1). An interesting feature is that at Santorini $O_3$ titration during the night is much more intense in relation to Finokalia station indicating more local sources near Santorini diluted to a shallower marine boundary layer.

The analysis of observations and modeled results (Fig. 2) indicate that there is a substantial increase of $O_3$ concentrations at both stations during period B, however, the simulated concentrations are continuously underestimated. In particular, on 26 July, the observed concentrations reach up to 90ppbv at both sites, while the simulations do not exceed 70ppbv. Furthermore, in contrast to the previous days, the two stations agree on the diurnal ozone variation and particularly on the minimum $O_3$ values recorded. This marked enhancement is the result of the combined effect of favorable atmospheric conditions inside the PBL (lower wind speeds in central and western Aegean, as the result of subsidence), medium-long range transport above the PBL and possibly reception of polluted plumes from northern latitudes. According to the HYSPLIT model, both stations receive the same plumes, which have travelled at low altitudes through polluted areas during period B. Furthermore, according to Terra/MODIS Fire and Thermal Anomalies product (https://earthdata.nasa.gov/labs/worldview/), on 25 July several fire spots along the central Aegean were detected while some of them persisted until 27 July. It should be considered that NO$_2$ tends to increase during the period B at both stations (not shown). In particular, the increase of NO$_2$ concentrations at Santorini was by a factor of 1.5-2 in relation to the previous days (not shown), a fact that supports the $O_3$ enhancement recorded in the NO$_x$-limited Aegean environment. During these
days the air masses reaching Santorini station are more aged and photochemically active compared to period A, as it is supported from the O₃ to NO₂ correlation. The model’s underestimation regarding O₃ is probably associated with limitations of the RADM2 mechanism and also ignorance of fire emissions.

![Image](image1)

**Fig. 1** Spatial distribution of modeled O₃ (ppbv) concentrations on 23 (left) and 26 (right) July 2013 at 15:00 UT. The spatial distribution of the wind flow is also presented.

![Image](image2)

**Fig. 2** Temporal evolution of measured and modeled O₃ concentrations at both stations (left) and similarly for SO₄ (right). Measurements (preliminary results) for SO₄ were performed only at Finokalia station. Ticks correspond to 00:00LST.

### 3.3 Aerosols and particle size distribution

The mass of aerosols measured at Finokalia (data not shown) follow the temporal variation of gaseous species. During period A, the concentrations range between 2 and 7μg m⁻³ for organics, between 1.5 and 5.0μg m⁻³ for sulfates and between 0.5 and 3.0μg m⁻³ for ammonium. The aerosol mass concentrations were higher during period B, ranging between 6.5 and 11μg m⁻³ for organics, between 3 and 10μg m⁻³ for sulfates, and 1.5 and 4 μg m⁻³ for ammonium. The increased concentrations persist until the noon of 27 July for sulfates, nitrates and ammonium while organics continue to remain enhanced until 30 July. The nitrates’ increase after 25 July may be related with the increased NOₓ concentrations observed at Santorini and their oxidation. Figure 3 presents the spatial distribution of the predicted sulfates on 23 and 26 July. The model reproduces the sulfates’ increase during the second period with average concentrations over the southern and central Aegean of the order of less than 2 μg m⁻³ on 23 and 5 μg m⁻³ on 26 July. For organics, a clear model underestimation is evident for all days mainly due to limited treatment of anthropogenic/biogenic VOC oxidation (not shown).

The temporal evolution of size distributions of PM1, is shown in Figure 4. The mean hourly total number concentration of the particles varied from ca. 9x10⁵ to 1.4x10⁷ particles cm⁻³ at Santorini and 1.7x10⁵ to 7x10⁵ at Finokalia. Most often the particles were observed in the Aitken and accumulation mode at both sites. Nucleation events have been also observed at both stations, but mainly at Santorini. On 23 July (period A), prior the elevated O₃ and secondary aerosols concentrations, ambient total particle number increased up to 7x10³ cm⁻³ and 14x10³ cm⁻³ at Finokalia and Santorini respectively. The fraction of particle number concentrations smaller than 25 nm was up to 85% at Santorini and up to 20% at Finokalia. This regional event appeared at 07:30LST and lasted until 14:00LST at Santorini, while it reached
Finokalia with a time lag (from 09:00LST until 15:00LST). This event coincides with the NOx increase at Santorini station (not shown) probably reflecting primary pollution reaching the area. On 26 July when the wind speeds were substantially lower with north western directions, both stations exhibit particles having diameter above 100 nm. The precursor species responsible for new particle formation events in coastal areas is still under investigation. Apart from iodine-containing species, increases of sulfuric acid (Lee et al. 2008), SO2/NO2 concentrations (Ulevicius 2002) and organic vapors, have been related to new particle formation events in marine environments.

Fig. 3. Spatial distribution of modeled SO4 concentrations on 23 (left) and 26 (right) July 2013 at 15:00 UT.

Fig. 4. Temporal evolution of particle size concentration distribution for Santorini (left) and Finokalia (right).

4 Conclusions

During our Santorini-Finokalia campaign, O3 concentrations exhibited a very similar pattern at both stations. The values ranged between 50 and 60ppbv, when the wind speeds were higher, while they exceeded 90ppbv at both stations when the wind speeds became lower. Preliminary results of the aerosols mass measured at Finokalia follow the temporal variation of gaseous species. Lower concentrations (2 -7 μg m^-3 for organics, 1.5-5μg m^-3 for sulfates and 0.5-3μg m^-3 for ammonium) correspond to period A, while the concentrations increase during period B (6.5-11μg m^-3 for organics, 3- 10μg m^-3 for sulfates, and 1.5-4 μg m^-3 for ammonium). The simulated concentrations are continuously underestimated, for both gases and aerosols. At both stations, the total number concentration of the particles having diameters from 10 to 500nm for Santorini and from 10 to 800nm for Finokalia varied from ca. 7x10^2 to 1x10^7 particles cm^-3. Most often the particles were observed in the Aitken and accumulation mode, but during the beginning of the elevated O3 and secondary aerosols concentrations, ambient particle number increased at both stations and new particle formation has been observed (nucleation mode).
References

Different approaches for the study of extreme events in atmospheric and wave data

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Within a complex and competitive framework set by today’s research and operational activities in environmental sciences, atmospheric and sea state data sets of high accuracy are required along with statistical analysis beyond the conventional standards. In particular, the credible evaluation of potential non-frequent/extreme values for environmental predictions is of critical importance for a number of applications, including renewable sources siting and operations, marine applications, offshore activities, transportation and other activities.

In the present work, a multi-parametric approach to this issue will be discussed based on a variety of numerical and statistical tools. High resolution numerical atmospheric and wave models in conjunction with advanced statistical tools will be employed leading to a number of criteria/tools for the estimation of extreme environmental conditions with emphasis to wind speed and wave height.

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1 Introduction

The credible estimation of extreme conditions, for atmospheric and sea state parameters, is of great importance due to the corresponding impact on the majority of onshore/offshore activities and structures (Caires and Sterl 2005). In this work three different statistical approaches for monitoring and predicting non-frequent wind and wave conditions are proposed and applied to sites located in Crete, Greece. Atmospheric and sea state data from high resolution hindcast modeling are utilized for the estimation of the likelihood, magnitude and the return period of extreme wind speed and wave height conditions. The analysis performed reveals the complexity of the issue and the advantages of a multi-parametric approach. It is pinpointed that key factors for estimating possible extreme values are the optimal choice of the theoretical distribution for the met-ocean data under study and the combined use of multiple statistical indices over extended datasets.

2 Data and Methodology

Targeting to the estimation and analysis of extreme values, high resolution numerical atmospheric and wave models have been utilized in conjunction with statistical techniques. In particular, different approaches have been applied to significant wave height and wind speed data aiming to define the theoretical distribution that optimally describe them and to give estimations of different statistical indices that characterize potential extreme values.

2.1 High Resolution Dataset-Numerical Models

The met-ocean data used in the present study have been derived from a 10-year high resolution wind-wave database set up by the Atmospheric Modeling and Weather Forecasting group (AM&WFG) of the National and Kapodistrian University of Athens (NKUA) in the framework of the FP7 project MARINA Platform. It is the outcome of state-of-the-art atmospheric and wave modeling systems operated in a hindcast mode for the years 2001 to 2010 on collocated high resolution grid (5x5km) for the entire European region, providing wind-wave parameters with a 1-hour time frequency.

For the simulation of the atmospheric circulation the SKIRON modeling system has been utilized. SKIRON is based on the ETA/NCEP model and has been further developed by AM&WFG in the framework of the national funded project SKIRON and the EU funded projects MEDUSE, ADIOS and recently CIRCE (Kallos et al. 1997). It is a full physics non-hydrostatic model with sophisticated convective, turbulence and surface energy budget scheme. The new SKIRON version, used for the development of the aforementioned database, incorporates a new processor that derives statistics for the slope steepness and orientation to describe more accurately the topographic variability. Moreover, a Rapid Radiative Transfer Model (RRTM) for both short-wave and long-wave bands has been also included in order to simulate the radiative transfer effects (Spyrou et al. 2013).

On the other hand, for the simulation of the wave fields, the wave model WAM has been adopted. WAM is a 3rd generation wave model that solves the wave transport equation explicitly without any presumptions on the shape of the wave spectrum. It represents the physics of the wave evolution and uses a full set of degrees of freedom of a 2-D wave spectrum. The version used in the present study is the ECMWF CY33R1 (Janssen 2000) where a number of improvements have been adopted. In particular, a new advection scheme has been implemented by the introduction of contributions from the corner points and a new parameterization of shallow water effects has been introduced. Moreover, two extreme wave parameters are simulated: the average maximum wave height and the corresponding wave period.
2.2 Statistical Approaches

The first statistical approach adopted is essentially based on the theoretical Probability Density Function (PDF) that optimally fits to the data under study. A variety of PDFs have been tested (Logistic, Normal, Gamma, Log-Gamma, Log-Logistic, Lognormal, Weibull, Generalized Logistic) by utilizing different fitting tests (Kolmogorov-Smirnov, Anderson-Darling as well as P-P and Q-Q plots). An estimation of extreme values is provided in terms of percentiles (e.g., 95th or 90th) of the obtained PDFs.

On the other hand, a direct extreme value theory is used based on the generalized extreme value (GEV) and the generalized Pareto distributions (GPD) (Jenkinson 1985, Coles 2001). The methodology is applied on datasets formed by selected maximum values, in order to estimate the return period of extreme events. The two methodologies employed in this paper are the Annual Maxima (AMM) and the Peak Over Threshold (POT).

The first method relies on the use of Gumbel distribution (GEV Type I) to fit the sample formed by preselected annual maximum values. This approach is valid for samples of at least 10 years/values length in order to reach reliable results (Cook 1985).

An alternative approach, leading to a considerably extended extreme value sample, is the peak over threshold (POT) method. Here the maximum dataset is selected by setting a separation interval between two consecutive events for independency and a threshold over which the events are considered as extremes. The obtained values are further analyzed using the exponential distribution (GPD Type I).

Both methodologies are utilized in this study to estimate the 50-year return period

3 Results

The techniques described above are used to estimate the extreme values for wind speed at 10m and significant wave at two sites: One onshore and one in an offshore area at the eastern part of Crete island, Greece. The first site is situated in Itanos region (Lasithi, P1) and the second in the sea area near Elounda (P2) (Fig.1). The data used for this analysis cover a 10 year (2001-2010) period from the high resolution database described in Section 2.1.

The PDF analysis of the full wind speed dataset at the P1 site indicates that the 95th percentiles derived from Weibull, Weibull 3P and Lognormal 3P range from 13.29 m/s to 14.11 m/s while Lognormal gives a rather elevated estimation, compared to the others, of 17.72 m/s (Fig. 4). Concerning the significant wave height values at P2 site, the 95th percentile range from 1.87 m to 2.20 m (Fig. 5).

![Fig. 4. Selected sites at the Eastern part of Crete Island. P1 is the onshore and P2 the offshore site illustrated along with their coordinates.](image)

Furthermore, an extreme value analysis was performed for the selected sites P1 and P2 using the AMM and the POT methods. Wind speed and significant wave height with return periods up to 50-years are derived and are presented in Fig. 2 and Fig. 3. More specifically, wind speed with a 50-year return period estimated by the POT method is slightly higher compared to that given by the AMM. However their confidence intervals overlap at least partly. As for significant wave height, AMM gives a value ~7.63m with a rather high uncertainty ~ 2.01m (26%) while POT provides an estimate of 7m height with a lower
uncertainty 0.80m (11%) (Table 1). The increased uncertainty in AMM is expected mainly due to the fact that this method is applied to small dataset (one value per year = 10-value dataset).

Fig. 2. Wind speeds at 10m (m/s) with return periods from 1 to 50 years along with their 95% confidence interval calculated with the Annual Maxima and the Peak Over Threshold methods.

Fig. 3. Significant wave height (m) with return periods from 1 to 50 years along with their 95% confidence interval calculated with the Annual Maxima and the Peak Over Threshold methods.

Fig. 4. The PDFs (Weibull, Weibull 3P, Lognormal, Lognormal 3P) that optimally fit wind speed at 10m for the P1 site in Crete, 2001-2010. For each theoretical distribution the shape, scale parameters and 95th percentile are presented.
The probability density functions (Weibull, Weibull 3P, Lognormal, Lognormal 3P) that optimally fit significant wave height for the P2 site in Crete, 2001-2010. For each theoretical distribution the shape, scale parameters and 95th percentile are presented.

Table 1. Wind speed and significant wave height with a 50-year return period as derived using the Peak Over Threshold (POT) and the Annual Maxima (AMM) methods.

<table>
<thead>
<tr>
<th>Methodologies</th>
<th>Wind Speed (m/s)</th>
<th>Significant Wave Height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMM</td>
<td>23.39±3.25</td>
<td>7.63±2.01</td>
</tr>
<tr>
<td>POT</td>
<td>24.70±1.85</td>
<td>7.00±0.80</td>
</tr>
</tbody>
</table>

4 Conclusions

The estimation and analysis of possible extreme/non-frequent values is of great importance for meteorological and oceanographic applications. A variety of methodologies have been developed targeting to the accurate description of their behavior with different advantages and shortcomings depending on the data characteristics. In this work, a multi-parametric approach based on PDF analysis of the full available data sets and return period estimation is discussed.

The basic outcomes are highlighted below.

- Long-term datasets are essential for this kind of analysis.
- High resolution atmospheric/wave models are capable of providing such information especially at locations where no local measurements are available.
- The estimation of extreme indices is strongly dependent on the choice of the optimum fitting distribution.
- The proper choice of the maxima dataset in order to ensure independency of the data is of critical importance.
- This independency is ensured in methods like AMM though the small maxima datasets obtained are not sufficient for further analysis.
- POT method is a good alternative producing larger samples but it is more complicated in terms of selecting the suitable thresholds and separation periods ensuring independency.

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References


Interaction of black smoke with solar radiation

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Incoming solar radiation is known to undergo an interaction with the constituents of the Earth’s atmosphere. This interaction is expressed by the mechanisms of absorption, scattering and reflection. The occurrence of each such mechanism depends on the size of the molecules in relation with the wavelength of the incoming radiation. Recently, the scientific interest has been drawn upon the study of the interaction of solar radiation with atmospheric aerosols; such an interaction is related to climate change issues. Among the aerosols, interest has been given to black smoke, since there has been found that anthropogenic aerosols have been playing an important role in their interaction with the incoming solar radiation. That is the reason for the recent discovery of the global dimming phenomenon. The present study is dealing with this issue. Mean daily solar radiation values from the Actinometric Station of the National Observatory of Athens (ASNOA) are compared with simultaneous ones of black smoke (BS) measured by the network of the Greek Ministry of Environment within the Athens basin, in the period 1990-2004. The study examines clear-sky conditions in order to show the influence of BS on solar radiation. The results show that increasing levels of BS cause greater absorption to solar radiation (both global and diffuse components) at a different rate, thus resulting in an attenuation of solar radiation; this attenuation rate is greater in the global component than in the diffuse one.

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1 Introduction

It is well-known that the incoming solar radiation is affected by the various constituents of the Earth’s atmosphere, such as gases and aerosols (e.g. Iqbal 1983). The solar-radiation attenuators may be of natural or of anthropogenic origin. Black Smoke (BS) from combustion units (industry, vehicles, central heating) has been of major concern for the Athens air quality during the ‘80s and ‘90s (e.g. Kambezidis et al. 1986, Kambezidis and Paliatsos 1991), since the air-pollution problem in that period was mainly smog.

The National Observatory of Athens (NOA) was the first institution to start air-quality measurements in the Athens basin by deploying six semi-automatic stations monitoring SO₂ and BS. The network operated in the period 1969 - 1984. After 1984, the Greek Ministry of Environment started deploying its own automatic stations in the same area as part of Greece’s obligations to EU for monitoring and reporting about the air quality in the city and its surroundings, including BS.

The levels of BS have been declining since the beginning of 2000s and, therefore, its measurements by the Ministry of Environment network were effectively stopped in 2005, as the air-pollution problem in the Athens area was gradually converted into photochemical within the ‘90s. Furthermore, the new EU directive commanded member states to monitor particulate matter (PM) with diameters of 10 μm and 2.5 μm (PM₁₀ and PM₂.₅, respectively). This EU regulation was adopted by Greece, too. The evolution of the mean annual BS concentration levels as well as those of GHI is shown in Figure 1.

The present study examines the attenuation caused by anthropogenic BS on the incoming solar radiation (both global and diffuse components) in a 15-year period (1990-2004). The values of the solar radiation components have been taken from the Actinometric Station of NOA (ASNOA).

![Fig. 1. Mean annual levels of BS (solid line, Patission station) and GHI (dashed line, ASNOA station) in the period 1990 - 2004. An anti-correlation between the two curves is seen. Clear days have only been considered in the plot.](image)

2 Data and Methodology

The data base for the present study consists of mean daily values of global horizontal solar radiation – GHI (W/m²), diffuse horizontal solar radiation – DHI (W/m²), cloud cover (octas), and 24-hr cumulative BS concentration (μg/m³). The first three parameters have been taken from the measurements of ASNOA; the latter from the air-pollution monitoring network of the Ministry of Environment. All parameters cover the period 1990 - 2004, as diffuse solar radiation measurements began at ASNOA in 1990.

From the daily values, mean annual ones have been calculated. In order to examine the influence of BS on solar radiation, clear-sky days have only been selected. The criterion for
the selection has been the cloud cover to be equal or less than 1.7 octas. Therefore, all values of the other parameters not corresponding to this criterion have been rejected and have not been considered in the subsequent analysis.

Care has also been taken for the diffuse solar radiation not to exceed the global component by 5% (10% the usual limit, e.g. Kambezidis et al. 1997). Also, any negative or missing values in all parameters of the data base have been excluded from the analysis. In summary, 5483 daily values constitute the initial data base formed for the study; after the quality-control criteria, 1892 daily values have been left for analysis.

3 Results

A first step in the study is to present a graph of GHI against BS concentration for the period 1990 - 2004. Figure 2 shows the mean monthly values for both parameters. The prediction limits refer to the region of the GHI uncertainties in predicting the response for a single additional BS observation in the range of 0 – 300 μg/m³. The confidence limits refer to the region of the uncertainties in the predicted GHI values for BS being in the range of 0 – 300 μg/m³.

![Fig. 2. Co-variation of mean monthly values of GHI with BS concentration for Athens in the period 1990 - 2004 under clear-skies. The best fit to the measurements is GHI = -0.99BS+555.95, R² = 0.25. The red band shows the prediction limits and the blue one the 95% confidence limits.](image)

Since clear days have been considered for the analysis, the graph verifies the influence of tropospheric smoke (found within the planetary boundary layer – PBL, mostly) on solar radiation. For higher concentrations of BS, lower levels of solar radiation are recorded as a higher attenuation of solar radiation by BS molecules occurs.

In a second step, a similar graph is derived for DHI and BS concentration for the same period of time. Clear-sky conditions are also chosen in order to avoid the influence of clouds on solar radiation. The same procedure was followed in the case of GHI, as mentioned in Section 2. The diffuse part of the solar radiation is mostly related to the scattering effect of solar light due to the presence of various scatterers in the atmosphere (molecules, aerosols).
Fig. 3. As in Fig. 2, but for the co-variation of DHI with BS concentration. The equation of the best-fit straight line is $DHI = -0.13BS + 106.89$, $R^2 = 0.05$.

One might expect to see increasing values of diffuse radiation with increasing values of BS concentration as this would imply greater scattering effect of global solar radiation in the presence of higher amounts of BS in the lower atmosphere. Nevertheless, the explanation is that BS mostly absorbs than scatters solar light. Therefore, a greater concentration of absorbers in the atmosphere (such as BS) results in a greater attenuation of the light; this is shown in Fig. 3 with lower DHI values as BS gets higher concentration values.

An interesting issue in this respect is to examine the rate of simultaneous attenuation of GHI and DHI. One should remember that GHI consists of DHI and direct solar components. This can be accomplished by investigating the behavior of the ratio DHI/GHI against BS; this behavior is shown in Fig. 4. As the coefficient in the GHI is higher (in absolute terms) than that of DHI, the best-fit curve to the data has an increasing trend as the BS values increase.

Fig. 4. As in Fig. 2, but for the co-variation of the ratio of DHI/GHI with BS concentration. The best-fit straight line has equation $DHI/GHI = 0.0002BS + 0.19$, $R^2 = 0.06$.

To see the effect of BS on solar radiation in an urban environment, such as that of Athens, let us consider two cases of BS concentrations; those of 100 and 250 $\mu$g/m$^3$ BS (the latter is the EU limit for taking extra measures by the State). In the first case the value of DHI/GHI is 0.21 and in the second 0.24. For a global radiation level of, say, 300 W/m$^2$ for both cases, the diffuse radiation is found 63 and 72 W/m$^2$, respectively, i.e. 9 W/m$^2$ less in the first case. In this example there is a reduction of 12.5% in the diffuse radiation. Conversely, considering a diffuse radiation level of 150 W/m$^2$, the above ratios lead to corresponding global radiation values of 714.29 and 625 W/m$^2$. In this case, the reduction in the global radiation is also 12.5%. These results agree fairly well with older ones in the Thessaloniki area.
(Sahsamanoglou and Bloutsos 1989), which showed a reduction of about 10% due to a combined water-vapour and dust effect on solar radiation.

4 Conclusions

The study has revealed an impact of the BS particles on the solar radiation levels in the Athens area for the period of 1990 - 2004. This impact is related to producing stronger absorption to the solar rays by the BS particles as their concentration becomes higher. The main conclusion of the study is the different impact of BS on GHI and DHI components. One unit of increase in the BS concentration reduces GHI by almost 1 unit and DHI by only 0.19 units. Therefore, the anthropogenically-derived BS within the PBL drastically influences the incoming solar radiation under clear-skies. It has to be mentioned here that unavoidably columnar parameters (such as GHI and DHI) are correlated with a point measurement (such as BS).

References

Air temperature conditions in relation to terrain and ground cover type in a region of the island Kefallinia, Greece

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This work focuses to the evaluation of air temperature conditions in the valley of Omala and in the adjacent mountain (Mt.) of Roudi, in Kefallinia island, Greece. For this purpose, data of the year 2011 were used from three meteorological stations. The first located nearby the Monastery of Saint Gerasimos in the valley of Omala, the second in ‘Agrapidies’ located in the Mt. Roudi and the third in ‘Gioupari’ at the top of the aforementioned Mt. Also, the thermal environment of the examined areas was investigated using a thermographic camera during the study year. Results showed that the terrain, the composition of vegetation and the ground cover type affected the air temperature conditions in the valley as well as in the forested areas of Mt. Roudi covered by cephalonian firs. Higher air temperatures during the day hours prevailed in the valley in relation with the other study areas. On the other hand, during the night and early morning hours the forested areas were warmer than the valley. Non-cultivated fields and canopy surfaces of vineyards were warmer than those of the Mt. Roudi forested areas during the summer while in winter, the surface temperatures between the forest areas and the non-vegetated surfaces showed smaller differences.

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1 Introduction

The topoclimes in natural and agricultural ecosystems are caused by the effect of topography, the more complex terrain, the composition of vegetation and the type of woodland (Seeman 1979, Barry and Chorley 2001). Also, the different thermal properties of the soil and ground cover leads to the variability of the air temperature near the ground surface (Blennow 1998, Geiger et al. 2003). Mountains and hillside areas are most sensitive to environmental changes in the atmosphere and include a rich variety of ecological systems (Jansky et al. 2002).

Air temperature (T) is the most important factor affecting vegetation and a controlling key of various ecological processes (Benavides et al. 2007) depending of the topographical characteristics. At the top of the mountains the air T conditions are different in comparison with those in the bottom of the valleys. Specifically, at high altitudes these conditions are influenced by synoptic circulation and tend to be similar to those of the free-air. On the other hand, the conditions in the valleys are affected by the surrounding topography (Barry and Chorley 2001, Pagès and Miró 2010).

Kefallinia island, a significant destination of tourist attraction in Greece is characterized by intense relief and various natural environments of great ecological importance. The Ainos mountain (Mt.) and a great part of Mt. Roudi, covered by the endemic fir Abies cephalonica, are situated in the central-south part of the island and characterized as National Park (MNHCI 1998). Also, the valley of Omala in the aforementioned region is surrounding by this Mts range and hills providing perfect conditions for the cultivated grapevine variety of “Robola”.

The aim of this work is to evaluate the air temperature conditions in relation to terrain and different ground cover types in the valley of Omala and in the Mt. Roudi, Kefallinia island, Greece.

2 Data and Methodology

The field experiment was carried out at three areas (Table 1) in Kefallinia island, Greece. The first one was located in the valley of Omala, near the Monastery of Saint Gerasimos (St.GER) which is characterized as a high quality viticulture district due to the presence of the vineyards of ‘Robola’ variety. In the northern and northeastern part of this valley there are the Mts Roudi (max. altitude 1125 m) and Korinthos (max. altitude 835 m) and in the eastern part of the aforementioned valley there are the Mts Kefali Petri (max. altitude 1025 m) and Ainos (max. altitude 1628 m). Also, at the western part of Omala valley the hills Falagga (max. altitude 564 m) and Limi (max. altitude 647 m) are located.

The second site of ‘Agrapidies’ (AGR) is located at the slope of the Mt. Roudi and is characterized by dense clumps of endemic fir, Abies cephalonica, and herbaceous species. Additionally, the third site of ‘Gioupari’ (GIOU) at the top of the Mt. Roudi is characterized by tall clumps of the endemic fir (National Park of Ainos – Roudi) with the presence of open fields covered by turf plant species. It is noted that these open areas in GIOU were used as pastures by the local farmers.

Air T data for the sites of AGR and GIOU were monitored from meteorological stations (MSs) of the Laboratory of General and Agricultural Meteorology (Agricultural University of Athens). Additionally, in the site of St.GER (valley of Omala) the aforementioned data were used from the MS of Peripheral Center of Plant Protection and Food Quality Control of Achaia.

In each study site the Sky View Factor (SVF), as an indicator of the shading effect, was calculated using the Rayman software (Lin et al. 2010). For the determination of SVF, fisheye images at each site were taken by the converter Nikon FC – E8 coupled to a Nikon CoolPix 4500 digital camera.

The thermal environment of the surroundings of the valley of Omalaas well as in AGR with regard to surface temperature, was visualized using a high sensitive infrared radiometric
camera (Thermo tracer model TH9100MR/WR, Japan) during the whole examined year and for the period between 13:00 and 15:00 Local Standard Time (LST).

Table 1. Examined sites and ground cover types of the valley of Omala and Mt. Roudi, in Kefallinia island, Greece.

<table>
<thead>
<tr>
<th>Locations (site)</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Alt. (m)</th>
<th>SVF</th>
<th>Ground cover type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valley of Omala (Saint Gerasimos)</td>
<td>38°09'59.0&quot;N 020°35'13.8&quot;E</td>
<td>386</td>
<td>0.780</td>
<td>Vineyards, fields</td>
<td></td>
</tr>
<tr>
<td>Mt. Roudi (Agrapidies)</td>
<td>38°11'28.5&quot;N 020°35'50.5&quot;E</td>
<td>775</td>
<td>0.072</td>
<td>Dense trees, shrubs</td>
<td></td>
</tr>
<tr>
<td>Mt. Roudi (Gioupari)</td>
<td>38°11'13.4&quot;N 020°36'56.0&quot;E</td>
<td>1107</td>
<td>0.115</td>
<td>Forested areas, pastures</td>
<td></td>
</tr>
</tbody>
</table>

Mt.: Mountain, Alt.: altitude, SVF: Sky View Factor.

3 Results

Air T data analysis showed changes of this parameter at the three study areas. The valley of Omala (Saint Gerasimos) was generally warmer than the west slope of Roudi (AGR) and its summit (GIOU) during the whole year. So, the mean air temperature for the year 2011 was 14.6 °C at St.GER but 2.6 °C and 3.7 °C lower at AGR and GIOU, respectively (Fig. 1).

![Fig. 1. Mean values of average air temperature (Tm), maximum (Tx) and minimum (Tn) temperature in the areas of Saint Gerasimos (St.GER), Agrapidies (AGR) and Gioupari (GIU) in Kefallinia island, Greece, during the year 2011. The vertical line in each bar represents the standard error of the mean.](image)

Mean annual maximum and minimum T values (Fig. 1) at ST.GER were 21.5 °C and 8.0 °C, respectively. Mean annual maximum T were lower by 4.6 °C and 6.5 °C than those of AGR and GIOU, respectively. In addition, mean minimum T of these areas was lower than those of St.GER by 0.6 °C and 1.8 °C, respectively. Thus, the reduction of the minimum T at the cephalonian fir forested areas of Mt. Roudi (AGR and GIOU) in relation with the Omala plain (St.GER) was clearly lower than the respective reduction of the maximum T.

The daily course of air T for all seasons was different at the three study areas. The hourly variations of T in the two extreme seasons, winter and summer are presented. Data analysis (Fig. 2a, b) showed that during the day of the summer period (08:00-20:00 LST) as well as of the winter period (10:00-20:00 LST), higher T values were recorded at St.GER area noticeably different than the other areas. Also, at this region (St.GER) low T values were recorded during the night hours and early in the morning (01:00-07:00 LST) while during the winter period T values were similar (03:00-08:00 LST) with those at GIOU, where the altitude is higher.

The higher air T values recorded at St.GER during the day period, could be attributed to the effect of up-slope wind due to the topography of the study region. The valley of Omala is surrounded mainly by the mountainous area of Roudi, by a part of Mt. Ainos and by hills. During the night, the lower T at St.GER could be attributed to the ground cover (there are no tall trees) which has a high value of SVF (0.780). Also, the rapidly nocturnal radiative cooling (Barry and Chorley 2001) in combination with the katabatic winds from the higher altitudes of Mt. Roudi, Kefali Petri and Ainos create a “pool” of cool area (Geiger et al. 2003) at the valley of Omala (St.GER).
The high values of air T recorded during the night and early in morning (22:00-07:00 LST, Fig. 2a and 21:00-09:00 LST, Fig. 2b) at AGR in comparison with the other areas, could be attributed to the dense cephalonian fir clumps (SVF=0.072) which prevent the loss of outgoing radiation from the ground to the environment.

The analysis of thermal images in combination with their respective visual images revealed changes of surface T which are attributed to the different ground cover types. In particular,
during the noon hours of a summer day (Fig. 3, upper left, right) the surface $T$ of the non-vegetated areas of the Omala valley was as much as $39.5 \, ^\circ C$ while the canopy surface $T$ of the vineyards of the variety “Robola” reached the value of $33.8 \, ^\circ C$, that is, higher by $12.0 \, ^\circ C$ and $6.0 \, ^\circ C$, respectively, in relation with those of the adjacent forest areas with higher altitudes. This $T$ change of the areas covered with various plant species can be attributed to the heat exchange between the phytomass and the atmospheric environment, to the different ability of different plants to accumulate thermal energy which is relative to the percentage of water of the plant tissues and to the physiological processes of photosynthesis and transpiration which control mainly the thermal condition of the plants (Chronopoulou-Sereli and Flocas 2010). During the winter period, the $T$ of the non-vegetated surfaces of the valley (non-cultivated field and vineyards without foliage) during the noon hours of the day was as much as $14.1 \, ^\circ C$, that is about $3-5 \, ^\circ C$ higher in comparison with the forested surfaces (Fig. 3 lower left, right).

Additionally, a change of the $T$ was observed according to the composition of vegetation. During the noon hours of a summer (Fig. 4 upper left, right) the upper part of the canopy of the forested areas covered with cephalonian fir at AGR was cooler by $6-7 \, ^\circ C$ in comparison with the adjacent vegetation of shrubs. This difference was reduced to $3-4 \, ^\circ C$ during a sunny day (Fig. 4 lower left, right) of the winter period.

It is noted that these differences of the surface $T$ of various ground covers are almost zero during the overcast days. So, at the same hours (13:00-15:00 LST) with the above cases during an overcast day (20.12.2011) of the winter period it was noticed that the surface $T$ difference was $1.0 \, ^\circ C$ which is due to the reduced thermal outgoing from the ground surface to the environment.

4 Conclusions

The findings of this research can be summarized as follows:

- The terrain, the composition of vegetation and the ground cover type played a noticeable role to the prevailing air temperature at the valley of Omala and the adjacent mountain district of Roudi in Kefallinia island, Greece.
- Higher values of air temperature in the valley prevailed in comparison with the forested areas of Mt. Roudi during the day hours in both extreme seasons (summer and winter). On the other hand, low temperatures were observed in the valley during the night and early morning hours.
Non-cultivated fields and canopy surfaces of the vineyards of the variety “Robola” were warmer, with regard to the surface T, than those of the Mt. Roudi forested areas covered by cephalonian firs at noon during the summer. Smaller differences of the surface T between the forest areas and the non-vegetated surfaces of the valley season were observed in winter.

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References

Past and future changes of organic and inorganic nitrogen global atmospheric deposition

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Nitrogen is an important nutrient that controls the productivity of terrestrial and marine ecosystems. Emissions of reactive nitrogen into the atmosphere are increasing due to human activities, affecting also nitrogen deposition to the surface. There is also growing evidence that a significant fraction of nitrogen deposition occurs in the form of organic nitrogen, although the chemical characterization of this fraction remains a challenge. The present study uses a global atmospheric chemistry transport model to calculate the global distribution of nitrogen deposition, accounting for both its inorganic and organic fractions in gaseous and particulate phases. Present-day simulations suggest that the global organic nitrogen cycle has a strong anthropogenic component with almost half of the overall atmospheric source (primary and secondary) associated with anthropogenic activities, while about 25% of total N deposition is in the form of organic nitrogen. Almost a 3 fold increase has been calculated by TM4-ECPL for N deposition fluxes due to increase in human activities from 1850 to present. Projections indicate changes in the chemical composition of N deposition and regional changes but not significant changes in the global flux.

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1 Introduction

Terrestrial and marine ecosystem productivity is controlled by the availability of nutrients like nitrogen. Atmospheric deposition of nitrogen (N) compounds can be beneficial for ecosystems (fertilization) or have negative impacts due to acidification and accumulation of excess nutrients (Driscoll et al. 2003). In addition, chemical trapping of reactive nitrogen on pollen particles (Franze et al. 2005) can be harmful for human health. Reactive nitrogen compounds are emitted to the atmosphere both in reduced and oxidized forms by natural (e.g. soils, lightning, plants, bacteria, and viruses) and anthropogenic sources (e.g. industries, transportation, and domestic wood burning). Recent observations and modeling studies have shown that organic nitrogen is a significant fraction of total nitrogen deposition, however the chemical characterization of this fraction remains a challenge (Kanakidou et al. 2012 and references therein).

In the Anthropocene era human activities have significantly increased the amounts of N emitted to the atmosphere, modifying the N biogeochemical cycle in both terrestrial and aquatic ecosystems (Galloway et al. 2008). This human-driven increase in reactive nitrogen emissions into the atmosphere affects nitrogen deposition to the surface. First estimates indicate that the human-induced increase in atmospheric N deposition to the oceans may account globally for up to ~3% of the annual new oceanic primary productivity (Duce et al. 2008). For semi-enclosed marine ecosystems such as the Mediterranean Sea, atmospheric deposition of N may account for up to 35-60% of new production (Christodoulaki et al. 2013). Reactive nitrogen is also involved in atmospheric chemistry, since ozone production is driven by nitrogen oxides availability, and atmospheric acidity is controlled by nitric acid and sulfuric acid formation and NH3 is the main neutralizing gas for these acidic compounds (Seinfeld and Pandis 2006). Thus, deposition of atmospheric N species also impacts atmospheric chemistry. Estimating the past and future changes in N atmospheric deposition is a perquisite for the evaluation of N emissions impact on the environment and climate. Projections for N emissions in the atmosphere are based on different scenarios that assume control of nitrogen oxide emissions, but not those of ammonia (Lamarque et al. 2013), pointing to expected changes in the chemical composition and thus possibly in the bioavailability of N deposition.

The present study uses the global atmospheric chemistry/transport model TM4-ECPL to evaluate past and future changes in atmospheric deposition of N that are driven mainly by human activities. It accounts for deposition of reactive nitrogen inorganic and organic compounds both in the gas and the aerosol phases, in particular the organic nitrogen (ON) in the aerosol phase that has been neglected in earlier studies.

2 Methodology- Model description

The global 3-dimensional atmospheric chemistry/transport model TM4-ECPL accounts for all major primary and secondary aerosol components, oxidants, volatile organic compounds chemistry, and secondary organic aerosol formation (Myriokefalitakis et al. 2011, Kanakidou et al. 2012).

In TM4-ECPL, the photochemical degradation of volatile organic compounds in the atmosphere forms secondary organic products, carbon monoxide, and, ultimately, carbon dioxide. Semi-volatile and low volatility organic compound products are also produced, which are subsequently partition between the gas and particulate phase in the atmosphere. Thus, only part of the emitted organics is ultimately deposited to the surface by dry or wet deposition processes in either the gas or particulate form. The deposition parameterization in TM4-ECPL uses solubility estimates for the individual compounds (Myriokefalitakis et al. 2011). Organic aerosol (OA) is simulated by using 20 tracers linked to various origins, which can be grouped as: i) primary OA from fossil fuel, biofuel and biomass burning; ii) primary OA from the ocean (Myriokefalitakis et al. 2010); iii) secondary OA from semi-volatile
organics formed by anthropogenic and natural gaseous volatile organics oxidation (Tsigaridis and Kanakidou 2007) or formed by multiphase chemistry (Myriokefalitakis et al. 2011); and iv) aged primary and secondary OA (Tsigaridis and Kanakidou 2003). TM4-ECPL has been further improved to account for primary biogenic particles of terrestrial origin and for organic matter associated with dust particles (Kanakidou et al. 2012).

The model uses primary emissions of N oxides, ammonia and a small amount of amines emitted from the oceans (Facchini et al. 2008) that form amine salts. The chemically-produced organic nitrates and oxygenated inorganic nitrogen compounds both in the gas and particulate phases are explicitly calculated (Myriokefalitakis et al. 2011). Most global atmospheric chemistry transport models account for the formation of organic nitrate during oxidation of volatile organic compounds using chemical schemes of various complexity. However, they do not explicitly account for the production of other forms of ON, particularly those associated with the primary and secondary particulate organic matter, thus underestimating the atmospheric burden of ON and its deposition to the surface. In this study, N concentrations were linked to source-specific OA tracers using varying N:C molar ratios as measured in the organic matter from different source types, following the methodology described in detail by Kanakidou et al. (2012) (Fig. 1).

For the present study, NOx from lightning is calculated online. Biogenic emissions of volatile organic compounds are taken from MEGAN emission inventory. Sea-salt emissions are calculated online as described by Vignati et al (2010). Dust emissions are offline, taken from the AeroCom emissions inventory but for the year 2005 (Dentener et al. 2006). Primary biogenic particles are distributed according to the Leaf Area Index spatial and temporal distribution. Anthropogenic and biomass burning emissions of nitrogen oxides, carbonaceous aerosols, sulfur dioxide and organics come from different databases since several simulations have been performed with different anthropogenic emission inventories: for 1850 (past) the historical ACCMIP (Lamarque et al. 2013) inventories; for 2005 (present day) both GAINSv4a (Klimont et al. 2013) and RCP6.0 inventories; for 2050 (future) GAINS v4a, RCP6 and RCP8.5 inventories have been used. As seen in Fig.1, RCPs and GAINSv4a do not show similar tendencies for the NOx emissions. All projections show that while NOx emissions are reduced by 2050, NH3 emissions still increase. Thus, reduced N emissions (alkaline compounds) are gaining importance compared to NOx emissions, which tend to acidify the atmosphere.

TM4-ECPL is driven by ECMWF ERA-interim meteorological fields. All simulations presented here have been performed using present-day meteorology, that of the year 2005. Natural emissions have been kept constant to those of the year 2005. Thus, the calculated changes are only due to anthropogenic emission changes.

3 Results

The global distributions of organic and inorganic fractions of nitrogen deposition are computed as the sum of the corresponding terms of the individual organic and inorganic nitrogen model tracers calculated by TM4-ECPL. Simulated particulate PM2.5 OC
concentrations have been evaluated against observations (Tsigaridis et al. 2014), and nitrogen deposition fluxes in Kanakidou et al. (2012). Modeled values fall within a factor of ten of the measured values, although the model tends to be biased low.

Table 1 below summarizes the changes in N atmospheric deposition due to human activities computed using different emission inventories on the global scale. While in the past NH₃ and NOₓ emissions have both increased leading to a similar increase in N atmospheric deposition, in the future NOₓ is expected to be limited while NH₃ emissions will continue to grow. These changes are reflected to the simulated deposition fluxes.

<table>
<thead>
<tr>
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<th>1850</th>
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<tr>
<td>NH₃ (NH₃/NH₄⁺)</td>
<td>18</td>
<td>65</td>
<td>53</td>
<td>84</td>
<td>63</td>
<td>64</td>
</tr>
<tr>
<td>NOₓ (NOₓ,HNO₃,NO₃p)</td>
<td>6</td>
<td>51</td>
<td>38</td>
<td>53</td>
<td>29</td>
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<td>ON</td>
<td>32</td>
<td>38</td>
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<td>Total N deposition</td>
<td>56</td>
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<td>173</td>
<td>134</td>
<td>128</td>
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</tbody>
</table>

Figure 2 shows the computed spatial distribution of inorganic and organic N atmospheric deposition for the three studied cases. Inorganic N deposition shows the highest fluxes over industrial areas of the NH and tropical biomass burning regions. The ON deposition flux maximizes in the tropics indicating the large contribution by primary biogenic particles and biomass burning and secondary OA formation. The atmospheric N deposition increased since the preindustrial period and is expected to further increase for 2050. The range in the computed deposition fluxes in RCPs due to emission scenarios indicates the degree of uncertainties. Fig. 3 clearly depicts the large changes that occurred over the heavily industrialized areas of the NH and those that expected to happen mainly in Asia. The global deposition flux changes calculated are based on twodifferent emission inventories (RCPs and GAINS) and are summarized in Figure 3.

**Fig. 2.** Atmospheric deposition of N in g-N/m²/y computed by TM4-ECPL for 1850 (left-ACCMIP), 2005 (middle-ACCMIP), 2050 (right RCP8.5). Top inorganic N, bottom organic N.

**Fig. 3.** Atmospheric deposition of reactive nitrogen as computed by TM4-ECPL based on ACCMIP and RCPs (left 3 columns) and based on GAINSv4a (right 2 columns). N deposition as inorganic reduced N (NH₃) in red, as inorganic oxygenated N (NOₓ) in green and as ON in blue. Noticeable are differences in the projections (increase vs decrease) between RCPs and the GAINS emissions.
4 Conclusions

Present day global total reactive N deposition is estimated between 125 and 150 Tg-N/yr. ON deposition is about 25% of the total nitrogen deposition and by about half is associated with human activities. However, targeted observational experiments are needed to improve parameterization of the chemical binding of N on organic aerosol under clean and polluted atmosphere. Large areas in the northern hemisphere are subject to total N deposition higher than the phytotoxicity threshold for vegetation. Total atmospheric N deposition has increased by a factor of about 3 since 1850, mainly due to the large increase of inorganic nitrogen. For the future, the reduction in NOx emissions is compensated by the continuing increase in NH3 emissions, and as a result the total N deposition is not expected to change much globally. However, regionally significant changes are expected, in particular over Asia. These results do not account for future changes in biogenic emissions due to climate change.

Acknowledgments. Nikos Daskalakis is supported by EU FP7 project PEGASOS. Stelios Myriokefalitakis acknowledges support by an NSRF Research Funding Program Program ARISTEIA 1 - PANOPLY. This research has been co-financed by the European Union (European Social Fund – ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) - Research Funding Program: THALES- ADAMANT. Investing in knowledge society through the European Social Fund.

References


The influence of North Sea-Caspian Pattern (NCP) on the precipitation regime over Europe and Mediterranean

Kapsomenakis I., Nastos P.T., Douvis K., Philandras K., Konsta D., Zerefos C.S.

The objective of this study is to examine, the impact of the upper level (500 hPa) teleconnection between the North-Sea and the Caspian (NCP) on the precipitation regimes in Europe and the wider Mediterranean region. At first, the atmospheric circulation is analyzed with respect to the positive and negative phases of NCP index. In the process, the correlation between precipitation totals and the NCP index has been assessed over the entire Euro-Mediterranean domain, for winter and summer season, within the period 1951–2012. It was found that during winter, a positive NCP phase (stronger dipole) is associated with below-average precipitation across central Europe and northern Mediterranean and above-average precipitation over Norway, Caspian and the Middle East. During summer, a positive NCP phase is linked with below-average precipitation across northern Europe and above-average precipitation over western Scandinavia, Italy and Balkan Peninsula. Finally, the impact of NCP index on atmospheric humidity for significant pressure levels within troposphere is analyzed.

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1 Introduction

An upper air (500 hPa) teleconnection that affects significantly the European climate is the North Sea–Caspian Pattern (NCP). Kutiel and Benaroch (2002) defined the North Sea–Caspian Pattern index (NCPi) as the normalised geopotential height difference between the two poles (North Sea centred between 0°E,55°N and 10°E,55°N and Caspian Sea centred between 50°E,45°N and 60°E,45°N) of the teleconnection. A positive NCP phase results a northerly anomaly circulation over major parts of Eastern Europe and the Mediterranean, causing a negative temperature anomaly (Kutiel et al. 2002, Brunetti et al. 2011, Nastos et al. 2011) and an opposite circulation and temperature anomaly over the Britain and Scandinavia (Brunetti et al. 2011). On the other hand the influence of the NCP on precipitation is less pronounced (Kutiel et al. 2002, 2005).

This study focuses on examining the impact of NCP on precipitation and atmospheric humidity over Europe and the wider Mediterranean region within winter and summer.

2 Data and Methodology

Monthly precipitation data for the time period 1951-2012 were retrieved from the gridded precipitation data CRU TS 3.21 (Climatic Research Unit, University of East Anglia; Mitchell and Jones 2005) at a spatial resolution of 0.5° x 0.5° for Europe and the Mediterranean (20°W - 40°E, 30°N - 70°N). CRU TS 3.21 data cover all land areas of the Earth with the exception of the Antarctic region. In addition, for the time period 1951-2012, mean monthly geopotential heights at the 500 hPa isobaric level, relative humidity and wind speed components at the 700 hPa isobaric level and surface CAPE (Convective Available Potential Energy) data were extracted from NOAA-CIRES 20th Century Reanalysis at a spatial resolution of 2.0° x 2.0°, for the under study area. From the mean monthly 500 hPa geopotential heights data, monthly NCP index time-series is calculated for the period 1951-2012 using the methodology described in Kutiel and Benaroch (2002). Pearson correlation coefficients between precipitation totals and NCPi were calculated for winter (DJF) and summer (JJA) season for each CRU grid-point in Europe and the Mediterranean, for the period 1951-2012. In addition, in order to identify the amplitude of NCPi influence on precipitation totals, the precipitation percentage anomalies from the mean precipitation during 1951 to 2012, for winters and summers, when NCPi values are higher than 90th / lower than 10th percentile, were calculated (see years with extreme high and extreme low winter and summer NCPi values in Table 1). Furthermore the anomalies in the atmospheric circulation at 700 hPa isobaric level during winters and summers with NCPi on its upper 90th / lower 10th percentile, respectively, were identified. Finally, the relative humidity at 700 hPa isobaric level and the CAPE composite anomalies from the mean values during 1951 – 2012 for winters and summers with NCPi on its upper 90th / lower 10th percentile were calculated.

<table>
<thead>
<tr>
<th>Years of Extremes</th>
<th>DJF NCPi (+)</th>
<th>DJF NCPi (-)</th>
<th>JJA NCPi (+)</th>
<th>JJA NCPi (-)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1964</td>
<td>1955</td>
<td>1959</td>
<td>1954</td>
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<tr>
<td>1972</td>
<td>1960</td>
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<td>1993</td>
<td>1999</td>
<td>1992</td>
<td>2010</td>
<td></td>
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</tbody>
</table>
3 Results

Fig. 1 (upper graphs) presents the correlation between precipitation and NCPi, for winter (left graph) and summer season (right graph) over Europe and the wider Mediterranean region. During winter, the major part of central Europe (40°N - 60°N) is dominated by negative correlation, to a great part statistically significant at 95% C.L. The lowest negative values are observed in France and in western and central Balkans (r<-0.7). On the contrary, statistically significant positive correlations (95% C.L.) were found in Norway (r>0.6), as well as in Tunisia, northern coasts of Egypt and Israel (r>0.4).

The spatial distributions of the composite precipitation totals as anomalies from their long-term mean (1951-2012) for the upper 90th percentile (middle graphs) and the lower 10th percentile (lower graphs) of NCPi, are depicted in Fig. 1, as well. It is evident that during winters with very high NCPi values, precipitation is significantly reduced (down to -50%) over southern Sweden, France, western and central Balkans and western Turkey. On the contrary precipitation increases (up to 50%) are restricted to Norway and the south-eastern coast of the Mediterranean (Egypt and Israel). The opposite results are found for the lowest 10th percentile NCP index winters with increased composite rainfall totals (up to 50%) over Spain, France, Sweden, western and central Balkans and Ukraine and reduced (down to -50%) over Norway, Tunisia, Libya, Egypt and Israel.

During summer, precipitation totals are negative correlated with NCPi over the major part of the latitudinal band 50°N - 65°N (statistically significant negative correlations down to -0.7). The lowest negative values, are observed in France and in western and central Balkans (r<-0.7). On the contrary, statistically significant positive correlations are depicted in northern Norway (r>0.6), Balkans, Italy (r≈0.5) and central and eastern Spain (r≈0.4). It is also found that during summers with very high NCPi values, precipitation is significantly reduced (down to -30%) over the latitudinal band 50°N - 65°N. On the contrary, precipitation is increased over northern Norway (up to 30%), Italy, Greece and western Turkey (up to 50%). The opposite results are found for the NCPi lowest 10th percentile.
The above mentioned precipitation anomalies are related to circulation anomalies. During winters with NCPi on its upper 90\textsuperscript{th} percentile (Fig. 2 upper left graph), westerlies at 700 hPaisobaric level increase in strength over Scandinavia. On the contrary, westerlies decrease in the latitudinal band 40\degree N - 50\degree N. Over Russia, Greece and Turkey a northerly anomaly flow is observed. During summers with NCPi on its upper 90\textsuperscript{th} percentile (Fig. 2 upper right graph), a southwesterly wind anomaly at 700 hPa level prevails, while an opposite anomaly (northeasterly) is observed in the latitudinal band 40\degree N - 50\degree N. The opposite results are found for the NCPi lowest 10\textsuperscript{th} percentile.

![Fig. 2](image)

**Fig. 2.** Spatial distribution of the composite vector wind (m/s) at 700 hPa anomalies from its long-term mean (1951-2012), grouped for the upper 90\textsuperscript{th} (upper graphs) and the lower 10\textsuperscript{th} (lower graphs) percentiles of NCPi. Left graphs are for winter and right graphs for summer season.

The spatial distribution of relative humidity anomalies from its long-term mean at 700 hPa level for winters and summers with NCPi on its upper 90\textsuperscript{th}/ lower 10\textsuperscript{th} percentiles are shown in Fig. 3. During winters with NCPi on its upper 90\textsuperscript{th} percentile, the major part of Europe (40\degree N - 65\degree N) is dominated by negative relative humidity anomalies. The lowest values (down to -10\%) are observed round the North Sea. Positive anomalies (up to 5\%) prevail over northern cost of Africa and Israel. During summers with very high NCPi, the spatial distribution of relative humidity anomalies is characterized by 2 poles. The first covers the band 50\degree N - 60\degree N and is characterized by negative anomalies (down to -5\%). The second covering Greece, Italy and Turkey is dominated by positive anomalies (up to 8\%). The opposite results are found for the lowest 10\textsuperscript{th} percentile.

![Fig. 3](image)

**Fig. 3.** Similar to Fig. 2 for relative humidity.
Finally, the CAPE anomalies from its long-term mean for winters and summers with NCPi on its upper 90th/ lower 10th percentiles are calculated (Fig. 4). During winters with NCPi values on its upper 90th percentile, negative CAPE anomalies are observed over Italy, Greece and Turkey (down to -20 J/kg) as well as over Great Britain and France (down to -10 J/kg). On the contrary, positive anomalies prevail over Norway, as well as over northern coast of Africa and Israel. During summer with very high NCPi values, negative CAPE anomalies are observed over continental areas of Europe in the band 50°N - 65°N (down to -50 J/kg), while positive anomalies prevail over France, Italy (up to 100 J/kg), Spain and Greece (up to 50 J/kg). The opposite results are found for the lowest 10th percentile of NCPi.

4 Conclusions

Correlation between precipitation totals and the NCP index has been assessed over the entire Euro-Mediterranean domain, for winter and summer season, within the period 1951–2012. During winter, a positive NCP phase is associated with below-average precipitation across central Europe and northern Mediterranean and above-average precipitation over Norway, Caspian and the Middle East. During summer, a positive NCP phase is linked with below-average precipitation across northern Europe and above-average precipitation over western Scandinavia, Italy and Balkans. The impacts of NCP index on atmospheric circulation, relative humidity at 700 hPa isobaric level and CAPE are also identified and interpret the findings with respect to the precipitation totals over the entire Euro-Mediterranean domain.

References

Mitigating the Impact of Climate Change on Drought: The potentiality of a precipitation enhancement project (DAPHNE) in Thessaly

Karacostas Th., Pytharoulis I., Tegoulias I., Katragkou E., Zanis P.

The project DAPHNE aims at tackling the problem of drought in the most vital agricultural area of Greece, Thessaly, by means of Weather Modification. The main objective is the development of necessary scientific tools to support the potentiality and applicability of a well designed precipitation enhancement program, to investigate its importance and assess thoroughly the impact of its implementation on the environment. Besides developing and applying state-of-the-art modeling tools, the project objectives are accomplished by performing measurement campaigns. During the experimental phase of the project, cloud seeding experiments take place on suitably chosen appropriate clouds over Thessaly area. Moreover, sampling of precipitated water and consequent soil is performed in order to investigate the impact of the seeding material on the environment. The experimental data, along with the support of the 3D regional meteorological model (WRF) and a 3D cloud model, support the establishment within the project DAPHNE of an innovative and integrated conceptual model, a useful tool for the mitigation of drought. Dissemination activities planned within DAPHNE will target to public awareness and importantly, the information of national and local authorities about methodologies for the potentiality and applicability of a precipitation enhancement methodology.

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1 Introduction

The effects of climate change and the continued increase in water needs, for both urban and agricultural use, have largely exhausted water supplies; therefore, an effort must be taken in order to find new ways to augment them. Weather modification has a rather unique status among water resource issues, dealing with cloud seeding that helps clouds more efficiently produce precipitation in the form of rain or snow, or reduce hailstone size in favor of raindrops. The most beneficial and ambitious methodology is that of the precipitation enhancement. In recent years, the development of new sophisticated atmospheric models, in conjunction with modern instruments for recording and measuring atmospheric and cloud physics data have increased the interest for weather modification, and particularly for precipitation enhancement projects (Silverman 2003).

The objective on this study is to present the project DAPHNE which is focused in the development of necessary scientific tools, to support the potentiality and applicability of a well designed precipitation enhancement program, by applying state-of-the-science modeling tools, performing measurement campaigns and cloud seeding experiments, and investigating the impact of its implementation on the environment. It is applied over the Thessaly plain, which is known as the most vital agricultural area in Greece, and thus weather and climate play a very important role in nation’s socio-economic status. Figure 1 partially depicts, in a schematic diagram, the proposed project DAPHNE.

Fig. 1. The schematic diagram of the proposed project DAPHNE.

2 Data and Methodology

The database of the project DAPHNE includes: a) surface observations from the available manual and automatic meteorological stations of the greater area of Thessaly, b) radiosonde data from the airport of Thessaloniki, c) weather radar images received and analyzed from the C-band (5-cm) weather radar, d) specially equipped aircraft measurements (e.g. temperature, humidity, liquid water content, height, etc.), e) meteorological data (air temperature, precipitation, humidity, atmospheric pressure and wind) from Larissa weather station for a period of 60 years (1950-2010), f) weather charts of daily analyses at 500 hPa at 1200 UTC, for the 10-year period 2001-2010, g) gridded analyses from the ECMWF/IFS system for the period 2001-2010, h) gridded projections of RegCM3 regional climate model (25km x 25km) carried out during ENSEMBLES project under the IPCC scenario A1B, for the period 2041-2050, i) chemical samples of soil and water from the seeded and unseeded areas, for environmental impact assessment studies.

The project DAPHNE integrates all contemporary components in order to have the most comprehensive state-of-the-science results. These components include the use of the state-of-the-art Weather Research and Forecasting (WRF) numerical model at very high resolution (1km x 1km), considering the different types of hydrometeors through sophisticated microphysical parameterizations, the adaptation and redevelopment of a 3D cloud model for performing simulations of seeding material dispersion and high-performance seeding aircraft.

It is the first time that these state-of-the-art tools and aircraft observations are combined in order to create the fundamental principles for the development of the Conceptual Model that
define the feasibility potential of a rain enhancement program in Thessaly. The conceptual model will define if, when, where and how a precipitation enhancement program would be applicable over the examined area. It sets the spatial, temporal and meteorological conditions that must be met, so as cloud seeding of appropriate cloud types will be feasible, aiming in precipitation enhancement and mitigation of drought in the area of Thessaly.

3 Results

The non-hydrostatic WRF model with the Advanced Research (WRF-ARW) dynamic solver (Skamarock et al. 2008, Wang et al. 2010) is installed on a parallel computing platform (cluster) and all the necessary pre and post-processing modules have been created. It was configured using telescoping nesting and focusing in the area of interest (Thessaly). Three interactive model domains (2-way nested) cover Europe (including northern Africa), Greece (including southern Balkans and southern Italy) and the wider area of Thessaly at horizontal grid-spacing of 15km x 15km, 5km x 5km and 1km x 1km (Fig. 2), respectively, utilizing the staggered Arakawa C grid. Fine-resolution data (30” x 30”) were used in the definition of topography and land use. The initial and boundary conditions of the coarsest domain can be optionally provided by: a) the NCEP/GFS analyses and forecasts (operationally), b) the ECMWF/IFS analyses and c) the RegCM3 regional climate model. The sea-surface temperatures (SSTs) can be provided daily by NCEP (National Centers for Environmental Prediction) at a horizontal resolution of 1/12°x1/12°, ECMWF analyses or by the RegCM3 fields. The NCEP SSTs are produced on a daily basis through the assimilation of the most recent 24-hours sea-surface observations and satellite SST measurements. In the vertical, 39 sigma levels (up to 50 hPa) with enhanced resolution at the boundary layer are used by all nests. The Goddard scheme, the Betts-Miller-Janjic scheme, the RRTMG, the Monin-Obukhov (Eta), the Mellor-Yamada-Janjic and the NOAH Unified model are employed in all nests to represent microphysics, sub-grid scale convection, longwave/shortwave radiation, surface layer, boundary layer and soil physics, respectively. The Goddard microphysical scheme (Tao and Simpson 1993, Tao et al. 2003) contains separate variables for the calculation of cloud water, rain water, ice, snow and graupel (or hail).

The WRF model is used to produce very high spatiotemporal resolution simulations of the atmospheric conditions in the area of interest and provide the forcing fields to the 3D Cloud model.

The 3D cloud model, initially developed by Telenta and Aleksic (1986) and modified by Spiridonov and Curic (2003), is applied to representative cases of past/present-weather and future projected conditions, using the actual radiosonde data of the nearest upper air station (Thessaloniki synoptic station) and the output of the WRF simulations. The cloud model sensitivity to the different sources of input data (radiosonde, WRF) is assessed for the present-weather cases.

![Fig. 2.](image-url)
Storm characteristics are obtained and identified from weather radar reflectivity images received and analyzed from the C-band (5-cm) weather radar, being located at Liopraso area, within the area of interest. The cell tracker TITAN (Thunderstorm Identification, Tracking, Analysis, and Nowcasting) (Dixon and Wiener, 1993) has been used to retrieve convective storm tracks and characteristics from radar reflectivity measurements that roughly have 750x750m spatial and 3.5min temporal resolution. The storm characteristics include: initiation time (UTC hour), duration (minutes), direction (°), speed (km/hr), volume (km³), area and precipitation area (km²), rain rate (mm/hr), maximum reflectivity (dBZ), cloud top (km) and many more parameters.

The prevailing synoptic conditions in the greater area of central Greece, during the 10-year period 2001-2010, have been classified, one by one day, according to the general circulation pattern of the middle troposphere. This information was retrieved by daily analyses of ECMWF at 500 hPa at 1200 UTC. The classification is based on the methodology introduced by Karacostas et al. (1992), and verified by WMO (2003). Following the same methodology and procedure, the mid-tropospheric synoptic circulation patterns, projected by RegCM3 regional climate model under the IPCC scenario A1B, during the period 2041-2050, will also be classified. The resulting daily synoptic circulation patterns will be statistically analyzed and compared, in order to investigate the prevailing near-present and future synoptic conditions. To meet the project objectives, representative cases of the near-present and future synoptic conditions will be selected for the model simulations.

The core experimental work of the project DAPHNE takes place from the 1st of March to the 31st of October 2014, with emphasis on the first 45 days and the last 31, due to the lack of existed previous data information. During these measurement campaigns, the following procedures will be scheduled to take place, according to our own operational meteorological forecasts. Appropriate surface and upper air meteorological measurements. Weather radar images will be received and analyzed from the C-band (5-cm) weather radar being located at Liopraso area, within the area of interest. Aircraft flights will be conducted, by specially instrumented and equipped aircrafts, with specialized on the subject pilots, in order to perform in-situ measurements. At the same time, and after meeting pre-specified criteria, cloud seeding experiments will carry out on selected clouds. Chemical samplings of soil and water from the seeded area will be conducted, in order to perform the impacts study analysis. Sampling from background areas will also take place for comparison purposes.

It is believed that the aforementioned field experiments and measurement campaigns, coupled with numerical model simulations and proper seeding technologies and procedures, could very well support the objective of the project DAPHNE and of this research.

4 Conclusions

The implementation scope of the project DAPHNE is to tackle the problem of drought in Thessaly by the scientific means of weather modification. The Thessaly plain is known to be a vital agricultural area in Greece, and thus the weather and climate play a very important role in its socio-economic status. Anthropogenic climate change is expected to further deteriorate the problem of drought and water shortage, posing a serious threat in human and agricultural activities. It appears, thus, a necessity to investigate the potential impact of present weather and climate change on drought, in order to suggest effective ways of tackling the already existed -and for sure- future problem.
Taking into consideration the aforementioned, the main objective of DAPHNE is to integrate all the presented contemporary scientific components, in order to have the most comprehensive state-of-the-science results, in the form of a Conceptual Model, emerging through out the analyzed and studied data information. Some of these components are: the use of the state-of-the-art WRF numerical model with sophisticated microphysical parameterizations, the adaptation of the 3D cloud model for performing simulations of cloud seeding experiments, the radar information from the C-band (5-cm) weather radar through the TITAN algorithm, the conduction of instrumented aircraft flights for in-situ measurements and to carry out actual cloud seeding experiments.

It is strongly believed, that it is for the first time that all these state-of-the-art tools and aircraft observations are combined, in order to create the necessary fundamental principles for the development of the Conceptual Model that will define the feasibility potential and applicability of a rain enhancement program in Thessaly. The conceptual model will define - if, when, where and how- a precipitation enhancement program would be applicable over the examined area. It sets the spatial, temporal and meteorological conditions that must be met, so that cloud seeding of appropriate cloud types will be feasible, aiming in precipitation enhancement and mitigation of drought in the area of Thessaly. Figure 3 demonstrates the form of a tentative schematic diagram of such Conceptual Model, which is expected to be fully developed through the analyses of the data by the end of the project DAPHNE.

**Acknowledgments** This research work of DAPHNE project is co-funded by the European Union (European Regional Development Fund) and Greek National Funds, through the action "COOPERATION 2011: Partnerships of Production and Research Institutions in Focused Research and Technology Sectors" in the framework of the operational programme "Competitiveness and Entrepreneurship" and Regions in Transition (OPC II, NSRF 2007-2013).

**References**


Metal-Doped TiO$_2$ nanopowders as potential cleansers of air-toxic pollutants: UV and visible photocatalytic activity of Co-, Mn-, and Mn/Co-doped TiO$_2$

Karafas E., Romanias M.N., Papadimitriou V. C., Papagiannakopoulos P., Binas V. D., Kiriakidis G.G.

The photocatalytic activity of Co-, Mn-, and Co/Mn-doped TiO$_2$ samples towards gaseous CH$_3$CHO, a common indoor and outdoor air pollutant, was determined under UV and Visible irradiation. The metal enrichment of TiO$_2$ samples was in the range 0.02–0.10%; they were prepared by co-precipitation method and characterized by XRD, SEM-EDX and UV-visible diffuse reflection spectroscopy. The photocatalytic activity was tested by using the Photochemical Static Reactor/FTIR technique. CH$_3$CHO decays were monitored with in-line FTIR spectroscopy after reaction mixture's exposure to UV- and Vis-light. Adsorption process was also measured under dark conditions, and the formation of volatile end-photocatalysis-products was monitored. High CH$_3$CHO conversions were observed under UV irradiation in all cases. However, 0.04% Co/Mn-doped TiO$_2$ samples induced substantially high degradation of CH$_3$CHO even under visible irradiation. CO$_2$ was the major end-photocatalytic-product, while CO was also detected at substantially lower levels, particularly under visible irradiation. The above UV and visible photocatalytic oxidation processes lead to sufficiently low yields of air-toxic products.

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Comparison of six spatial interpolation methods for the estimation of missing daily temperature and precipitation data

Karagiannidis A.F., Feidas H.

This paper examines the efficiency of six different spatial interpolation methods in imputing missing daily temperature and precipitation data in historical records. Four deterministic (inversed distance weighted, local polynomial interpolation, natural neighbor and regularized splines) and two probabilistic (ordinary kriging and multiple linear regression) methods were used in the analysis. In the case of the multiple linear regression method, geographical and topographical data along with satellite derived precipitation and land cover data were used as predictors. A set of 12 days without missing daily temperature and precipitation values at the Macedonia airport of Thessaloniki was selected as a test sample. These values were then estimated by all six methods and compared against the measured ones. Two subsets of data were used for the estimation of each parameter; the first one comprised all the available stations while the second one consisted of only those stations located within a 150km radius from the Thessaloniki station. Comparison statistics and scatter plots were employed to assess the results. It was found that the best daily temperature estimation was obtained by the multiple regression method and the use of all the available stations while for the daily accumulated precipitation, the best results were obtained by the ordinary kriging using only the closest stations.

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1 Introduction

Missing values on historical data records is a known problem that can be addressed by employing a vast variety of methodologies. These methodologies proved to be quite successful on imputing missing monthly, seasonal or annual values in time series. Regarding daily values, many of those methodologies may lead to large estimation errors, especially for parameters presenting high spatial variability. In order to improve the estimation efficiency, the available spatial information should be exploited.


2 Data and Methodology

Daily average air temperature values and total precipitation amounts obtained from 89 measuring stations of the Hellenic National Meteorological Service network were used.

Fig. 1. The spatial distribution of the 89 measuring stations. The right map shows only those stations that are situated within a 150Km radius from the Thessaloniki station.

Four deterministic (inversed distance weighted (IDW), local polynomial interpolation (LPI), natural neighbor (NN) and regularized splines (Spl)) and two probabilistic (ordinary kriging (Kr) and multiple linear regression (MR)) methods were employed on station data in order to create temperature and precipitation surfaces over Greece. In the case of the multiple linear regression method, geographical and topographical data along with satellite derived precipitation and land cover data are used as predictors. The geographical and topographical data were extracted from a Digital Elevation Model (DEM) using an off-the-shelf GIS package. The satellite derived data consist of a set of gridded daily precipitation values, extracted from the Tropical Rainfall Measuring Mission (TRMM) database with a 0.25°x0.25° spatial resolution and a set of monthly Normalized Difference Vegetation Index (NDVI) gridded with 0.05°x0.05° spatial resolution.

Two sets of 12 days without missing daily values at the Macedonia airport of Thessaloniki were selected as test samples. The selected days extend throughout the whole year. They also
cover the average range of temperature and precipitation values that are found in the Greek area. The first set was used for the temperature analysis and the second for the precipitation analysis. The daily value of Thessaloniki station was estimated based on the surfaces produced by the spatial interpolation methods using all the other available stations (geographic, topographic and satellite data is also used when MR was applied). The procedure was performed first using all the available stations in the interpolation and then using a subset of only the stations located within a 150 km radius from Macedonia Airport station.

In order to assess the efficiency of the estimations, comparison statistics between estimates and real values (Mean Biased Error (MBE), Mean Absolute Error (MAE), Root Mean Square Error (RMSE), and square of the correlation coefficient ($R^2$)) and scatter plots were employed.

### 3 Results

Table 1 (left) presents the comparison statistics of the estimates of the six different spatial interpolation methods with observed values for temperature using all the available stations. Based on $R^2$ values, that are all significant at a 95% confidence level, it can be stated that all methods performed well enough without differentiations. The MBE is negative for the IDW, Kr, NN and Spl methods indicating a general underestimation of the real values. The examination of MBE, MAE and RMSE for all methods shows that MR is clearly the most efficient in terms of error statistics.

<table>
<thead>
<tr>
<th>Method</th>
<th>$R^2$</th>
<th>MBE</th>
<th>MAE</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>IDW</td>
<td>0.982</td>
<td>-1.213</td>
<td>1.271</td>
<td>1.610</td>
</tr>
<tr>
<td>Kr</td>
<td>0.987*</td>
<td>-1.214</td>
<td>1.271</td>
<td>1.512</td>
</tr>
<tr>
<td>LPI</td>
<td>0.985</td>
<td>-1.313</td>
<td>1.333</td>
<td>1.628</td>
</tr>
<tr>
<td>MR</td>
<td>0.983</td>
<td>0.179*</td>
<td>0.886*</td>
<td>1.062*</td>
</tr>
<tr>
<td>NN</td>
<td>0.986</td>
<td>-0.994</td>
<td>1.075</td>
<td>1.382</td>
</tr>
<tr>
<td>Spl</td>
<td>0.978</td>
<td>-0.675</td>
<td>1.021</td>
<td>1.348</td>
</tr>
</tbody>
</table>

The use of the stations located within a radius of 150 km from Macedonia Airport (Table 1 (right)) produced results only slightly different from the previous findings. All the examined methods estimated the average temperature quite well, with the exception of IDW which present high MAE and RMSE values.

Table 1 (left) presents the comparison statistics of the estimates of the six spatial interpolation methods with observed values of the total amount of daily precipitation when all the available stations are used. In general, all the techniques present a worse performance for precipitation compared to that of temperature with lower correlation coefficients and significantly higher errors. This is attributed to the higher spatial variability of precipitation field which does not favor the simulation of this parameter. MR is clearly the worse method while IDW performs best. All the examined methods underestimate daily precipitation.

The use of stations located within the 150 km radius seems to have different impact on the various methods (Table 2 (right)). The two probabilistic methods (Kr and MR) present a distinct improvement when the closest stations are used as input, while the four deterministic ones (IDW, LPI, NN and Spl) do not show significant changes in their performance. The scatter plots in Fig. 2 illustrate the improvement of the MR method performance. Only the stations within 150 km radius are used, presenting a more evenly distributed pattern which is in agreement with its highest correlation coefficient squared (0.635 against 0.461). Daily precipitation amounts are underestimated by all methods. Finally, Kr seems to be the better
method for the estimation of total daily precipitation when stations within a radius of 150 km are used.

Table 2. Comparison statistics for daily precipitation estimation using all the available stations (left) and only the closest stations (right). The asterisk (*) marks the best value of each statistic. Statistically significant correlation coefficients at a 95% confidence level are in italics.

<table>
<thead>
<tr>
<th>Method</th>
<th>$R^2$</th>
<th>MBE</th>
<th>MAE</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>IDW</td>
<td>0.625*</td>
<td>-1.622</td>
<td>6.520*</td>
<td>8.708*</td>
</tr>
<tr>
<td>Kr</td>
<td>0.503</td>
<td>-3.707</td>
<td>7.696</td>
<td>10.277</td>
</tr>
<tr>
<td>LPI</td>
<td>0.591</td>
<td>-5.195</td>
<td>7.826</td>
<td>10.008</td>
</tr>
<tr>
<td>MR</td>
<td>0.461</td>
<td>-8.507</td>
<td>9.786</td>
<td>13.345</td>
</tr>
<tr>
<td>NN</td>
<td>0.609</td>
<td>-2.741</td>
<td>7.184</td>
<td>9.137</td>
</tr>
<tr>
<td>Spl</td>
<td>0.582</td>
<td>-1.511*</td>
<td>9.640</td>
<td>12.069</td>
</tr>
</tbody>
</table>

Fig. 2. Predicted vs observed scatter plots for MR daily precipitation (mm) when all (left) and only the stations within a 150 km radius (right) are used.

Figure 3 presents the scatter plots of the estimated versus observed values of the best estimation method for temperature (MR – all stations) and precipitation (Kr – 150 km stations). It is evident that temperature estimates are better than that of precipitation.

Fig. 3. Predicted vs observed scatter plots for MR temperature – all stations (left) and Kr precipitation - stations within a 150 km radius (right).

4 Conclusions

Based on the results, the following conclusions can be drawn:
1. Daily temperature is estimated very efficiently by all the examined spatialization methods. The daily precipitation estimation efficiency is also very good, although not as good as temperature.

2. Average daily temperature is better estimated than total daily precipitation due to the low spatial variability of the temperature field.

3. All methods tend to underestimate temperature and precipitation.

4. The two probabilistic methods (inversed distance weighted and ordinary kriging) present a significant improvement for the total daily precipitation when only the stations within 150 km are used. Regarding the average daily temperature, no such improvement was found.

5. Daily temperature is better estimated by the multiple regression method and the use of all the available stations.

6. For the daily accumulated precipitation, the best results were obtained by the ordinary kriging using only the closest stations.

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References

Meteorological parameters affecting the air pollution of the city of Patras

Karagiannidis A.F., Poupkou A., Giannaros C., Giannaros Th., Dimopoulos S., Liora N., Melas D., Argiriou A.A.

In the present paper the impact of meteorological conditions on air pollution in Patras, Greece, is assessed. The assessment is based on meteorological parameters, estimated using the numerical weather prediction model WRF, together with measurements of pollutant concentrations. Three local circulation indices (ventilation factor, wind run and recirculation factor) are also computed and used. The analysis is performed for the winter and the summer of the year 2010 separately, since the two seasons present different meteorological characteristics. During winter, PM$_{10}$ concentrations are rather unaffected by all examined meteorological factors and indices, except temperature. CO decreases during days of elevated boundary layer top and strong horizontal ventilation. O$_3$ concentration increases with the increase of boundary layer depth through a relatively complicated mechanism of combined local scale atmospheric chemistry and possible transport from outside the city. The local stagnation of near-surface air masses is reducing the production and concentration of O$_3$. Summer PM$_{10}$ and CO concentrations are influenced by the pollution transport from sources outside the city, especially during days of increased boundary layer depth. The increase of horizontal local ventilation reduces the PM$_{10}$ concentration. Finally, summertime O$_3$ is increased during days of reduced local stagnation.

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1 Introduction

Air quality in the area of Patras is affected by the meteorological setting of the area. Analysis of the relations between meteorological conditions and atmospheric pollution may help to successfully forecast extreme air pollution episodes, providing the necessary time and information to prepare for, or even avoid them.

Many researchers have already addressed the problem. Melas et al. (2005) using a 3-D, higher-order turbulence model, showed that during days of sea-breeze the Athens basin suffered horizontal recirculation that often resulted in increased pollutants levels. Kallos et al. (1993) studied a series of air pollution episodes in Athens during the period 1983-1990 concluding that “days with critical balance between synoptic and mesoscale circulations and/or days of warm advection in the lower troposphere” favor such episodes. Triantafyllou (2001) studied high PM$_{10}$ concentration episodes in Eordea valley and showed that stagnant meteorological conditions are most frequently associated with these episodes. Karagiannidis et al. (2013) analyzing the meteorological setting of a particulate air pollution episode is the Amyntaio-Ptolemais-Kozani basin showed that weak horizontal wind field near the surface and reduced mixing height combined with lack of synoptic forcing resulted in the trapping of pollutants in the lower troposphere and increased airborne particulate matter concentrations. Vardoulakis and Kassomenos (2008) analyzed PM$_{10}$ data from Athens and Birmingham in order to find relationships to other pollutants and meteorological parameters and found significant positive correlations between PM$_{10}$ and NO$_x$, CO, and solar radiation. Negative correlations between PM10 and O$_3$, wind speed and precipitation were also found. These correlations became weaker during warm seasons. Flocas et al. (2009) concluded amongst others, that air pollution episodes in the Thessaloniki area are primarily associated with anticyclonic conditions, small temperature rise and sea breeze circulation. Kassomenos et al. (2011) in an effort to identify the sources and processes affecting particulate pollution in Thessaloniki, Greece, found higher combustion-related emissions during the cold season, whereas increased contribution of secondary particles was suggested during the warm season. Finally, Kassomenos et al. (2012) in an analysis of coarse particle levels in three European capitals (London, Madrid and Athens) showed that the levels of coarse particles present significant seasonal, weekly and daily variability. The local meteorological conditions and the air mass history indicating long-range atmospheric transport of particles of natural origin are also significant parameters that influence the levels of coarse particles in the three cities especially during episodic events.

2 Data and Methodology

Daily values of CO and PM$_{10}$ concentration data recorded at two monitoring stations operating inside the city of Patras are used in this study. O$_3$ concentrations are also measured at one of the two stations. These three pollutants were selected as representative of the primary, mixed-origin and secondary pollutants. Table 3, presents the main characteristics of the two measuring sites. The monitoring stations are located very close to the center of Patras and are expected to be influenced by the pollutants emitted from the enhanced anthropogenic activities that take place in it.

<table>
<thead>
<tr>
<th>Location</th>
<th>Site Name</th>
<th>Type of station</th>
<th>Type of area</th>
<th>Characteristics of zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Square Drosopoulou</td>
<td>Sta1</td>
<td>Traffic</td>
<td>Urban</td>
<td>Residential/commercial</td>
</tr>
<tr>
<td>Square St. George</td>
<td>Sta2</td>
<td>Traffic</td>
<td>Urban</td>
<td>Residential/commercial</td>
</tr>
</tbody>
</table>

Daily WRF-ARW output data of a series of synoptic and dynamic parameters for January, February, July and August 2010 are also used. These parameters are temperature at 10 meters
above ground level (T), relative humidity at 10 meters above ground level (RH), wind speed at 10 meters above ground level (WS) and maximum boundary layer height (MBPL) and are estimated for the center of Patras (38.252°N, 21.738°E).

Following Allwine and Whiteman (1994) and Melas et al. (1998), 3 indices of local circulation (ventilation factor (V), wind run (S) and recirculation factor (R)) are also computed on a daily basis. These indices are defined as:

\[
V = \sum_{j=1}^{N} (U_j \cdot 1_j)
\]

(1)

\[
S_j = T \sum_{j=1}^{N} U_j
\]

(2)

\[
R_j = 1 - \frac{L_j}{S_j}
\]

(3)

where \(U\) the wind speed at 10 meters above ground level (AGL), \(U_j\) and \(V\) the west-east and south-north components of wind, \(h\) the boundary layer depth, \(i = 1, 2, ... , N\), \(N\) the total number of series data points and \(p = \frac{c}{\tau} - 1\), \(\tau\) the desired transport time, and \(L_j\) the resultant transport distance, defined as:

\[
L_j = \sqrt{X_j^2 + Y_j^2}
\]

(4)

with

\[
X_j = \sum_{j=1}^{N} (U_j)
\]

(5)

and

\[
Y_j = \sum_{j=1}^{N} (V_j)
\]

(6)

Ventilation factor (V) values close to zero indicate stagnant conditions regarding horizontal ventilation of an area, just like the wind run (S). Ventilation increases with the increase of ventilation factor. Recirculation factor (R) values approaching zero indicate straight line transport, while values approaching one means negligible net transport and extended horizontal recirculation.

Correlation coefficients between the CO, PM\(_{10}\) and O\(_3\) concentrations and the presented meteorological parameters and local circulation indices were calculated. The 95% confidence level was also calculated in order to assess their statistical significance. The results are presented in the following sections.

### 3 Results

Tables 2 and 3 present the correlation coefficients between the three pollutants average daily concentration and the seven meteorological parameters and indices for winter (January – February) and summer (July – August) respectively. The coefficients that are statistically significant at the 95% confidence level are noted in red.

As shown in Table 2, where the winter correlations are presented, PM\(_{10}\) concentrations are positively related to temperature, which is a rather unexpected result. This correlation may be affected by meteorological parameters that are not examined in the present study. Daily CO concentrations increase as the boundary layer becomes thinner. CO is a primary pollutant emitted locally (inside the Patras urban area) and its concentration increases with the decrease of the boundary layer depth, because a thin boundary layer leaves a limited volume of air for the pollutant to be diluted. Strong winds and increased horizontal ventilation reduce the
stagnation of air masses, dispersing CO in the atmosphere, decreasing thus its concentration. O₃ concentrations during winter are positively correlated to boundary layer depth. This is considered to be the result of a relatively complicated mechanism of combined local reduced destruction and possible transport from outside the city. According to this scheme, the increase of PBL decreases the NOₓ concentrations due to increased volume for dispersion. Since NOₓ act as O₃ sink, lower NOₓ concentrations result to increased O₃ concentrations. Moreover, a deep boundary layer may allow O₃ that was produced outside the city to be transported inside the city and increase the local concentrations. High temperatures favor as expected the production of O₃, since they are associated with increased solar radiation, necessary for the photochemical production of O₃. The positive relation to the wind speed and ventilation that was found is attributed to the facts that O₃ production in the Patras city center is not favored by stagnant conditions and that some O₃ may be transported from sources outside the city.

Table 2. Correlation coefficients between the pollutants concentration and the meteorological parameters and indices for winter. Statistically significant coefficients at the 95% confidence level are noted in red.

<table>
<thead>
<tr>
<th></th>
<th>WS (m/s)</th>
<th>T (deg)</th>
<th>RH (%)</th>
<th>MPBL (m)</th>
<th>V (m²/s)</th>
<th>S (m)</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM₁₀ Sta1 (μg/m³)</td>
<td>-0.17</td>
<td>0.39</td>
<td>0.14</td>
<td>0.02</td>
<td>0.01</td>
<td>-0.15</td>
<td>0.13</td>
</tr>
<tr>
<td>PM₁₀ Sta2 (μg/m³)</td>
<td>-0.20</td>
<td>0.30</td>
<td>0.07</td>
<td>-0.15</td>
<td>-0.03</td>
<td>-0.17</td>
<td>0.27</td>
</tr>
<tr>
<td>CO Sta1 (mg/m³)</td>
<td>-0.25</td>
<td>-0.20</td>
<td>0.09</td>
<td>-0.33</td>
<td>-0.48</td>
<td>-0.28</td>
<td>0.19</td>
</tr>
<tr>
<td>CO Sta2 (mg/m³)</td>
<td>-0.39</td>
<td>-0.23</td>
<td>0.04</td>
<td>-0.41</td>
<td>-0.62</td>
<td>-0.38</td>
<td>0.44</td>
</tr>
<tr>
<td>O₃ Sta1 (μg/m³)</td>
<td>0.36</td>
<td>0.49</td>
<td>0.25</td>
<td>0.33</td>
<td>0.68</td>
<td>0.41</td>
<td>-0.27</td>
</tr>
</tbody>
</table>

Summer correlations are presented in Table 3. The positive correlation of PM10 and maximum PBL shows that significant amounts of airborne particulate matter is transferred in the area through the circulation of the troposphere. The increased boundary layer height allows PM10 to enter the city area and increase the local concentrations. PM10 is also positively correlated to temperature. This fact can be considered as an indirect relation, since high summer temperatures tend to increase the boundary layer depth. The negative correlation with the RH is expected since temperature and RH and negatively correlated. Increased local ventilation is decreasing PM10 concentrations since strong ventilation leads to strong dispersion of the pollutant inside the boundary layer. CO concentrations are higher during days of deep boundary layer suggesting that CO is not only locally produced. Since central heating is absent and transport is substantially reduced inside the urban area during summertime, transported CO could play a role in the configuration of CO levels in the urban center. The positive correlation of CO with MPBL suggests that such a process is quite significant. The positive correlation of temperature and negative correlation of RH with CO can be explained in the same way as it was explained for PM10. The negative correlation between CO and V is expected because in a local scale, ventilation helps in the dispersion of CO in the boundary layer of Patras. Finally, the positive correlation of O₃ and ventilation is attributed to the fact that the increase of O₃ values is not favored by stagnant conditions inside urban areas.

Table 3. Correlation coefficients between the pollutants concentration and the meteorological parameters and indices for summer. Statistically significant coefficients at the 95% confidence level are noted in red.

<table>
<thead>
<tr>
<th></th>
<th>WS (m/s)</th>
<th>T (deg)</th>
<th>RH (%)</th>
<th>MPBL (m)</th>
<th>V (m²/s)</th>
<th>S (m)</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM₁₀ Sta1 (μg/m³)</td>
<td>0.18</td>
<td>0.72</td>
<td>-0.46</td>
<td>0.44</td>
<td>-0.41</td>
<td>0.22</td>
<td>-0.07</td>
</tr>
<tr>
<td>PM₁₀ Sta2 (μg/m³)</td>
<td>0.01</td>
<td>0.78</td>
<td>-0.40</td>
<td>0.49</td>
<td>-0.40</td>
<td>0.00</td>
<td>-0.01</td>
</tr>
<tr>
<td>CO Sta1 (mg/m³)</td>
<td>-0.04</td>
<td>0.53</td>
<td>-0.42</td>
<td>0.33</td>
<td>-0.38</td>
<td>0.00</td>
<td>0.03</td>
</tr>
<tr>
<td>CO Sta2 (mg/m³)</td>
<td>0.11</td>
<td>0.27</td>
<td>-0.34</td>
<td>0.23</td>
<td>-0.26</td>
<td>0.12</td>
<td>-0.10</td>
</tr>
<tr>
<td>O₃ Sta1 (μg/m³)</td>
<td>0.20</td>
<td>-0.02</td>
<td>0.36</td>
<td>-0.15</td>
<td>0.38</td>
<td>0.16</td>
<td>-0.25</td>
</tr>
</tbody>
</table>
4 Conclusions

The previous analysis yields five basic conclusions for the relation between the selected pollutants and the meteorological parameters and indices.

1. During winter, CO is produced primarily locally and, as a result, a deep boundary layer and strong ventilation reduce its concentrations inside the city of Patras.
2. The increase of O$_3$ levels during wintertime is favored by the increased temperatures, significant turbulence and increased boundary layer depth. The later enhances the dispersion of NO$_x$, leading to less O$_3$ destruction. A deep boundary layer also allows the transport of O$_3$ inside the urban city center.
3. During summer significant amounts of PM$_{10}$ and CO are transported inside the city, allowed by the increased boundary layer depth.
4. Local ventilation reduces the summer PM$_{10}$ and CO levels as it helps in the dispersion of the pollutants.
5. Summer O$_3$ concentrations are increased during days of increased ventilation. The later decreases near-surface air masses stagnation that does not favor O$_3$ formation.

Acknowledgments This work is financed by the European Territorial Cooperation Programme Greece-Italy 2007-2013 project CESAPPO, co-financed by the European Union (ERDF) and by National Funds of Greece and Italy.

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McKendry IG (2000) PM10 Levels in the Lower Fraser Valley, British Columbia, Canada: An Overview of Spatiotemporal Variations and Meteorological Controls, J Air Waste Manage 50-3: 443-452
An integrated assessment of climate change impacts from the regional scale of the area of Peloponnese to the local scale of the area of Messinia


An integrated assessment of the climate change impacts for the vulnerable area of Peloponnese with a special focus on Messinia region was performed within the framework of the NSRF/Cooperation 2009 project XENIOS. To this end, output from selected regional climate models developed within the framework of EU project ENSEMBLES using the A1B emissions scenario, is employed. Changes in mean and extreme climate indices, concerning air temperature, precipitation, as well as sector-specific indices for forest fire risk and energy demands are estimated. These changes are calculated between a 30-year reference period (1961–1990) and two future periods (2021-2050 and 2071-2100) taking the ensemble mean of the RCMs. Furthermore, in order to study Messinia’s climate evolution due to climate change, the Thin Plate Spline (TPS) interpolation method is used to downscale the climatic output of the ENSEMBLES RCMs from the initial grid of 25km spatial resolution for Peloponnese into a finer one of 5km. In general, the results suggest an increase in the number of hot days (Tmax>30°C) of up to 60 additional days per year and an increase in the number of dry days up to 30 days per year, leading to greater energy requirements and higher fire risk conditions by the end of the century.

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1 Introduction

Recent studies both on present and future climate have shown that the Eastern Mediterranean and Greece, in particular, is one of the most vulnerable regions regarding climate change due to its sensitivity to rising temperatures and precipitation reduction (IPCC 2007, Giorgi and Lionello 2008, Zanis et al. 2009). This paper presents an assessment of the impacts of climate change for the vulnerable region of Peloponnes, and more specifically for the high biodiversity area of the Messinia, within the framework of NSRF/Cooperation 2009 project XENIOS. In particular, the XENIOS Project addresses the climate change synergistic impacts on the aforementioned areas and focuses on the consequences for the tourism sector in the near future. In this paper, emphasis is given to indices relevant to maximum temperature, daily precipitation, fire risk and energy requirements.

2 Data and Methodology

In the current study, daily output data from three regional climate models (RCMs) developed at KNMI (Netherlands), METO (UK) and MPI (Germany) within the framework of the EU ENSEMBLES project have been used (www.ensembles-eu.org). All models have a horizontal resolution of 25 km × 25 km and use the A1B greenhouse gases emissions scenario (Nakicenovic et al. 2000).

In order to study Messinia’s climate evolution due to climate change, Thin Plate Spline (TPS) interpolation method has been used to downscale the RCMs output from the grid of 25km into a finer one of 5km spatial resolution. TPS is a stochastic method that creates a surface which passes through the control points and has the least possible change in slope at all points. In the present study, a three-dimensional (3D) interpolation method of position and elevation is used based on the TPS interpolation as proposed by Hutchinson (1998), who investigated the climatic dependence on topography and showed that there is a small but significant elevation effect on the daily climatic data.

Furthermore, in order to assess fire risk in the domain of study the Canadian Fire Weather Index (FWI) is used. The FWI model is non-dimensional, based on physical processes and has been used at several locations, including the Mediterranean basin (e.g. Moriondo et al. 2006, Karali et al. 2014). It provides numerical ratings of relative fire potential based solely on weather observations. The meteorological inputs to the FWI System are daily noon values of temperature, relative humidity, 10m wind speed and precipitation during the previous 24 hours and are described in detail in van Wagner (1987).

The impacts of temperature increases on energy requirements, especially during summer period, are investigated using the concept of cooling degree days that are defined as the difference of mean air temperature from a base temperature. In the current study, the base temperature of 25°C is used as defined for the Mediterranean region by Giannakopoulos et al. (2009).

Finally, past experience has shown that no single model is perfect for all climate variables and statistics considered (Christensen and Christensen 2007). Therefore, in this study, the ensemble mean of daily output data from the aforementioned RCMs is used. Present day simulations cover the period 1961-1990 and are used here as reference for comparison with future projections for the periods 2021-2050 (near future) and 2071-2100 (distant future).

3 Results and discussion

As far as present day climate is concerned, according to the ensemble mean output, the number of hot days, namely the days with maximum temperature greater than 30°C, range from 5 to 90 days per year. Higher values are depicted in the southern part (including
Messinia) and north western parts of Peloponnese (Fig. 1a). The number of dry days, the days with daily total precipitation amounts less than 1mm, increases from 250 per year in the north-west to 330 days per year to the south-east (Fig 1b) of Peloponnese. Messinia depicts 250-290 dry days per year. The number of days requiring heavy cooling (i.e. days requiring cooling of more than 5°C from the base temperature of 25°C), follow the same pattern as hot days. Messinia prefecture requires 0-12 days of heavy cooling per year for the control period (Fig 1c). The drier conditions and higher temperature throughout the year in the eastern side of Peloponnese (not shown) lead to the higher number of days with elevated fire risk, as depicted in Fig. 1d. For Messinia, elevated fire risk days range between 20 and 60 days per year.

Figures 2 and 3 depict spatial patterns of change for the selected extreme indices. Hot days are estimated to occur more frequently in the whole domain of study. In particular, an increase of 20-30 additional days per year is expected throughout Peloponnese in the near future (Fig. 2a) while this increase will be up to 2 months/year in the distant future (Fig. 2b). Regarding precipitation, models predict that in the near future the number of dry days may increase by 5-12 days/year (Fig. 2c). Greater increases up to 30 days/year almost in the entire domain are expected in the number of dry days by the end of the century (Fig 2d).

Consistent with the findings for the reference period, the ensemble mean projections suggest greater increases in the number of days with high energy requirements in Messinia and eastern coastal areas up to 25days per year (Fig. 3a). Quite dramatic changes in CDD for the period 2071-2100, with 40-60 additional cooling days in the same areas are expected (Fig. 3b). As far as future fire risk is concerned, decrease in total winter precipitation in combination with an increase in mean summer temperature (not shown) leads to an increase in the number of days with elevated fire risk in the entire domain for both the near and distant future. In Messinia, an increase of up to 20days/year is expected in the near future while this increase is 40 additional days per year in the distant future (Fig.3c,d).
Fig. 2. Changes in the (a,b) number of days with $T_{\text{max}}>30^\circ\text{C}$ and (c,d) number of dry days ($P<1\text{mm}$) in the near (left column) and in the distant future (right column).

Fig. 3. Changes in the (a,b) number of days with $\text{CDD}>5$ and (c,d) in the number of days with $\text{FWI}>30$ in the near (left column) and in the distant future (right column).
4 Conclusions

In the current study an assessment of the impacts of climate change for the vulnerable region of Peloponnese and in particular of the Messinia prefecture within the framework of XENIOS project is presented. Thin Plate Spline interpolation method has been used in order to downscale the RCMs output from the grid of 25km into a finer one of 5km spatial resolution. The ensemble mean of the three RCMs used, suggests an increase of up to 2 additional months/year with temperatures exceeding 30°C, while increases up to 30 days/year almost in the entire domain are expected in the number of dry days by the end of the century. In Messinia, quite dramatic changes in CDD for the period 2071-2100, with 40-60 additional cooling days are expected. As long as elevated fire risk is concerned, an increase of 40 additional days per year is anticipated. Synthesis of our results with results concerning extreme geophysical phenomena and air pollution is needed, in order to study the synergistic interrelation between climate change impacts and natural disasters so as to study the tourism development of Messinia.

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Evaluation of Kalman filter on temperature forecasts simulated by numerical weather prediction models

Karoutsos G., Karacostas Th., Pytharoulis I., Zanis P.

In order to make predictions more accurate and to reduce the systematic errors of numerical weather prediction models, a bulk of methods have been developed. One of them is Kalman filtering, designed by R.E. Kalman back in 1960, as a solution to the state space Wiener problem. Kalman filtering has been applied on 3-day forecasts of air temperature at 2m above ground from three numerical weather prediction models (WRF, Skiron/Eta and GFS). Observations of air temperature at 2m were obtained from the weather station located at the airport of Thessaloniki, Greece. WRF and Skiron/Eta forecasts are produced by the Department of Meteorology and Climatology of the Aristotle University of Thessaloniki using initial and boundary values from GFS. It is shown that a simple estimation of the forthcoming predicted value made using data from the 10 past predictions is sufficient to significantly reduce the mean error. Moreover, the annual fluctuation of the error changed when the filter applied in all three models. The winter months maintained the original error, while the summer months reduced it, so that, maximum values transferred from summer to winter. When the error was systematic, the method revealed greater skill, with a reduced mean absolute error.

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1 Introduction

Numerical weather prediction models exhibit errors while simulating the physical processes in the atmosphere. An effective way to reduce these errors and increase the performance of a numerical weather prediction model is the application of statistical methods to the output of the model.

One of the most convenient approaches to the problem is the use of Kalman filtering (Kalman 1960, Maybeck 1979). Among the advantages of this method is the fact that it is a relatively simple method which does not require large amounts of data, easily adapts to changes in the model and has minimal computational cost (Galanis 2002). Thus, it gives an easy but effective and useful solution to the problem of correctly predicting the value of a variable.

In this study, Kalman filtering has been applied on temperatures forecasts from three numerical weather prediction models (WRF, GFS and Skiron/Eta) for a period of a year, in order to find the reduction of the error that can be observed with this method. The aim is to remove the systematic error of the forecast, which will result in zeroing the mean value of the forecast error. In this way, the output from the model will be modified so that it will be closer to the true value.

2 Data and Methodology

2.1 Data

The dataset that has been used covers the period from June 2011 up to July 2012. Hourly measurements of temperature at 2m were obtained from the meteorological station of the airport of Thessaloniki for this period. The station’s altitude is 4m above sea level and its geographical coordinates are 40.527°N, 22.971°E.

The measurements are compared to 2m temperature forecasts predicted by three numerical weather prediction models: Weather Research and Forecasting (WRF), Skiron/Eta model (Kalos et al. 1997) and Global Forecasting System (GFS). WRF and Skiron/Eta 3-day forecasts are produced by the Department of Meteorology and Climatology of the Aristotle University of Thessaloniki using initial and boundary values from GFS run at 1200 UTC.

WRF runs are performed using a domain with low spatial resolution (15x15km) which covers Europe and a high spatial resolution domain (5x5km) which covers Greece. The vertical levels are thirty-nine (39) and the dynamical core is the Advanced Research WRF – ARW. Data is stored every 6 hours (0000, 0600, 1200 and 1800 UTC). The domain of the Skiron/Eta runs covers the Central and Northern Greece with a 5x5 Km resolution. The vertical levels are thirty-eight (38) reaching the surface of 25hPa (Pytharoulis 2009). Data is stored every 3 hours (0000, 0300, 0900, 1200, 1500, 1800 and 2100 UTC). GFS runs are performed by NOAA. The model is based on the normal equations of conservation of mass, momentum, energy and moisture. The spatial resolution of the model is about 27km (T574) and has 64 vertical levels in a hybrid system. Data is stored every 3 hours on a 0.5°x0.5° resolution. The grid cell temperature nearest to the station location has been used from each model.
2.2 Methodology

The Kalman filter is essentially a set of mathematical equations that implement a predictor-corrector type estimator that is optimal in the sense that it minimizes the estimated error covariance - when some presumed conditions are met (Welch and Bishop 2004).

Let $x_k$ be a vector (the state vector) denoting an unknown process at time $k$ and $z_k$ a known (observable) relevant vector at the same time. It is assumed that the change of the process $x$ from time $k$ to $k+1$ is given by the system equation:

$$x_{k+1} = F_k x_k + w_k$$

and the relation between the observation vector and the state vector is given by the observation equation:

$$z_k = H_k x_k + v_k.$$ 

The vectors $w_k$ and $v_k$ are assumed (i) to have a normal distribution with zero mean, (ii) to be independent from one another and (iii) to be time independent. The value of the system vector at time $k+1$ is estimated by the equation:

$$x_{k+1|k} = F_k x_k$$

and its variance is given by the equation:

$$P_{k+1|k} = F_k P_{k|k} F_k^T + Q_k$$

where $Q_k$ is the covariance matrix of $w_k$.

As soon as a new observation $z_{k+1}$ is being known an updated estimation is possible. This new estimation is given by the equation:

$$x_{k+1|k+1} = x_{k+1|k} + K_{k+1} [z_{k+1} - H_{k+1} x_{k+1|k}]$$

and its new variance will be:

$$P_{k+1|k+1} = (I - K_{k+1} H_{k+1}) P_{k+1|k} (I - K_{k+1} H_{k+1})^T + K_{k+1} R_{k+1} K_{k+1}^T$$

where $R_{k+1}$ is the covariance matrix of $v_k$ and

$$K_{k+1} = P_{k+1|k} H_{k+1} [H_k P_{k+1|k} H_{k+1}^T + R_{k+1}]^{-1}.$$ 

Although Kalman filter has been applied on temperature forecasts for the period from June 2011 to July 2012 (fourteen months), the statistical analysis was carried out only for the last twelve months of this period, in order to be independent from the initial values that have been used. The statistical study of errors has been made using some statistics, such as the bias of the error and the absolute bias of the error, (Wilks 1995). In this study the systematic part of the error of the forecast for a short period of time has been used as the system vector $x_k$ and the error of the forecast as the observation vector $z_k$. The value of $F$ and $H$ has been set $F = H = I$, as there is no solid evidence to rely on concerning the change of $x_k$ in time. Moreover, the covariance matrices of $w_k$ and $v_k$ are given by the equations:

$$Q_{k+1} = \frac{1}{N-1} \sum_{i=1}^{N} (w_{k+1} - \sum_{i=1}^{N} w_{k+1})^2, R_{k+1} = \frac{1}{N-1} \sum_{i=1}^{N} (v_{k+1} - \sum_{i=1}^{N} v_{k+1})^2$$

where $w_k = x_{k+1} - x_k$, $v_k = z_k - v_k$ (Galanis 2002) and $N$ is the number of days with data used. For parameter $N$ the values 4, 7, 10, 15 and 30 have been used. The filter has been applied on each forecast hour of the three models separately.

3 Results

It is showed that when data from the past 10 days ($N = 10$) were used, a greater reduction of forecast errors was observed. Both the percentage of cases were predictions were improved after the application of the filter was greater when $N=10$ and the annual absolute bias was smaller in all three models.

Although, annual bias exceeds 1.0°C on most of the forecast hours of the three models, it is reduced to values smaller than 0.1°C by the Kalman filter. On Table 1 the annual absolute bias is showed before and after Kalman filter is applied for every model and forecast hour for the first 48 hours of the forecast. The reduction of the absolute bias is not the same every time; there are cases where it is remarkable and other with no reduction. The error of the $21^\text{st}$.
the 45th and 69th forecast hour of Skiron/Eta was over 2.6°C before the application of the filter but only 1.4°C after, resulting in an almost 50% decrease. On the other hand the value of the absolute bias of the 3rd, the 15th and the 39th forecast hour decreased slightly or not at all. The absolute bias of the WRF model is almost always greater than 2.0°C, but the application of the filter forced it to be less than 2.0°C. Nevertheless, the reduction is not always the same, but varies from 0.1°C to 1.1°C. Similarly, the annual absolute error of the 30th, and 54th forecast time of GFS reduced from 2.7°C to 1.2°C and 1.4°C respectively (65% and 48%), however there is no reduction of the bias of the 15th and 39th forecast hour.

Table 1. Annual absolute bias in °C before and after Kalman filter is applied.

| Forecast Horizon | 03 | 06 | 09 | 12 | 15 | 18 | 21 | 24 | 27 | 30 | 33 | 36 | 39 | 42 | 45 | 48 |
|------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| WRF              |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Before           | 2.5| 1.8| 2.0| 2.0| 2.2| 2.0| 2.2| 2.2| 2.2| 2.2| 2.2| 2.2| 2.2| 2.2| 2.2| 2.2|
| After            | 1.3| 1.7| 1.8| 1.4| 1.4| 1.8| 1.8| 1.6| 1.6| 1.6| 1.6| 1.6| 1.6| 1.6| 1.6| 1.6|
| Skiron           |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Before           | 1.1| 1.3| 1.8| 1.9| 2.1| 2.0| 2.6| 2.2| 1.5| 1.4| 1.9| 2.1| 2.2| 2.1| 2.8| 2.3|
| After            | 1.1| 1.1| 1.5| 1.6| 1.8| 1.4| 1.4| 1.2| 1.2| 1.5| 1.6| 1.8| 1.5| 1.4| 1.3| 1.3|
| GFS              |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Before           | 2.2| 2.7| 2.0| 1.9| 2.0| 2.1| 1.7| 1.5| 2.3| 2.7| 2.1| 1.9| 2.0| 2.0| 1.7| 1.6|
| After            | 1.1| 1.1| 1.5| 1.7| 2.0| 1.9| 1.6| 1.3| 1.2| 1.2| 1.5| 1.7| 2.0| 1.9| 1.6| 1.4|

The reduction of the annual absolute bias depends on the value of the annual bias of the forecast hour. When, the absolute bias is between -0.6°C and 0.6°C there is no noticeable reduction of the absolute bias of the forecast but when it is outside this interval, Kalman filter improves the forecast significantly.

Monthly bias is always reduced with Kalman filter and its value resides between -0.5°C and 0.3°C even though it was over 1.0°C most of the times without the filter. There is a reduction in the monthly absolute bias in each month of the three models with the exception of March from Skiron/Eta, where the value of the absolute bias remains unchanged. For the WRF model the reduction is greater during November, December and July where the absolute bias is reduced by more than 0.8°C and it is smaller during March and April, where this value is reduced only 0.1°C and 0.2°C respectively. Similarly for model Skiron/Eta during August, September and December the absolute bias is reduced more than 1.0°C. There is no month with an average absolute bias greater than 2.0°C, whereas previously there were six. For GFS the greatest reduction is observed on July (1.3°C) followed by June (0.9°C), while the smallest is observed on March (0.1°C). There were six months with an absolute bias greater than 2.0°C before the use of the filter, but only one after that. The reduction of monthly absolute bias was smaller when the monthly bias was too close to zero (between -0.5°C and 0.5°C).

In Fig. 1 seasonal absolute bias is shown for every model. The reduction of the absolute bias in winter and spring months is smaller in all three models than the reduction on summer and autumn months. This is because during summer the forecast error is mostly systematic and during these months large values of absolute bias are observed. The maximum monthly absolute bias moved from November to January for WRF, from November to March for Skiron/Eta and from July to March for GFS, and the smallest seasonal absolute bias is observed during summer after the application in all three models.
Finally, the probability of having a successful temperature forecast, according to ECMWF’s standards (successful forecast ⇔ absolute error less than 2°C) was increased with Kalman filter. The results for Skiron/Eta model are showed in Figure 2. The probability a temperature forecast error to be less than 2°C is greatly increased on months were it was low (summer, autumn). Even though there were only four months with probability greater than 60% without the use of the filter, after that this value was greater than 60% in all months and in some cases greater than 80% (June-September). WRF and GFS forecasts also improved the same way resulting in an increase of this value from 54% to 80% on average.

4 Conclusions

It is shown that Kalman filter is an effective method that can improve the forecast of air temperature. The application of an one dimensional filter using data from the previous 10 days seems to be the optimal choice. The aim was to remove the systematic error of the forecast and as Kalman filter is defined, so as to give to the state vector the most probable value, the mean error of the forecast was eliminated and thus the absolute bias reduced and the forecast were more accurate. Regardless of whether the initial forecast overestimates or underestimates the real value, Kalman filter reduced the error.

From the above it appears that the application of the filter, with the use of a small time series data is able to give better forecasts of temperature, since a portion of the observed error (the systematic part) is removed from the forecast.
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Coupled Weather – Wildland Fire Model for fire behavior interpretation

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Fire behavior can be estimated when meteorological conditions, topography and fuel properties are known. An interpretation of physical processes and flow dynamics associated with atmosphere-fire interactions is attempted, using the coupled Weather – Wildland Fire Model, WRF-SFIRE. Vertical distributions of potential temperature, water vapor mixing ratio and horizontal wind components, surface pressure and fuel properties were considered as input data information, while topography has been eliminated. Ideal simulations with a forecast horizon of 2.5 hours were carried out in Large-Eddy Simulation mode at a horizontal resolution of 50 m and 5 m for the meteorological and the SFIRE model, respectively. The results showed that WRF-SFIRE is capable of analyzing the atmosphere-fire interactions to a large extent, while a well defined vertical circulation is generated due to sensible and latent heat fluxes from the fire. Convergence, downwind of the fire-line, is associated with a pair of positive and negative vertical vorticity, although this feature was not persistent, due to highly perturbed background flow. Changes in atmosphere’s relative humidity affected propagation rates of the fire, as well the dynamical characteristics of the pyro-convective plume. An increase in water vapor mixing ratio, within the column, was observed which is attributed to latent heat fluxes.

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1 Introduction

Meteorological conditions play a significant role in fire behavior. Weather affects the way in which a fire develops and spreads, while the release of sensible and latent heat fluxes by a wildland fire modifies the surrounding atmosphere. As a result, a two-way interaction is taking place with complex physical processes across a range of physical scales. Over the last two decades, the development of atmosphere-fire numerical models for simulating wildland fire behavior has shown the complexity of atmosphere-fire interactions. Clark et al. (1996b) demonstrate “dynamic fingering” while Jenkins at al. (2011) investigate the impact of vertical shear, in a unidirectional ambient wind field, on fire-line propagation. On the other hand, Kochanski et al. (2013) address the lack of evaluation and validation of a coupled Weather-Wildland Fire model by using in situ-scale observational data.

In this study, the WRF-SFIRE modeling system (Mandel et al. 2011) is used for the interpretation of physical processes and flow dynamics associated with atmosphere-fire interactions under certain ideal conditions.

2 Data and Methodology

The non-hydrostatic Weather Research and Forecasting model with the Advanced Research dynamic solver (WRF-ARW Version 3.4) was initialized in the ideal simulations (Wang et al. 2012) and used in a highly idealized large eddy simulation (LES) configuration. WRF-Fire is a physics module in WRF that allows the user to simulate the growth, propagation and decay of wildland fires. Although there was no nesting in this study, in general only the innermost atmospheric domain is coupled with the fire model (SFIRE). At the surface, each atmospheric grid cell is divided into two-dimensional fuel cells, where rate of spread and post-frontal sensible and latent heat fluxes are calculated (Mandel et al. 2011).

The single model domain has a west-east and south-north extent of 7.5 km with no topography, while the model top was set to 2 km. The horizontal grid spacing in x-y dimensions was 50 m. A hyperbolically-stretched vertical grid was used (60 levels), defining a computational domain of 150 x 150 x 60 (x,y,z) grid points. The model time step was 0.25 s. Open boundary conditions were applied on the lateral boundaries. Atmosphere to fire refinement ratio was 10, which implies a grid spacing of 5 m for the SFIRE model. Only the MM5 surface layer and the 5-layer surface model were activated, while the rest of microphysics were disabled.

In order to initialize the atmospheric conditions in which the fire ignites, vertical distributions of potential temperature ($\theta$) and water vapor mixing ratio (r) (Fig. 1) were specified. The surface pressure was 1015 hPa and a uniform westerly wind field of 2 (WND_2.0) and 4 m/s (WND_4.0) was set at the western lateral boundary, of the two experiments that were performed.

![Fig. 1](image) Vertical distributions or potential temperature ($\theta$) and water vapor mixing ratio (r) as input data during WRF’s initialization.

For the initialization of SFIRE model, fuel properties must be specified (Table 1). Fuel category 10 (Timber - litter and understory), upon 13 Anderson fuel categories, was assigned across the entire model domain, while fire ignition took place 1830 s after the start of the
simulations. The initial 30 min were accounted as the spin-up period. The ignition mechanism was considered as a 500m south-north long line with a 50 m width. Similar ignition mechanisms are used in Jenkins et al. (2011), Coen et al. (2013) and Kochanski et al. (2013).

In order to describe flow dynamics, horizontal divergence and the vertical component of relative horizontal vorticity on constant heights are accounted for.

### Table 1. Fuel properties of Anderson’s fuel category 10 (Timber-litter and understory). The identifiers are as used in SFIRE (Mandel et al, 2011, Wang et al. 2012 p. A-5).

<table>
<thead>
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<th>Symbol</th>
<th>Description</th>
<th>Identifier</th>
<th>Value</th>
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<td>α</td>
<td>Wind adjustment factor</td>
<td>windrf</td>
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<tr>
<td>zf</td>
<td>Fuel wind height (m)</td>
<td>fwh</td>
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<td>Fuel roughness height (m)</td>
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<td>Fuel depth (m)</td>
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### 3 Results

#### 3.1 Flow dynamics due to atmosphere-fire interactions

Fig. 2 depicts the vertical vorticity and divergence in the x-y plane, as they are calculated (using 2nd order central finite differences) at 10 m above surface for WND_4.0 experiment, 2 h after the ignition. The convergence region of negative vertical vorticity (arrow in Fig. 2) in front of the fire-front is evident, suggesting that this flow characteristic acts as the propagation mechanism described by Clark et al. (1996a) and Jenkins et al. (2011).

At the fire-front, a cyclonic and anticyclonic vortex couplet, of nearly the same magnitude (∼ 0.1 s⁻¹), is present (Fig. 2a), shaping the fire-line. This couplet is associated with strong convergence (Fig. 2b), with maxima of 0.08 s⁻¹. Vertical vorticity at the convergence zone is stronger in magnitude (max. 0.13 s⁻¹) than the pair of vortices at the fire-front, implying that the origin of the propagation mechanism is due to that convergence region, ahead of the burning fire-front. Although this dynamic characteristic is well defined in Fig. 2, it was not so distinct elsewhere during the simulation but it was appeared. For clarity, this structure was observed both in WND_4.0 and WND_2.0 (not shown) experiments. The maximum wind speed, at 10 m, is 9.6 m/s (2h after the ignition) and is located just ahead of the fire-front, while the maximum vertical velocity is 16.2 m/s at nearly 800 m above the ground and it is not co-located with any near surface vortex.

The convergence column is vertically extended until 500 m, intensifying its strength at 200m where the anticyclonic vertical vorticity is 0.13 s⁻¹ (not shown). At 100 m above the ground and in-front of the fire-line, a cyclonic vortex of equal magnitude as the anticyclonic vortex, is located south-west of it. It is believed that this vortex is the vertical extension of the cyclonic vortex described in Fig. 2a. Pairs of clockwise and counter-clockwise vortices are present at 500 m, due to highly perturbed flow, while the strength and the magnitude of the vortices are decreasing as the height increases. At 1800 m above the ground, there is a uniform westerly wind field, implying that there is no turbulence due to atmosphere-fire interactions at that level.
3.2 Impact of relative humidity on atmosphere fire interactions

In order to estimate the impact of relative humidity in atmosphere-fire interactions, a ±20% change in vertical distributions of water vapor mixing ratio (Fig. 1) was attempted. Identical simulations were carried out with fuel moisture model on and off. Fuel moisture model considers the atmospheric state of WRF and provides fuel moisture to SFIRE. In all experiments, a uniform westerly wind field of 2 m/s is considered as input data information.

Different humidity conditions in atmosphere result in different pyro-convective plume dynamics, heat fluxes, vertical velocities and overall fire behavior. Fig. 3 depicts fire area (km$^2$) up to 2.5 h after the onset of each simulation. WND_2.0 experiment, with fuel moisture model on and off, was initialized with Fig. 1's vertical distributions of $\theta$ (K) and $r$ (g/kg) and acts as control run in each case. Increasing the relative humidity in the atmosphere with fuel moisture model off (MST_UP_MDL_OFF), fire area increases relative to WND_2.0 (1.78 km$^2$ to 1.23 km$^2$, respectively). The same behavior is observed and in MST_DWN_MDL_OFF (20% decrease in mixing ratio) experiment, where the burned region is 1.41 km$^2$ (Fig. 3). With fuel moisture model active, humidity conditions affected fuel moisture, where fuel was considered as a 1hr moisture class. Although the burned area decreased in both cases (dashed lines in Fig. 3), increased relative humidity resulted in increased fire area in contrast to drier conditions. It is believed that, this behavior is strongly connected with the larger amounts of total sensible heat fluxes released in MST_UP experiments. In MST_UP simulations, the average total sensible heat fluxes from the fire to the lower atmosphere, were 7325 MW (fuel moisture model off) and 4913 MW (fuel moisture model on) respectively. In MST_DWN experiments, when fuel moisture model was disabled, the average total sensible heat fluxes were 5608 MW compared with 4199 MW when the fuel moisture model was activated.

Fig. 2. Vertical component of relative vorticity (a) and divergence (b) 2h after the ignition at 10 m above surface (contours). Wind vectors are calculated at 10 m. Solid line represents fire area at surface. The depicted domain is zoomed from the original for better representation.

Fig. 3. Fire area (km$^2$) at 2.5 h, for all experiments. Solid lines represent simulations with fuel moisture model disabled, while dashed lines indicate the same experiments with fuel moisture model on. WND_2.0 and WND_2.0_MDL_ON are considered as control runs. The annotation “MST_UP” declares a 20% increase in water vapor mixing ratio, while “MST_DWN” a 20% decrease, respectively.
Maximum values of rate of spread (ROS), in the normal direction of the fire-line, were taken into consideration in order to estimate the impact of relative humidity into propagation rates. In particular, wetter conditions with fuel moisture model disabled lead to increased fire spread rates where the mean maximum ROS increased from 0.07 ms\(^{-1}\) (control) to 0.4 ms\(^{-1}\) (MST_UP). Similar behavior was observed and in MST_DWN experiment (0.07 to 0.25 ms\(^{-1}\)). When fuel moisture model was activated, control run’s (WND_2.0_MDL_ON) mean maximum rate of spread was increased to 0.18 ms\(^{-1}\), despite the overall smaller fire area which was produced (Fig. 3). With fuel moisture model active, drier conditions increased mean maximum ROS by 58.2% compared with control run, while an increase in water vapor mixing ratio lead to an increased mean maximum rate of spread by 55.8%.

The vertical extent of the well defined pyro-convective plume, in MST_UP experiments, is found to be greater than in MST_DWN simulations due to the increased sensible heat fluxes from the fire. This feature is in agreement with Luderer et al. (2009) and the role of the sensible heat release in the pyro-convection dynamics. An increase in water vapor mixing ratio inside the pyro-convective plume was observed in each simulation, as in Clements et al. (2006).

4 Conclusions

The WRF-SFIRE modeling system is capable of analyzing the atmosphere-fire interactions to a large extent. Certain flow dynamics where captured and analyzed, such as the convergence region ahead of the fire-front and the vortex couplet cyclonic and anticyclonic vertical vorticity at the fire-line. The maximum values of vertical vorticity (\(\zeta\)) at 10 m were found to be of order 0.1 s\(^{-1}\), which is tornado-strength. Until 1500 m above surface, new vortices are generated, characterized by smaller values of vertical vorticity. Relative humidity in the atmosphere was found to be of great importance, affecting pyro-convection, heat fluxes from fire to atmosphere, propagation rates and overall, fire behavior in a non-linear way. Increasing the water vapor mixing ratio resulted in larger burned regions, while drier atmospheric conditions led to smaller fire areas. Higher values of water vapor mixing ratio correspond to higher values of virtual temperature (\(T_v\)) and therefore higher pressure gradients, which seems to affect propagation rates. Work in progress includes simulations taking into consideration real atmospheric conditions, topography and fuel properties.

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Effectsofmineraldustonglobal distribution of nitrates

Karydis V.A., Tsimpidi A.P., Lelieveld J.

Inorganic particulate nitrate contributes significantly to the total aerosol mass. While nitrate is predominantly present in the submicron mode, coarse mode aerosol nitrate can also be produced by adsorption of nitric acid onto airborne soil particles. Naturally emitted particles affect the phase partitioning of nitrate, especially in areas where dust comprises a significant portion of total particulate matter, and the simulation of these effects can considerably improve model predictions. However, most thermodynamic models used in global studies lack a realistic treatment of crustal species. This work aims to improve the representation of nitrate aerosols in the global chemistry climate model EMAC, and discusses shortcomings of previous models. EMAC calculates the aerosol microphysics and gas/aerosol partitioning by using the GMXe aerosol module. Gas/aerosol partitioning is simulated using the ISORROPIA-II thermodynamic equilibrium model, which considers the interaction of K⁺-Ca²⁺-Mg²⁺-NH₄⁺-Na⁺-SO₄²⁻-NO₃⁻-Cl⁻-H₂O aerosol components. A sensitivity run with the dust-aerosol chemistry switched off is used to quantify the effect of mineral dust on nitrate aerosol concentration. After considering the interactions of nitrate with mineral dust cations, the total predicted domain average nitrate aerosol concentration increases by 18% while the coarse and fine modes of nitrate increased by 12% and 25%, respectively.

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1 Introduction

Atmospheric aerosols, notably those from anthropogenic sources, adversely affect human health and play an important role in changing the Earth’s climate. Inorganic particulate nitrate constituents contribute significantly to the total aerosol mass, especially in urban areas and industrialized regions, (Jöckel et al. 2010). Nitrate aerosols mainly form if sulfate is irreversibly neutralized and atmospheric ammonia is available in excess. Nitrate is predominantly present in the submicron mode, often observed in the form of ammonium nitrate at continental sites.

One of the challenges in atmospheric aerosol modeling is the partitioning of semi-volatile nitrate and ammonium between the gas and aerosol phases. Many thermodynamic equilibrium models have been developed over the past decades for this purpose. However, aerosol nitrate is not only associated with ammonium in the accumulation mode. Coarse mode aerosol nitrate can be produced by adsorption of nitric acid on sea salt particles (Savoie and Prospero 1982) and soil particles (Wolff 1984). Metallic species like calcium, magnesium, sodium, and potassium can be associated with nitrate. Naturally emitted particles affect the phase partitioning of nitrate, especially in areas where dust comprises a significant portion of total aerosol, and the simulation of these effects can considerably improve model predictions (Karydis et al. 2010). In order to account for the effect of crustal species on the partitioning of nitrate, they have been added to the suite of components of a few thermodynamic models (i.e., SCAPE2, EQSAM3, ISORROPIA II). However, most thermodynamic models used in global studies lack a realistic treatment of crustal species. In fact, only a limited number of global models have been used to estimate particulate nitrate concentrations and their regional distributions (Adams et al. 1999, Metzger et al. 2002, Liao et al. 2003, Rodriguez and Dabdub 2004, Feng and Penner 2007, Xu and Feng 2012). Even fewer studies have include the interactions of mineral cations with nitrate (Feng and Penner 2007, Xu and Feng 2012), however, without focusing on the actual effect of mineral dust on global aerosol nitrate concentrations.

The present work aims to improve the representation of nitrate aerosol formation and size distribution in a chemistry-climate model (CCM) and addresses the shortcomings of previous models by including nitrate interactions with mineral dust, using the thermodynamic equilibrium model ISORROPIA II (Fountoukis and Nenes, 2007). A sensitivity run with the dust-aerosol chemistry switched off is used to quantify the effect of mineral dust on nitrate aerosol concentration.

2 Methodology

For the purpose of this work the ECHAM5/MESSy Atmospheric Chemistry (EMAC) model has been used. This is a numerical chemistry and climate simulation system that includes sub-models describing lower and middle atmospheric processes and their interaction with oceans, land and human influences. It uses the Modular Earth Submodel System (MESSy2) and the atmospheric dynamical core is the 5th generation European Centre - Hamburg general circulation model (ECHAM5) and has been extensively described and evaluated against observations and satellite measurements (Jöckel et al., 2010).

The EMAC model calculates fields of gas phase species online through the Module Efficiently Calculating the Chemistry of the Atmosphere (MECCA) submodel. MECCA calculates the concentration of a range of gases, including aerosol precursor species such as SO_2, NH_3, NO_x, DMS, H_2SO_4 and DMSO. The concentrations of the major oxidant species (OH, H_2O_2, NO_2, and O_3) are also calculated online. The loss of gas phase species to the aerosol through heterogeneous reactions (e.g., N_2O_5 to form HNO_3) is treated using the MECCA_KHET submodel. The aqueous phase oxidation of SO_2 and the uptake of HNO_3 and NH_3 in cloud droplets are treated by the SCAV submodel.
Aerosol microphysics and gas/aerosol partitioning are calculated by the Global Modal-aerosol eXtension (GMXe) aerosol module. This submodel is computationally efficient and is suitable for medium to long-term simulations with global and regional models. Aerosol microphysics are treated using an extended version of the M7 modal aerosol scheme, which describes the aerosol size distribution by 7 interacting lognormal modes (4 hydrophilic and 3 hydrophobic modes). The 4 hydrophilic modes cover the aerosol size spectrum (nucleation, aitken, accumulation, and coarse modes) with a fixed size boundary and a variable mean radius while the 3 hydrophobic modes have the same size range apart from the nucleation mode. The aerosol composition within each mode is uniform with size, though the composition can vary between modes.

Gas/aerosol partitioning is simulated using the ISORROPIA-II thermodynamic equilibrium model (Fountoukis and Nenes 2007). ISORROPIA-II is an inorganic equilibrium model that is able to calculate the gas-aerosol equilibrium partitioning of the K⁺-Ca²⁺-Mg²⁺-NH₄⁺-Na⁺-SO₄²⁻-NO₃⁻-Cl⁻-H₂O aerosol system. Therefore, ISORROPIA-II model can assist in simulating the formation of aerosol nitrate as it includes interactions between HNO₃ and the cations of mineral dust. The emissions of mineral dust cations (calcium, potassium, and magnesium) represent 2.4%, 1.5%, and 0.9% of the total dust emissions respectively based on the global average abundance of these elements in soil and crustal rock (Sposito 1989). ISORROPIA-II solves for the equilibrium state by considering the chemical potential of the species and minimizes the number of equations and iterations required by considering specific compositional “regimes”. In ISORROPIA-II, the aerosol can be in either a thermodynamically stable state (where salts precipitate once the aqueous phase becomes saturated) or in a metastable state (aerosol is composed only of a supersaturated aqueous phase). In this application the stable state option has been tested.

3 Results

The predicted total (gas and aerosol) nitrate on average exceeds 5 μg m⁻³ in the industrialized areas of Europe, central and eastern Asia, North America, as well as over open biomass burning regions in the tropics (Fig. 1a). Marine nitrate concentrations are low (less than 2 μg m⁻³ on average) nearly everywhere. Fine aerosol nitrate is predicted to be higher in populated areas over Europe, China, and the Eastern US (up to 2.5 μg m⁻³), mostly produced from local photochemistry, and decreases with distance from the urban source areas, due to evaporation and deposition, remaining at low levels in surrounding areas (lower than 0.5 μg m⁻³) (Fig. 1b). Predicted coarse aerosol nitrate is found to be enhanced over the Arabian Peninsula, Central Asia, and the Southwestern US (up to 5 μg m⁻³), where the presence of high total nitrate concentrations together with high mineral dust concentrations from local deserts results in the condensation of HNO₃ in the coarse mode (Fig. 1c). However, the assumption of thermodynamic equilibrium in the coarse mode may have result in an overprediction of coarse aerosol nitrate, since the equilibrium timescale for large particles is typically larger than the timestep of the model (Meng and Seinfeld 1996). Assuming bulk equilibrium only for the fine aerosols and a dynamical approach for coarse particles could eliminate these errors (Capaldo et al. 2000).

Mineral dust mostly originates from the large deserts (e.g. N-Africa, S and E Asia) and can be transported over very long distances (Figure 2a). The long-range transport of dust particles can influence the composition and dynamic state of the atmosphere thousands of kilometers downwind of the source region. Under favorable conditions, dust particles originating from the Sahara, Kalahari, and Namib deserts may be elevated and travel across the Atlantic Ocean toward the Caribbean or across the Mediterranean toward Europe, affecting air quality in southern Europe. The northwestern USA is mostly affected by dust originating from the Great Basin Desert. Dust from the Arabian, Turkestan, Great Indian, and Gobi deserts significantly
affects the air quality over the Middle East and Asia. Dust-affected regions in the southern hemisphere are found in South America, e.g. the Peruvian, Atacama, and Patagonian deserts, and Australia, e.g. from Cape Grim, Norfolk, and the New Caledonia deserts.

Fig. 1. Predicted annual average concentration (μg m⁻³) during the years 2005 to 2008 at ground level for: (a) total nitrate (sum of gas and aerosol phase), (b) nitrate aerosol in fine mode and (c) nitrate aerosol in coarse mode.

In areas where the dust concentrations are high, nitric acid is associated with non-volatile mineral cations (Ca²⁺, K⁺, Mg²⁺) forming salts in order to maintain the charge balance in the aerosol phase. To estimate the effects of mineral dust on nitrate aerosol concentration, we conducted a sensitivity run which ignored the presence of the reactive dust components by switching off the dust-aerosol chemistry. The fractional decrease of aerosol nitrate concentration from the basecase is depicted in Figure 2b. The predicted aerosol nitrate increases due to the formation of salts (Ca(NO₃)₂, KNO₃, Mg(NO₃)₂). This is not reflected in the simulation where dust reactive components are ignored, and nitric acid remains in the gas phase. The contribution of mineral dust to aerosol nitrate is not only important over areas with high dust concentrations (up to 100% change over deserts) but also downwind of its sources (i.e., across Southern Europe, Western US, and Eastern China). The predicted fractional change of nitrate aerosol concentration due to the interaction with mineral dust cations is up to 100% over the Sahara desert, up to 90% over Asian deserts (Great Indian, and Gobi), up to 70% over the Great Basin desert, and up to 30% over the deserts of the Southern Hemisphere (i.e., Peruvian, Patagonian, Namibian, New Caledonia). The total predicted domain average nitrate aerosol concentration increases by 18% after considering the interactions of nitrate with mineral dust cations. More precisely, fine aerosol nitrate increased by 12% and coarse aerosol nitrate increased by 25%. Therefore, the fraction of aerosol nitrate in the coarse mode increased on the basecase simulation since most of the mineral cations exist in the coarse mode. In particular, the model predicts that 49% of the global mean total aerosol nitrate is in the coarse mode. In the sensitivity simulation where the presence of the reactive dust components is ignored, the corresponding fraction of coarse mode nitrate to total aerosol nitrate is 44%. Over the deserts, the fraction of nitrate on the coarse mode is nearly 100% and reduces significantly with distance from the dust source regions. Since the model assumes that equilibrium is established separately for each mode, the presence of mineral cations in the coarse mode absorbs nitric acid vapors thus lowering the nitric acid gas-phase concentration. The fine aerosol then loses mass as evaporation is required to maintain equilibrium with the gas phase. As a result, the predicted fine aerosol nitrate may occasionally decrease in the presence of mineral dust. However, over areas where nitric acid is not the
limited reactant, nitrate increases in the fine mode, since a fraction of mineral dust exist in the fine mode as well.

**Fig. 2.** (a) Predicted annual average mineral dust concentration (μg m⁻³) during the years 2005 to 2008 at ground level, and (b) fractional decrease of nitrate concentration after ignoring the presence of reactive dust components.

### 4 Conclusions

This study assesses the effect of mineral dust particles on nitrate aerosol formation by using the thermodynamic equilibrium model ISORROPIA-II, in which the thermodynamics of the K⁺-Ca⁺-Mg⁺-NH₄⁺-Na⁺-SO₄²⁻-NO₃⁻-Cl⁻-H₂O components are taken into account. Fine aerosol nitrate is predicted to be higher over highly populated and industrialized areas (up to 2.5 μg m⁻³), while coarse aerosol nitrate is found to be higher over the deserts (up to 5 μg m⁻³). The contribution of mineral dust to nitrate aerosol concentrations is significant in areas with high dust concentrations (i.e., over and downwind of deserts) with impacts that can extend across southern Europe, western USA and eastern China. The total predicted domain average nitrate aerosol concentration increases by 18% after considering the interactions of nitrate with mineral dust cations, while the coarse and fine modes of nitrate increased by 12% and 25%, respectively. Given that all the results on this study are expressed as annual averages, this contribution can be even more important during specific dust storm episodes.

### References


Current state of knowledge about aerosol trends over northern India

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Atmospheric aerosols over south Asia constitute a major environmental and climate issue and this work reviews the current knowledge of aerosol trends over India and the reasons behind them. Numerous studies dealt with analyzing the aerosol properties, focusing mainly on the spatio-temporal distribution of the Aerosol Optical Depth (AOD) and possible feedbacks of aerosols on climate and monsoon. With the increase in population, urbanization, industrialization and demands for energy, the aerosol load over India is gradually increasing having significant impact on regional climate, which exhibits large spatio-temporal differences being more intense during winter season and, especially over northern India. Except of the general increasing aerosol trend over India, MODIS and MISR observations firstly revealed a declining AOD trend over Indo-Gangetic Plains in the late pre-monsoon and monsoon months (May to September) during the 2000s. These mostly declining trends have been verified via ground-based measurements over Delhi and Kanpur and are attributed to a declining trend in dust activity over the region. Prolonged dry conditions during 2002 (monsoon) and 2003 (pre-monsoon) have as a result the enhancement in dust activity and accumulation of aerosols over northern India, thus contributing significantly in the overall trend.

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1 Introduction

Atmospheric aerosols over south Asia constitute a major environmental and climate issue. Numerous studies dealt with analyzing the aerosol properties, focusing mainly on the spatio-temporal distribution of the aerosol optical depth (AOD) and possible feedbacks of aerosols on climate and monsoon. With the increase in population, urbanization, industrialization and demands for energy, the aerosol load over India is gradually increasing having significant impact on continuation of the solar dimming phenomenon (Badarinath et al. 2010, Kambezidis et al. 2012). This work summarizes the current knowledge obtained by long-term analysis of ground-based and satellite remote sensing observations concerning the trend of aerosols over northern India.

2 Aerosol built-up over India and south Asia

Both ground-based measurements and satellite observations agree to an overall increase in AOD over Indian sub-continent (Ramachandran and Cherian 2008, Moorthy et al. 2013). These studies limited mainly to yearly variations and trends; the monthly and/or seasonal trends of AOD over different sub-regions had not been analyzed so far. More recently, the aerosol trend analysis over India emphasizes also on seasonality, like the studies by Kharol et al. (2011) using sun photometer and MODIS observations over Hyderabad, Dey and di Girolamo (2011) using MISR data over Indian subcontinent and adjoining oceanic areas, Kaskaoutis et al. (2011) using MODIS data over south Asia with emphasis over Arabian Sea, Bay of Bengal, Northern Indian Ocean and Indo-Gangetic Plains (IGP), Kaskaoutis et al. (2012a) using AERONET data over Kanpur, Ramachandran et al. (2012) using MODIS data over the capitals of each Indian State, Lodhi et al. (2013) using sun photometer observations over Delhi. Overall, an increasing trend in aerosol loading is highlighted by all these studies (10.17% during 2000-2009 over whole South Asia, according to Kaskaoutis et al. 2011), which exhibits large spatio-temporal differences being more intense during winter season and, especially over northern India. The AERONET data over Kanpur, available till 2001, gives us the possibility of examining possible trends in the almucantar-derived parameters also, like size distribution, single scattering albedo and refractive index. Such an analysis (Kaskaoutis et al. 2012a) revealed that the statistically significant increasing trend in post-monsoon/winter AOD is reflected in a shift of the columnar size distribution towards relatively larger particles in the accumulation mode, indicating coagulation and condensation of the primarily fine aerosols over a progressively turbid environment.

![Fig. 1. Inter-annual variability and trend of the AOD$_{500}$ daily values over Kanpur for 2001-2010. The slope of the regression analysis along with the % difference and the P value are given. Black for AOD$_{500}$, green for α(440-870), blue for α(380-500) and red for α(675-870). [Source: Kaskaoutis et al. ERL, 2012](image-url)]
The concurrent increase (7.69%) in AOD$_{500}$ and in Ångström exponent (5.5%) during the period 2001-2010 suggests an increase in anthropogenic aerosols over Kanpur, especially after 2005 (Fig. 1). The increasing aerosol emissions, mainly from anthropogenic activities, are responsible for the presence of the atmospheric brown clouds, which have significant climate implications in view of heating the middle and upper troposphere and influencing the monsoonal circulation (Ramanathan et al. 2007).

3 Evidence of declining aerosol trend over IGP during pre-monsoon monsoon seasons

Except of the general increasing aerosol trend over India, MODIS (Kaskaoutis et al. 2011) and MISR (Dey and di Girolamo 2011) observations firstly revealed a declining AOD trend over IGP during late pre-monsoon and monsoon months (May to September) during the 2000s. However, in the majority of the cases, this declining trend is not statistically significant due to large intra-annual fluctuations in AOD over IGP. However, its presence attracted the scientific interest to be examined further. Analysis of the AOD trends using Kanpur AERONET data (2001-2010) verified this feature, revealing an AOD decrease of ~0.01 per year in June, when the dust activity is at its maximum (Kaskaoutis et al. 2012a). The analysis of the size distribution over Kanpur showed a general decrease in coarse-mode fraction associated with variable dust activity during the 2000s, verified the results of attenuation in dust activity during the second half (2005-2010) of the previous decade. Thus, the AOD decrease seems to be attributed to weakness of dust activity in the northern part of India during the last decade. GOCART (Goddard Global Ozone Chemistry Aerosol Radiation and Transport) model simulations over south Asia revealed a pronounced decreasing trend in dust AOD and in dust contribution to the total AOD over south Asia during 2000-2007, which are in general agreement with the ground-based and satellite observations. However, much more analysis and longer dataset are required for establishing this evidence.

4 Reasons for the AOD declining trend

Since the main aerosol type over northern India in late pre-monsoon and monsoon seasons is dust transported mainly from the Thar Desert, the fluctuations in dust emission, transport and dust-aerosol lifetime are of considerable importance in order to explain the AOD variability over this region. Kanpur (Fig. 1) as well as Delhi aerosol dataseries revealed considerable high AODs during monsoon of 2002 and late pre-monsoon of 2003, so the interest was focused on examining these periods. A synergy of satellite and ground-based radiometric observations, along with chemical transport modeling and NCEP/NCAR reanalysis data, was used for the assessment of the influence of the weather conditions of summer/monsoon 2002 and 2003 on aerosol properties over northern India (Kaskaoutis et al. 2012b). The meteorology data showed prevalence of westerlies under anti-cyclonic circulation and subsidence favoring the accumulation of aerosols. Subsequently, the anomalous and prolonged dry conditions favored heavy aerosol buildup as indicated by strong positive anomalies (20-80%) of MODIS AOD over northern India (Fig. 2). In contrast, the drought monsoon years over India seem to be associated with lower AOD (mostly dust) over Arabian Sea suggesting lower dust outflow over the marine environment. Recent analysis has shown a positive correlation between rainfall anomalies over India and dust over Arabian Sea, with the dust exposure to increase during the normal monsoon years.
Fig. 2. (a) Monthly normalized rainfall anomaly (%) for July 2002 and for May-June 2003 based on the monthly rainfall climatology of TRMM 3B43 V6 during the period 1998-2009, (b) percentage deviation of the Terra-MODIS AOD$_{550}$ for July 2002 and for May-June 2003 from the monthly mean value during the period 2000-2009. [Source: Kaskaoutis et al. JGR, 2012]

Ground-based sun photometer observations at Delhi and Kanpur also revealed enhanced presence of desert-dust aerosols during July 2002 and May-June 2003, characterized by large AOD and significantly low Angstrom exponent values. The analysis suggested a cause-and-effect association between the deficit of monsoon rainfall, and increased dust activity as well as prolonged aerosol lifetime that influences the dynamics and persistence of the spatiotemporal aerosol loading, and associated optical properties over northern India. The role of rainfall in aerosol properties and variations is very crucial during the monsoon season. On the other hand, the increase in aerosol loading over northern India may also affect precipitation and hydrological cycle (Lau et al. 2006). However, it is difficult to quantify the influence of rainfall in AOD trends over Kanpur, since anthropogenic emissions and dust transport play a significant role in influencing aerosol loading and properties. In synopsis, the deficit of rainfall during monsoon of 2002 and late pre-monsoon of 2003 caused an increase in dust activity and atmospheric aerosol lifetime over northern India strongly influencing the AOD trends over IGP during the last decade.

5 Conclusions

It is well known that the two main contrasting seasons over northern India (late post-monsoon/winter and pre-monsoon/monsoon), dictate variations in aerosol type and their spatial, temporal and vertical distribution. Recently, ground-based and satellite observations agree to a significant differentiation in aerosol-loading trends between these two seasons. The trends (increasing for the first and declining for the second season) have been established and consolidated by several recent works and the critical is to examine if they will be in force during the next years also. However, some critical issues have to be better clarified and answered in order the current knowledge about aerosol trends in India to be enhanced further. Some of these issues are summarized in the followings:

Why the neutral-to-declining trend is observed only during the hot and dry period of the year, when the natural aerosols dominate over northern India? Why this phenomenon is not so obvious over the central Deccan plateau and along the coastal regions? Does it depend only on the anomalous high aerosol loading during pre-monsoon of 2003 and monsoon of 2002 or do other factors play a role as well? Is the change in meteorological conditions, monsoon
system and/or El-Nino Southern Oscillation in specific periods and years able to control the aerosol trends and over which regions? Recent investigations have shown an excess of dust aerosols over Arabian Sea during the El-Nino years, while others have shown excess of dust over Arabian Sea during the normal monsoon years and lower dust over Arabian Sea during the weak monsoon years. In order to have a clear view of all the above-mentioned queries, systematic monitoring of the aerosol properties from ground and space is needed, along with improvement in the current inventories that the chemical transport models use for the aerosol simulations. Furthermore, the specific role of the synoptic and dynamic meteorology in the aerosol trends over India as well as the changes in the monsoon circulation and annual variations of ENSO have to be better consolidated.

References


Meteorological conditions associated with severe dust storms in the Sistan region, Iran

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The present work focuses on examining the synoptic and dynamic meteorological conditions associated with dust-storm outbreaks in the Sistan region, southeastern Iran during the summer season (June-September) for the years 2001 to 2012. The dust-storm days (total number of 356) are related to visibility records below 1 km at Zabol meteorological station, located well within the dust source region. RegCM4 model simulations reveal that the local intense Levar wind, blowing from northern directions during the summer season, plays a major role in dust outbreaks. Furthermore, the high surface heating and the valley-like characteristics of the region strongly influence the meteorological dynamics, the Levar wind and the formation of a low-level jet over the region that are strongly linked with dust exposures. NCEP/NCAR reanalysis reveals that the dust storms are associated with low sea-level pressure conditions over the whole south Asia during summer, while at 700 hPa a trough of low geopotential heights over India along with a ridge over Arabia and central Iran is the most common scenario.

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1 Introduction

The frequency and intensity of dust outbreaks are closely linked to local climate conditions, such as temperature, rainfall, evaporation, wind speed as well as to land-surface characteristics (vegetation cover, soil moisture) and boundary-layer dynamics (Engelstaedter et al. 2006). The synoptic and dynamic meteorology, along with the position and movement of the Inter-Tropical Convergence Zone (ITCZ), the surface heat lows and low-level jet, play a crucial role in dust emissions over arid environments (Cavazos-Guerra and Todd 2012). Furthermore, wind which may have various genesis causes, characteristics, intensity and seasonality, depending on the region, has a key role on dust entrainment in the atmosphere and transport over neighboring regions, like the Levar or ‘120-day’ wind that blows over Sistan in Iran. The largest frequency of blowing dust and dust storms over Middle East occurs in the Sistan region in southeastern Iran as a result of the strong north-westerlies (Levar) blowing in summer (June-September) and entrain large quantities of dust from the Hamoun dry-bed lakes into the atmosphere influencing regional climate, visibility, PM concentrations, local economy and human health (Rashki et al. 2012, Rezazadeh et al. 2013). The present work attempts to shed light on the synoptic and dynamic conditions, as well as the anomalies from the mean climatology that prevail over south Asia and are associated with dust exposures from Sistan basin during the summer months (June-September) of the period 2001-2012. Furthermore, it assesses the impact of local topography and wind field in the emission, uplift and transport of the dust plumes via model (RegCM4) simulations.

2 Data and Methodology

The meteorological observations, surface wind at 10 m above ground level (agl), air temperature (2 m, agl), relative humidity (RH), atmospheric pressure and visibility (vis) that are used in the present study were obtained from the Zabol meteorological station located ~10 km away from the Hamoun lakes (Rashki et al. 2012). The threshold of vis<1 km (daily mean values) was considered to identify the dust-storm events over the region based on Zabol meteorological recordings. The proximity of the Zabol meteorological station to the dust source region allows us to consider vis<1 km as threshold for the dust-storm days in Sistan, which were found to be 356 during the summer months (June-September) of 2001-2012.

Additionally, the Regional Climate Model (RegCM4) was used over south Asia to simulate meteorology parameters (surface temperature, relative vorticity, atmospheric pressure, wind speed and direction) mostly related to dust uplift and transport with emphasis over Sistan region and the usage high (20 km) resolution parameterizations. RegCM4 is based on the initial model by Giorgi et al. (1993) with continuous upgrades (Pal et al. 2007). It is a hydrostatic model, which uses the Arakawa-B horizontal grid for the velocity variables, while the terrain follows the sigma vertical coordinate system. The model simulations correspond to specific periods during the summer seasons, using six-hourly lateral boundary conditions (air temperature, atmospheric pressure, relative humidity, wind speed and direction) from ERA-Interim reanalysis.

Furthermore, the NCEP/NCAR database was used, consisted of Mean Sea Level Pressure (MSLP) and geopotential height at 700 hPa (Z700) daily values on the dust storm days during the period 2001 – 2012, covering a broad region of south-central Asia “(40° to 120° E and 0° to 50° N, at 2.5° x 2.5° spatial resolution)”. The 356 dust-storm days over Sistan, were classified into the four summer months and then the corresponding composite maps for the MSLP and Z700 were constructed for the dust-storm days of each month. Furthermore, the anomalies of the meteorological fields during the dusty days from the mean 30-year (1981-2010) NCEP/NCAR summer month climatology were studied aiming to reveal the meteorological patterns that favor the dust outflows from Sistan.
3 Results

The wind field (velocity, direction and vertical profile) has been simulated over the region by means of RegCM4 model with and without including the regional topography in the simulations (Figs. 1 and 2).

**Fig. 1.** Seasonal (JJAS, 2001) mean wind velocity (m s\(^{-1}\)) over Sistan region and surroundings via RegCM4 simulations at 00:00 GMT (LST=GMT+3:30) with (a) and without (b) the underlying topography. The contour interval is in 1 m s\(^{-1}\) and values greater than 7 m s\(^{-1}\) are drawn.

**Fig. 2.** Seasonal (JJAS, 2001) mean vertical profiles of wind velocity (m s\(^{-1}\)) over Sistan basin (32°N, 61°E, where the wind velocity is maximum) via RegCM4 simulations with (a) and without (b) underlying topography at 00:00, 06:00, 12:00 and 18:00 GMT (LST=GMT+3:30).

During the simulation period (June – September, 2001) the Hamoun lakes had totally dried out and the frequency of the dust outbreaks increased dramatically (Rashki et al. 2013). The results reveal a considerable influence of the topography in the wind field, mainly in the velocity. The mountainous topography around Sistan creates a canal strengthening the northern winds, since sheltering and channeling are known to enhance the wind flow. The wind profile shifts to larger vertical gradient, with much higher values near the surface (950-900 hPa) and lower above 750 hPa. The simulation reveals a diurnal variation in the wind speed for levels below 800 hPa with maximum values during nighttime and early morning (18:00 and 00:00 GMT), when the nocturnal low-level jet is stronger.

In Fig. 3 the mean composite MLSP and Z700 maps during the dust-storm days at Sistan region for each summer month (JJAS) reveal the influence of the prevailing atmospheric circulation over southwest Asia on the Sistan dust storms. The cyclonic circulation over central Pakistan and northwestern India along with the high pressure gradient between the Pakistan low pressure center and the high pressure regime over west-central Asia induce the strong northerly Levar wind, which is responsible for dust storms in the Sistan region. As the monsoon season progresses, the low pressure system weakens significantly and so does the dust activity over Sistan (Rashki et al. 2012). The Z700 maps (lower panels) illustrate the
Synoptic-scale atmospheric circulations associated with the dust transport and confirm the dust-plume pathways from Sistan towards the south. The ridge over Africa and Middle East combined with the trough over the Indian subcontinent induce a strong northerly flow (associated with the flow of the low-level jet) over Iran-Afghanistan-Pakistan borders as simulated via RegCM4 model (Fig. 1). Sistan dusty air masses travel towards the Oman Sea through the north-to-south corridor motivated by the strong northerly low-level jet.

**Figure 3.** Composite-mean MSLP maps (upper panels) and Geopotential Height at 700 hPa (lower panels) of the dust-storm days over Sistan during the period 2001-2012 for the summer (JJAS) season.

Figure 4a, b provides the synoptic maps of the anomalies of the period 2001-2012 and of the dust-storm days during this period from the climatology 1981-2010 for MSLP and Z700, respectively. Anomalies of the period 2001-2012 can reveal atmospheric circulation characteristics which may be responsible for the pronounced drought that Sistan region went through during that period. Furthermore, the differences between the two set of maps (i.e. anomalies of 2001-2012 vs anomalies during the dust-storm days) reveal the specific conditions that dominate during the dust storms in response to non-dust-storm days during the examined period 2001-2012.

**Figure 4a, b:** Anomalies of MSLP (a) and Z700 (b) from the mean climatological situation (1981-2010) for the whole period 2001-2012 (upper panels) and for the dusty days in the period 2001-2012 (lower panels).
The anomaly patterns are found more or less similar independently of the month, atmospheric level (MSLP and Z700) and dust-storm or non-dust-storm days, mainly characterized by positive anomalies (enhancement) in the high-pressure system centered over Caspian Sea and central Asia. However, the positive anomalies over Caspian Sea and central Asia are much more intense (range from +2 to +5 hPa) during the dust-storm days, suggesting enhancement of the anticyclone and of the west-to-east pressure gradient, which is the inaugural force for the Levar wind and the low-level jet. Similar distribution of the anomalies exists at Z700, with the major finding to be the higher geopotential height (5-45 gpm) over Caspian Sea, contributing to the enhancement of the pressure gradient.

4 Conclusions

Sistan region in Iran-Afghanistan borders has been identified as a major dust source in southwest Asia and one of the windiest arid environments over the globe. The dust storms over the region were found to be mostly associated with local-regional phenomena, such as higher wind velocities and dryness of the Hamoun ephemeral lakes. RegCM4 model simulations highlighted the specific role of the local and regional topography in the formation and maintenance of thermal lows at Sistan topographic low basin, thus being the genesis cause for the dust uplift. The mountain range forms a natural canal around Sistan increasing the wind velocity (above 12-15 ms⁻¹) due to channeling, thus having as end result the frequent outbreaks of massive dust storms during the summer period. The establishment of the thermal Indian Low, extending over south-western Afghanistan - western Pakistan during summer, turns the Sistan dusty air masses towards northeast (in a cyclonic circulation) and is also uplifting them in height. The NCEP/NCAR synoptic maps revealed that the strong Levar winds and the intensification of the low-level jet over the region were linked to the strong north–to-south pressure gradient force between the low-pressure system over the desert regions and northern Arabian Sea and the persistent high pressure over central Asia. The stronger northern winds over Sistan during the dust-storm days were related to increase in pressure gradient due to positive anomalies in the high-pressure system over central Asia and Caspian Sea along with negative ones over Hindu-Kush – Karakoram range.

Acknowledgments

The NCEP/NCAR and RegCM4 scientific teams are highly acknowledged for making the data available in the current work.

References

A study of the atmospheric electric field at an AERONET site in Xanthi, Greece, and its relation to AOD

Kastelis N., Kourtidis K., Rapsomanikis S.

A full year of measurements (06/2011 – 05/2012) of the atmospheric electric field (Potential Gradient – PG) at an AERONET site (Xanthi, Greece) has been used to study the local electrical climatology and correlate atmospheric electrical properties with optical ones. In fair weather conditions, although both global and local effects determine the diurnal variation of PG, local influences at the study site are by far more intense. While the first maximum appears at about 11:00 to 13:00 LT as a result of the morning convective conditions and human activity, the second one occurs at around 20:00 to 22:00 LT, and is mainly the result of global thunderstorm activity. Two daily PG minima occur at approximately 5:00 and 19:00 LT. The seasonal variation in the timing of the diurnal extremes is attributed to seasonal effects and variations in local parameters. The annual variation of the mean monthly PG values is consistent with ones reported for other sites, with a winter maximum and a summertime minimum. Finally, AOD was used as an indirect measure of columnar resistance and its relation to PG was studied.

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1 Introduction

Electrical properties of the boundary layer can offer useful information about pollution, acting as a pollution index (Retalis et al. 1991), and contribute in identifying or forecasting certain meteorological processes such as fog, convective clouds or lightning (Piper and Bennett 2012).

In the present work, the local electrical climatology as defined by Potential Gradient (PG) measurements of a peri-urban site in Northern Greece (Xanthi) is presented. We also use Atmospheric Optical Depth (AOD) at 500 nm as a potential indicator of atmospheric columnar resistance and study its relation with PG.

2 Data and Methodology

A CS110 (Campbell Scientific) Electric Field Meter (EFM) has been operating since February 2011 at the AERONET site of Xanthi, Greece. Data are sampled at 1Hz frequency, and recorded as 1-min means. In this work, we use hourly and monthly means. From the total experimental dataset, the 12 successive months with the greatest data coverage were selected (06/2011 – 05/2012) to construct the annual electrical climatology of the site. AOD level 1.5 data at 500 nm were acquired from http://aeronet.gsfc.nasa.gov/ for the same period. The CS110 EFM and the CIMEL AERONET sunphotometer are collocated, at a distance of about 50 m.

3 Results

The mean annual PG, calculated from hourly means, is 66.23 ±649.82 V/m (1σ) and the corresponding median is 65.68 V/m. The standard deviation (STD) is quite high due to frequent local thunderstorms at the study site, especially during the afternoon (Fig. 1). Fair Weather (FW) conditions were defined as conditions when the PG ranged between 0 V/m and 350 V/m (Israelsson and Tammet 2001). 73% of the total hourly PG values fall within this range, with 69% of it having STD <50V/m (Fig. 2).

In Fig. 1, the mean diurnal variation of PG for FW and all weather (AW) conditions is presented together with the diurnal variation of mean hourly STDs. The FW–PG is always higher than the AW one (Retalis and Retalis 1997), while the latter exhibits its highest variability around 15:00 - 16:00 LT.

The mean diurnal variation of FW–PG is more or less typical of a continental site, exhibiting double oscillation during some months (Fig. 3). However, the second maximum is suppressed, due to local factors, and when present is not very pronounced.

The primary maximum appears at about 11:00 to 13:00 LT, as a result of the morning convective conditions and human activity, while the secondary one occurs at around 20:00 to 22:00 LT and is mainly the result of global thunderstorm activity. Two daily PG minima occur at approximately 5:00 and 18:00 - 19:00 LT. The seasonal variation in the timing of the diurnal extremes is attributed to seasonal effects and variations in local factors.

The annual variation of the mean monthly PG is consistent with ones reported for other continental sites (Retalis and Retalis 1997), with a winter maximum and a summertime minimum. PG values in June 2011 are unusually high for that season.
Fig. 1. a. Annual mean diurnal variation of hourly mean PG for AW and FW conditions. AW-PG is smoothed (5-hr running average). b. Annual mean diurnal variation of hourly STDs for AW and FW conditions.

Fig. 2. a. Histogram of hourly mean PG in 10 V/m bins. b. Histogram of STDs of hourly means estimated from mean 10-min PG values.
Fig. 3. Monthly mean diurnal variation of FW-PG.

Fig. 4. Mean annual variation of FW-PG (calculated from hourly means).
Fig. 5. Correlation of daily mean PG and AOD (calculated from hourly means). The color scale and the circle size show the number of common hourly means used for the calculation.

Since both columnar resistance (Rc) and AOD are affected by aerosols of the lowest layers of the atmosphere, we could assume that AOD is a potential indicator of Rc.

To compare FW-PG and AOD, the common hourly mean values were selected and daily means were calculated for each month. Linear regression was applied to daily means and the estimated $R^2$ values are also presented (Fig. 5).

During the period March – October (summer period), PG and AOD appear to be negatively related, while the opposite occurs from November to February (winter period). The only exception is December 2011, when PG decreases with increasing AOD. In the summer period, the available data are more than winter, since FW conditions are more common.

A probable cause of the seasonal variation in the PG-AOD relationship, could be the seasonality of planetary boundary layer (PBL) depth. In the summer period, convective conditions are more intense, resulting in a deeper PBL. Surface aerosols are thus ventilated upwards, decreasing their concentration near the ground, and causing conductivity to increase; consequently, surface PG decreases. Also, intense convection increases the vertical load of aerosols, leading to an increase in the columnar resistance and a decrease of the conduction current, which is the generating force of PG. The opposite happens in the winter period, and Ohm’s law is fulfilled. December’s diversity implies the existence of other, complementary mechanisms.

4 Conclusions

In this work, the local electrical climatology of Xanthi, Greece AERONET site is studied and found to be typical of continental sites, with a pronounced effect of local factors. Finally, AOD, which is a potential indicator of Rc, is found to have a seasonal relationship with PG.

References

First results on the thermal comfort conditions in the Athens Metro during the summer period

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The continuous upgrade of human thermal comfort standards, especially in indoor environments, creates an imperative need to further study and investigate the thermal conditions in more complicated settings, such as the Metro. The present preliminary study aims to investigate the human thermal comfort conditions inside train carriages of both types, air-conditioned and naturally ventilated, in the Athens underground railway network. A series of experiments were carried out in the underground section of Line 3, one of the busier lines of the network. In situ measurements of air temperature and relative humidity were conducted inside the trains, from 0700 LST to 1900 LST, in June, July and August 2012. The widely known indices of predicted mean vote (PMV) and predicted percentage dissatisfied (PPD) were employed. A possible linkage between the environmental parameters and the number of passengers inside the trains was also investigated. The overall picture reveals that in the Athens Metro the human thermal comfort conditions could be characterized as acceptable only in the air-conditioned carriages during the summer period, while there are noticeable differences between the air-conditioned and the naturally ventilated cabins.

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1 Introduction

In the recent years the underground railway, also known as the Athens Metro, has become one of the most preferable transportation means in the metropolitan city of Athens, Greece, since it is not influenced by the road traffic. About 938,000 passengers use the Athens Metro on a daily basis, sharing the thermal conditions, inside the trains, the platforms and the other Metro dwellings. This number of passengers shows an upward tendency as a result of the construction of new stations and the extension of the existing lines.

Human thermal comfort has received little research attention in the underground railway environment, whereas it has been extensively studied in other indoor settings, such as office or residential buildings. Special attention was given by Ampofo et al. (2004) to the complications and difficulties associated with defining “acceptable” thermal comfort criteria, for underground railway environment. According to their study, for such an environment, the predicted percentage of dissatisfied people in the space (PPD) could be considered as acceptable for values up to 40% - 50%. A field study in the subway of Shanghai by Ye et al. (2010), based on thermal sensation vote (TSV), reports that the thermal environment in Shanghai metro stations is slightly warm. Various zones of the Tehran metro were investigated by Abbaspour et al. (2008), indicating different levels of the human comfort tolerance among the considered spaces. In the Budapest metro, the thermal environment in the passenger areas of deep level stations was found to be slightly warm in summer, whereas the PPD values were between 5% and 30% (Ordódy 2000). However, the study also reported that in certain cases the PPD values raised up to 80 %, as an outcome of the so-called “piston effect”, which is the result of one or two trains arriving at a station, causing high air velocities. A weak linear correlation between the air temperature and the number of passengers inside the cabins was found in the Korean subway during the rush hour (Kwon et al. 2008). In the Athens Metro, the recent study by Assimakopoulos et al. (2013) focused on the air quality inside the train coaches, recording the highest concentrations of pollutants during rush hours. The association of different pollutants with air temperature and among each other is also reported.

The present study aims to investigate the human thermal comfort conditions inside train carriages of both types, air-conditioned and with natural ventilation, in the Athens Metro, taking also into consideration the number of passengers.

2 Data and Methodology

A series of experiments were carried out in the underground section of Line 3, from Egaleo to Doukissis Plakentias station, one of the busier lines, which is 16.4 km long and includes 16 stations. The experimental campaign took place in June, July and August 2012, from 0700 LST to 1900 LST (Local Standard Time). In situ measurements of air temperature and relative humidity were conducted with a portable instrumentation installed in the central carriage of the train. The measurements were taken at the 1.1 m level, a representative height for sedentary as well as for standing occupants (ASHRAE 55 2013). Both environmental parameters were monitored with the Tinytag Plus 2 Dual Channel TGP-4500. The range of relative humidity sensor is from 0% to 100% with an accuracy of ±3% at 25 °C. The range of air temperature sensor is from -25 °C to 85 °C with an accuracy of ±0.4°C at 25 °C. In order to ensure the precision of the measurements, all sensors were calibrated before the experiments. The data logging interval of the instrument was set at 10 s. At the same time, the number of passengers was continuously recorded inside the train carriage. Two types of trains were involved in the experimental procedure, those with air-conditioned cabins and those with natural ventilation. It is worth noting that the tunnels and the passenger areas of the stations are equipped with ventilation system in order to supply fresh air under normal operation. Air-conditioning units are installed only in certain areas of the stations with sensitive equipment.
In order to evaluate the human thermal comfort conditions, the predicted mean vote (PMV) and the predicted percentage dissatisfied (PPD) indices were employed. Both indices are incorporated in ISO 7730 (2005) and ASHRAE 55 (2013) Standards in order to predict the general thermal sensation and the percentage of thermally dissatisfied people exposed to moderate indoor thermal environments. The PMV model utilizes heat balance principles to relate six primary factors, i.e. metabolic rate; clothing insulation; air temperature; air humidity; mean radiant temperature; air speed, for thermal comfort to the average response of people on the 7-point thermal sensation scale, i.e. +3 = hot; +2 = warm; +1 = slightly warm; 0 = neutral; -1 = slightly cool; -2 = cool; -3 = cold.

In the present analysis, the PMV and PPD calculations were carried out employing a computer code in R language program. The output was verified with the code and the examples presented by ISO 7730 (2005). Taking into consideration the possible activity level of the occupants inside the carriages and the time period of the experiments, the metabolic rate was estimated at 70 Wm$^{-2}$, indicating resting activity, whereas the clothing insulation was estimated at 0.5 clo, suggesting typical clothing ensemble when the outdoor environment is warm (ASHRAE 55 2013). According to the BSRIA report in UK (Booth and Galliers 2001), the measured parameters of air temperature and globe temperature appear to be the same in London underground railway environment. Taking this into account, in combination with the fact that there is no radiant panel system installed in the Athens Metro and with the absence of solar radiation in such an environment, it was considered that the mean radiant temperature does not unduly depart from the air temperature. Thus, it was considered that inside the train carriages the mean radiant temperature equals the air temperature. The air velocity was set constant at 0.2 ms$^{-1}$ inside the train carriages. Furthermore, the Pearson correlation analysis was employed in order to identify any accurate linear correlation between the number of passengers and the environmental parameters.

### 3 Results and Discussion

The ASHRAE Standard 55 (2013) specifies an upper humidity ratio limit of 0.012 kg$_{\text{water}}$/kg$_{\text{dry air}}$, which corresponds to a dew point temperature of 16.8 °C at standard pressure or a vapour pressure of 19.1 hPa for the comfort zone. A visual inspection of the results indicates that in air-conditioned cabins the 50% of vapour pressure values exceed the aforementioned comfort limit (Fig. 1a). The interquartile ranges between 18.3 hPa and 20.7 hPa, with an average value of 19.5 hPa. On the other hand, all critical levels of vapour pressure increasein naturally ventilated cabins, with all the values exceeding the upper specified limit. In particular, the interquartile ranges between 23.7 hPa and 26.5 hPa, with an average value of 25.1 hPa. As far as the lower humidity limit is concerned, the ASHRAE Standard 55 (2013) does not specify such a limit for human thermal comfort. However, in compliance with the fact that low air humidity can dry the skin and mucous surfaces and lead to comfort complaints about dry nose, throat, eyes and skin, the ASHRAE recommends that the dew point temperature of occupied spaces should not be less than 2.2 °C (ASHRAE 2009), which corresponds to a vapour pressure of 7.2 hPa. The results reveal that the environment inside both air-conditioned and naturally ventilated cabins cannot be characterized as dry.

The descriptive statistics of air temperature reveal that the values in air-conditioned cabins are formed at lower levels, showing a greater dispersion compared to the values in naturally ventilated cabins (Fig. 1b). In particular, less than 25% of the values exceed 30 °C in air-conditioned carriages. On the contrary, all the values, with the exception of the lower outliers, exceed 30 °C in naturally ventilated cabins. The ASHRAE Standard 55 (2013) recommends limits of operative temperature for human thermal comfort and not for the air temperature alone. However, the standard allows air temperature to be used as an approximation for operative temperature in spaces where mean radiant temperature does not unduly depart from air temperature. The underground railway environment can be considered as such a case. Thus,
the recommended limits range between 23.6 °C and 28.3 °C for the summer comfort zone. A visual inspection of the results indicate that all the values in naturally ventilated cabins exceed the upper limit, while in air-conditioned carriages more than 25% of the values lie in the aforementioned comfort limits.

The average PMV is 1.06 in air-conditioned cabins, indicating that the thermal environment inside the carriages is slightly warm (Fig. 2a). The descriptive statistics of PMV reveal that 50% of the values range between 0 and 1 of the thermal sensation scale and can be characterized as neutral to slightly warm. The rest of the values lie between 1 and 2, indicating slightly warm to warm thermal conditions. On the other hand, the PMV values in naturally ventilated cabins show less dispersion, with an average value at 2.03, indicating that the thermal environment inside the carriages is warm (Fig. 2a). A visual inspection of the PPD results shows greater dispersion of the values in air-conditioned cabins (Fig. 2b). In particular, the average PPD is 30%, while 75% of the PPD values do not exceed 40%. On the contrary, the average PPD is significantly higher (77%) in naturally ventilated cabins and the dispersion of the values ranges between 60% and 93%, excluding the lower outliers. Three classes of acceptable indoor thermal environment for general comfort are proposed by ASHRAE 55 (2013). The comfort class C is less restrictive, defining that PPD values should be lower than 15% and PMV values should range between 0.7 and -0.7. Even in the air-conditioned cabins only the 7.5% of the PPD values can be classified into this comfort zone. The above result further confirms the aspect that the acceptable human thermal comfort criteria for an office as an example may not be achievable in an underground railway environment (Ampofo et al. 2004). Therefore, an underground thermal environment characterized as slightly warm with PPD values up to 35% could be considered as acceptable, considering the relatively short time that the passengers spend in such an environment.
The Pearson correlation analysis indicates no linear correlation between the number of passengers and the environmental parameters in the air-conditioned carriages. In the naturally ventilated cabins no linear correlation is noted between the number of passengers and the average air temperature. On the contrary, statistically significant positive correlation is observed between the number of passengers and the average vapour pressure. The linear correlation is strong (0.73 to 0.96) in 8 out of 28 routes, moderate (0.41 to 0.66) in 10 cases and weak (0.10 to 0.37) in 7 cases. This outcome could be explained by the fact that the people’s breathing and body evaporation are the main sources that affect air humidity inside the carriages. In cases with weak or moderate correlation, the temporal variation between the number of passengers and the average vapour pressure shows similar tendency, with a delay. In these cases, a cross correlation was carried out and the results indicate significantly higher correlation coefficients. The maximum correlation coefficients are achieved at a delay of 1 or 2, which refers to the transition time from one station to the next. All correlations mentioned above are significant at the 0.05 level (2-tailed). The temporal variation of vapour pressure and number of passengers, throughout a route, is displayed in Fig. 3 for two representative cases of strong and weak linear correlation.

![Fig. 3. Temporal variation of vapour pressure (VP) and number of passengers (N) for two cases, with a) strong and b) weak linear correlation throughout a train route. The correlation coefficients, the lag correlation coefficient and the mean and standard deviation of air temperature (T_a) are also provided.](image)

### 4 Conclusions

In the present study the human thermal comfort conditions inside train carriages of both types, air-conditioned and with natural ventilation, are investigated in the Athens Metro. The results reveal that the thermal environment inside the air-conditioned cabins can be characterized as slightly warm, while in naturally ventilated cabins it is warm. Vapour pressure values in the naturally ventilated cabins are higher than in the air-conditioned carriages. The results further confirm the aspect that the acceptable human thermal comfort criteria for an office as an example may not be achievable in an underground railway environment. Therefore, an underground thermal environment characterized as slightly warm with PPD values up to 35% could be considered as acceptable, considering the relatively short time that the passengers spend inside a train carriage. A statistically significant positive linear correlation is observed between the number of passengers and the average vapour pressure in naturally ventilated cabins.

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References


A transient high resolution regional climate simulation for Greece for the period 1960-2100

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In the framework of the GEOCLIMA project a transient high resolution (10 km x 10 km) simulation was carried out over Greece for the period 1960-2100 using the regional climate model (RCM) RegCM3. This high resolution simulation was a nested run of a coarser in resolution (25 km x 25 km) simulation of RegCM3 carried in the framework of EU-project ENSEMBLES with lateral boundary conditions from the global circulation model (GCM) ECHAM5 r3 under IPCC A1B scenario. A station-based evaluation of the simulation was carried out for the period 1975-2000 using near surface temperature and precipitation data from 79 meteorological stations of the Hellenic National Meteorological Service network. Our future projections for the period 2021-2050 indicate small changes with temperature increasing mostly over land by less than 1.6°C and precipitation change ranging between ±15%, being mostly negative in the southern part of the domain. At the end of the century (2071-2100), the projected changes become larger with temperature increasing by about 3.5 to 4°C over land and precipitation decreasing by 10% to 40% from the north to the south.

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1 Introduction

Decision makers in governments, non-governmental organizations and industry as well as the general public need detailed information on future regional climate in order to evaluate the risks of the anticipated climate change as a consequence of the anthropogenic enhancement of the greenhouse effect. Regional climate models (RCMs) have been developed for the application of dynamical downscaling methods to enhance the regional information provided by Global Circulations Models (GCMs) or by the large scale reanalysis fields (Giorgi 1990). The added value of using RCMs is their ability to simulate atmospheric processes at a wide range of spatial and temporal scales because they represent topographical features in more detail due to their higher resolution. Greece is a country characterized by complex topography and hence downscaling to higher resolution is necessary (Kostopoulou et al. 2007, Tolika et al. 2008, Zanis et al. 2009a, Tolika et al. 2012). Here we present results of a transient high resolution (10 km x 10 km) simulation with RegCM3 over the period 1960-2100 that constitutes a climate simulation, for the first time to our knowledge, with such a high resolution, for Greece.

2 Data and Methodology

The high resolution transient regional climate simulation (1960-2100) was performed with the regional climate model RegCM3 over Greece. This high resolution simulation was a nested run of a coarser in resolution (25 km x 25 km) simulation of RegCM3 carried out in the framework of the EU-project ENSEMBLES with lateral boundary conditions from the global circulation model (GCM) ECHAM5 r3 under IPCC A1B scenario. The coarser resolution (25 Km) RegCM3 simulations over Europe were obtained by the International Centre for Theoretical Physics (ICTP, https://www.ictp.it/). The model configuration was based on sensitivity simulations using different convection schemes. Results of the sensitivity and evaluation study indicated that a modified Emmanuel convection scheme optimizes model performance over the selected domain (Mystakidis et al. 2012). Model results are produced on a 3-hourly basis. Monthly mean timeseries of surface temperature and precipitation were extracted from model fields in order to be compared with observational station based data. The model evaluation was based on observations from the Hellenic National Meteorological Service (HNMS) observational network. The data were subjected to a series of quality control tests including internal consistency checks and identification of outliers in the monthly values. An algorithm to correct for missing values based on the current WMO guidelines was also applied (Marougianni et al. 2012). Data from 70 stations with coverage from 1975 to 2000 were used for the current model evaluation analysis. The metrics used for model evaluation are i) the mean annual bias, providing an estimation of the over- or underprediction of the selected meteorological variable ii) the correlation coefficient R of the observed and modeled timeseries over the HNMS stations to identify their temporal agreement iii) the normalized standard deviation (NSD), which is the ratio of the model standard deviation monthly values to the standard deviation of the observed values. This measure ideally equals unity and becomes either >1 or <1 depending on whether the model over- or underestimates the amplitude of variability of the evaluated variable.

3 Results

Figure 1 shows the mean annual surface temperature (top) and precipitation (bottom) bias of the high (10 Km) and coarse resolution (25 Km) RegCM3 simulations (hereafter RCM10 and RCM25) for the time period 1975-2000. Table 1 summarizes the three evaluation metrics (Bias, R, NSD), their 25\textsuperscript{th}, 50\textsuperscript{th} (median) and 75\textsuperscript{th} percentiles, as well as their mean, minimum
and maximum values for surface temperature (Table 1a) and precipitation (Table 1b). The results indicate that the mean annual bias is reduced in RCM10 by 1.8°C compared to RCM25. The percentile analysis indicates that the whole range of temperatures is shifted to higher temperatures, making the climate representation in RCM10 more accurate than in RCM25, with respect to surface temperature. Precipitation, on the other hand, has a larger negative bias in RCM10 than RCM25. However RCM25 produces too much convective precipitation over the mountains. The larger negative bias in precipitation and the lower negative bias in temperature for RCM10 compared to RCM25 are linked to the different convective schemes used in RCM10 and RCM25 through a feedback mechanism (Zanis et al. 2009b). RCM10 used the modified Emmanuel convective scheme while RCM25 the Grell convective scheme with Fritsch-Chappell (FC) closure assumption (Zanis et al. 2009b).

![Image]

**Fig. 1.** Mean annual surface temperature (top) and precipitation (bottom) bias (1975-2100) for the high (left) and the coarse resolution (right) regional climate simulations.

The temporal correlation for RCM10 results with observations is is high for temperature, ranging from 0.92 to 0.96 at all stations but becomes quite lower for precipitation with values ranging from 0.09 to 0.52. Generally, climate models have difficulties to represent successfully the amount of precipitation and its spatial and temporal characteristics since it is controlled by a number of factors including the convection scheme, the energy and water budget and topography. The higher spatial resolution in RCM10 compared to RCM25 has no impact on the correlation for temperature and only slightly improves it in precipitation.

As far as the NSD is concerned the values are similar for both RCM10 and RCM25 especially with respect to temperature. The NSD in temperature ranges between 0.7 and 1.14 in RCM10 and between 0.72 and 1.33 in RCM25 with a median value close to unity (0.96) for both RCM10 and RCM25 suggesting that the amplitude of variability is very close to the observational value. The NSD in precipitation for RCM10 gets lower values than RCM25. It is anticipated that RCM10 underestimates the amplitude of variability in precipitation to a greater extent than RCM25 because of the reduction of convective precipitation in RCM10 due to the modified Emmanuel scheme.
Fig. 2. Mean annual surface temperature (top) and precipitation (bottom) change in 2021-2050 and 2071-2100 compared to 1975-2100, for the high (left) and the coarse resolution (right) regional climate simulations.

The projected changes in surface temperature and precipitation between the control time slice (1961-1990) and two future time slices, 2021-2050 and 2071-2100 (hereafter FUT1 and FUT2) under the A1B IPCC scenario are shown in Figure 2. In the first half of the century small changes are shown for temperature and precipitation. Temperature increases mostly over land by no more than 1.5°C and precipitation change ranges between ±15%, being mostly negative in the southern part of the domain. At the end of the century larger changes in both temperature and precipitation are projected under the A1B scenario. Temperature clearly increases by about 3.5 to 4°C over land while precipitation is projected to decrease by 10% to 40% with the stronger decrease shown over south Greece.

Table 1a. Annual mean statistics (25th, 50th and 75th percentiles and min/mean/max values) of surface temperature: absolute bias, temporal correlation and normalized standard deviation.

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Table 1b. Annual mean statistics (25th, 50th and 75th percentiles and min/mean/max values) of precipitation: absolute bias, temporal correlation and normalized standard deviation.

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<td>Bias (mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P25</td>
<td>-35.10</td>
<td>-15.39</td>
<td>0.29</td>
<td>0.24</td>
<td>0.45</td>
<td>0.63</td>
</tr>
<tr>
<td>P50</td>
<td>-15.97</td>
<td>-3.26</td>
<td>0.35</td>
<td>0.33</td>
<td>0.64</td>
<td>0.8</td>
</tr>
<tr>
<td>P75</td>
<td>-4.43</td>
<td>4.22</td>
<td>0.43</td>
<td>0.41</td>
<td>0.94</td>
<td>0.96</td>
</tr>
<tr>
<td>Mean</td>
<td>-20.82</td>
<td>-2.83</td>
<td>0.34</td>
<td>0.32</td>
<td>0.69</td>
<td>0.91</td>
</tr>
<tr>
<td>Min</td>
<td>-75.16</td>
<td>-54.03</td>
<td>0.09</td>
<td>0.07</td>
<td>0.21</td>
<td>0.35</td>
</tr>
<tr>
<td>Max</td>
<td>5.50</td>
<td>86.86</td>
<td>0.52</td>
<td>0.52</td>
<td>1.40</td>
<td>3.73</td>
</tr>
</tbody>
</table>
4 Conclusions

The key points of this work can be summarized as follows:

1. A transient high resolution (10 km x 10 km) simulation (RCM10) was carried out with RegCM3 over the period 1960-2100. This is the first to our knowledge, climate simulations with such a high resolution in Greece.

2. The mean annual bias in temperature is reduced in RCM10 by 1.8°C compared to the coarser resolution forcing simulation (RCM25) but the bias in precipitation becomes more negative mainly due to the different convective schemes.

3. In the first half of the century changes in temperature and precipitation are shown to be small but become larger at the end of the century with temperature increasing by about 3.5 to 4°C over land and precipitation decreasing by 10% to 40% from the north to the south.

Acknowledgments

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References


Evaluation of a WRF-hindcast ensemble within the EURO-CORDEX project.


In the current work we present results of regional climate simulations performed with the WRF regional climate model over the EURO-CORDEX domain for the time slice 1990-2008. Different parameterizations in microphysics, convection and radiation schemes are used in six hindcast simulations over the period 1990-2008. All hindcasts are forced by the ERA-interim reanalysis and have the same grid resolution (0.44°). Results are evaluated against the E-OBS observational dataset for surface temperature and precipitation. Temperature is generally underestimated, especially in winter over the Northeast part of Europe with a maximum bias of -7°C. Summer values have a smaller amplitude range of variability than winter values and the summer bias ranges between 0.1 to -2°C in different model configurations over Europe. Precipitation is mostly overestimated by all WRF configurations and the bias is higher in summer ranging from 30 to 90%. In winter the positive bias is smaller on average over all European subregions ranging from 10 to 55%. There is not a single model configuration that excels in performance in both meteorological variables examined in this work. The ensemble produces better results when compared to individual model performance.

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1 Introduction

Model evaluation is an integral part of model development and a procedure confirming that processes governing the climatology of a region are represented with a reasonable degree of fidelity. Quantification of model performance is necessary before an RCM is used to dynamically downscale future climate projections of a global circulation model. The standard evaluation procedure is to force the RCM with a re-analysis product, in order to isolate model biases introduced by the nesting procedure and the regional model formulation, from biases introduced by a potentially erroneous large scale forcing. A state of the art set of RCM projections is already underway in the framework of the CORDEX initiative (Giorgi et al. 2009). CORDEX aims to provide an internationally coordinated framework to compare, improve and standardize regional climate downscaling methods. In this work, we analyze the performance of a WRF multi-physics ensemble within EURO-CORDEX.

2 Data and Methodology

All model simulations in the current analysis are performed with the WRF-ARW model (Skamarock et al. 2008) covering the period 1989–2008. The 6-hourly ERA-Interim meteorological reanalysis (0.75°) were used as forcing data at the boundaries with nesting methods depending on the model. Different configurations were applied to each simulation; therefore model analysis will contribute to the quantification of internal model variability of WRF with respect to surface temperature and precipitation. More details on the institutions participating in the study and the selected model configurations can be found in Vautard et al. 2013.

2.1 Data

The mean daily EOBS (v9; 0.44) data were used for model evaluation. Table 1 provides the basic model configurations used in the six WRF simulations. All models used the NOAH land surface model, the Yonsei University planetary boundary layer scheme and the MM5 similarity surface layer option (WRF-ARW user’s guide, 2012). In this respect, the model spread discussed below is basically originating from the different options in the microphysical, convection and radiation options listed in Table 1 and other configurations of the model setup including vertical resolution, implementation of boundaries and interpolation options. More details on the different options can be found in WRF user’s guide.

2.2 Methodology

Model data were interpolated from their native grid to the EOBS 0.44 grid using the nearest neighbor method. The nearest neighbor method has the advantage of conserving physical properties of the model column, preserving extreme values and temporal variability. Model temperatures were adjusted by assuming the standard 6 K/km gradient between the model orography and the observation station height. The temporal resolution of all model simulations is 3 hours. For evaluating mean biases we use seasonal 1990-2008 averages of daily mean 2m-temperature and precipitation. We separate winter (December to February) and summer (June to August) seasons, since we expect that processes driving European temperatures are strongly season-dependent. The European domain is divided into eight subregions and evaluation metrics are calculated for each region separately. The selected regions are the standard Rockel regions including the Alps (AL), the British Isles (BI), Eastern Europe (EA), France (FR), the Iberian Peninsula (IP), Mediterranean (MD), Mid-Europe (ME) and Scandinavia (SC).
Table 1. WRF configurations of experiments contributing to this study

<table>
<thead>
<tr>
<th></th>
<th>Nz TOA(hPa)</th>
<th>Micro-physics</th>
<th>Cum</th>
<th>Rad</th>
</tr>
</thead>
<tbody>
<tr>
<td>AUTH</td>
<td>30/50</td>
<td>WSM6</td>
<td>KF</td>
<td>CAM3</td>
</tr>
<tr>
<td>BCCR</td>
<td>30m/50</td>
<td>WSM6</td>
<td>KF</td>
<td>CAM3</td>
</tr>
<tr>
<td>CRPGL</td>
<td>50/20</td>
<td>WSM6</td>
<td>KF</td>
<td>CAM3</td>
</tr>
<tr>
<td>IDL</td>
<td>40/50</td>
<td>WSM6</td>
<td>BMJ</td>
<td>CAM3</td>
</tr>
<tr>
<td>IPSL</td>
<td>32/50</td>
<td>WSM5</td>
<td>GD</td>
<td>RRTMG</td>
</tr>
<tr>
<td>UCAN</td>
<td>30m/50</td>
<td>WSM6</td>
<td>GD</td>
<td>CAM3</td>
</tr>
</tbody>
</table>

The letter “m” indicates manual configuration of vertical levels.

3 Results

The mean climatological patterns of temperature (not shown) are captured quite well for summer and winter by all model configurations, following the spatial characteristics of EOBS. This supports the view that major processes governing surface temperature climatology are represented with a reasonable degree of fidelity by all model configurations.

Fig. 1 shows the model winter surface temperature bias with respect to EOBS over Europe averaged over the time slice 1990-2008. Table 2 summarizes the EOBS DJF temperature means and the absolute bias of all simulations over the different European subregions. All model configurations underestimate surface DJF temperature, especially over Northeast Europe. This bias is strongly model dependent extending from -7°C (AUTH) to -1°C (IPSL) over Scandinavia. Mooney et al. 2013 found that the radiation scheme (LW) had a great impact on winter surface temperature in another WRF-multi physics ensemble forced by ERA-interim. Their results relate the CAM radiation scheme with greater negative bias over north and east Europe in comparison to RRTM. In our WRF-ensemble, the use of RRTM radiation scheme in the IPSL configuration confirms this finding. Further investigation is needed to give some insight into the causes of the negative winter bias over Northeast Europe and unveil the physical mechanisms involved.

Analysis of the standard deviation in temperature (not shown) suggests that the temperature variability is considerably smaller in summer than winter. The most pronounced summer negative bias (Fig. 2) appears in the UCAN configuration which has an average of -2°C over the whole domain. Preliminary analysis indicates that the Grell-Devenyi cumulus scheme suffers from a large cold bias in summer, which is more or less pronounced depending on the combination of the radiation and micro-physics scheme. Further analysis is needed to confirm this statement. All other model configurations have smaller bias ranging from -1°C (BCCR) to 0.1°C (IDL) over Europe.

Fig. 1. Mean winter 1990-2008 (DJF) surface temperature bias (model-EOBS).
The precipitation climatology (not shown) is reproduced by all simulations and namely the main precipitation maximum over the Alps, a secondary over west Norway and the dry regions over the Mediterranean in summer. The annual cycle is also well reproduced, with reductions of precipitation in winter over the Alps, East and Mid-Europe and Scandinavia and increase over the rest European sub-regions.

Precipitation is mostly overestimated for both seasons (Table 2). Summer precipitation climatology is seemingly more difficult to capture in comparison to winter precipitation, which is more driven by lateral boundaries rather than internal model physics. The highest precipitation bias in summer over Europe appears in the BCCR configuration, with the most severe underestimation over France. In winter, the overestimation is less severe in all configurations. IDL has the worst performance with a relative bias of about 55% over Europe.

![Mean summer 1990-2008 (JJA) surface temperature bias (model-EOBS).](image)

**Table 2a.** Means of 1990-2008 winter (DJF) precipitation for observations (EOBS) and deviations of model means from observational mean (Model-EOBS) in different European subregions. Unit is degree mm/day.

<table>
<thead>
<tr>
<th>Regions</th>
<th>EOBS</th>
<th>AUTH</th>
<th>BCCR</th>
<th>CRGPL</th>
<th>IDL</th>
<th>IPSL</th>
<th>UCAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>AL</td>
<td>2.53</td>
<td>0.40</td>
<td>0.36</td>
<td>0.65</td>
<td>1.03</td>
<td>0.44</td>
<td>0.18</td>
</tr>
<tr>
<td>BI</td>
<td>3.63</td>
<td>-0.41</td>
<td>-0.16</td>
<td>-0.16</td>
<td>-0.46</td>
<td>-0.40</td>
<td>-0.17</td>
</tr>
<tr>
<td>EA</td>
<td>1.13</td>
<td>0.50</td>
<td>0.58</td>
<td>0.74</td>
<td>0.67</td>
<td>0.68</td>
<td>0.73</td>
</tr>
<tr>
<td>FR</td>
<td>2.15</td>
<td>0.96</td>
<td>0.72</td>
<td>0.81</td>
<td>0.43</td>
<td>0.39</td>
<td>0.52</td>
</tr>
<tr>
<td>IP</td>
<td>1.94</td>
<td>0.13</td>
<td>0.20</td>
<td>0.22</td>
<td>-0.08</td>
<td>-0.29</td>
<td>-0.17</td>
</tr>
<tr>
<td>MD</td>
<td>1.98</td>
<td>-0.29</td>
<td>0.66</td>
<td>0.64</td>
<td>0.28</td>
<td>0.02</td>
<td>0.20</td>
</tr>
<tr>
<td>ME</td>
<td>1.92</td>
<td>0.80</td>
<td>0.44</td>
<td>0.73</td>
<td>0.53</td>
<td>0.58</td>
<td>0.60</td>
</tr>
<tr>
<td>SC</td>
<td>2.01</td>
<td>0.09</td>
<td>0.28</td>
<td>0.48</td>
<td>0.55</td>
<td>0.45</td>
<td>0.43</td>
</tr>
</tbody>
</table>

**Table 2b.** Same as Table 2a for summer (JJA)

<table>
<thead>
<tr>
<th>Regions</th>
<th>EOBS</th>
<th>AUTH</th>
<th>BCCR</th>
<th>CRGPL</th>
<th>IDL</th>
<th>IPSL</th>
<th>UCAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>AL</td>
<td>3.20</td>
<td>0.26</td>
<td>1.18</td>
<td>0.90</td>
<td>0.78</td>
<td>0.46</td>
<td>0.68</td>
</tr>
<tr>
<td>BI</td>
<td>2.45</td>
<td>0.36</td>
<td>0.83</td>
<td>0.56</td>
<td>0.65</td>
<td>-0.02</td>
<td>0.15</td>
</tr>
<tr>
<td>EA</td>
<td>2.22</td>
<td>0.51</td>
<td>0.91</td>
<td>1.08</td>
<td>0.87</td>
<td>0.81</td>
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<tr>
<td>FR</td>
<td>1.75</td>
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<td>0.82</td>
<td>0.28</td>
<td>0.64</td>
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<tr>
<td>IP</td>
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<td>0.42</td>
<td>0.42</td>
<td>0.17</td>
<td>0.21</td>
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<tr>
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<td>0.78</td>
<td>0.53</td>
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<td>0.49</td>
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<tr>
<td>ME</td>
<td>2.35</td>
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<td>1.07</td>
<td>0.98</td>
<td>0.81</td>
<td>0.80</td>
<td>0.55</td>
</tr>
<tr>
<td>SC</td>
<td>2.46</td>
<td>0.64</td>
<td>0.81</td>
<td>0.97</td>
<td>1.34</td>
<td>0.53</td>
<td>0.17</td>
</tr>
</tbody>
</table>

### 4 Conclusions

First results of the evaluation analysis indicate that all WRF simulations generally underestimate temperature especially in winter over Northeast Europe, where the average ensemble temperature ranges from -2 to -3°C. Preliminary analysis indicates that this feature is triggered by the combination of the selected radiation and microphysical schemes. Further
investigation is needed to identify possible feedback mechanisms involved. Summer surface temperatures have smaller amplitude of variability and the bias ranges between 0.1 to -2oC in different configurations over Europe. Precipitation is generally overestimated by all WRF configurations and the bias is higher in summer ranging from 30 to 90%. In winter, the positive bias is smaller on average over all European subregions ranging from 10 to 55%. There is not a model configuration that excels in performance in both meteorological variables examined in this work. The ensemble produces better results when compared to individual model performance. Future work should be directed towards the understanding of those physical mechanisms leading to large bias over specific areas and model configurations.

Acknowledgments. We acknowledge the E- OBS dataset from the EU-FP6 project ENSEMBLES (http://ensembles-eu.metoffice.com) and the data providers in the ECA&D project (http://www.ecad.eu). AUTH simulations were performed in the EGI/Hellasgrid infrastructure. AUTH acknowledges the Research Committee for the financial support.

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The coupled atmosphere-ocean wave modeling system WEW

Katsafados P., Papadopoulos A., Varlas G., Korres G.

It is commonly accepted that there is an urgent need for a better understanding of the factors that contribute to the air-sea interaction processes. In this sense it is absolutely important to develop advanced numerical prediction systems that treat the atmosphere and the ocean as a unified system. The realistic description and understanding of the exchange processes near the ocean surface, requires the exact knowledge of the sea state and its evolution. This can be achieved by considering the sea surface and the atmosphere as a continuously cross talking dynamic system. Therefore this study aims to present the joint effort between the Hellenic Centre for Marine Research and the Harokopio University towards developing a new, high-resolution, two-way fully coupled atmosphere-ocean wave models in order to support operational and research activities. The atmospheric component of the coupled system is based on the modified non-hydrostatic version of the Eta model which is part of the operational POSEIDON forecasting system. The ocean-wave component is based on the WAM Cycle 4 wave prediction model which is also used in the POSEIDON system. The resulting coupled system has been named WEW. Software considerations, data exchange as well as computational and scientific performance of the coupled system are also discussed throughout this study.

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1 Introduction

The development of fully coupled simulation systems between atmosphere and ocean is the “state of the art” in the research evolution of numerical models. During the last years, the importance of this coupling at regional scales has become a considerable research topic. Generally, the coupled atmosphere-ocean wave systems pass the near surface wind vector from the atmospheric to the ocean wave, and the friction velocity from the surface wave to the atmosphere (Chen et al. 2013). Therefore, the two-way coupling allows the introduction of a sea surface roughness feedback on the momentum flux at the air-sea interface (Lionello et al. 2003). Primarily, the impact of the ocean wave stress on the intensification of a storm or a cyclone, under strong wind conditions, plays a critical role on the characteristics of the atmospheric system. In more details, the hurricane-force winds increase the drag coefficient levels of the sea surface and a negative feedback is observed on the wind field near the surface. As a consequence, that negative feedback decreases the wind velocity and changes its direction. Generally, the feedbacks ultimately create non-linear interactions between different components and can make it difficult to access the full impact on each specific model (Warner et al. 2010).

This paper describes the strategy and current procedure in developing and evaluating a new, advanced, fully coupled atmosphere-ocean wave model for supporting the research and operational activities of the Hellenic Centre for Marine Research (HCMR) in collaboration with the Harokopio University of Athens. A specific issue it is emphasized here is the determination and parameterization of the air-sea momentum fluxes under conditions of extremely high and time-varying winds.

2 Overview of the modeling components

The coupled system consists of two components: the atmospheric model of the POSEIDON system and the 4th generation ocean surface wave model WAM Cycle 4. The atmospheric model used is based on the latest version of the SKIRON/Eta mesoscale meteorological model which is a modified version of the Eta/NCEP model (Kallos et al. 1997, Papadopoulos et al. 2002). This version became the core of the second generation POSEIDON weather forecasting system (Papadopoulos and Katsafados 2009) and is fully parallelized to run efficiently on any parallel computer platform. It uses a two-dimensional scheme for partitioning grid-point space to Message Passing Interface (MPI) tasks. The Eta model is designed to use either the hydrostatic approximation or the non-hydrostatic correction in order to be able to resolve high resolution atmospheric processes. For the specific application special care was taken in the estimation of the near surface wind speed, the friction velocity and the roughness. The application of the Monin-Obukhov similarity theory and the introduction of a viscous sublayer permit the realistic estimation of the surface parameters.

The wave forecasting system is based on WAM Cycle-4 code written with OpenMP directives. The model uses 24 directional bins (15° directional resolution) and 30 frequency bins (ranging between 0.05Hz and 0.793Hz) to represent the wave spectra distribution. The model runs in shallow water mode without depth or current refraction (Korres et al. 2011).

3 Theoretical background and coupling considerations

In the offline coupled mode, the atmospheric model parameterizes the air-sea momentum applying a constant non-dimensional surface roughness (or Charnock coefficient). In the viscous sublayer scheme, the roughness $z_0$ over sea surface is estimated by the formula

$$z_0 = \frac{a_w \cdot u_*^2}{g}$$

(3.1)
using the constant Charnock coefficient \( a_w = 0.018 \), throughout the simulation. The ocean-wave model passively receives the near surface wind components and there is no interaction between the two models.

Meanwhile, the WAM model includes a set of diagnostic equations for modeling the sea surface roughness feedback on the near surface atmospheric boundary layer (Janssen 1991). The spatial and temporal variability of the Charnock coefficient is estimated at each WAM timestep by

\[
a_w \equiv \frac{0.01}{\sqrt{1 - \tau_w / \tau}}
\]

In (3.2) \( \tau_w \) is the wave induced stress given by

\[
\tau_w = \rho_w \frac{k}{\omega} \cdot S_{in} \cdot d\omega d\theta
\]

(3.3)

The wave induced stress is mainly determined by the high frequency part of the wave spectrum consisting of the waves that have the largest growth rate due to the wind. In (3.3) \( S_{in} \) represents the wind input term in the wave model, \( \omega \) is the angular frequency, \( \theta \) is the propagation direction and \( k \) is the wavenumber. The total stress \( \tau \) is estimated as

\[
\tau = \rho_a \cdot C_D \cdot U_{ref}^2
\]

(3.4)

where \( U_{ref} \) is the wind speed at a reference height and \( C_D \) is the drag coefficient equals to

\[
C_D = \left( \frac{\kappa}{\log\left( \frac{z_{ref}}{z_0} \right)} \right)^2
\]

(3.5)

with \( \kappa \) being the von Karman constant. Combining (3.4) and (3.5) the total stress is given by

\[
\tau = \left( \frac{\kappa \cdot U_{ref}}{\log\left( \frac{z_{ref}}{z_0} \right)} \right)^2
\]

(3.6)

The estimated sea surface roughness is

\[
z_0 = \frac{0.01 \cdot \tau}{\rho_a \cdot g \cdot \sqrt{1 - \tau / \tau}}
\]

(3.7)

Finally, the computed friction velocity \( u_* = \sqrt{\tau / \rho_a} \) is applied in the wind input source function \( S_{in} \). WAM at each timestep provides the atmospheric model with consistent values of Charnock, roughness and total surface stress. The atmospheric model applies the variable parameters directly in the Mellor Yamada surface layer parameterization scheme for the next timestep estimation of the near surface wind components (Fig. 1a). In a two-way coupled mode the Eta and WAM models utilize different domain projections, fundamental time integration, grid orientation and grid cell size. Therefore, a major effort has been done in order to homogenize and handle the data exchange between the atmospheric and the ocean-wave components of the coupled system. These exchanges are built upon the MPI since it becomes a standard for developing applications under parallel environments. Under the parallel environment of Multiple Program Multiple Data (MPMD), the two components are carried out as parallel tasks on different processors and they exchange information in a direct way (Fig. 1b).

![Fig. 1.](image)

(a) Information flow for offline coupled (1) and two-way coupled simulations (2). (b) The WEW intra- and inter-communicators.

Currently the atmospheric model sends to the wave model the near surface wind components and receives the variable Charnock array which is applied for the estimation of \( z_0 \) in the surface layer parameterization scheme. Each data exchange requires re-projection from the atmospheric model Arakawa-E grid to the ocean-wave model regular lat-lon grid and vice versa (Fig. 2a). The current version (v0.1) of WEW has been configured on a 2x2 topology (2
additional processes are allocated for setting I/O servers) for the atmospheric component. The ocean-wave component is parallelized using OpenMP directives and it is currently configured with 2 threads. Thus, WEW is practically running on HCMR Intel Xeon platform cluster using in total 8 threads but it is easily portable in any other architecture and flexible to adopt a different topology.

4 Current configuration and sensitivity tests

The domain of the WEW simulations encompasses the Mediterranean Sea and the Black Sea on a horizontal resolution 0.10°x0.10°. Gridded data from the European Centre for Medium range Weather Forecast (ECMWF) are used as initial and boundary conditions of the atmospheric component.

The grid of the wave model for the Mediterranean and Black Seas covers the geographical areas 8°W – 42°E και 29°N – 48° N as it is shown in Fig. 2b (black line) on a similar resolution. The different projection of the two components yields a mismatch between the two domains. Thus, the constant formula of Charnock is implemented for the sea grid points of the atmospheric domain near the western boundary. A smoothing filter is also applied over the transition zone of the ocean-wave domain to the atmospheric one in order to reduce artificial generated waves.

The initialization of WAM is based on a previous model run (hot start) or on a wind–sea spectrum computed on the basis of the initial wind field and it is produced in the preprocessing stage of the atmospheric model (cold start). The propagation timestep is 300 sec while the source timestep is 600 sec. Each component of WEW keeps its own timestep and the coupling procedure exchanges data on the fundamental timestep of WAM, DT_w=600 sec. The relevant timestep of the atmospheric model is DT_a=30 sec and the timestep ratio between the two components is N=DT_w/DT_a=20. Thus, the exchanging procedure activates every 20 timesteps of the atmospheric model. Every hour (3600 sec) WEW stores its unified outputs (including atmospheric and ocean-wave fields) on the native Arakawa-E grid.

The system has been evaluated in a number of preselected case studies related to the development of extreme sea state conditions in the Mediterranean. In this framework WEW is compared against the offline coupled simulations (CTRL hereafter), in which the Charnock
parameter remains constant throughout the atmospheric simulation and the ocean-wave model retrieves hourly wind field updates. In CTRL and WEW experiments the Charnock coefficient logarithmically increases with the wind speed up to 20 m s$^{-1}$ (Fig. 3). However, WEW indicates up to 10% decrease of the simulated near surface wind speed and the significant wave height comparing against the CTRL one. Consequently, CTRL simulations underestimate the near surface wind speed and significant wave height while WEW slightly enhance this underestimation. The saturation of Charnock coefficient for wind speeds exceeded the 20 m s$^{-1}$ indicates that near hurricane wind conditions the sea surface friction conserves or decreases offering a positive forcing to the flow. This finding has been also confirmed in relevant studies (e.g. Makin 2005).

4 Conclusions

WEW is the recently developed two-way coupled atmosphere-ocean wave model for supporting air–sea interaction research and operational activities. The continuous exchanges of near surface winds and the Charnock coefficient between the two system components result in a more realistic representation of the surface friction variability especially under hurricane conditions. Despite the fact of the underestimation affecting both wind speed and significant wave height it offers an overall improvement of their RMS error up to 11% comparing against buoys measurements and satellite retrievals. Near future developments include further homogenization of the code and introduction of alternative parameterizations for the surface friction estimation and the sea salt production.

Acknowledgments This research is supported by the EU funded project MyWave (FP7-SPACE-2011-1/CP-FP, SPA.2011.1.5-03).

References


Surface total solar radiation variability at Athens, Greece since 1954

Kazadzis S., Founda D., Psiloglou V., Kambezidis H.D., Pierros F., Meleti C., Mihalopoulos N.

Long-term time-series of Surface Solar Radiation (SSR) have shown significant temporal variation of the incoming solar radiation intensity for different locations worldwide. Measurements of surface SSR prior to ‘80’s have shown a global decrease; attributed to changes in the transparency of the atmosphere and more specifically to alterations in cloudiness, atmospheric aerosols and gases interacting with incoming solar radiation. On the other hand, a large number of studies based on surface SSR measurements after the ‘80’s have shown a reversal of this trend. Finally, solar networks operating after 2000 have shown mixed tendencies. The National Observatory of Athens (NOA) has been conducting SSR measurements at the historical station of Thiseion (Athens center) intermittently since December 1953. Results from an analysis of NOA’s SSR time-series show short-term variability related to cloud-cover variations. In addition, a decrease is found in the annual SSR intensity in the order of 2.1% for the period 1954-1983 and an increase of 4.4% from 1983 till today.

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1 Introduction

In the past decades solar radiation and the transmission of the atmosphere have been of increasing interest because of the related impacts on climate. Solar variations have been investigated in several studies using ground based total surface solar radiation (SSR) from various monitoring networks (Ohmura 2009) worldwide and also by satellite derived estimations (Kambezidis et al. 2010). Recent studies (Wild 2009 and references therein) have reported a worldwide decrease of solar incoming radiation for the period 1960 to 1980 (known as global dimming) followed by an increase (global brightening) from 1980 since today. The changes in cloud coverage and atmospheric transmission are the factors that are investigated in order to determine the possible causes of these changes.

The effect of clouds and aerosols on the solar radiation variations over the past 50 years have been investigated by Ohmura (2009). Using the 20-year dimming phase from 1960 to 1980 and the 15-year brightening phase from 1990 to 2005, it was found that the aerosol direct and indirect effects played about an equal weight in changing global solar radiation.

Concerning Europe, Ruckstuhl et al. 2008 suggested that the brightening phase occurred under cloud free conditions and it is related with decreasing aerosol emissions (Streets et al. 2006).

Weather systems are the main reason for changes in the radiation levels of the order of days. On the contrary, the presence of pollutants in the atmosphere through the processes of absorption and scattering could cause more systematic effects. The gaseous and particulate air pollutants may reduce solar radiation by up to 40% during air pollution episodes in polluted areas (Jauregui and Luyando 1999). This attenuation is much larger during biomass burning events and volcanic eruptions.

Long term series of SSR measurements are essential for such studies. Such measurement series have been recorded from the past 60 years at the center of Athens and are presented in this work.

2 Data and Methodology

The SSR data used in this study cover the period from December 1953 to December 2012 and were measured by a series of pyranometers mentioned in table 1. The instruments operated continuously at the National Observatory of Athens (Lofos Nymfon, Thiseio), that is located at the center of Athens, Greece (38.0N, 23.7E, 107 m a.s.l.). Apart of the instruments and the period of operation, table 1 presents the maximum error on the calculation of daily and monthly values. The instrument spectral response is from 285-2800 nm and since 1986 it is a first class station.

<p>| Table 1. Information on instruments operated at NOA since 1953 |
|-----------------|---------------|-----------|-----------------|-----------------|</p>
<table>
<thead>
<tr>
<th>Instrument</th>
<th>Period</th>
<th>Class</th>
<th>Maximum error</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Solarigraph GOREZYNSKI</td>
<td>1953-1959</td>
<td>2nd</td>
<td>5%</td>
<td>Coulson (1975)</td>
</tr>
<tr>
<td>2 Eppley 180 pyranometer</td>
<td>1960-1973</td>
<td>2nd</td>
<td>5%</td>
<td>Coulson (1975), Drummond (1965)</td>
</tr>
<tr>
<td>3 Eppley pyranometer, type 8-48</td>
<td>1974-1986</td>
<td>2nd</td>
<td>3.5%</td>
<td>Hulstrom (1989)</td>
</tr>
<tr>
<td>4 Eppley Precision Spectral Pyranometer</td>
<td>1986-2013</td>
<td>1st</td>
<td>1.2%</td>
<td>Hulstrom (1989)</td>
</tr>
</tbody>
</table>

Complementary to this study, cloud cover observations from the National weather service from 1954 have been used. The observations have been recorded at a site 7.5 Km away from the Observatory. Cloud observations were recorded in octas of cloud sky coverage.
SSR data are processed using a set of quality control tests in order to ensure the quality of the data set. Post correcting procedure included: the rejection from the analysis of measuring days with more than 3 hours of missing data or two or more hours of consecutive missing measurements. Hourly missing values have been estimated by fitting the data on a two hour window.

Mean daily insolation has been calculated from SSR (Joules/m²). Months with more than 20 days of measurements have been used in the statistical analysis. Over the 59 years of measurements, only three months did not fulfill this criterion.

3 Results

Mean daily insolation have been calculated using the complete data set. The annual pattern of mean daily insolation over the whole period, along with the 1-σ standard deviation is presented in fig. 1.

![Fig. 1. Annual variability of insolation (green) along with the 1 σ standard deviation](image1)

After calculating the mean daily insolation for each month we have calculated the de-seasonalized monthly values. Most of the cases are well within the ±10% from the normal while a few are exceeding ±20%. The yearly de-seasonalized means from mean daily measurements have been calculated and presented in fig. 2. In addition, mean monthly cloud coverage in octas has been calculated. Cloud octas averages for observations during the day have been used. In addition, each value has been weighted by a factor depending on the average SSR of the particular time compared with the daily SSR sum.

![Fig. 2. De-seasonalized monthly (dash line) and yearly insolation (blue line). Also, de-seasonalized cloud coverage is presented in green. The correlation of yearly insolation and the mean yearly cloud coverage is presented in the superimposed figure.](image2)
The whole period was divided in two 30 year periods (1954-1983) and (1983-2012) in order to determine possible changes over the two periods based on a climatology of 30 years of SSR measurements for each one. In order to detect possible seasonal dependence on the results, the differences for each particular month were calculated. Using two separate 30 year climatologies we have found a total change in the order of 4.4% comparing the two periods. In addition, linear trends for the separate 30 year periods have been calculated and showed a total decrease of 2.2% for the first period followed by an increase of 4.5% for the second, while for the whole series an increase of 6% has been calculated. Signs of the Pinatubo eruption could possibly be observed in the early 1990’s. It has to be clarified that linear trends on any period have been calculated using different monthly normal values which are consistent with each period.

4 Conclusions

SSR for Athens area using a unique dataset covering a period of 59 years is presented. Results from the first 30-year period include uncertainties related with the calibration of the measurements; however the categorization of the station as second class provides the opportunity for useful information of solar radiation during that period.

De-seasonalized monthly calculations of SSR and comparison with mean cloud coverage can be used in order to detect a SSR negative change till the start of the 70’s that can be partly attributed to enhanced cloud presence. Then a positive change till 2012 is observed, with hints of larger rates on late 70’s-early 80’s and for the past decade.

Finally, we have tried to investigate possible changes on different periods for the whole 59 year data set. In order to accomplish that we have calculated linear trends over various time scales presented in figs. 4 a and b.

Fig. 3. Left: differences between the two 30-year periods. Green line represents the differences for each month. Right: De-seasonalized monthly means of SSR for the two periods.
Fig. 4. Left: calculation of changes in % per decade for different timescales used (15 to 30 years). Each point on the line represents the middle year of the period used for the trend calculation. Right: % change per decade for different timescales and for different months using 1954 as the starting year. (last 30 year period is magnified with changes presented as % per decade)

The quite evident anti-correlation of the independent sets of SSR and cloudiness provide useful information on explaining a large portion of year to year changes over the period.

Comparing the 30-year periods (1954-1983 and 1983-2012) we have found a difference of 4.4% that shows no predominant link with seasonal features except for a possible drop in the difference during the last three months of the year. Following the month to month analysis presented in fig. 3. Comparing this set of measurements with the results of various studies showing the dimming and brightening effects of the certain periods. We have observed a similar pattern (-2.1 and +4.5% respectively) with a lower magnitude.

Analysis of changes of SSR for different time scales revealed that negative changes are observed till the seventies followed by positive ones in the order of 2-3% till today, excluding the possible effect of the Pinatubo eruption and the years that followed (negative and positive change in the start of 90’s).

The decadal variations of SSR measured since 1954 at Athens, Greece originate from the alterations in the atmosphere’s transparency, (namely clouds, aerosols and atmospheric pollution). The changes that have been presented include the cloud variability over the period, the increased anthropogenic pollution of the area till the mid 80’s and the decrease afterwards. The SSR database presented here provides a unique opportunity of investigating and separating such effects over different periods.

References


Solar energy prediction and verification using model forecasts and ground-based solar measurements

Kazadzis S., Kosmopoulos P.G., Lagouvardos K., Kotroni V.

The present study focuses on the prediction and verification of Solar energy using model forecasts and ground based solar measurements. For this purpose we used the National Observatory of Athens network of solar radiation measurements as well as solar radiation operational forecasts provided by the MM5 model. Correlations between observations and model simulated values were calculated on a seasonal and hourly basis. The mean bias error & the root mean square error for various sky conditions was calculated and used to verify the reliability of our forecast model. We present total contours of the sky conditions for a whole year of daily measurements, as well as a classification of sky conditions based on the calculated clearness index.

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1 Introduction

Greece is one of the few EU countries endowed with potential for electricity production from renewable sources because of its geographical position. To manage the electricity grid with a large amount of solar energy will require high-quality information on every aspect of solar power generation, and in particular, solar radiation forecast. In this work, we present a comprehensive evaluation study of the reliability of global horizontal irradiance (GHI) forecasts provided by the National Observatory of Athens (NOA)’s operational weather forecasting chain, based on the PSU/NCAR mesoscale model (MM5 model: http://www.mmm.ucar.edu/mm5/mm5-home.html). The study is carried out over the area of Greece, and uses 48 h forecasts of GHI at a 2-h temporal resolution. The aim is to investigate the current performance of the model for solar yield forecasting in the study region, one of the areas with larger solar capacity in the EU.

2 Data and Methodology

2.1 Data

The automated surface meteorological stations deployed by NOA are of type Davis Wireless Vantage Pro2 Plus, manufactured by Davis Instruments (USA). As part of NOA's automated surface meteorological station network, total solar radiation is also measured at a number of stations uniformly distributed across Greece. For the purposes of this study, total solar radiation measured at 8 stations was used at: Amfiklia, Arta, Chania, Drama, Florina, Kranidi, Paralia Achaias and Spata. Solar irradiance is measured with pyranometers covering a wavelength range of 400-1100nm and having an irradiance resolution of 1 Wm$^{-2}$. Agreement between the pyranometers and the radiative transfer model LibRadtran is of the order of 5%. GHI measurements were collected every 10 min and were integrated to match the NOA’s model temporal resolution of 2-h.

Short wave solar radiation forecasts have been also used. These forecasts are provided by the operational weather forecasting chain based on MM5 model which has been running at NOA since 2001 (Kotroni and Lagouvardos 2004). The radiation scheme used in the operational chain is based on that proposed by Stephens (1984). The scheme is sophisticated enough to account for longwave and shortwave interactions with explicit cloud and clear air atmospheres and provides surface radiation fluxes. The GHI forecasts have been extracted at 2-h intervals for the first day (D1) and second day (D2) of the forecast chain for the year 2012. For each one of the surface stations, the model grid point closest to the station location has been selected. Four grid points surrounding the selected one are used for validation.
2.2 Methodology

Our goal was to try to evaluate the influence of different solar zenith angles during the day and the influence of different meteorological conditions throughout the year, on the forecasting skill of the model, as well as the performance of the model under different sky conditions: clear sky, scattered clouds, broken clouds and overcast conditions (all established with reference to the clearness index). Forecasts were evaluated in terms of the mean bias error (MBE) and the root mean square error (RMSE), defined in absolute terms as follows:

\[ MBE = \bar{\varepsilon} = \frac{1}{N} \sum_{i=1}^{N} \varepsilon_i \]  
\[ RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^{N} \varepsilon_i^2} \]

where \( \varepsilon_i = x_f - x_o \) are the residuals (forecast errors), calculated as the difference between the forecasted values \( (x_i) \) and the observed values \( (x_o) \), and where \( N \) is the total number of values. MBE quantifies the overall bias and detects if the model is producing an overestimation (MBE>0) or an underestimation (MBE<0). On the other hand, the RMSE accounts for the spread of the error distribution. Relative MBE and relative RMSE error measures were also computed. The clearness index \( \kappa_t \), described by the relationship \( \kappa_t = H/H_0 \) in terms of \( H \) the global solar radiation (pyranometer measurements) and \( H_0 \) the extraterrestrial insulation (LibRadtran simulations), was also calculated. The clearness index is a valuable tool in the characterization (or classification) of sky conditions. For the present study the following sky condition regimes were used: \( \kappa_t > 0.8 \) for clear-sky, \( 0.6 < \kappa_t < 0.8 \) for scattered clouds, \( 0.3 < \kappa_t < 0.6 \) for broken clouds and \( \kappa_t < 0.3 \) for overcast conditions.

3 Results

3.1 GHI forecast evaluation: dependence on season and time of the day

Figure 1 (left) presents the relative RMSE of the eight ground stations as a function of the season of the year. As expected, the model forecast RMSE values show a clear seasonal dependence over the study region.

![Relative RMSE values of MM5 model GHI forecasts as compared with ground measured values for each station.](image1.png)

![Averaged (over all stations) relative RMSE values for each time horizon (forecast D1 and D2) at 2-h intervals over the course of the day.](image2.png)

The lowest relative RMSE values (closest agreement with ground measured values) are found in summer and the highest relative RMSE values in winter. The highest relative RMSE values occur at Amfiklia station (with the exception of the winter season) and the lowest relative RMSE values occur at Chania and Kranidi stations. The most homogeneous values are found in winter (smaller scatter of values), while the largest scatter of values is found in spring. Fig. 1 (right) shows the relative RMSE as a function of the time of the day. The model forecast relative RMSE values show clear time dependence with the highest values occurring after 12:00 UTC (local noon). Fig. 2 shows the temporal reliability of the MM5 model near local
noon (at 10:00 UTC). The forecasts accuracy tends to improve during summer (in line with the lower relative RMSE values for this season seen in Fig.1).

Fig 2. Temporal reliability of the MM5 model at 10:00 UTC. Values are the percentage difference between the observed measurements and the model for forecasts D1 and D2.

Table 1 summarizes the performance of the model GHI forecasts as a function of season and time of the day at Kranidi and Amfiklia, the stations depicting the lowest and highest relative RMSE values. Positive values of the MBE indicate that the model tends to overestimate the GHI. For the seasonal analysis MBE values tend to be higher in spring and lower in winter and autumn. RMSE values show a steady intra-annual variability with highest values in winter and lowest values in summer. As expected, the forecasts accuracy tends to decrease with the forecast lead time. For the time-of-the-day dependent analysis negative values of MBE are found at 6:00 UTC, indicating that the model tends to underestimate the GHI. Positive values are found at 12:00 UTC, indicating that at this time the model tends to overestimate the GHI. The highest RMSE values occur at 12:00 UTC while the highest relative RMSE values occur at 14:00 UTC and the lowest relative RMSE values occur at about 8:00 UTC.

Table 1. GHI forecast evaluation results as a function of season and time of the day for the stations of Kranidi and Amfiklia. The model MBE and RMSE statistical scores are shown in absolute units (W/m²) and as relative magnitude (percentages in brackets).

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Forecast horizon</th>
<th>Kranidi</th>
<th>Amfiklia</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>MBE</td>
<td>RMSE</td>
</tr>
<tr>
<td>Seasonal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D1</td>
<td>Winter</td>
<td>21.8 (8.2)</td>
<td>206.2 (73.5)</td>
</tr>
<tr>
<td></td>
<td>Spring</td>
<td>67.7 (14.9)</td>
<td>217.1 (45.8)</td>
</tr>
<tr>
<td></td>
<td>Summer</td>
<td>52.8 (9.6)</td>
<td>84.7 (15.3)</td>
</tr>
<tr>
<td></td>
<td>Autumn</td>
<td>6.6 (1.7)</td>
<td>166.1 (42.4)</td>
</tr>
<tr>
<td></td>
<td>Annual period</td>
<td>40.5 (9.4)</td>
<td>171.4 (38.6)</td>
</tr>
<tr>
<td>D2</td>
<td>Winter</td>
<td>46.8 (17.6)</td>
<td>195.2 (69.5)</td>
</tr>
<tr>
<td></td>
<td>Spring</td>
<td>61.8 (13.6)</td>
<td>211.1 (44.6)</td>
</tr>
<tr>
<td></td>
<td>Summer</td>
<td>51.7 (9.4)</td>
<td>89.1 (16.1)</td>
</tr>
<tr>
<td></td>
<td>Autumn</td>
<td>-2.0 (-0.5)</td>
<td>171.8 (43.9)</td>
</tr>
<tr>
<td></td>
<td>Annual period</td>
<td>41.2 (9.6)</td>
<td>168.9 (38.1)</td>
</tr>
<tr>
<td>D1</td>
<td>6</td>
<td>-32.2 (-14.1)</td>
<td>90.2 (32.7)</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>21.3 (4.2)</td>
<td>171.6 (33.4)</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>74.0 (11.5)</td>
<td>228.6 (34.1)</td>
</tr>
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<td></td>
<td>12</td>
<td>89.8 (15.3)</td>
<td>233.0 (38.2)</td>
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<td></td>
<td>14</td>
<td>59.5 (16.2)</td>
<td>147.3 (37.4)</td>
</tr>
<tr>
<td>D2</td>
<td>6</td>
<td>-32.4 (-14.2)</td>
<td>90.4 (32.8)</td>
</tr>
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<td></td>
<td>8</td>
<td>21.4 (4.3)</td>
<td>171.1 (33.3)</td>
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<td>10</td>
<td>74.8 (11.6)</td>
<td>217.4 (32.4)</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>86.1 (14.6)</td>
<td>231.7 (38.0)</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>62.0 (16.9)</td>
<td>152.4 (38.7)</td>
</tr>
</tbody>
</table>
3.2 GHI forecast evaluation: dependence on sky conditions

Figure 3 shows the relative RMSE values of the stations as a function of the clearness index \( k_t \) regime (section 2.2). The forecast accuracy for the whole region shows a marked dependence on sky conditions. For the annual period, values range from below 30% for clear sky conditions, are about 55% for scattered clouds and 125 to 150% for broken clouds, and are more than 250% for overcast conditions. Similar results were obtained by Lara-Fanego et al. (2012) in an evaluation study of the GHI forecasts for southern Spain.

![Fig 3. Relative RMSE values of the model GHI forecasts for all ground stations in comparison to ground measured values as a function of the clearness index regime.](image)

Figure 4 shows a contour plot of the clearness index \( k_t \) in the daily and 10-min time domains at the Amfiklia and Kranidi ground stations. This figure in fact, summarizes the climatological patterns in the study region as well as the geographic and the topographic conditions that form the regional sky conditions.

![Fig 4. Contour plot of the clearness index in the daily and 10-min time domains, coloured according to sky condition regime for (left) Amfiklia and (right) Kranidi station.](image)

4 Conclusions

In this work, different analyses were carried out for the GHI forecasts in Greece. The seasonal analysis showed that the MM5 model tends to overestimate GHI for all the seasons of the year except for some cases in autumn (Chania). The relative RMSE also showed a clear seasonal dependence with values ranging from about 20% during summer to over 50% during the rest of the year. The time-of-the-day analysis showed a marked dependence of forecasting error on the time of the day. The sky-conditions-dependent analysis showed a clear dependence of forecasting error on sky conditions. We found that differences between sky conditions could result in forecasts varying by a relative factor of more than 10. Nevertheless, it should be noted that GHI forecasts depend not only on the radiation scheme implemented in the numerical weather prediction model but are highly dependent on the model’s ability to
correctly reproduce the spatial and temporal distribution of clouds. Thus in cases of low predictability of cloud/precipitation conditions, the GHI forecasts might present larger errors.

References


Solar Radiation Measurements and Model Calculations at Inclined Surfaces

Kazadzis S., Raptis I.P., Psiloglou V., Kazantzidis A., Bais A.F.

Inclined panels have been in use to maximize capture of incoming solar radiation. Various approaches are in use for determining of the ideal tilt angle for a specific location according to the latitude and the time of the year. Such algorithms rarely take into account the effect of cloud coverage, which in many cases is an important factor causing large deviations from “cloudless case” theory. A set of four pyranometers, located at the National Observatory of Athens at Penteli, have been used to record solar radiation year round. In this study we compare Global Horizontal Irradiance to Irradiance falling at tilted and vertical surfaces. Horizontal surface records agreed with theoretical calculations on cloudless days, absorbing more radiation during summer months but trailing year round to the inclined surface. A more complicated state is observed during cloudy occasions, when the diffuse component of irradiance could lead to higher values of Horizontal Irradiance in wintertime periods, when theoretical calculations predict the opposite.

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1 Introduction

Maximizing the portion of incoming solar irradiation by using inclined panels, has been a common practice. Incoming irradiance on a tilted surface can be analyzed in the components of the direct beam irradiation, diffuse irradiation and ground reflectance. Simulating the irradiance on tilted surfaces, when global horizontal radiation (GHI) and diffuse horizontal radiation (DHI) are known, the direct irradiation (DI) can be calculated by the geometrical relation among the surface of interest and the sun angle. GHI on a tilted surface depends on the sun’s zenith angle and geographical latitude (φ) of each site. A number of approaches have been proposed to calculate the diffuse component, which have been summed up and evaluated by Demain et al. (2013). Examining the sun path at a specific location and using each model for the diffuse component lead to a number of suggestions, which are usually presented as φ+15 (wintertime) and φ-15 (summertime), if a change is possible (Yadav and Chandel 2013). More changes of slope angle during the year can lead to larger values of absorbed energy (Gunerhan and Hepbasli 2007). Cloud coverage is the main parameter that leads to different estimations among the various diffuse schemes, ending in different proposed angles (Kelly and Gibson 2011). In this work we aimed to record incoming irradiance at different angles over long time periods and evaluate the effect of cloud coverage in each case.

2 Data and Methodology

The data set used in this study, was recorded at the Actinometric Station of NOA in Penteli (latitude 38.05°N, longitude 23.86°E, elevation: 500 m a.s.l.), by a set of four pyranometers. The recording frequency was one minute and data are available for 2012 and 2013. The actinometers for measuring the GHI and DHI irradiance measurements at Penteli are Kipp-Zonen CM11 pyranometers; in addition, the diffuse radiation is measured by using a Kipp & Zonen shadow ring over the pyranometer. Also a Kipp-Zonen pyranometer is installed facing southward and with an angle of β=38° in order to record global irradiation on the suggested by bibliography optimum angle. The fourth pyranometer was placed vertically facing either west, east, south or north, changing orientation every 10 days. Correction for the dark signal has been made. Data points had been flagged as cloudy or cloudless by using the horizontal irradiance data and a cloudless sky model. Each minute was characterized as cloudy or cloudless: for the characterization of a day as cloudless we chose to assume that at least 70% of the data were characterized as cloud free and the total daily radiation was at least 80% compared with the cloudless sky model.

Mean monthly values from the model Photovoltaic Geographical Information System (PVGIS), available from Joint Research Center as a web application were used. This model calculates, beam, diffuse and reflected components of the clear-sky and real-sky global irradiation for horizontal or inclined surfaces, at 1km x 1km resolution. The main input parameters to the model are solar radiation from 566 ground meteorological stations containing monthly and yearly averages of daily global irradiation on a horizontal surface, ratio of diffuse to global irradiation and clear sky index. It also takes into account topography (Šúri et al. 2007).

In addition, solar irradiance on the sloped surface using recordings of GHI and DHI, have been calculated. The direct beam irradiance, is obtained from the measured GHI and DHI (Psiloglou et al. 1996) using the solar zenith angle and the angle of incidence of each minute. Reflected from the ground, irradiance, received by the plane of tilt, is calculated (Psiloglou et al. 1996) using a constant ground albedo of 0.2.

Then two different approaches are employed for the calculation of DHI received at the sloped surface. The first one uses an isotropic model for the diffuse component, hereafter called ISO. The second one is obtained by using the Hay’s model (Hay, 1979, Hay and McKay, 1988), hereafter called HAY; this uses the total attenuation compared with the extraterrestrial spectrum and the specific tilt angle in order to calculate the diffuse component.
To establish a valid set of measurements for the validation of the ratio $GHI / \text{Total-38deg.}$ and also the performance of the HAY and ISO diffuse models the 1-minute mean $GHI$ and $DHI$ values were compared. A routine quality-control procedure was applied; erroneous data were excluded. The quality tests screened out all (i) $DHI$ values greater than 110% of the corresponding total horizontal ones; (ii) $GHI$ values greater than 120% of the seasonally correct solar constant; (iii) $DHI$ values greater than 80% of the seasonally correct solar constant; (iv) $GHI$ values equal to or less than 5 W/m$^2$, during sunrise and sunset, due to the pyranometers’ sensitivity; (v) data for a solar altitude less than 5 degrees; and (vi) data with the direct-beam solar component exceeding the extraterrestrial solar irradiance. Results of the comparison of the measured and model values are presented in Fig. 1 and Table 1.

![Fig. 1 Intercomparison of all (1 minute) values measured at 38º inclination and calculated from HAY model for January (a), March (b), August (c) and October (d), 2012, at Penteli, Athens](image)

### 3 Results

Averaging year round values for each pyranometer shows that the solar zenith angle is the most important factor for calculating incoming irradiation in each case. When cloud free conditions, we can observe the effect of different zenith angles, as expected from the theory, in Fig. 2a. In Figs. 2b and 2c, data has been separated according to the cloud flags; we observe that at large zenith angles the appearance of clouds makes the $GHI$ to have higher values than the incoming on the tilted surface. At the case of vertically placed surfaces, Fig. 2d, results vary according to the alignments. When the pyranometer is facing eastwards, for a big portion of a day corresponding to early morning hours, it receives more energy than any other placement, even the one inclined at 38º southwards. Obviously after noon, irradiation received in this case becomes quite low. The exact opposite behavior is observed when the vertical surface is facing west. In the case of southward facing surface, a similar diurnal pattern to that of the 38º tilted pyranometer, can be noticed. As expected, in the northern hemisphere, the case of a vertical surface facing north provides low amount of energy.
We calculated total irradiation for each day and each orientation, by summing up all values. Also the ratio between the GHI and the irradiance at the 38º inclined surface southward has been calculated. This ratio provides an easily understood picture of which inclination pattern provides more irradiation on each day including solar position and other atmospheric effects (clouds, aerosols). Clear sky days correlate very well with model estimations, (Figure 3) revealing that during summer months the horizontal surface collects more irradiance than the inclined and vice versa in winter. Cloudy days have a more complicated behavior, often changing the dominant inclination. The major factor for this change are the different cloud conditions that affect the angle of incidence of solar radiation at each surface by limiting the direct beam and enhancing the part of diffuse radiation on the total incoming radiation. The portion of the direct to total radiation is the dominant factor leading to higher radiation received by the tilted surface compared with the horizontal for winter months (low solar zenith angles). As this portion becomes low due to the presence of clouds, the difference of the solar radiation received on the horizontal and the tilted surfaces diminish.

Table 1. Statistics of the comparison provided in figure 1.

<table>
<thead>
<tr>
<th>Month</th>
<th>RMSE (expressed in % of the mean monthly GHI)</th>
<th>GHI mean monthly values (W/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January 2012</td>
<td>7.11</td>
<td>396.9</td>
</tr>
<tr>
<td>March 2012</td>
<td>4.05</td>
<td>510.9</td>
</tr>
<tr>
<td>October 2012</td>
<td>4.50</td>
<td>469.6</td>
</tr>
<tr>
<td>August 2013</td>
<td>5.04</td>
<td>607.2</td>
</tr>
</tbody>
</table>

Fig. 3. Total Irradiance ratio (GHI/global 38º) per day, year round. Daily integrals of measurements of clear sky and cloudy days and HAY and ISO daily models can be seen; PVGIS model has monthly values. The DHI/GHI ratio is also shown.
A permanent state for cloudy days cannot be resumed, but it appears that during months of expected advantage (winter period) of the inclined surface, in many cases clouds reverse the picture, making a horizontal surface preferable. PVGIS provides a good picture for the year-round behavior of the ratio, but fails to describe deviations, caused by cloud coverage, which is expected using monthly values. Values from HAY and ISO correlate with measurements for the inclined surface very well as seen in Fig. 3. Some deviations can be explained from the uncertainty (at least 1 degree) of the positioning of the tilted surface, the constant and spatially independent albedo assumed for the reflectance component and the diffuse radiation model parameterization.

4 Conclusions

Year round fixed inclined surface at 38° leads to higher energy received compared with the one received on a horizontal surface. The experiment that was conducted using measurements of solar radiation for different surfaces (four vertical, one at 38 degrees, a total horizontal and the diffuse horizontal), aimed to compare theoretical climatological model and more sophisticated (using actual horizontal and diffuse measurements) ones, with actual measurements. We have found a quite good agreement between modeled values and measurements and we tried to assess the effects of clouds on the ratio of the tilted to horizontal surface. The maximization of the incoming solar radiation depends on the ability to track the sun (or the sun’s principle plain; also on the accurate parameterization of the cloudiness which can alter the theoretical excess of the radiation received by a tilted surface compared to the horizontal in wintertime.

Acknowledgments The study has been partially supported by the Hellenic Network of Solar Energy (HNSE) project, funded by the General Secretariat for Research and Technology (GSRT), Greek Ministry of Education and the project THESPIA of the action KRIPIS of GSRT co-financed by Greece and the European Regional Development Fund of the EU in the frame of NSRF and the O.P. Competitiveness and Entrepreneurship and the Regional Operational Program of Attica.

References

Current state report on Weather Intelligence for Renewable Energies (WIRE) in the frame of COST Action ES1002

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The COST Action ES1002 “Weather Intelligence for Renewable Energies WIRE” was launched in November 2010 to promote the short-term forecasts of energy production for wind and solar energy. Its goals are 3-fold: to evaluate the accuracy of existing forecast systems (including post processing algorithms) by validating their results with in-situ measurements performed mainly at power plant sites, to promote the use of ground-based standard and remote sensing measurements together with satellite-borne information and to analyze the potential to increase the quality of the short-term forecast with such systems and, finally, to strengthen the collaboration between end-users and modelers in order to best characterize their needs and requirements based on the modeling results. In the frame of the Action, an assessment report on the latest achievements in the fields of production forecasts and integration in the existing electrical grids has been prepared. The current state report and numerous activities (benchmarking exercise, instrument intercomparison) will be presented.

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1 Introduction

The concept of a European approach to cope with tomorrow’s higher penetration of renewable energies is moving forward. The need of production short-term forecasting is becoming more and more evident on the production level. It is today also widely acknowledged that, at the distribution level, the resulting challenges for the electrical grid managers have to be taken into account to guarantee the optimal penetration of renewable energies in the energy mix.

2 The COST Action ES1002 “Weather intelligence for Renewable Energies WIRE”

The main goal of the COST Action ES1002 “Weather intelligence for Renewable Energies WIRE” is to promote the collaboration between the meteorological / modeling community on one side and the industrial development of renewable energies in Europe on the other. A number of Working Groups has been defined in order to fulfil the tasks outlined in the Memorandum of Understanding defining the goals of the Action:

- Working Group 1 – Modeling and post-processing
  The focus is to evaluate the adequacy of numerical weather models coupled with dedicated power conversion modules to deliver accurate power production forecasts.

- Working Group 2 – Measurements and Observations
  The focus is to evaluate how including ground-based and space-borne (satellite) remote sensing technologies will improve the quality of the production forecasts.

- Working Group 3 – Power Plants and Electrical Grid Management
  The development of improved forecasting systems is assessed in cooperation with end users in order to guarantee a good match between the scientific developments and the user’s requirements. The focus is to investigate the influence of “Dynamic Line Rating DLR” for the weather dependent increased efficiency of energy transport for power lines.

  With more than 200 participants from 27 countries in Europe (and contributions from USA, Australia, Canada and Japan), WIRE has attracted a wide number of participants from different countries and, most important, from different fields of activities ranging from modeling (production forecasts) to measurements (intercomparison of instruments dedicated to renewable energy applications) and to applications for power plant and electrical grid management, including DLR affecting the distribution of energy (power lines).

3 Results

3.1 Benchmarking of short-term prediction of power output

A proposal for the participation to a Benchmark exercise has been sent to the Action participants and other external bodies. The aim of this exercise is to bring together and evaluate the merits of forecast results based on different modeling approaches and input data. The exercise is expected to contribute to a better knowledge of the state of the art, to assess the evolution of forecast performances with respect to benchmarking exercises that took place in the past and finally to identify the challenges for improved accuracy in the future.
In a first step, 4 power plants (2 solar and 2 wind power plants) have accepted to submit their data for verification of the production forecasting efforts and about 18 groups (including individuals) have volunteered to contribute to this activity. The available historical data sets include measurements of power output and meteorological variables from the installations as well as numerical weather predictions for the considered sites. The Benchmark started in April 2013: first results have been presented at the recent EWEA Technical Workshop (December 3rd-4th 2014, Rotterdam, NL).

The Action’s members hope that the first results of the Benchmark will encourage power plant and electrical grid managers to more open collaboration with the R&D community.

### 3.2 DNI Intercomparisons

Following discussions held during the first Action Workshop which was held in March 2011 in Nice, France, MeteoSwiss took the initiative of conducting intercomparisons of radiometers measuring Direct Normal solar Irradiance (DNI) as contribution to the Action. The goal was to compare “standard” instruments for measuring DNI to high quality radiation monitoring instruments (reference) from the Baseline Surface Radiation Network (BSRN) located at Payerne, Switzerland. The equipment that was tested was instruments that can be operated without high maintenance and whose cost allows the deployment at production sites and in networks.

The intercomparisons were limited to the assessment of the instrument performances. This represents a first step towards establishing a basis on which subsequent similar activities will allow defining Standard Operating Procedure (SOP) for the use of such instruments and verifying the adequacy of their performances to the requirements of the solar energy sector.

This intercomparison took place during the period summer 2012 – summer 2013 at the MeteoSwiss Aerological station in Payerne. It was supported by three COST Short-Term Scientific Missions STSMs.

The organization of an Intercomparison of solar instruments dedicated to renewable energy applications is a major success of the Action: this is the first time that such an activity is organized and it is strongly hoped that similar efforts will be initialized in the field of wind energy. A final report describing the evaluation results will be published soon.

Parallel to the field comparisons, a Workshop on the requirements expected from DNI measurements for solar energy applications took place on September 20th-21st 2012 with the participation of IEA SHC Task 46 members. Particularly discussed were the influential factors when relating radiation observations to solar energy production and the users’ requirements on the specifications of the instruments.

It must be here noted that the new FP7 program (DNICast: “Methods for the estimation of the Direct Normal Irradiation (DNI)”) has been discussed during the Workshop. DNICast was later successfully submitted with the active support of the COST Action ES1002. This program includes an important number of WIRE participants.

### 3.3 Dynamic Line Rating

Rating practices are linked to security aspects such as the sag of power line conductors due to the temperature of the conductors which is dependent on the power load, the ambient temperature, the solar radiation, the precipitation and the wind speed and direction. Dynamic Line Rating offers a possibility to increase the efficiency of power lines by taking into account the variability of the external conditions and, consequently, their forecast. Efficiency increase when using DLR algorithms may reach 30% on an annual basis. Developing methods and tools to be able to determine the potential for DLR for specific locations based on historical data and weather models would allow TSO/DSO to make much better decisions
on where they could/should implement DLR to solve congestion and curtailment issues in their network. For example, increasing line electrical capacity on borders can mitigate market pressure and lower average generation prices thus increasing welfare.

The main problem for DLR forecast is to choose between a deterministic approach (which is currently already operational) and a probabilistic approach with the use of so-called “ensemble forecasts” to deliver the probability of the DLR values along the track of the OHL. The ensemble forecast method seems to be best suited for DLR when considering the positive experiences obtained with the probabilistic forecast of wind energy production. A mix of both approaches could be considered: high resolution deterministic forecast for the best possible local forecast, and probabilistic high resolution ensemble forecast for the probabilistic distribution and longer forecasting windows, an ensemble of high resolution forecasts being one of the discussed possibilities.

The aim of WIRE is to come up with 2 position papers on DLR forecast and planning including a description of the achievable results, an estimation of the R&D tasks required to attain these goals and the timing and financial support these tasks require. These position papers will be published early 2014 and are intended to be used to convince Transmission/Distribution Network Operators to fund the research for their own immediate needs, to submit a proposal for EU funding of this research as follow-up to the currently ending FP7 Twenties project.

Furthermore, on the initiative of the Action members involved in Cigré, a proposal for the creation of a new subtask in the Cigré Study Committee B2 (Overhead Lines) was prepared and submitted to the appropriate evaluation instances: if successful, this will represent a major success for the Action.

Numerous meetings and workshops have been organized to deal with the use of weather intelligence for the management of electrical grids. It is a very positive signal that these meetings have attracted more and more participants from the industrial world (power plant managers, TSOs).

### 3.4 Current State report

Following the goals defined in the MoU, a Current State report has been prepared with the participation of an important number of the Action’s participants. The report is presently in its final version and is published on the Action’s website (www.wire1002.ch). Its content includes different approaches to the Renewable Energy problematic in general, and to more specific topics:

- Research and Development: the European approaches
- Production forecast of Wind energy
- Production forecast of Solar energy
- Weather forecast for Grid management, including Icing and Dynamic Line Rating
- Political, economic and technical framework
- National activities

### 3.5 Inter-disciplinary networking

One of the goals of this COST Action is to increase the collaboration between the meteorological / modelling community on one side and the industrial development of renewable energies in Europe, including the distribution of energy through the electrical grids. This is still a challenging task, as may be seen from the difficulties to obtain operational production data from the solar and wind power plant managers/owners (see “Benchmark” above). However, the numbers of groups which have registered to participate to this exercise
show that there is a need for increased standardization of the evaluation procedures of production forecasts on the European (worldwide?) level.

The COST Action ES1002 is inter-disciplinary in itself: its participants are coming from the weather modelling and energy production communities, from the wind and solar measurement domains and from the industrial world (Transmission System Operators TSOs, Distribution System Operators DSOs, regulators). Furthermore, its members are practically all active in different European projects (ECMWF, SafeWind, Modops, Cosmo…) and in world-wide activities (instruments’ Intercomparison sponsored by WMO/CIMO, participation to IEA PVPS Task 14 meetings, participation to IEEE and CIGRE Conferences…). Finally, WIRE attracts many young researchers as may be seen from the high participation to a Summer School organized by the Action which took place July 1st-5th 2013 near Toulouse, France, immediately after ICEM-2013.

An article dedicated to the activities of WIRE was published in the December 2012 issue of the International Innovation magazine:
http://www.research-europe.com/magazine/ENVIRONMENT/2012-15/index.html (pp. 75-77)

4 Conclusions

With these important activities in different fields linked to weather intelligence, the COST Action ES1002 WIRE is clearly on the right track to deliver a major contribution to the wind and solar energy forecasting community and to the collaboration with the power production and distribution operators.

Acknowledgments All participants in the COST ES 1002 Action are acknowledged for their contribution.

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Development of a neural network model of cloudiness forecasting for solar energy purposes

Kazantzidis A., Zagouras A., Salamalikis V., Nikitidou E.

Although a considerable number of studies have been appeared for the estimation of global horizontal irradiance (GHI) over large areas, the accurate estimation with high spatial and temporal resolution is still a major challenge. Ground-based measurements of GHI are provided at many stations around the world but a sufficient coverage cannot be ensured everywhere since solar radiation is still rarely sampled compared to other environmental variables. To complement the surface networks, numerous methods have been developed to estimate the GHI from radiances measured from polar orbiting and geostationary satellites. In this study, we present a novel method for the short-term (0-240 minutes) forecasting of GHI in Greece taking into account that cloudiness is the main atmospheric factor for the spatial and temporal distribution of surface solar irradiance. Images from the Spinning Enhanced Visible and Infrared Imager (SEVIRI) on the Meteosat Second Generation (MSG) were processed to retrieve the cloud modification factor (CMF) which is the GHI reaching the ground taking into account the presence of clouds and GHI for a cloud-free sky. Satellite data in a 2 year time period and with high spatial and temporal resolution (0.05°, 15 minutes) have been used for the training and testing of an artificial neural network (ANN).

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Introduction

The solar irradiance reaching the ground is affected by numerous atmospheric constituents like aerosols, clouds and atmospheric gases. From these factors, the effect of clouds is dominant due to their high values of optical depth (and the attenuation they cause on solar irradiance) and their high spatial and temporal variability. Therefore, the knowledge of cloudiness (cloud optical depth and coverage) is considered as the most important factor for the solar irradiance variability at the ground as well as for forecasting.

The variability of irradiance is very difficult to be captured by a ground-based network. For this reason, several methods have been developed in recent years to estimate GHI taking advantage of the high spatial and temporal resolution of geostationary satellites. In the frame of the Hellenic Network of Solar Energy (HNSE, www.helionet.gr), a method was developed by Zagouras et al. (2013) for the estimation of GHI using images from the Spinning Enhanced Visible and Infrared Imager (SEVIRI) on the Meteosat Second Generation (MSG). The method, originally described in Verdebout (2000) provides estimations of surface solar irradiance every 15min with 0.05° spatial resolution.

In recent years, several models for forecasting GHI have been presented, such as those based on time series methods, Artificial NeuralNetworks (ANNs) (Mihalakakou et al. 2000, Tymvioset al. 2005, Marquez and Coimbra 2011, Pedro and Coimbra 2012, Marquez et al. 2013a, Marquez et al. 2013b), satellite-derived cloud motion forecast models and stochastic prediction models that use the volatility of the data over the whole time period. These models were used to obtain the daily irradiation or the mean hourly distribution of GHI. Some of these models work very effectively in normal weather conditions, but not as well in extreme weather situations or when the weather conditions change dramatically.

From the point of view of energy management, surface solar irradiance and the resulting solar power for short time horizons is of great importance. Due to the increasing levels of solar power in the electric grid, its high variability caused by weather could have a strong impact on the grid stability. In this paper, a new method for the short-term (0-240 minutes) forecasting of GHI in Greece is presented taking into account that cloudiness is the main atmospheric factor for the spatial and temporal distribution of GHI.

2 Methodology

2.1 Data

The satellite-derived cloud modification factor (CMF) data for the period 2009-2011 was obtained from SEVIRI on MSG satellite. CMF is defined as CMF = I_{cloudy}/I_{clear}, where I_{cloudy} is the GHI reaching the ground taking into account the presence of clouds and I_{clear} is the GHI for a cloud-free sky. CMF can range from 0 (the theoretical overcast situation with very thick clouds that reflect back all radiation) and 1 (representing the cloudless sky) or more when the diffuse component contributes to global irradiance under partly cloudy conditions. The data were divided into two datasets; the subset 2009-2010 is used as the training set for determining the weights and biases of the network and the data from year 2011 are considered as an out-of-sample test set to perform the forecasting process.

2.2 ANN

In this study, we use a back-propagation multi-layer feed (ANN) for predicting CMF from satellite-derived data. The implemented neural network follows the typical structure of the
three layers; one as an input, the intermediate hidden one and the output layer. The tangent sigmoid transfer function serves as the transfer function and the network’s weights updated through a number of up to 1000 epochs. Each of the input and hidden layers are composed of 100 neurons or nodes. Before the training stage, all the input data were normalized in the range [0.1-0.9] to be consistent with the slow changes of the sigmoid function in the intervals [0.0-0.1] and [0.9-1.0], using the following linear transformation:

\[
x_{\text{norm}} = 0.8(x_0 - x_{\text{min}})/(x_{\text{max}} - x_{\text{min}}) + 0.1
\]

(Equation 1)

where \( x_{\text{min}} \) and \( x_{\text{max}} \) are the minimum and maximum values in the dataset, respectively. The simulation results are appropriately deormalized to the original scale after the training process.

The main concept to accurately predict CMF values over the area of interest is to train a neural network that receives as input the values of a 3x3 spatial gridded data window (Figure 1) at times \( t \) to \( t-3 \) and predict the value of the central grid point of the window at future time \( t+n \), where \( n \) represents following 15-minutes time steps. It is apparent that the prior knowledge of the measurement values at locations that directly encircle a specific target location, i.e. the central grid point, could be considered as constructive to make forecasts for future values. During the training stage the networks learn how to predict the values of any pixel at \( n \) consecutive future time steps by their 3x3 neighborhood window input values at 4 earlier samples.

**Fig. 1.** A satellite-derived image of CMF values over Greece (34-42 °N and 19–28 °E) for a time \( t \). To predict each of the pixel values (180x160), an input vector that contains a 3x3 window around the target (red) pixel is used at the training process.

Considering a spatial distribution of the Greek domain into 22 clusters of similar CMF variability (Fig. 2) presented by Zagouras et al. (2013), the simulation process is applied at each cluster by appropriately training 22 individual neural networks. Additionally, in order to reduce the computational intensity a random fraction of the 2/3 of total number of pixels per cluster is used at the training process as well as another random 50 percent fraction of the days that composes the training set. The created network is finally used to generate the output values for each particular pixel of the area of interest for all the days within the test set, with respect to the cluster that each pixel belongs and the forecasting horizon time \( t+n \).

After assembling the predicted values to build up the cloudiness imageries for the domain of Greece, the mean square error (MSE) and the mean absolute error (MAE) are used as different performance measures to compare the estimates from the ANNs and the observed satellite-derived data.
3 Experiments and Results

The neural network of each individual spatial cluster was trained with input data from the training dataset that represent the CMF values for each pixel along with its surrounding 8 pixel values at time t-3 to t, where t is the 8:45 UT. The output consists of 17 consecutive single-valued predictions representing the CMF values of each location at a future time every 15 minutes ahead. Next, the 22 full-trained ANNs are used to generate the output values for the total days of the test set. We measure the performance of the simulation process by calculating the MSE and MAE between the output and target values. The seasonal spatial average errors per 15 minutes time step of the forecast horizon is displayed in Figure 3. Adequate small errors for both the measures indicate a good performance of the proposed system. Note that the error values are dimensionless as the CMF index values.

Fig. 2. The partition of the area over Greece into 22 clusters (from Zagouras et al. 2013). Some domains are presented in the same color, although they are classified differently.

Fig. 3. Spatial average measured errors between the actual and forecasted CMF values during summer (left) and winter (right). The errors increase with the time horizon.
In Fig. 4, we plot the seasonal average MSE per pixel regarding the timestamps at 15 minutes, 2:15 hours and 4:15 hours ahead of t time for the summer and winter. As expected, a smaller average MSE is obtained during the summer, which is consistent with the meteorological conditions of Greece. The estimated and the measured values of CMF are in good agreement: the maximum average MSE after 4:15 hours is 0.06 and 0.1 during summer and winter respectively and corresponds to an error of 6 and 10% in GHI. Similarly, the maximum average MAE for the two seasons is 0.09 and 0.15. Although the errors are higher during wintertime, the absolute difference between forecasted and measured irradiance is higher during summertime, when the usual sky conditions include cloud-free atmosphere and low solar zenith angles.

4 Conclusions

We present a novel method for the short-term (0-240 minutes) forecasting of GHI in Greece, based on satellite-derived CMF values for 3 years for the training and testing of a neural network and taking into account that cloudiness is the main atmospheric factor for the spatial and temporal distribution of surface solar irradiance. Based on the ANN results, the estimated and the measured values of CMF are in good agreement: the maximum average MSE after 4:15 hours is 0.06 and 0.1 during summer and winter respectively and corresponds to an error of 6 and 10% in GHI.

Acknowledgments. The authors would like to thank EUMETSAT for providing the MSG satellite data. J. Verdebout is highly acknowledged for the original algorithm.
References

Atmospheric nucleation and cloud condensation production

Kerminen V.M.

A growing number of investigations demonstrate the importance of atmospheric nucleation in producing cloud condensation nuclei (CCN) both regionally and in the global atmosphere. Here I review the current understanding on this subject based on field observations, laboratory measurements and model simulations. As a summary, it can be concluded that CCN production associated with nucleation is a frequent and wide-spread phenomenon in the continental boundary layer, and probably so in the free troposphere as well. The contribution of nucleation to the global CCN budget and indirect radiative forcing spans, however, a relatively large uncertainty range. To reduce these uncertainties, we need more information on i) the factors controlling atmospheric CCN production and ii) the properties of primary and secondary CCN and their dependence on each other. In future studies of this subject, one should more effectively apply experimental and modeling approaches together.

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1 Introduction

Understanding the relation between aerosol and their precursor emissions, atmospheric aerosol particle populations, clouds and climate is not possible without quantification of the sources responsible for atmospheric cloud condensation nuclei, CCN (Andreae and Rosenfeld 2008). One such source is atmospheric nucleation and subsequent growth of nucleated clusters to larger sizes. Field experiments have demonstrated substantial local enhancements in CCN concentrations due to atmospheric nucleation (e.g. Wiedensohler et al. 2009, Sihto et al. 2011). Model investigations suggest nucleation to be an important contributor to CCN, and thereby to indirect radiative forcing, in the global atmosphere (e.g. Merikanto et al. 2009, Kazil et al. 2010, Makkonen et al. 2012). In the following, we will synthesize the existing knowledge on CCN production associated with atmospheric nucleation.

2 Overview

2.1 When nucleated particle can act as CCN?

Cloud condensation nuclei (CCN) are being defined as particles capable of activating into cloud droplets at given water vapor saturation ratio, $S$. For a certain value of $S$, the ability of an aerosol particle to act as CCN depends primarily on its size and secondary on its hygroscopicity determined by the particle chemical composition. Other factors that may influence the CCN activity are the presence of water-soluble gaseous compounds and potential kinetic limitations related to the water transport between the particles and surrounding air (McFiggans et al. 2006).

In real atmospheric clouds, it is the maximum water vapor saturation ratio ($S_{\text{max}}$) that distinguishes cloud droplets from particles not able to act as CCN (Reutter et al. 2009). The value of $S_{\text{max}}$ tends be higher for convective clouds and boundary-layer clouds (higher cloud updraft velocities), and higher for clean than polluted conditions. Depending on the meteorological situation and aerosol chemical composition, the minimum dry diameters at which particle can act CCN in boundary-layer clouds is typically between about 50 and 100 nm under clean conditions and somewhat more under polluted conditions (Kerminen et al. 2012).

The initial size of freshly-nucleated particle is about 1–2 nm, so they need to grow from a few hours up to couple of days in the atmosphere to become CCN. During their growth to larger sizes, particles may be lost by their coagulation with larger pre-existing particles, by their scavenging by rain, or by dry deposition. The probability by which a nucleated particle will eventually reach a CCN size is called as the CCN formation efficiency. Typical CCN formation efficiencies reported for regional atmospheric nucleation events are in the range of 1–20% (Kerminen et al. 2012). Lower CCN formation efficiencies are certainly frequent as well, but such cases remain easily undetected as atmospheric new particle formation and growth events.

2.2 Atmospheric observations

Atmospheric observations indicate that nucleation followed by growth to CCN (>50 nm diameter) takes place frequently and over relative large spatial scales in continental boundary layers, including forested areas at mid and high latitudes, other remote continental regions, urban areas and even highly-polluted environments (see Kulmala and Kerminen 2008). The same appears to be true in the lower free-troposphere based on continuous measurements at a
high-altitude stations. In the marine boundary layer, both nucleation and subsequent CCN productions seem to be rare.

In addition to regional nucleation events, production of new CCN has been found to occur in association with more localized nucleation, such as nucleation taking place in power plant plumes and coastal areas (e.g. Stevens et al. 2013). In the free troposphere, cloud outflow regions associated with convection seem to be active regions for nucleation (Hermann et al. 2003), yet there is little evidence on subsequent CCN production due difficulties in following particle growth in that environment.

Only few studies have linked nucleation measurements directly to CCN or cloud droplet number concentration measurements. The existing studies confirm that, in many cases, CCN concentrations can be estimated relatively accurately from particle number size distribution measurements using the concept of a “threshold diameter”. This is the dry particle diameter above which all particles in the aerosol population are counted as CCN. The “threshold diameter” depends on the assumed water vapor saturation ratio, being in most cases between about 50 and 150 nm (Kerminen et al. 2012).

A few studies have also estimated the contribution of atmospheric nucleation to the regional CCN budget based on long-term measurements of particle number size distribution measurements. The information obtained from such analyses, while valuable, has remained qualitative for many reasons. First, a big challenge in any observational-based analysis is to distinguish between primary particles and particles formed originally by atmospheric nucleation. Second, it is very difficult to take into account the problems associated with making measurements at a fixed location. These include rapid or gradual changes in measured air masses, diurnal evolution of the boundary layer, and local sources of primary particles. Finally, there is no standardized procedure developed for such an analysis, making it difficult to compared results from individual studies with each other.

\[ \text{2.3 Model studies} \]

Model simulations have pointed out that atmospheric CCN production associated with nucleation depends in a non-linear way on the nucleation rate, subsequent growth of nucleated particles to larger sizes, and the presence of primary aerosol particles (Pierce and Adams 2009, Makkonen et al. 2012). Both nucleation and growth are very challenging processes to be simulated in large-scale modeling frameworks. In case of nucleation, this is due to our incomplete understanding of the atmospheric nucleation mechanisms and due to nucleation taking place in model sub-grid scale plumes (Stevens et al. 2013). In the case of nuclei growth, the main challenge is the proper treatment of the chemistry and gas-particle partitioning of organic compounds (Riipinen et al. 2011). Primary particles complicate the issue further by acting as a sink for low-volatile vapors and freshly-nucleated particles, and by providing additional CCN as a result of their aging during atmospheric transportation (Pierce and Adams 2009, Spracklen et al. 2011).

While the models simulating atmospheric CCN production differ considerably in terms of how nucleation and other aerosol processes are treated, the results from the model investigations conducted so far share a number of common features. First, nucleation taking place in the upper free troposphere appears to be a major source of CCN in the global troposphere. After transport and growth, these particles dominate frequently CCN number concentrations in the remote marine boundary layer and contribute to CCN present in continental background areas. Second, boundary-layer nucleation enhances CCN number concentrations almost everywhere over the continents. Third, organic compounds play a crucial role in the CCN production in continental boundary layers and, possibly, elsewhere due to their ability to grow nucleated particles effectively into larger sizes. Finally, the contribution of nucleation to the total CCN budget in the troposphere is definitely non-negligible, and it might be even larger than 50% at water vapor supersaturations approaching 1%.
3 Outlook

Existing field observations and model investigations have demonstrated the CCN production associated with atmospheric nucleation is frequent and wide-spread in many types of continental boundary layer. Several key research areas on this topic exist, however, that require further attention in the future.

The first area is which factors control atmospheric CCN production. From the process-level point of view, CCN production associated with atmospheric nucleation is affected by three quantities: the nucleation rate, the growth rate of nucleated particles, and the rate by which growing particles are removed by coagulation or deposition. Most of the available investigations suggest that atmospheric CCN concentrations tend to be more sensitive to the particle growth rate than to the atmospheric nucleation rate. Primary particle emissions influence all the three process-related quantities mentioned above, and especially their relative importance in atmospheric CCN production. More information is clearly needed on the global emission rates of primary aerosol particles, on their number size distribution, and on the spatial and temporal variability of the emissions.

The second area is how to distinguish between primary and secondary CCN. It takes from a few hours up to several days before particles nucleated in the atmosphere reach sizes at which they are able to act as CCN. The field studies published so far have had limited capabilities in differentiating between primary and secondary CCN, which prevents us from making any quantitative estimates on the contribution of atmospheric nucleation to regional CCN budgets. In order to improve the situation, more versatile measurements of atmospheric CCN production are clearly needed. From the modeling point of view, a major issue that has not attracted enough attention is how CCN resulting from nucleation should actually be defined. In global models, for example, a fraction of aerosol particles formed by atmospheric nucleation are counted as primary aerosol particles. This fraction may be very large downwind of power plants.

The third area is combining observations and model simulations. There is currently a major gap between the two main approaches used to investigate CCN production resulting from atmospheric nucleation: field measurements and modeling. Existing field investigations provide a regional view of this phenomenon, the spatial scale of which depends on the characteristics of the measurement site, whereas the vast majority of model studies reported so far operate in a global scale. We recommend two ways to narrow down this gap. First, results from large-scale model simulations should be compared systematically with long-term field measurements from multiple sites. Second, analyses of field measurements should be aided with model simulations, preferably employing models of different complexity.

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References


Assessment of human-biometeorological conditions in urban areas embedded in complex topographies – The example of Stuttgart

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The region of Stuttgart, located in the south-western part of Germany, favors warm and humid climate accompanied by a low wind speed. Stuttgart lies in a basin-like sink and is surrounded by hills, a fact, which enforces the specific formation of these thermal and air quality conditions. The Urban Heat Island (UHI) of Stuttgart and its spatial distribution were assessed using thermal indices Physiologically Equivalent Temperature (PET) for different time of the year and for day and night situations. Urban-rural PET differences are highest in daytime, while air temperature UHI is highest during night-time. The UHI is mostly enhanced due to topography, besides during periods with inversions. The highest hourly UHI appears during summer as it is strongly radiation driven.

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1 Introduction

Spatial and temporal differences of meteorological parameters between neighboring urban and rural areas develop due to changes of aerodynamic surface structure and radiation fluxes (Landsberg 1981, Oke 1982). Thereby, the urban heat island (UHI) expressed by air and surface temperature differences are the most prominent and world-wide studied characteristics (Alcoforado and Andrade 2006, Bejaran and Camilloni 2003, Katsoulis and Theoharatos 1985, Ren et al. 2013, Runnalls and Oke 2000). The urban heat island in Stuttgart, Germany is analyzed within the project “Mitigation and Adaptation of the Urban Heat Island” (www.eu-uhi.eu).

Human-biometeorological methods are used to analyze UHI in matters of city dwellers and in support of city planners. Thereby, the thermal perception of humans is considered as the integral effect of air temperature, wind speed, air humidity and radiation fluxes and expressed by thermal indices (Höppe 1993).

The aim of this study is the human-biometeorological quantification of the urban heat island as well as the analysis of its spatial distribution.

2 Data and Methodology

![Map of Stuttgart](image)

Fig. 1. Map of Stuttgart with wind roses of every measurement station Echterdingen (rural), Hohenheim (suburban), Schwabenzentrum (city centre), Neckartal and Schnarrenberg (both urban). The wind roses depict the frequency of a wind direction and according wind speed (see color code).

Stuttgart (Fig. 1) is located in complex topography in the south western part of Germany, which is also one of the warmest areas of Germany. While the city center is located in a sink-like basin, urban quarters are spread across several hills. Stuttgart is the capital city of Baden-Württemberg constituting its industrial, educational, cultural and political center. Subsequently, Stuttgart experiences population growth in recent years, after some decades of weak depopulation tendencies. The average temperature was 11.8 °C in the city center and 9.8 °C at the airport in Stuttgart-Echterdingen. The average annual precipitation was 732 mm
in the surroundings while in the city center it is about 60 mm less. Stuttgart’s city dwellers suffer from strong daytime heat load, high UHI intensity, and also from strong air pollution caused by frequent weather conditions with low wind speed and air temperature inversions (Ketterer and Matzarakis 2014).

<table>
<thead>
<tr>
<th>Measurement station</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Altitude</th>
<th>Feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schwabenzentrum</td>
<td>48:46</td>
<td>09:10</td>
<td>250 m asl</td>
<td>City center; on the top of a 25 m high building</td>
</tr>
<tr>
<td>Schnarrenberg</td>
<td>48:50</td>
<td>09:12</td>
<td>314 m asl</td>
<td>Vineyard, SW-exposed</td>
</tr>
<tr>
<td>Neckar valley</td>
<td>48:47</td>
<td>09:13</td>
<td>224 m asl</td>
<td>River valley, urban</td>
</tr>
<tr>
<td>Hohenheim</td>
<td>48:42</td>
<td>09:02</td>
<td>405 m asl</td>
<td>Suburb</td>
</tr>
<tr>
<td>Echterdingen</td>
<td>48:41</td>
<td>09:14</td>
<td>371 m asl</td>
<td>Airport</td>
</tr>
</tbody>
</table>

Four measurement stations in Stuttgart are used in this study: Schwabenzentrum (city center, 250 m asl), Schnarrenberg (vineyard, 314 m asl), Neckar valley (224 m asl) and Hohenheim (suburb, 405 m asl). The rural reference station is located at the airport in Echterdingen at 371 m asl (Table 1).

The Physiologically Equivalent Temperature (PET) (Mayer and Höppe 1987, Höppe 1999, Matzarakis et al. 1999) follows the concept of an equivalent temperature and is based on the Munich Energy Balance Model for Individuals (Höppe 1993). The assessment scale of PET is described in Matzarakis and Mayer (1996) who describe the thermal comfort zone between 18-23 °C and the wider comfort zone between 13-29 °C.

3 Results

Low wind speed is characteristic for Stuttgart region due to its sheltered position. Wind speed is lower than 3 ms\(^{-1}\) in the Neckar valley by 80 % of the time period 2000-2010 (Fig. 1). In the city center, the wind speed rarely (2 %) exceeds 6 ms\(^{-1}\). Wind direction is determined by the alignment of the underlying topography and the morphology of the city. Hence, thermal-induced local wind systems, like the nocturnal “Nesenbachtäler” wind system usually occurring at a frequency of 63 % in Stuttgart-West, are often dominant. Wind measurements in Echterdingen and Hohenheim are rather representative for the greater region of Stuttgart. The most frequent wind direction is the south and south-west, followed by south-east and north. But even in Echterdingen, wind speed is lower than 3 ms\(^{-1}\)by almost 75 % of the time.

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**Fig. 2.** Frequency of different air temperature classes at the measuring stations Echterdingen (E), Hohenheim (H), Neckar (N), Schnarrenberg (S) und Schwabenzentrum (Schw) for the period years 2000-2010 (left), during summer, 2000 to 2010 (middle) and during summer of 2003 (right).
The urban climate conditions are analyzed using air temperature (not shown) and PET (Fig. 2) throughout the years 2000-2010 in terms of frequencies. Additionally, the summer of 2003, characterized by two strong heat waves, is compared to the average conditions in the period 2000-2010 (Figure 2). During summer 2003, air temperature was over 60 % higher than 20 °C in Neckartal and at Schwabenzentrum while in a normal summer, this is only 40 %. The air temperature is highest at Schwabenzentrum, followed by Neckartal, Schnarrenberg, Hohenheim and Echterdingen. However, PET is higher at Neckartal, followed by Schnarrenberg, Schwabenzentrum, Hohenheim and finally Echterdingen. PET higher than 25 °C indicates heat stress according to Matzarakis and Mayer (1996). Heat stress occurs by 34 % during a normal summer, but by 41 % in summer of 2003. This means additional 110 hours of heat stress from June to August in summer 2003 compared to an ordinary summer. On the other hand, PET smaller than 0 °C occurs by an average 10 % less in urban areas compared to Echterdingen.

At night-time, the average air temperature differences are largest at Schwabenzentrum (2.5 K), followed by Neckartal (2.1 K), Schnarrenberg (1.2 K) and Hohenheim (0.7 K). At Neckartal, the nocturnal air temperature differences are only slightly higher than at daytime. Neckartal is the lowest measuring site and features very low wind speed. During daytime, lower air temperature and PET are observed frequently in Neckartal and Schwabenzentrum compared to their neighboring rural surroundings. This is due to air temperature inversions and frequent urban cooling island occurring in summer between 9 to 11 AM. The air temperature and PET differences between Hohenheim and Echterdingen have a small standard deviation and they are larger at night-time than at daytime. In Hohenheim, UHIPET is negative almost by 50 % of the time due its higher elevation compared to Echterdingen. The urban-rural PET differences are highest in daytime, while UHITa is highest during night-time. During night-time, UHIPET is comparable to UHITa.

4 Conclusions

The urban heat island and its spatial and temporal characteristics were studied in Stuttgart using human-biometeorological methods. The frequent occurrence of local, thermally induced wind like the “Nesenbachtäler” in Stuttgart is due to the prevailing low wind speed. The average urban heat island expressed in air temperature is about 2 K between city center and the rural reference station in Echterdingen and only 0.3 K between the suburbs on the hills.

The maximum urban heat island is up to 12 K. The UHIPET is in average 3.3 K and maximum 20 K. The spatial distribution of the UHI is governed by topography, land use and structure of urban morphology. The heat stress occurs more frequent at Neckartal as a daytime phenomenon, but the nocturnal urban heat island is higher and more frequent at Schwabenzentrum. At Schwabenzentrum, the UHI is between 0 - 5 K by 97 % of the time. Anyway, the assessment of the UHI frequencies is preferable and more meaningful as the urban-rural temperature differences are not normal distributed. Furthermore, the heat stress
occurs in the daytime, for which reason the nocturnal UHI is less harmful to city dwellers in Stuttgart.

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The International Severe Weather Survey – an interim report

Keul A.G., Nunes L.H., Sharma S., Bowden K.A., Allen J.

An International Severe Weather Survey started in 2011 to supplement existing WMO guidelines and national surveys about the user quality of public weather service products. Meteorological hazards have a social dimension. Scientific analysis, prognosis and warning need mass media and social networks to reach the endangered population, develop its weather attention and preparedness. A pilot survey was performed in three countries: Brazil (N=104), India (N=100), and Germany (N=80). Meteorological knowledge varied, main weather hazards were rated realistically. Age was a predictor for interest, whereas education, gender and recalled damage were not. Severe weather information and preparedness were not optimal. After the pilot phase, the survey was also run at Oklahoma City, USA (N=100), and around Melbourne, Australia (N=105). An interim report on the international results is presented here and consequences for an improvement of the general situation derived. Hazard information should be promoted by local media and their social impact evaluated.

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1 Introduction

Worldwide, severe weather events in the period 2002 to 2011 caused an annual average of 107,000 fatalities and 268 millions of affected people (Guha-Sapir et al. 2013). Munich RE recorded a rising number of events in the categories hydrology, meteorology and climatology (2013). Natural hazards result in emotional distress and trauma; therefore, disaster preparedness and response is a main planning issue (Peek and Miletí 2002). Weather knowledge, interest, and risk assessment of lay people are the key elements of severe weather warning efficiency (Doswell in press). For this area of knowledge, a cross-cultural perspective is necessary to get a general and culture-sensitive picture of the strengths and weaknesses in hazard warnings, preparedness, and public response. Lay knowledge (Furnham 1988) is not static, but shows a “diffusion of innovations” (Rogers 1995) triggered mostly by media.

2 Previous research

The World Meteorological Organization promotes quality management of weather information. Technical documents dealt with e.g. public understanding and response to warnings (Davidson and Alex 2002), or best practice in communicating weather information (Martin 2007). Summaries of the Public Weather Services Programme PWSP followed. A PWS list (PWS WMO undated) reviewed weather service quality up to 2010. 15 surveys were done in Ireland, the Indian Ocean services, Germany, Great Britain, Australia, South Africa, Belarus, Hong Kong, USA, The Seychelles and via WMO, concentrating on product quality and image.

To understand weather service products, people need basic weather knowledge, special knowledge and preparedness for severe weather which can be tested. Media user field surveys in Austria 2008-2011 (N=247, 237) on the lay relevance and legibility of radio and television weather reports (Keul and Holzer 2013) noticed a high level of meteorological knowledge, pluralistic media usage with TV, radio and internet as leading media, high interest for (local) warnings, more recall problems with radio messages and a wish that weather elements should always appear in the same order.

3 Samples, methods

A pilot study was planned and performed by team-work in Brazil, India, and Germany. From 1981 to 2010, weather-related events were the main natural disaster source for Brazil (88.8%), India (83.7%) and Germany (93.4%), according to EM-DAT (2013). For Brazil and India, the most common hazard was floods (54.6%, 42.9%), while in Germany, storms triggered more impacts (57.4%).

The German layperson questionnaire had 38 items about media weather (report) interest/sources/legibility, basic weather knowledge, subjective risk assessment (especially on lightning), preparedness, self-reported behavior, actual physical damage by weather events, and socio-demographic data. In India, an English version was used, in Brazil, a Portuguese translation.

Brazilian survey data (N=104) come from Campinas, NW of São Paulo city, 685 m above sea level, in São Paulo state, 1 million inhabitants. It has a subtropical climate with 70% precipitation from spring to summertime. Heavy rainfall and winds are common. Urban expansion and deforestation resulted in increased floods (Nunes 2011).

The sample from India (N=100) was collected in mountainous (160-3,841 m a.s.l.) Nagaland state in northeast India (NSDMA 2012). A population of 1.9 million lives in a humid subtropical climate with mild summers and heavy rainfall from June to August.
Nagaland is geologically unstable, which, together with monsoon rain, leads to damaging landslides.

The German survey (N=80) chose the Rosenheim (447 m a.s.l., SW of Munich), Bavaria, foothills north of the Alps, at the border of an oceanic/humid and warm summer continental climate. The temperature maximum falls into July, shower and thunderstorm precipitation is high from late spring throughout summer.

After the pilot phase, a US survey (N=100) covered the Oklahoma City, OK, area in 2013 after two damaging tornado events in May. At 397 m a.s.l. and with a metro population of 1.3 million, the area has humid subtropical climate with hot, humid summer months and—in the center of “Tornado Alley”—a severe weather maximum in April and May.

An Australian sample (N=100) came from the Melbourne area, Victoria, 14 m a.s.l, metro population 4.3 million, on the continent’s south coast. It has a moderate oceanic climate with spring and summer cold fronts due to land-sea temperature differences.

4 Intermediate survey results

Five national street survey quota samples (N=80-100) had a mean age of 36 to 39 years. Four samples were gender-balanced. Household sizes were 1.5 to 3 adults and under 1 to 2 children. The US and Australian samples had a high-education bias. Single houses were more common in Brazil and USA, multistory dwellings in Bavaria, Germany (Tab.1).

Weather interest ranged over 50% in four countries (Germany 80%), in Australia 42%. Use of media weather reports varied: India 31%, Brazil and Germany 53%, Australia 65%, USA 77% “(very) often”. The main sources of meteorological information were TV and newspapers in India, TV and internet in Brazil and USA, internet and TV in Australia, and internet/radio/TV in Germany. MET report legibility was rated medium except high by Australia and USA.

<table>
<thead>
<tr>
<th>Table 1 Survey sample population characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>India</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>Sample (N)</td>
</tr>
<tr>
<td>Mean age yrs.</td>
</tr>
<tr>
<td>Age range yrs.</td>
</tr>
<tr>
<td>Male %</td>
</tr>
<tr>
<td>Female %</td>
</tr>
<tr>
<td>Adults/househ.</td>
</tr>
<tr>
<td>Children/househ.</td>
</tr>
<tr>
<td>Basic educ. %</td>
</tr>
<tr>
<td>High educ. %</td>
</tr>
<tr>
<td>Single houses</td>
</tr>
<tr>
<td>Multistor h. %</td>
</tr>
</tbody>
</table>

Subjective risk assessment (Fig.1) identified landslides as the most-feared risk in India, floods in Brazil and Australia, tornadoes in USA (dread risk) and Germany. Compared to the most frequent disaster events of the up-to-date OFDA/CRED International Disaster Database (EM-DAT 2013), respondents from Brazil (EM-DAT: flood 54.6%), Germany (EM-DAT: storm 57.4%) and USA (EM-DAT: storm 61.8%) showed correct subjective risk assessment, Indians (EM-DAT: flood 42.9%) and Australians (EM-DAT: storm 46.2%) assumed other main risks, which were true for mountainous Nagaland (landslides) relative to the Indian continent.
Meteorological lay knowledge—operationalized by definitions of high/low, coldfront, tornado, and cloudnames—was low in India (e.g. 83% knew no cloud names), medium in Brazil, high in the USA, Australia and Germany.

Recalled physical damage events (Fig. 2) were sparse in India (4-11%), medium in Brazil (9-30%), Australia (4-48%) and Germany (23-41%), high in the USA (9-75%) due to “Tornado Alley”.

Severe weather information (“good” 25% India, 14% Brazil, 50% Germany, 67% Australia, 91% USA) and preparation (“good” 7% Brazil, 31% India, 24% Germany, 32% Australia, 63% USA) definitely show room for improvement. Insurance for natural hazards seems to be neglected in Brazil (altogether 11%).

Education effects: Meteorological interest or behavior did not correlate with education in Brazil, USA, and Germany. In India, more educated residents had higher weather interest and assumed a higher lightning risk. In Australia, people with lower education expressed more weather interest and found hurricanes and tornadoes more dangerous. In flood-prone São Paulo State, Brazil, the estimated flood risk correlated with local weather information and preparedness.

Age effects: Americans, Australians and Germans of higher age reported significantly more interest in weather. Australians, Brazilians and Germans followed daily weather reports more closely. Older Germans more often held weather-hazard-insurances. In India, no age effects were noticed.

Gender effects: In Germany, female respondents reported more weather hazard fear. In India, more males (as householders?) reported weather insurance. In Brazil and Australia, more females reported weather hazard preparation.
5 Discussion, preliminary conclusions

Although study results with relatively small survey areas in big countries/continents, some with an education bias, should not be over-interpreted, there are several interesting findings:

Weather interest and information involvement did not show up as an education-based “privilege”, but depend on personal factors (and age in four countries). Even with low meteorological lay knowledge, as in India, media weather information is accessible.

Lay weather risk assessment is no rational decision process, but frightening “dread risks” (landslide, tornado, lightning) generate emotion-based attention (Slovic 2000). Recent hazard events are more available for lay risk assessment. Hazard awareness does not necessarily lead to better preparedness. To get maximum warning efficiency, preventive information has to be repeated in the local media (NDIS 2000), and its information quality has to be monitored and user evaluated. As actual exposure to meteorological hazards is either low or forgotten soon, media severe weather information should always address hazards and their prevention possibilities. The message should not be helplessness (Wilkins 1985), but awareness.

A high CG flash rate influences population risk parameters when it results in visible physical damage. Therefore, media should show material consequences of the lightning hazard to stimulate attention and preparedness. Formal education is no predictive factor since lightning is no school subject. Thus, lightning protection information should be a continuous seasonal media subject.

Similar to educational material issued by the WMO for their weather services, severe weather hazards and preparedness should be accessible to all relevant media. An unfavorable situation can be improved by subjecting media to a benchmark evaluation process – It is of commercial interest to be “quality weather info medium”.

References


PWS WMO (undated) List of Public Weather Services Survey Questionnaires and Results.


Impact of International Shipping Emissions On Regional Air Quality of Istanbul Megacity

Kilic A., Gokgoz M., Unal A., Pozzoli L., Kindap T.

Air pollution is an important environmental problem in the Eastern Mediterranean where high ozone (O3) and particulate matter (PM) levels are often exceeding the limits imposed by the current legislations. The Megacity of Istanbul, which has a population larger than 12 million, is affected by severe air pollution problems, and due to its particular geographical conformation. The Bosphorus strait crossing the entire city for a length of about 30 km, one of the components of air pollution is significantly represented by emissions from international shipping. In this work, we estimated shipping emissions by using AIS (Automatic Identification System) that can follow ships in close-range. Shipping emissions were calculated instantaneously by using AIS data that contains coordinates, routes, speeds, ship sizes, and technical data about ships. We used the Community Multiscale Air Quality Modelling (CMAQv4.7.1) with a horizontal resolution of 10 x 10 km to simulate October 2008, when the largest ship emissions were estimated based on AIS data. Other anthropogenic emissions were taken from TNO/MACC inventory. The differences of monthly mean PM2.5 concentrations due to ship emissions (AIS based new inventory – without ships emissions) for the simulated period (October 2008) show large differences up to 14 µg/m³ along the Bosphorus and Canakkale straits.

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1 Introduction

Air pollution is an important environmental problem in the Eastern Mediterranean where high ozone (O$_3$) and particulate matter (PM) levels are often exceeding the limits imposed by the current legislations. In particular the Megacity of Istanbul, which has a population larger than 12 million, is affected by severe air pollution problems, and due to its particular geographical conformation. The Bosphorus strait crossing the entire city for a length of about 30 km, one of the components of air pollution is significantly represented by emissions from international shipping. The strait is also the only access to Black Sea from the rest of international waters, thus, there is very dense ship traffic along the transit cruising line of Marmara Sea occupied by oceangoing vessels involving international ship borne trade.

In this work, we estimated shipping emissions by using AIS (Automatic Identification System) that can follow sea vehicles in close-range. Passenger ships, international ships which are above 300 Gross Register Tonnage (grt) and local transport ships which are above 500 grt carry AIS, and simulated their impact on the PM2.5 levels using CMAQ chemistry and transport model.

2 Shipping Emission Inventory

Shipping emissions were calculated instantaneously by using AIS data that contains coordinates, routes, speeds, ship sizes, and technical data about ships. We estimated ship emissions for a region covering the entire Marmara, Sea including the Bosphorus and Canakkale straits (39.15-42.0N; 24.5E-30.8E), and for one entire year between 19 August 2008 and 18 August 2009.

In this study, the shipping emissions in the Turkish sea traffic, is currently based on AIS activity data, considering ships engine powers from Lavender (2002). The Entec UK Limited emission factors for the year of 2000 were modified to obtain proper factors for more generalized ship types of AIS data (Entec 2005). Emissions from each ship were calculated depending on the different engine loads, number of engines, emission factors, time spent in each operation modes and percentage of engine use:

\[ E_{i,m}(g) = T_m \cdot E_{Fi,m,t}(P_{ME} \cdot LF_{ME,m} + \#AE_m \cdot P_{AE} \cdot LF_{AE,m}) \]  (1)

where; $E_{i,m}$ is emission amount of pollutant (i) in gram unit from all engines during the time period of operation mode (m), $T_m$ is the total time spent in the m operation mode, $E_{Fi,m,t}$ is the emission factor of the pollutant i for ship type t and operation mode m, $P_{ME}$ is the total power of all main engines at %80 MCR (Maximum Continuous Rating), $LF_{ME,m}$ is the main engine load factor at the operation mode, $\#AE_m$ is the number of AE running at the operation mode m, $P_{AE}$ is the power of one AE, $LF_{AE,m}$ is the load factor of one AE.

The total annual emission are estimated as 605 ktons NO$_x$, 495 ktons SO$_2$, 29.63 Mtons CO$_2$, 25.6 ktons HC and 53.3 ktons PM, and the vessels are consumed 9.33 Mtons of fuel.

The emissions were gridded at a 0.01 x 0.01 degrees spatial resolution. In Fig. 1 we show the annual NO$_x$ emissions, where the main ship tracks entering into the Marmara Sea from the Black Sea through the Istanbul Strait, and from the Aegean Sea through the Canakkale Strait are clearly visible.

Different global emission inventories are available for ship emissions. The ECCAD database (Emissions of Atmospheric Compounds & Compilation of Ancillary Data) provides a number of the available inventories (e.g. ACCMIP, MACCity and RCP4.5). ACCMIP, RCP4.5 and MACCity have almost same emission database values for shipping emissions. We have gridded our ship emission estimates at the resolution of ECCAD (0.5 Lat$^\circ$ x 0.5 Lon$^\circ$) and compared with other inventories in Fig. 2.
3 Impacts of Ship Emissions on Air Quality

We used the newly developed ship emission inventory to quantify the impacts on air quality in Istanbul and the Marmara Sea region. We used the Community Multiscale Air Quality
Modeling (CMAQv4.7.1) with a horizontal resolution of 10 x 10 km to simulate October 2008 air quality levels, when the largest ship emissions were estimated. Other anthropogenic emissions were taken from TNO/MACC inventory. In Fig. 4, effects of new ship emission inventory on TNO/MACC inventory are shown. Upper one is the original TNO and lower one is the updated with AIS shipping emissions.

Fig. 4. Effects of new AIS ship emissions on TNO emissions from all sectors.

The differences of monthly mean PM2.5 concentrations due to ship emissions (new inventory – without ships emission) for the simulated period (October 2008) show large differences along the Bosphorus and Canakkale straits, up to 14 µg/m³, but a large area, covering all the Marmara Sea and populated cities like Istanbul and Kocaeli, is also affected, with monthly mean differences larger than 4-5 µg/m³ (Fig. 5).

We also evaluated the impact of ship emissions in the case of the institution of an Emission Control Area (ECA) for the Marmara Sea according to the regulation of the International Maritime Organization (IMO). Three cases were considered: the current ECA limits ship fuel sulfur content to 1.5%, and a decreasing percentage in the coming years, 1% and 0.1% before and after 2015, respectively. A simulation with CMAQ of one entire year, August 2008- August 2009 is currently ongoing.
Fig. 5. Effects of ship emissions on daily mean PM2.5 concentrations.

References

Meteorological Ensemble Simulations for Hydrological Applications

Kioutsioukis I., Salamalikis V., Kotti M.C., Kazantzidis A.

In the frame of the FP7 project ENORASIS, aimed to develop an integrated Decision Support System for environmentally optimized irrigation management, an ensemble WRF system has been developed that brings together information from satellite precipitation data, data assimilation techniques, ensemble forecasting and cloud resolving models to dynamically downscale precipitation data. The proposed process is considered highly valuable as it transfers the quantitative information about the uncertainty of the rainfall forecast to the hydrological model and, thus, to the irrigation management system. The system provides in real-time ensemble 3-day prediction at pilot areas across Europe. This study assesses the effects of the implemented forecasting chain on the predictive skill of precipitation, temperature, humidity and wind speed.

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1 Introduction

Irrigation is the predominant water consumer globally, accounting for 70% of the total consumption and therefore constitutes a significant environmental challenge. In this light, ENORASIS offers an irrigation management Decision Support System for environmentally optimized and sustainable irrigation management for farmers and water management organizations. ENORASIS is a server based system that gathers data from satellite observations and remote sensing field equipment and exploits meteorological forecasting models to provide high spatial accuracy estimations for irrigation water needs, by taking into account information on specific crops and other factors affecting the irrigation process. These estimations are transformed in optimal irrigation rules (using FAO56 model) that are communicated to ENORASIS end users (farmers) via web or mobile.

The meteorological driver in ENORASIS is the Weather Research and Forecasting (WRF) system; it is a mesoscale numerical weather prediction system used for operational forecasting and atmospheric research (Skamarock et al. 2008). It offers multiple physics options that allow its usage to a wide range of applications. To address the need for uncertainty – quantified rainfall forecasts for water management purposes within the ENORASIS project, high-resolution predictions have been adopted in a probabilistic manner (Kalnay, 2003). This work addresses a first comparison of the WRF ensemble against the station data at the four pilot farms of ENORASIS across Europe (PL, SRB, TR and CY).

2 Data and Methodology

2.1 Observed Data

Weather stations operate at the four pilot areas since spring 2013 yielding hourly records of many meteorological variables. The conversion procedure of the hourly observations into daily for hydrological modelling and meteorological validation utilises two filters. The aim is to maintain the maximum amount of data with the minimum loss in distortion of the aggregated observed time-series. Specifically, we discard a day if any of the following is true:
- more than one-third of the daily records are missing (i.e. keep a daily average that has been produced by at least 16 values)
- more than one-fourth of the daily records are missing sequentially (i.e. throw a daily average if six continuous hourly values are missing)

The presented results are from the first available period (1st April – 31st October 2013). Besides the applied filters, no other quality test was applied.

2.2 Model Configuration

The WRF model with a multiple domain nested configuration has been set up, that covers Europe at a resolution of 32km, with the smallest domain having a resolution of 2 km (Figure 1). Initial and lateral boundary conditions are provided by a coarse-resolution global forecasting system (GFS).
Two configurations have been considered for the input uncertainty:

1) the model is driven by “perfect” initial conditions, i.e., its initial state is assimilated with satellite observations (yes/no)

2) the model is driven by an ensemble prediction system that accounts for the perturbations in the physics options (microphysics, surface layer, planetary boundary layer)

The ensemble design is always limited by the available computer power. In ENORASIS, we chose to sacrifice the ensemble size for the high-resolution simulations (2km) (Clark and Gallus 2009, Liguori et al. 2009). The ensemble members that run operationally since spring 2013 are given in Table 1.

### Table 1. Ensemble design.

<table>
<thead>
<tr>
<th>Ensemble Member</th>
<th>ICBC</th>
<th>Microphysics</th>
<th>Radiation</th>
<th>Surface Layer</th>
<th>PBL</th>
<th>Cumulus Convection</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>GFS</td>
<td>Thompson</td>
<td>RRTM/Goddard</td>
<td>Eta/Noah</td>
<td>MYJ</td>
<td>BMJ</td>
</tr>
<tr>
<td>2</td>
<td>GFS</td>
<td>WSM-6</td>
<td>RRTM/Goddard</td>
<td>Monin Obukov/Noah</td>
<td>YSU</td>
<td>BMJ</td>
</tr>
<tr>
<td>3</td>
<td>GFS+GDAS</td>
<td>Thompson</td>
<td>RRTM/Goddard</td>
<td>Eta/Noah</td>
<td>MYJ</td>
<td>BMJ</td>
</tr>
</tbody>
</table>

### 3 Results

The time-series of the modeled rainfall (PREC), relative humidity (RH), minimum and maximum temperature (TMIN, TMAX) and wind speed (WS) at all sites and ensemble member against the observations are presented in Fig. 2. It also gives an outlook picture for data availability. To support the temporal analysis of the presented results, summary statistics for the whole period are given in Fig. 3 (bias) and Table 2 (root mean square error, standard deviation ratio). The following inferences can be drawn for the direct model outputs:

[PREC]: Considering only the stations at PL & SRB, where many events occurred, the optimal WRF scheme significantly varies with latitude. The best scheme (2) in PL brings the highest error in SRB (and vice versa). Bias is positive in PL and negative at all other sites. The RMSE in PL is in the range 5-7 mm, with CC~0.6 and generally the modeled variance is higher, particularly for the schemes 1&3 (doubled). Unlike PL, at SRB all schemes give comparable results, with RMSE~11mm and modeled variance is roughly half the observed one.

[RH]: All schemes give quite consistent results. Bias is negative at all pilots except PL, where positive bias is seen by schemes 1&3. In relative terms, scheme 2, with the exception of PL, exhibits larger errors. The RMSE ranges from ~8 in the north (light under-dispersion, CC>0.8) to ~12 in the south (light over-dispersion, CC<0.7).
[TMAX]: All model configurations are comparable in behavior. Maximum temperatures exhibit both positive (north) and negative (south) bias. At all sites, WRF correctly simulated the observed variance, with RMSE ~2°C and correlation higher than 0.9.

[TMIN]: Model results for the three different configurations are marginally comparable. The bias has the opposite latitude dependence of the maximum temperatures, i.e. it exhibits positive bias in the south and negative bias in the north and in addition, it is at least twice in amount. The last property is not valid for scheme 2 in the north. The observed variance was correctly simulated in PL while it was under estimated at the other sites, deteriorating gradually as we move southwards. RMSE was ~3°C (~5°C in CY) and correlation ~0.8.

[WS]: WRF mostly overestimates the wind, especially in the south. Scheme 2 has always somewhat higher variance and error. At PL, all schemes correctly simulate the observed variance, achieving correlation between 0.7-0.8 and RMSE ~1 ms⁻¹. As we move southwards, on top of over-dispersion the error is doubled.

Fig. 2. Time series of modeled and observed fields (columns) at the four pilots (rows). Columns represent PREC (1st), RH (2nd), TMAX (3rd), TMIN (4th) and WS (5th). Rows correspond to pilot site at PL (1st), SRB (2nd), TR (3rd) and CY (4th). The observed time series are given in black, the ensemble members (1-3) in color.

The influence of different parameterization schemes on the RMSE (Table 2) shows that scheme 2 is the optimal combination for PL, for all variables except WS. As we move southern at the other sites, scheme 3 (or scheme 1) produces better results than scheme 2. Scheme 3 provides only a minor improvement over Scheme 1, for the examined 3-day forecasts, implying that the initial conditions perturbations need more time to evolve. Members 1 and 3 had highly correlated errors for all continuous variables. Both reach their least error correlation with member 2 for RH.

Fig. 3. Mean bias of modeled fields (columns) at the four pilots (rows). The first three bars correspond to the ensemble members and the 4th bar represents the ensemble average.
4 Conclusions

This study evaluated the ability of a WRF ensemble to reproduce the meteorological patterns at four irrigation test pilots. Results from a preliminary analysis conducted on the available measurements pointed out the following:

1. A clear latitude dependence of the error was evidenced (north is better).
2. No single member was found to outperform for all pilots, variables and metrics. Scheme 2 (WSM6, Monin Obukov, YSU) was superior at higher latitudes (PL) and scheme 1 or 3 (Thompson, Eta, MYJ) at the southern sites (SRB, TR, CY).
3. Physics ensemble produced higher spread than the dynamics perturbations for the first 3-days.
4. The ensemble members with the same physics and different dynamics were redundant.
5. The analysis will be repeated for gridded datasets covering Europe at high resolution to provide significance to the results. The impact of resolution will also be addressed. The ultimate goal is to generate local correction coefficients that will further improve the forecast skill of the ensemble, in particular for the timing and amount of rainfall events. This work is ongoing.

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References

Long-term particulate matter variability in Cyprus and the Eastern Mediterranean

Kleanthous S., Vrekoussis M., Mihalopoulos N.

The main objective of this study is to identify and assess the contribution of the natural and anthropogenic PM sources influencing the ambient air in Cyprus and the Eastern Mediterranean Area. To this end, we present an extended time-series of seventeen years of particulate matter (PM$_{10}$) observations conducted at the background Agia Marina monitoring station in Cyprus (EMEP, 532m a.s.l.). The analysis showed that the mean PM$_{10}$ levels at the Agia Marina-EMEP station (29.6±10.1 μg m$^{-3}$: 1997-2012) are comparable to the ones reported for other East Mediterranean sites suggesting a common regional influence on the observed levels. Spatial particulate matter observations at all major urban centers in Cyprus showed that on an annual basis almost 40% of the days in the city centers are characterized by elevated PM$_{10}$ levels (>50 μg m$^{-3}$). However, when taking into account the regional PM levels recorded at Agia Marina the respective number of the computed exceedances emanating exclusively from local emissions becomes significantly lower (21 days per year on average).

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1 Introduction

Monitoring airborne particulate matter (PM), is in the forefront of ongoing environmental research studies because of its important impact on human health (Pope and Dockery 2006) and climate (IPCC 2013); the latter is related to changes in scattering and absorbing radiation leading to perturbations in the global radiation balance. Atmospheric aerosols are emitted by natural processes, including sea spray, dust outbreaks, volcanic emissions and man-made fires (Seinfeld and Pandis 2006). Aerosols with an aerodynamic diameter of 10 μm or less, identified as PM$_{10}$, are usually categorized as coarse particles; contrary, particles with one fourth of the above diameter or less, PM$_{2.5}$, are considered to be fine in size. PM$_{2.5}$ and PM$_{1}$ are high risk particles in terms of health impact because of their small size that can penetrate into the lungs.

Measurements of PM$_{10}$ and PM$_{2.5}$ exclusively conducted at urban sites may not provide the information needed on the origin of the tropospheric aerosols (Querol et al. 2009) because of the difficulty in estimating the regional influence on the observed levels. To account for that, background measurement representative for the broader regional influence were performed at the Agia Marina (EMEP) remote station. The study aims to present the multiannual, annual and interannual variability, the analysis of the observed exceedances and comparison of the background levels with the respective urban ones. The acquired information is of particular importance in the view of abatement and effective mitigation strategies.

2 Data and Methodology

Continuous observations with a temporal resolution of one hour were provided with the Tapered Element Oscillating Microbalance (TEOM) technique at the Agia Marina station covering the period 1997 to 2012. Additional measurements took place at all major urban cities including the capital Nicosia (2005-2012), Larnaca (2003-2012), Limassol (2006-2012), Paphos (2006-2012) as well as at the industrial Zygi area (2002-2012) (see Fig.1). In all stations, continuous PM$_{2.5}$ observations were conducted for the period 2010-2012.

Fig. 1: The location of the background Agia Marina station and the major urban centers of Nicosia, Larnaca, Limassol and Paphos in Cyprus. The analysis involved also the industrial Zygi area.

3 Results

3.1 Trend and seasonal variability of PM$_{10}$ at the background Agia Marina station

The average PM$_{10}$ concentration at Agia Marina for the sixteen years of observations was 29.6±10.1 μg m$^{-3}$. Interestingly, this value corroborates with the respective 28±30 μg m$^{-3}$ characterizing the ambient air at the remote Finokalia station in Crete, Greece during the period 2004-2005 (Gerasopoulos et al. 2006) and the rural Erdemli station in Turkey (36±28μg m$^{-3}$: 2000-2001) suggesting a common regional influence on the observed levels. The multiannual variability (fig. 2, left panel) showed that annual averages have decreased
over the years which is in line with the overall decreasing (significant at α<0.05) trends observed in rural background stations in Europe (Pérez et al. 2008, Colette et al. 2011, Barbadim dos et al. 2012) and attributed to effective mitigation pollution strategies and changes in the frequency of dust outbreaks (Pey et al. 2013).

Interestingly, the statistical analysis of the deseasonalized annual PM$_{10}$ data (not shown in fig. 2) revealed a significant decreasing trend of $-0.75\mu g \text{ m}^{-3} \text{ y}^{-1}$ (Mann-Kendall, α<0.05, Z=-2.3).

The above monthly mean PM$_{10}$ values of the period 1997-2012 have been averaged to produce one single value for January, February and so forth aiming to extract information on the seasonal variability of PM$_{10}$ in Cyprus. The results (Fig. 2, right panel) depict a bimodal seasonal variability with the highest values observed in summer (36.2±7.5 $\mu g \text{ m}^{-3}$) and spring (35.7±13.8 $\mu g \text{ m}^{-3}$) and the lowest in winter (18.6±6.3 $\mu g \text{ m}^{-3}$). The spring maximum is attributed to the frequent African dust episodes (Kalivitis et al. 2007, Pey et al. 2013) and the summertime one to a number of factors including re-suspension of particles, low precipitation, pyrogenic emissions and enhanced formation of secondary aerosols (Querol et al. 2009).

### 3.2 PM$_{10}$ and PM$_{2.5}$ comparison between different sites in Cyprus

To draw conclusions on the spatial variability of PM$_{10}$ in Cyprus we compared the multiannual evolution of PM$_{10}$ levels at all major urban centers (Nicosia, Larnaca, Limassol and Paphos) as well as at the Zygi industrial area with the ones described before for the background Agia Marina site. The analysis suggested a decreasing trend for PM$_{10}$ observed at all stations (Fig. 3, left panel) that is accelerated during the last two years of the study (2011-2012). The observations clearly highlight the anthropogenic influence on the urban and industrial PM$_{10}$ levels leading to an enhancement up to 65% compared to the background PM$_{10}$.

![Fig. 2](image2.png)

**Fig. 2:** The left panel depicts the daily (black dots), monthly (red line) and annual (blue circles) means of particulate matter concentrations observed at the background Agia Marina station during the temporal period 1997-2012. The right panel presents the seasonal variability of the PM$_{10}$ observations for the same station and temporal period based on the computed monthly averages (black squares) and medians (open circles).

![Fig. 3](image3.png)

**Fig. 3:** The left panel depicts the annual variability of PM$_{10}$ in Agia Marina (black line), Nicosia (red), Larnaca (blue), Limassol (brown), Paphos (green) and Zygi (grey) area. The right panel depicts the seasonal variability of those PM$_{10}$ observations for the period 2005-2012, when concurrent measurements occurred in all stations.
The mean annual cycle (Fig. 3, right panel) of PM$_{10}$ at the capital Nicosia (in red) denotes a winter maximum related to anthropogenic emissions. This finding is supported with the two peaks observed in the daily evolution of PM$_{10}$ levels in Nicosia during the rush hour (transport-traffic) and the nighttime (heating) which are absent in the daily evolution of PM$_{10}$ at Agia Marina (not shown). Enhancements in the wintertime PM$_{10}$ levels were observed in all urban centers albeit the differences in magnitude. An important remark drawn is that the overall seasonal variability of PM$_{10}$ in all stations includes the intra-annual variability described before for the Agia Marina station with a peak observed during the dust season in spring and an additional peak in summer.

During the period 2010-2012, concurrent PM$_{2.5}$ observations took place at the Agia Marina, Nicosia, Larnaca and Zygi stations with the mean levels being equal to 12.3±4.1, 21.8±5.3, 18.7±5.5, 16.1±5.8 μg m$^{-3}$, respectively. The ratio PM$_{2.5}$ to PM$_{10}$ (PM$_{2.5/10.0}$) for the background Agia Marina station was found to be equal to 52% denoting a balance in the concentrations of the fine and coarse particles; this is in very good agreement with the PM$_{2.5/10.0}$ of 45-60% reported for the Finokalia remote station (Koulouri et al. 2008). Similarly, by subtracting the concentration of the fine particles (PM$_{2.5}$) from the total PM$_{10}$ [PM$_{10-2.5}$=PM$_{10}$-PM$_{2.5}$], we computed the concentration of the coarse particles in Nicosia, Larnaca and Zygi area; it was found that the coarse particles, mostly of natural origin, contribute to almost half of the total PM$_{10}$ mass ranging between 47% and 53%.

**3.3 Exceedances of EU levels of ground-level PM$_{10}$ and PM$_{2.5}$ concentration standards**

As in the case of ozone concentrations (Kleanthous et al. 2014), frequent exceedances of the EU ground level particulate matter concentrations for protecting human health (Directive 2008/50/EC) occur in Cyprus. The mean annual threshold of 40 μg m$^{-3}$ was exceeded at the traffic sites of Nicosia (50.4±16.2 μg m$^{-3}$), Larnaca (51.1±17.7 μg m$^{-3}$), Limassol (52.2±16.1 μg m$^{-3}$), Paphos (42.7±12.6 μg m$^{-3}$) and the industrial Zygi area (42.8±15.6 μg m$^{-3}$) six times during the last eight years. Interestingly, during the last two years of the study (2011-2012) an important decrease was observed in the ambient PM$_{10}$ concentrations. This reduction, possibly driven by both the abatement-mitigation strategies and the ongoing economic recession resulting in reduced anthropogenic emissions (e.g. Vrekoussis et al. 2013), has led the PM$_{10}$ concentrations below the above threshold of 40 μg m$^{-3}$ in all stations. At the background Agia Marina station and for the same period 2005-2012, the observed PM$_{10}$ were below the accepted limit (PM$_{10}$=28.4±15.6 μg m$^{-3}$).

Regarding the 24-h threshold of 50 μg m$^{-3}$, significant exceedances have been observed in all urban stations during the period 2005-2012. In Paphos, 25% of the days on a yearly basis encountered PM$_{10}$ levels higher than the 24-h limit, while in Nicosia, Limassol and Larnaca the respective value was 37-41% (135-148 days per year). Nonetheless, by subtracting the background levels of the Agia Marina station from all other stations, assuming their being representative of the regional transported pollution, the respective number of the computed exceedances, emanating exclusively from local emissions, at the above urban centers becomes significantly lower (9-33 days per year). Finally and for the PM$_{2.5}$ particles, the EU annual threshold of 25 μg m$^{-3}$ was not exceeded during the three years of measurements (see section 3.2) in any of the above stations.

**4 Conclusions**

The analysis of a long-term series (1997-2012) of particulate matter concentrations with aerodynamic diameter of 10 μm or less at the background station of Agia Marina (EMEP) in Cyprus revealed that a) the multiannual mean PM$_{10}$ levels of 29.6±10.1 μg m$^{-3}$ are in very good agreement with similar measurements conducted at other Eastern Mediterranean sites in the neighboring countries of Greece and Turkey denoting a common regional background and b) the annual PM$_{10}$ levels progressively decrease during the last years. The seasonal
variability of the PM$_{10}$ concentrations showed a bimodal behavior with two peaks during the dust outbreaks in spring and the dry season in summer. On a spatial level, decreasing trends have been observed in all major urban centers of the island. The analysis of the PM$_{2.5}$ mass concentrations showed that on average, half of the measured PM$_{10}$ concentration emanated from coarse particles mainly of natural origin (e.g. Sahara dust and soil re-suspension). Overall, Cyprus encounters frequent exceedances of the annual and 24-hour EU PM$_{10}$ concentrations limit of 40 and 50 μg m$^{-3}$, respectively. However, an important fraction of them can be associated with transported air masses affected by anthropogenic (e.g. Balkans, Central Europe, Turkey) and natural (e.g. mineral African dust) emissions that impact on the regional background of pollution in the Eastern Mediterranean.

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References


Variability and trends of tropospheric ozone in Cyprus and the Eastern Mediterranean

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This study focuses on the temporal and spatial variability of surface ozone levels in the Eastern Mediterranean area, a region affected by transported air masses of various origins with variable chemical composition and by high insolation. Valuable new information on the origin and temporal variability of ozone emanated from the statistical analysis of a long-term record (1997-2012) of continuous ozone concentrations at the rural Agia Marina (EMEP) station in Cyprus. The observations revealed the presence of a prominent seasonality with maxima and minima observed during summer (54±5ppb) and winter(39±3ppb), respectively. The deseasonalized annual data suggest a non-significant upward trend over the 16 years. To assess the ozone spatial variability simultaneous measurements have been performed in 2011-2012 at Inia and Cavo Greco, two remote marine sites located to the west and the east of the island respectively. Our results show that the ambient ozone levels over Cyprus are mostly influenced by the regional transported background ozone while the local precursor emissions play a minor role (less than 6%).

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1 Introduction

The Mediterranean area often experiences high values of ozone concentrations due to a) enhanced insolation leading to strong photochemical activity, b) frequent biomass burning events and c) occurrence of polluted air-masses (Lelieveld et al. 2002). The Mediterranean region typically has the highest ozone mixing ratios in Europe with values often being higher than 60 ppbv in summer across the entire basin (Kalabokas et al. 2008). High annual mean levels of ozone have been recorded at background stations in the East Mediterranean including the Finokalia station in Crete (49±11 ppbv: 1997 - 2004, Gerasopoulos et al. 2005) and the Gozo island in Malta (50.2 ppbv: 1997 - 2006, Saliba et al. 2008). Based on measurements on board the “El-Greco” vessel, Kouvarakis et al. (2002) showed that no statistically significant latitudinal variability is observed over the Aegean Sea; the latter is indicative of the regional origin of ozone. Similar findings have been reported by Gerasopoulos et al. (2006) suggesting that the local photochemistry accounts for less than 4% of the observed ozone levels in Crete, Greece.

Further, free tropospheric ozone measurements were performed at the Mt. Cimone station (2165 m a.s.l.) in Italy (Bonasoni et al. 2000) in the period 1996-1998, with the reported annual mean concentrations of 53±8 ppbv being in close agreement with the surface ozone values of the previously mentioned studies in Malta and Greece. The present study builds on the above findings by taking into account the extended database of ozone mixing ratios recorded at the background EMEP Agia Marina station during the period 1997-2012. Additional information regarding the spatial variability of ozone in Cyprus was used for the estimation of the local contribution on the observed ambient surface ozone levels.

2 Data and Methodology

Depending on their availability, chemical (O₃, NO, NO₂, CO) and meteorological data (WS, T, RH, SR) from three monitoring stations (Fig. 1) of the network of the Air Quality Section of the Department of Labour Inspection, (DLI, http://www.airquality.dli.mlisi.gov.cy/) have been used in this study including a) the rural inland Agia Marina (EMEP) station (35.04N - 33.06E, 532 m a.s.l), b) the rural-marine Inia (34.99N - 32.40E, 672 m a.s.l) to the east of Cyprus, and c) the lower altitude and more exposed to sea-breeze circulation rural Cavo Greco (35.02N - 34.09E, 23 m a.s.l) to the west of Cyprus. The quality of the measurements at all stations was assured following the specific reporting protocols set for the EMEP network stations such as Agia Marina.

Fig. 1. The location of Cyprus in the Eastern Mediterranean region (left panel) and the DLI monitoring stations (middle panel, yellow circles). The right panel shows the Agia Marina station.

3 Results

3.1 Temporal Variability

The complete database of ozone concentrations, with a temporal resolution of one hour has been used to extract daily, monthly and annual averages. Notably, the daily data coverage for
the period 1997-2012 was greater than 90%. The observed mean value of 47.5±8.2 ppb, in rural Agia Marina is in close agreement of the 49.9±11.0 ppbv reported for the Finokalia station in Greece (Gerasopoulos et al. 2006) and the 50.2 ppbv of the Gozo station in Malta (Saliba et al. 2008). When taking into account the overall low nitrogen monoxide mixing ratio (0.2±0.2ppbv) and relatively low carbon monoxide concentrations of 145.5±27.6ppb, it is apparent that local anthropogenic sources make a limited contribution in the observed ozone levels. It was found that, at the EMEP station, the computed CO-to-NO, molar ratio (~82) is closer to 100, suggesting long-range transport as the main source of Agia Marina pollution (Parrish et al. 2009).

3.1.1 Multi-annual variability of the ozone levels and trends
The monthly means have been deseasonalized following the classical decomposition method. The analysis revealed a non-significant increasing trend (Mann-Kendall test, a<0.05) of 0.11±0.12 ppbv y⁻¹ corresponding to an overall not statistically significant trend of 1.8±1.9ppbv during the sixteen years of measurements (see also Kleanthous et al. 2014).

3.1.2 Seasonal variability of the ozone concentrations
The above monthly mean ozone values have been averaged to produce one single value for January, February and so forth aiming to extract information on the seasonal variability of ozone in Cyprus. The results (Fig. 2, left panel) indicate a well-defined seasonal variability with the highest values observed in summer (54.3 ± 4.7ppb,) and the lowest in winter (38.7 ± 2.6ppb). Similar ozone seasonality has been observed in the previously mentioned East Mediterranean sites supporting the findings of Gerasopoulos et al. (2006) and Kalabokas et al. (2008) stating that the lower tropospheric ozone variability in the Eastern Mediterranean region is to a large extend controlled by the synoptic meteorology and their impact on the transported air masses.

![Fig. 2](image)

**Fig. 2.** The left panel presents the annual cycle of ozone (ppb,) and the right one the annual variability of nitrogen oxide (ppbv) and total nitrogen oxides (ppbv), carbon monoxide (ppbv), temperature (°C), relative humidity (%), wind speed (m s⁻¹) and solar radiation flux (W m⁻²) computed from the respective monthly mean EMEP values for the period 1997-2012 except for CO that is computed from the 2011-2012 time series.

As depicted in the lower right panel of fig. 2, the solar radiation levels are on average high; however, the relatively small annual variability and the low abundance in precursor species (NO, NOy, CO) suggests, once again, a limited role of the impact of local photochemistry on ambient ozone levels. The wind climatology, based on the analysis of the 5-day back-trajectories (e.g. Kouvarakis et al. 2000) computed by the HYSPLIT model (Hybrid Single-Particle Lagrangian Integrated Trajectory Model), suggests a prevalence of north and north-westerly winds during the entire year, bringing continental air from Turkey and Eastern/Central Europe; the occurrence of northerlies is associated with a an enhancement of the ozone concentrations (3-5%) compared to westerlies and southerlies. Another parameter influencing the observed ozone summer levels is associated with the lower RH levels in
summer that are indicative of the subsidence of drier air masses, rich in ozone, from the free troposphere to the boundary layer (Zanis et al. 2013).

3.2 Spatial variability and exceedances of EU ground-level ozone concentration standards

To assess the ozone spatial variability, simultaneous measurements, in addition to the ones presented for the Agia Marina station, have been performed in 2011-2012 at Inia and Cavo Greco, two remote marine sites located to the west and the east of the island, respectively.

The results show that on an annual basis, northerlies and westerlies are related to a gradient decrease of the ambient ozone levels when air masses are transported from Inia to Cavo Greco, with typical differences of 1.5 and 1.0 ppbv, respectively (Fig. 3). This is the net result of the surface deposition and the chemical titration/formation from local sources. Given a) a mean ozone deposition velocity in the range of 2-10 cm s\(^{-1}\) (Wesely 1989), b) the distance between the two stations of 150 km and c) the mean recorded wind speed is 3 m s\(^{-1}\), the expected ozone depletion due to deposition would range between 0.3 and 3.0 ppbv.

![Fig. 3. Local impact on the observed ozone levels under polluted (upper panel), clean (middle panel) and Sahara dust (lower panel) conditions. Overall, the local photochemistry together with the surface deposition of ozone accounts for ~6% of the observed ambient ozone levels.](image-url)
During southerlies, ozone reaches first Cavo Greco. In that case, an absolute difference of 2.4 ppbv is observed, with the lowest values being recorded again at the receptor point, which in this case is the Inia station. The above yields again the net loss attributed to surface deposition and the photochemical production and destruction of ozone. This finding clearly highlights that high ozone levels over Cyprus are directly linked to long-range-transport and that local photochemistry/deposition can account for up to about ~6% of the observed ozone levels.

This is of particular importance as the exceedances of EU ground-level ozone concentration standards for protecting human health (Directive 2008/50/EC) were found to be significant for Cyprus. It is worth mentioning that for the complete 2011-2012 period, the threshold of 60 ppbv maximum daily eight-hour mean was exceeded during 24% of the time of observations at the EMEP station, 41% at INIA and 18% at Cavo Greco. In the summer period the situation is worse; 60% of the maximum daily eight-hour mean observations in the EMEP station, 87% in INIA and 27% in Cavo Greco exceed the given threshold.

4 Conclusions

The analysis of 16 years of ozone measurements at the rural Agia Marina station in Cyprus showed that the observed mean levels of 47.5±8.2 ppb, are in good agreement with other measurements in the East Mediterranean region suggesting common regional scale mechanisms controlling atmospheric transport and photochemistry. Concurrent ozone observations at the Inia and the Cavo Greco stations located to the west and east of the island, respectively, reveal important information on the local conditions impacting the observed ozone levels. The above observations together with the wind origin climatology, based on the Hypsit model analysis for the period 2011 - 2012 show that, on an annual basis, a net ozone loss of 1.0 to 2.4 ppbv occurs when advection occurs from northerly and southerly directions, respectively; in other words, local photochemistry and/or deposition mechanisms accounts for a minor fraction (~6%) of the observed ozone amounts. This shows that the large number of the summertime exceedances of the maximum daily eight-hour mean observations (>60ppbv) at the EMEP (60%), Inia (87%) and Cavo Greco (27%) stations is mainly due to transported air masses from outside Cyprus.

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References


A model-based study of the wind regime over the Corinthian Gulf, in Greece

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The Corinthian Gulf is a narrow maritime strip which is surrounded by a steep complex topography consisting of high mountains, elevated and sea-level gaps. The wind flow over the gulf is strongly affected by the complex terrain and under specific synoptic conditions high winds might be produced with consequences on the commercial and recreational activities over the area. In order to investigate the wind regime across the Corinthian Gulf a 5-yr model-based study has been performed, as the observational data over the area are absent and spatially sparse. The 5-yr data analysis of MM5 model simulations reveals that the strong easterly winds at the western edge of the gulf occur more frequently, with a frequency of occurrence of the order of 70%. Moreover, the strongest winds are found to occur during the winter season (December, January, and February). Finally, the synoptic patterns, which lead to the strongest wind events in the studied area, have been investigated.

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1 Introduction

The Corinthian Gulf represents a narrow maritime strip separating Peloponnese from mainland Greece that is surrounded by steep topography (Fig. 1). The gulf axis has an east-west orientation about 120 km long and 20 km wide and it is bounded at the east by the Isthmus of Corinthos, a strait which includes the shipping route between the Corinthian and the Saronic Gulf, and at the west by Rio Strait (2 km wide) which links the Corinthian Gulf to the Gulf of Patras and the Ionian Sea. The narrow steep channels on both sides of the gulf favor the establishment of strong winds under certain meteorological conditions, which often disrupt the maritime routes over the Rio strait and may cause traffic restrictions over the strait bridge. Moreover, the strong winds in the Corinthian gulf play an important role in the expansion of forest fires in the surrounding coastal areas.

Despite the fact that the strong wind events have important societal impacts the wind climatology of the Corinthian Gulf has not been investigated in detail. A major reason is the absence of long term, in situ measurements of meteorological variables in the area. Therefore, model-based climatologies are imperative in areas where observations are sparse or absent. The primary aim of this study is to examine the wind field within the Corinthian Gulf, using 5-yr data provided from model simulations. From these model results, detailed study of the wind regime across the gulf as well as an attribution of synoptic pattern leading to strong wind events is obtained.

Fig. 1. Topographical details of the studied area. RS refers to Rio Strait and IC to Isthmus of Corinthos. The colored five-point stars show the location of the ground meteorological stations along the coast of Corinthian Gulf (black: Rio, red: Antikira and yellow: Isthmos).

2 Data and Methodology

In the present study, numerical simulations from MM5 non-hydrostatic model running operationally at the National Observatory of Athens (NOA) were used. Several physical parameterization schemes are available in the model for the boundary layer (MRF scheme), the radiative transfer, the microphysics and the cumulus convection. Three one-way nested grids are defined and used on operational basis. Grid 1 has 24 km horizontal grid increment, covering the major part of Europe, the Mediterranean and the northern African coast. Grid 2 has 8 km horizontal grid increment, covering the Greek territory and all the Greek islands. Finally, Grid 3 has a 2 km horizontal grid increment, covering the entire Athens area and the adjacent water bodies. This study is based on the analysis of model simulations provided by Grid 2. In the vertical direction, twenty-four unevenly spaced full sigma levels are used, with the maximum resolution in the boundary layer.

Data of 6 hourly model 10-m wind fields from the first 24 h of simulation from Grid 2 during the period January 2007–December 2011 were used. In order to overcome any spin-up problems, the estimation of the wind regime across the Corinthian Gulf is being developed using the output data six hours after the initialization of the model. With the aim to study the wind flow over the maritime areas, only the sea grid model points have been considered in the analysis.

The results are compared with 2-yr wind observations (2010-2011) of three surface automated meteorological stations (Fig. 1). Finally, in order to indentify the synoptic patterns that lead to strong wind events in a specific area across the gulf, gridded analysis data from
the ECMWF have been used. The dataset has a horizontal resolution of 0.5 degrees and the time interval is 6 h.

3 Results

The results reveal that the maximum wind speeds are found at the western edge of the Gulf of Patras with mean speed values around 5–5.5 m s\(^{-1}\), as well as on both sides of Rio strait (Fig. 2).

![Fig. 2. Mean wind speed at 10 meters derived from 6 h model data for the period January 2007-December 2011.](image)

The frequency distribution of wind speed direction, using wind roses, is an important climatological element, and is a complementary constituent for investigating the wind climatology (Fig. 3). Easterly and southwesterly winds prevail at the western edge of Rio strait (red star), with a percentage of about 34% and 27%, respectively, while the moderate and the strong winds are mainly from the east. On the other hand, at the eastern edge of the Rio strait (yellow star), a clockwise shift of the prevailing direction is obvious, due to the surrounding gap orientation, with east-southeasterly and west-southwesterly directions prevailing with 36% and 30%, respectively. Inside the Corinthian Gulf, the western sea grid point (green star), has a similar wind rose to Rio’s sea grid points, but it is further rotated clockwise following the geometry of the Corinthian Gulf. At the eastern grid point of the gulf (light blue star), north-northeasterly winds dominate with a percentage of occurrence ~ 19%. This direction is associated with the local scale topographic effects on wind field, such as downslope and gap flow that are generated from the surrounding complex terrain. Finally, the prevalence of northwesterly winds on both sides of the Isthmus of Corinthus is caused by the channeling of the wind through the aforementioned strait. At the western edge of strait (black star) the northwestern sector (northwesterly and north-northwesterly winds) prevails with a frequency of ~ 40%, A similar pattern is seen at the eastern sea grid point (light grey star), with the northwesterly winds presenting an occurrence percentage of 23%. 

Fig. 3. Wind roses at six locations denoted by colored four-point stars on the area map. Three different wind speed categories are included in each wind rose: light (orange line, 0–5 m s\(^{-1}\)), moderate (green line, 5–10 m s\(^{-1}\)) and strong winds (red line, >10 m s\(^{-1}\)). Rings are drawn at 2% interval.

The comparison between simulated and observed wind field is achieved using the nearest to the surface station grid point. For the qualitative validation wind rose diagrams have been plotted for the period 2010-2011 (not shown). In addition, a quantitative validation has been performed by calculating the statistical measures of bias (mean error, ME) and mean absolute error (MAE) for the same period. The mean error is defined as \(ME = P_s - P_o\), where \(P_s\) is the simulated and \(P_o\) the observed wind speed, and the mean absolute error is defined as \(MAE = |P_s - P_o|/n\), where \(n\) is the number of records. At almost all of these stations the wind direction distribution is well reproduced by the model as wind roses analysis reveals. The mean absolute errors are of the order of 2 m s\(^{-1}\), which is comparable with MAE values reported by Lagouvardos et al. (2003) and by Akylas et al. (2007) who verified models wind forecasts against surface stations. Simulated wind speed is in good agreement with observations; however the differences between them can be attributed to the different spatial representativeness of a model grid as compared to in situ measurements, especially over complex terrain areas. Local effects like those of terrain obstacles are captured by the surface meteorological stations while they could be smoothed out in 8 km x 8 km grid.

Seasonal analysis for strong winds has been integrated for all wind data of the 5-yr period that exceed the threshold of 12 m s\(^{-1}\). West of Rio strait (red star) the eastern sector of wind directions (easterly and east-southeasterly winds) dominates, with a yearly percentage of occurrences of ~74%. Easterly and east-southeasterly winds prevail mainly during winter (~43%), followed by the transitional seasons (autumn and spring) with total percentage of ~28%. Southwest winds (south-southwest up to west-southwest) are less common, and present their greater percentages (~3-5%) during winter and spring.

To illustrate concisely the atmospheric circulations that generated strong easterly winds at Rio strait, upper-air and surface analysis data from the ECMWF were used. Composite fields have been created for the days that at the west of Rio strait (red star) eastern sector winds exceeds 10 m s\(^{-1}\). Since gap flow events in Rio strait often last several days, care has been taken to ensure that data for a specific day are used only once in the creation of composites. Thus, an event is considered as the first day where the composite criteria is satisfied and an
interval of at least 48 hours not meeting the criteria was required for the next event to be considered independent from the previous one. From the 6 h data set of an event, the timestamp with the maximum wind speed was selected in order to produce the composite. In addition, following the results of the seasonal analysis, only winter events (December, January, and February, hereafter DJF) were selected.

During the study period of 451 winter days, a total of 25 events (69 days) in DJF have been met the above criteria. The composite field of 500-hPa reveals a weak upper level southwesterly flow over Greece. At the surface the atmospheric configuration produces a strong pressure gradient (~4 hPa/100 km) with isobars tilted in a northwest-southeast direction resulting in a strong southeasterly flow over western Greece and a weaker northeasterly flow over the Aegean Sea (Fig. 4b). As a result, a strong pressure gradient is concentrated across the Corinthian Gulf, forcing the easterly wind flow at Rio. The synoptic set up of these composite fields resembles with the anticyclonic bora wind event which is characterized by a powerful high pressure system over Central Europe (upstream of Dinaric Alps) without a well-defined cyclone to the south (Gohm and Mayr 2005).

![Fig. 4](image)

4 Conclusions

The investigation of wind regime across the Corinthian gulf using a 5-yr model based wind climatology showed that: (a) the windiest areas are located at the open sea of the Gulf of Patras as well as on both sides of Rio strait, (b) the eastern sector winds prevail on both sides of Rio strait, while at the Isthmus of Corinths the dominant wind direction is from northwest (the finding of this study is in agreement with previous studies concerning gap flows worldwide: Sharp and Mass, 2002; Colle and Mass, 2000), (c) west of Rio strait, the eastern wind sector dominates (~ 74%) with winter months contributing almost half of the cases, (d) the synoptic pattern related with these high winds suggests the presence of a strong wind shear over the area of western Greece and especially across the Corinthian Gulf (an atmospheric wind shear over a complex terrain many times is associated with the creation of mean state critical levels above mountain tops enhancing the development of low level high winds: Bacmeister and Pierrehumbert 1988, Colle and Mass 1998, Koletsis et al. 2009).

Acknowledgments

ECMWF is kindly acknowledged for the provision of gridded analyses data. The topographic maps which are presented in this study have been downloaded from the web site [http://www.maps-for-free.com/](http://www.maps-for-free.com/). The authors are grateful to Dr. Nikolaos Mazarakis for his help to produce the composite fields.
References


The impact of the forest fire episode at Mount Athos in August 2012 on the air quality of the city of Thessaloniki

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The present case study analyzes the impact on air quality in urban and rural area of Thessaloniki, from a forest fire episode that occurred in the area of Mount Athos (Regional Unit of Chalkidiki) during 8 to 13 August 2012. In this study an integrated approach was applied that combines, the mesoscale meteorological model WRF (Weather Research and Forecasting) -driven with analysis data from the ECMWF (European Centre for Medium-Range Weather Forecasts). To provide the meteorological input data the atmospheric dispersion model FLEXPART was applied at high resolution (1km) for the wider region of Thessaloniki aiming to identify and quantify the influence of the fire emitted particles and gases on the air quality of the city of Thessaloniki. The dispersion modeling experiment was accompanied with measurements of particulate matter and gases from the network of air pollution stations of Thessaloniki district. From the analysis of the measurements it is observed an increase in particulate matter and CO concentrations mainly at stations of Eastern Thessaloniki. The dispersion modeling analysis indicates that the weather conditions were such that favored the transport of pollutants emitted from the forest fire at the region of Monoxilitis Halkidiki towards the greater area of Thessaloniki.

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1 Introduction

The present work investigates the impact on the air quality of the city of Thessaloniki from an intense forest fire episode that occurred in the area of Mount Athos (Regional Unit of Chalkidiki) during 8 to 13 August 2012 near the expanse of Chilandrinou Abbey in Monoxylites region. Forest fires burn considerable areas of the south European landscape with intensive occurrences during summer periods with most of the fire episodes taking place in the Mediterranean region. One of the several disturbing effects of forest fire smoke is that significantly impacts air quality and human health since large amounts of pollutants are emitted into the atmosphere during the process. Smoke from forest fires includes significant amounts of carbon dioxide (CO₂), carbon monoxide (CO), methane (CH₄), nitrogen oxides (NOₓ), ammonia (NH₃), particulate matter (PM), non-methane volatile organic compounds (VOC’s), sulphur dioxide (SO₂) and other chemical species (Miranda et al. 2005). The effects of these emissions vary at different levels affecting: from the contribution to the greenhouse effect to the occurrence of local atmospheric pollution episodes (Miranda et al. 1994, Borrego et al. 1999, Simmonds et al. 2005). In a changing climatic scenario forest fires may escalate triggering even larger sources of air pollutants to the atmosphere (Amiro et al. 2001, Carvalho et al. 2007). In order to identify and quantify the influence of the fire emitted particles and gases on the air quality of the city of Thessaloniki an integrated approach was applied using the mesoscale meteorological model WRF driven with analysis data from the ECMWF to provide the meteorological input data for the atmospheric dispersion model FLEXPART.

2 Data and Methodology

2.1 Data

Weather Research and Forecasting model (WRF) is a non-hydrostatic mesoscale numerical meteorological model with the Advanced Research dynamic solver (WRF-ARW Version 3.2.0, Skamarock et al. 2008, Wang et al. 2010) that was utilized in the numerical experiments. The ARW solves the fully-compressible, non-hydrostatic Euler equations using a finite-difference scheme on an Arakawa C-grid staggering in the horizontal plane and a terrain-following, dry hydrostatic pressure vertical coordinate (Porter and Ashworth 2010).

Global data from the ECMWF was used as input into WRF to increase the resolution focusing on the local topography of the studied domain in order to provide output data to feed FLEXPART. ECMWF integrates vast number of synoptic observations from weather stations, meteorological balloons, satellites and feed them into a global model, which run continuously in forecast mode and also produces re-analysis of older data. WRF utilizes nested grids with different resolutions in order to get better predictions in the area of interest sustaining enough data for the surroundings as well.

FLEXPART, is a Lagrangian particle dispersion model designed for calculating the long-range and mesoscale dispersion of air pollutants from point sources (Stohl et al. 2010) capable of forward and backward trajectory simulations of particles (presented as infinitively small air parcels) released from point, line or volume sources. Different versions of the model enable the use of input data from global numerical weather prediction models from ECMWF, NOAA (GFS) as well as mesoscale models (MM5, WRF, COSMO). Removal processes incorporated into the model include radioactive decay, dry and wet deposition and OH reaction. (Stohl et al. 2005).
**2.2 Methodology**

For WRF a one-way interactive model domains covering a part of eastern Europe, Greece and the major area of Central Northern Greece (Macedonia) at horizontal grid-spacing of 11.7 km x 11.7 km (d1), 3.9 km x 3.9 km (d2) and 1.3x1.3km (d3) (Fig.1) have been used, utilizing the staggered Arakawa C grid. As initial and lateral boundary conditions for the coarse domain, ECMWF 6-hourly analyses were used. The analyses were available on a 0.125° x 0.125° regular grid. The necessary fields were retrieved at and near the surface and on the pressure levels of 1000, 950, 925, 900, 850, 800, 700, 600, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 20, 10 mb. WRF was initialized in 08/08/12 at 00:00 and terminated in 13/08/2012 at 18:00 with output every 180 min for d1 and 60 min for d2 and d3 respectively.

The d3 data output with 1.3 km resolution is utilized as input for FLEXPART for the period 08-13/08/2012. FLEXPART was set up to run forward and the particles were released in the area of the case study for 1 hat pressure levels from 0-1 km at 08/08/2012 between 22:00 and 23:00 pm at 8 vertical levels starting from 1 km with 3h output and 180 min sampling rate.

**3 Results**

The Hovmöller diagram for near surface wind speed at 10 m from both ECMWF (Fig. 2) and WRF (not shown) between 08 and 13/08/12 indicates that the day after the initiation of the forest fire there are easterly winds (6 m/s) that contributed to the resurgence and the escalation of the fire intensity that lifted the fire plume and made the dispersion even more intense. This is further evident from the output results of FLEXPART (Fig. 3) which clearly indicates the plume formation and particle dispersion of the fire that affected southeastern Thessaloniki’s area. Finally the intensity of the forest fire phenomenon and the direction of the plumes at one point can be observed and clearly depicted in (Fig. 4) from the satellite views from the NASA Earth Observing System Data and Information System (EOSDIS). The dispersion modeling experiment was also accompanied with measurements of particulate matter and gases from the network of air pollution monitoring stations of Thessaloniki district. From the analysis of the measurements it is observed an increase in particulate matter and CO concentrations mainly at stations of eastern Thessaloniki. The dispersion modeling analysis indicated that the weather conditions were such that favored the transport and dispersion of pollutants emitted from the forest fire at the region of Monoxilitis Halkidiki and affected the greater area of Thessaloniki.
Fig. 2. Hovmöller diagram (time versus longitude) for near surface wind speed at 10 m based on ECMWF. The area of the forest fire occurrence is located at longitude around 24.1 E.

Fig. 3. Visualized output of dispersion by FLEXPART-WRF on (1) 8/8/2012 at 22:00 UTC, (2) 9/8/12 at 02:00 UTC, (3) 9/8/12 at 03:00 UTC and (4) 9/8/12 at 04:00 UTC.

Fig. 4. NASA (EODIS) satellite photo on 09/08/2012.
4 Conclusions

This work investigated a forest fire episode that occurred in the area of Mount Athos (Regional Unit of Chalkidiki) from 08/08/12 to 13/08/12 and the impact on air quality of the greater area of the city of Thessaloniki with the use of the Lagragian particle dispersion model FLEXPART driven by high resolution simulation with WRF model. Our preliminary results indicate a satisfactory model's performance in capturing the evolution and the geographical extension of the plume which is further supported by satellite measurements from the NASA Earth Observing System Data and Information System as well as particulate matter and CO concentrations mainly at stations of eastern Thessaloniki.

References


Homogenization of mean monthly precipitation time series

Kolokythas K.V., Argiriou A.A.

Climatic data may provide essential information related to the human environment since these are the basis for studying the climate behavior and its changes. In order to achieve that, climatic time series as consistent, precise and complete as possible have to be used in order to reflect the real climate changes and not changes due to other artificial factors. A series of climatic data where variations are caused only by variations in climate is considered as homogeneous. One of the most crucial climatic parameters is considered to be precipitation since it affects and determines the climate of a whole region. In this study the homogeneity of a subset of precipitation time series from meteorological stations of western Greece, belonging to the Hellenic National Meteorological Service network, is examined using three different homogenization methods, MASH, Climatol and HOMER. Aim of this process is to indentify probable breakpoints, outliers and trends and correct them. Moreover, the differences of trends of precipitation time series before-after homogenization are also discussed.

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1 Introduction

As climatic time series may provide essential information in a series of atmospheric science disciplines, these must reflect the real changes of the climate and not those of other artificial factors. A series of such data where variations are caused only by variations in climate is considered as homogeneous (Aguilar et al. 2003). Recently, many methods for climate time series homogenization have been developed. These are mainly classified in two categories: the “absolute” and “relative”, which differ in the way they process the climate time series (e.g. Markovic 1975, Peterson et al. 1998, Aguilar et al. 2003).

In this study, the Multiple Analysis of Series for Homogenization (MASH v3.02), Climatol v.2.1 and HOMER – three relative homogenization methods – are used for the homogenization of precipitation time series from a network of 8 WMO weather stations of Western Greece, for the period 1955 – 2003. The aim is to identify probable breakpoints, outliers and trends, correct them and investigate the impact of homogenization on the trends of the precipitation time series for the above period.

2 Data and Methodology

2.1 Data

The stations network used is summarized in Table 1 where the WMO code and latitude – longitude are given along with the years of missing data. All stations belong to the same climatic type defined as humid Mediterranean according to Flokas (1992) or as warm temperate climate with dry and hot summers (type Csa) according to the Köppen-Greiger climate classification (2006).

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<th>Longitude (E)</th>
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</table>

2.2 Methodology

The applied homogenization methods, as referred in section 1, are MASH v.3.02, Climatol v.2.1 and HOMER v.2.6. MASH - Multiple Analysis of Series for Homogenization (Szentimrey 2007) is a homogenization method that does not assume the reference series as homogeneous. Possible break points, outliers and shifts are detected and adjusted through mutual comparisons of difference time series which are constructed by subtracting the candidate (each time) from the weighted reference time series.

The homogeneity test of Climatol (Guijarro 2011) is applied on a time series which is the difference between the values of the tested station and those of a reference series calculated as a weighted average of the respective values of time series of nearby stations. It should be noted that weighting is optional. However, unlike in the MASH method, the stations used for constructing the reference series are not selected using as the only criterion proximity; a correlation criterion is also used. In order to detect outliers and shifts in the mean, Standard Normal Homogeneity Test (SNHT), (Alexandersson 1986), is applied to anomaly series
constructed through the process in two stages: a. on windows of 120 terms moved forward in steps of 60 terms (default values) and b. on the whole series.

HOMER (Mestre et al. 2013) is a recently developed method for homogenizing monthly and annual temperature and precipitation data. It is an outcome – among others – of the European COST Action ES0601 called HOME, devoted to evaluate the performance of homogenization methods used in climatology. It includes the best features of some other state-of-the-art methods, namely PRODIGE (Caussin and Mestre 2004), ACMANT (Domonkos 2011) etc. HOMER is based on the methodology of optimal segmentation with dynamic programming, the application of a network-wide two factor model both for detection and correction, and some new techniques in the coordination of detection processes from multi-annual to monthly scales.

3 Results

The breakpoints detected by the three methods in the precipitation time series were significantly fewer than those detected in the corresponding temperature series (processed in a previous study not presented here – Kolokythas and Argiriou 2012). The detected break points, the outliers and the sign (positive or negative) of the corrected value are presented in Table 2. The precipitation series of Kalamata passed successfully homogenization tests without any break. Climatol detected only outliers in the series of the remaining stations except for those of Aktio. MASH detected break points in the series of Aktio, Kefalonia, Zakynthos and Andravida and only one outlier in the station of Kefalonia, while HOMER detected only break points in four time series, those of Kerkyra, Agrinio, Zakynthos and Andravida.

Table 2. Breakpoints, outliers and sign of shifts after homogenization (in parenthesis) per station by MASH, Climatol and HOMER.

<table>
<thead>
<tr>
<th>Station</th>
<th>Breaks</th>
<th>Outliers</th>
</tr>
</thead>
<tbody>
<tr>
<td>s</td>
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<tr>
<td>KR</td>
<td>1964(-)</td>
<td></td>
</tr>
<tr>
<td>AG</td>
<td>1971(-)</td>
<td></td>
</tr>
<tr>
<td>KF</td>
<td>1991(+)</td>
<td></td>
</tr>
<tr>
<td>RX</td>
<td>1966(-)</td>
<td></td>
</tr>
<tr>
<td>KL</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Concerning the distribution of detected breakpoints and outliers, it seems that there is no sufficient consensus among methods. Only in the time series of Andravida MASH and HOMER detected a common breakpoint, in 1995, while Climatol detected an outlier in the same year and of the same sign as well. In the other series breakpoints or outliers are detected by the three methods on different dates. Furthermore, MASH detected only one outlier in July 1993 for Kefalonia, while Climatol detected one of the outliers of this station 15 months later, in October 1994. For Andravida, except of the break in 1995, Climatol detected the first outlier in 1966 while MASH detected a breakpoint a year later. The smaller number of breakpoints was detected by HOMER (4), one in each of the stations mentioned above, while Climatol detected the larger number of outliers (12).
The examination of the total results reveals that the precipitation time series did not change significantly after homogenization. Figure 1 presents the average annual precipitation of raw time series of all stations, together with the time series homogenized by MASH, Climatol and HOMER and their corresponding trend lines. In Fig. 2 a boxplot depicts the standard deviation of the average annual precipitation of total network and for the period 1955 – 2003 computed also from raw and homogenized (by the three methods) data; with the exception of HOMER the absence of a substantial deviation among these series is evident; this was not the case for the homogenization of the temperature time series of the same stations (Mamara et al. 2012).

Regarding seasonal series, summer has the lowest standard deviations while winter the highest among seasons. It should be mentioned that in the majority of time series HOMER showed the lowest standard deviation after homogenization among all methods. Apart from that, in the cases, of Aktio and Kefalonia, the standard deviations of the annual time series after homogenization by MASH and Climatol appeared slightly higher than before. Nevertheless, this change may be attributed to the important number of missing values these series had and not to the detected break-points or outliers. On the other hand, the annual series of Zakynthos demonstrates the most pronounced (in relation to the others) standard deviation decrease after homogenization by all methods, while only HOMER resulted in an almost same magnitude decrease of standard deviation of the annual series of Kerkyra.
Table 3. Difference of standard deviation of average annual time series before minus after homogenization by the three methods.

<table>
<thead>
<tr>
<th></th>
<th>MASH</th>
<th>Climatol</th>
<th>HOMER</th>
</tr>
</thead>
<tbody>
<tr>
<td>KERKYRA</td>
<td>6.5</td>
<td>1.0</td>
<td>36.6</td>
</tr>
<tr>
<td>AKTIO</td>
<td>-6.9</td>
<td>-18.0</td>
<td>0.0</td>
</tr>
<tr>
<td>AGRINIO</td>
<td>4.3</td>
<td>6.8</td>
<td>19.9</td>
</tr>
<tr>
<td>KEFALONIA</td>
<td>-2.6</td>
<td>-4.8</td>
<td>0.0</td>
</tr>
<tr>
<td>ZAKYNTHOS</td>
<td>25.6</td>
<td>42.1</td>
<td>35.6</td>
</tr>
<tr>
<td>ARAXOS</td>
<td>5.3</td>
<td>9.2</td>
<td>0.0</td>
</tr>
<tr>
<td>ANDRAVIDA</td>
<td>11.2</td>
<td>5.1</td>
<td>25.0</td>
</tr>
<tr>
<td>KALAMATA</td>
<td>3.0</td>
<td>1.9</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Table 3 shows the differences of standard deviation of average annual time series before-after homogenization. After homogenization, HOMER shows lower standard deviations in almost all stations. A main reason is that before homogenization by HOMER, the data were quality controlled because of the restrictions of the particular method. The other two methods are more tolerant in missing values, especially Climatol, and due to that the processed data by these two methods were used in their raw form.

4 Trend analysis

The trends of the mean seasonal and annual precipitation time series before and after homogenization were evaluated using the two sided Mann-Kendall test (Kendall 1976) with a selected significance level of 95%.

Table 4 Trends per decade of annual time series before and after homogenization. With bold the trend is significant in significance level of 95%.

<table>
<thead>
<tr>
<th>Trends mm/10yr</th>
<th>KR</th>
<th>PZ</th>
<th>AG</th>
<th>KF</th>
<th>ZA</th>
<th>RX</th>
<th>AD</th>
<th>KL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inho</td>
<td>-87.0</td>
<td>-65.1</td>
<td>-41.5</td>
<td>-59.4</td>
<td>-76.4</td>
<td>-4.2</td>
<td>-61.9</td>
<td>-3.4</td>
</tr>
<tr>
<td>Hom_MASH</td>
<td>-79.6</td>
<td>-22.7</td>
<td>-49.8</td>
<td>-36.6</td>
<td>-57.5</td>
<td>-0.9</td>
<td>-36.9</td>
<td>4.2</td>
</tr>
<tr>
<td>Hom_Climatol</td>
<td>-89.5</td>
<td>-52.1</td>
<td>-56.0</td>
<td>-47.4</td>
<td>-49.5</td>
<td>-0.9</td>
<td>-47.2</td>
<td>3.2</td>
</tr>
</tbody>
</table>

In Table 4 the trends per decade of annual time series before and after homogenization are provided. Trends which are significant are marked with bold. 38% of the raw time series showed a significant trend; this percentage remained unchanged after homogenization by MASH, increased to 63% after homogenization by Climatol and finally dropped to 0% for the series homogenized by HOMER. Moreover, after homogenization it was found that winter, autumn and annual precipitation series of all stations (with the exception of Kalamata) showed a negative trend, which in the case of Kerkyra, Agrinio (only the winter series) and Andravida (only the annual series) was found to be significant for MASH and Climatol. Spring time series revealed negative trend after homogenization by HOMER for all station, while after MASH and Climatol homogenization six of the stations showed negative, one slightly positive trend (Araxos) and in the case of Aktio the application of the two methods resulted to opposite trends, positive for MASH and negative for Climatol. Summer series showed slightly positive but not significant trend in almost all stations and for all methods, except those of Kerkyra after homogenization with HOMER (which was the only homogenized seasonal series showed significant trend after processed by HOMER). Lastly, autumn series showed negative trends for the majority of stations and used methods, which in case of Kerkyra were significant before and after homogenization with MASH and Climatol.
5 Conclusions

For the purpose of this work, the MASH, Climatol and HOMER homogenization methods were applied on precipitation time series of a network of stations located in Western Greece, for the period 1955 – 2003, in order to test their homogeneity and assess the impact the homogenization may have on the trends of the series for the above period. Breakpoints and outliers were detected and the time series were adjusted on a monthly, seasonal and annual basis. It may be concluded that the processing of precipitation series led series free of missing values. However, the detected breakpoints were different in the majority of stations and homogenization methods and the series after the procedure remain almost unchanged. Only HOMER did manage to result in series temporally consistent, with generally lower standard deviations than before homogenization, and the reason for its better performance might be the use of quality controlled data, which had no missing values. Apart from that fact, from the whole procedure it should be pointed out the negative trend of annual and winter series in almost all stations and for all methods as well as the slightly increasing trend in summer precipitation time series.

From the above analysis it should be stressed that there is a difficulty in homogenizing precipitation data, which in consequence, leads to less improved data (Venema et al. 2012). Nevertheless, the homogenization process resulted to more complete time series which may be used for comparing homogenization results with those of previous or future works. However it should be noted that an important obstacle was the lack of metadata. If this knowledge would exist, better and safer conclusions could be drawn concerning the validity and the causes of the detected non-homogeneities (Auer 2003).

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Solar UV Index forecast and observational network of the National Observatory of Athens

Kopania T., Kazadzis S., Lagouvardos K., Meleti C., Bais A.F., Vougioukas S.

The Institute for Environmental Research and Sustainable Development of the National Observatory of Athens (NOA) is providing 5-day forecasts of clear sky and cloud-cover corrected ultraviolet (UV) Index for the Greek area since 2011 and 2013 respectively, as well as in-situ UV measurements from the NOA/UV network of 10 automated weather stations. For the UV Index forecast, information on solar zenith angle, ozone column forecast, aerosol load from satellite measurements, altitude, surface albedo, and cloud cover forecast is used as input in LibRadTran radiative transfer model. Verification of forecasted UV Index values is undertaken, using solar UV measurements from an actinometric station in Thessaloniki. In addition, both model derived UV Index values and UV measurements provided from NOA/UV observational network, are validated over specific regions with satellite-derived overpass data from OMI sensor (AURA satellite).

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1 Introduction

During the last decades, ozone depletion raised awareness for the health risks posed by human overexposure to solar ultraviolet (UV) radiation. Although small amounts of UV radiation are essential for the production of vitamin D in human body, prolonged exposure to solar radiation may result in acute and chronic health effects on the skin, eye and immune system, such as sunburn, premature skin aging, photodermatoses, actinic keratosis, skin cancer, photokeratitis and cataracts (WHO 2002).

The UV Index (UVI), first introduced in Canada in 1992 (Fioletov et al. 2010), is a measurement of the erythemal (sun-burning) strength of the UV solar radiation, indicating the risk of overexposure to the sun on a scale from 0 (low) to 11 or more (extremely high) (EPA 2013). For an integrated and long-term public health approach to sun protection, the Global Solar UV Index (UVI) was developed in an international effort by the World Health Organization (WHO) in collaboration with the World Meteorological Organization (WMO), the United Nations Environment Programme (UNEP), and the International Commission on Non-Ionizing Radiation Protection (ICNIRP) (WHO 2002).

In many countries UVI forecasts are produced to promote sun protection, to raise public awareness of the risks of excessive exposure to UV radiation, and to alert people about the need to adopt protective measures (WHO 2002). In 2003, UVI forecasts web pages were available in more than 30 countries, including Greece.

The Institute for Environmental Research and Sustainable Development of the National Observatory of Athens (IERSD/NOA), Greece, has started developing a network of solar radiation monitoring stations since 2006. IERSD/NOA is also providing 5-day clear-sky UVI forecast maps since 2011, while in 2013 (February 27th) the effects of cloud cover on the clear-sky UV Index were also included in the forecasting process (http://www.meteo.gr/meteoplus/uv.cfm). Validation of all measurements and forecasted UVI values is very important for the reliability and the improvement of the forecasting method, as well as the future development of the NOA/UV observational network.

2 Data and Methodology

2.1 Measurement data

Ground-based spectral UV irradiance measurements were performed in the actinometric station of the Laboratory of Atmospheric Physics (Thessaloniki, Greece). UVB measurements were recorded per minute, for the years 2011-2013, by a Yankee UVB-1 radiometer with spectral response 208-320 nm.

Ground-based UVI data were also available from the continuously developing UV observational network of automated stations of IERSD/NOA. For the purposes of this study, UVI measurements, recorded every 10 minutes, were used from 10 NOA/UV stations for the summer period of 2013 (from June to August).

Daily Level 3 gridded (1°x1°) data from the Ozone Monitoring Instrument (OMI) on board the NASA AURA satellite were collected for the summer of 2013. Satellite-derived data corresponded to four parameters: a) local noon time clear-sky UVI, b) local noon time UVI, c) column ozone amount, and d) radiative cloud fraction (OMTO3d and OMUVBd products). OMI UV data have been corrected for aerosol absorption according to Arola et al. 2009.
2.2 Methodology

UV Index forecasts are based on the forecast of several input parameters (e.g. solar zenith angle, total ozone, surface albedo, and aerosol parameters) which are used in models to calculate the radiation levels. LibRadTran radiative transfer model is used by the National Observatory of Athens, in order to daily produce 5-day clear sky UVI forecasts at 08:00, 10:30, and 13:00 UTC, for 22 grid cells (~1.5° x 1.5°) of Greece. The forecast for maximum exposure conditions (clear sky) is also presented to the public on a gridded map. The parameters used as input data in the model are: the solar zenith angle (SZA) per minute; Ozone column forecast values by KNMI/ESA; long-term climatology of aerosols from NASA satellite measurements (MODIS); mean altitude for each ~1.5° x 1.5° grid cell of Greece (22 regions in total).

Derived from BOLAM model (Lagouvardos et al. 2003), three hourly total cloud fraction forecasts, in tenths, as well as cloud fraction forecasts of 3 levels (low, middle, and high clouds), are used for the calculation of cloud-cover corrected UVI values. Cloud modification factors (CMF), based on the method of Alados-Arboledas et al. 2003, are combined with cloud fraction forecasts in order to produce the total attenuation of UV radiation due to cloud cover. The model first estimates the clear sky UV Index using the parameters mentioned above. Next, the clear sky UVI is multiplied by the attenuation of UV radiation by clouds.

3 Results

UVI forecast by IERSD/NOA has showed that in case of cloud presence, UV Index decreases from 10% (1/10 cloud cover, thin clouds) up to 80% (10/10 cloud cover, deep clouds). Figure 1 shows the UV Index spatial and temporal variability over all 22 grid cells of the Greek area including the effect of cloud coverage.

![Fig. 1. Local noon UVI forecast for clear sky (left) and with the inclusion of clouds (right) for all 22 cells of Greece (27/02/2013 – 31/12/2013).](image)

The comparison of UVI forecast values with the UVB-I radiometer measuring at Thessaloniki, Greece, is presented in Fig. 2. The results from the comparison of the UVI forecasts and the radiometer are summarized in Table 1. The results show a quite good agreement of the forecasted UVI data and the actual measurements. Cases of cloudless sky (not presented) show a correlation higher than 0.95 and Mean Bias Errors (MBEs) as low as 0.1. MBEs presented in Table 1 are well within the instrument calibration uncertainties and the model forecasted uncertainties, especially taking into account the cloud forecast estimation.

The results of 10 NOA stations during the summer period of 2013 have been analyzed and have been compared with the OMI satellite data. The location of the stations together with statistics of the mean difference of the collocated OMI UVI local noon measurements are shown in Fig. 3.
Fig. 2. Comparison (left) of UVI measurements (blue line) in Thessaloniki in 2013, from a Yankee UVB-1 radiometer, with UVI 1-day forecast values using a) the total attenuation due to 3-level cloud covers (Forecast a, red dots) and b) the total attenuation due to total cloud cover (Forecast b, green dots). Correlation (right) of UVI 1-day forecast values (using the total attenuation due to 3-level cloud covers) with UVI measurements, in Thessaloniki in 2013, for 08:00 UTC, 10:30 UTC (local noon), and 13:00 UTC (blue, red, and green dots respectively).

Table 1. Correlation coefficients and mean bias errors for the cloud-cover corrected UVI forecast values of 08:00, 10:30 and 13:00 UTC, depending on the forecast time, in Thessaloniki in 2013.

<table>
<thead>
<tr>
<th>Forecast Time</th>
<th>Correlation Coefficient (CC)</th>
<th>Mean Bias Error (MBE)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>08:00 UTC</td>
<td>10:30 UTC</td>
</tr>
<tr>
<td>0-24</td>
<td>0.91</td>
<td>0.88</td>
</tr>
<tr>
<td>24-48</td>
<td>0.89</td>
<td>0.86</td>
</tr>
<tr>
<td>48-72</td>
<td>0.87</td>
<td>0.84</td>
</tr>
<tr>
<td>72-96</td>
<td>0.88</td>
<td>0.82</td>
</tr>
<tr>
<td>96-120</td>
<td>0.86</td>
<td>0.81</td>
</tr>
</tbody>
</table>

Fig. 3. Map of Greece, indicating the geographical location of the 10 NOA/IERSD UV stations. The table shows the mean differences (MD) between UVI measurements derived from the stations and OMI UVI data.

The performance of the forecasted UVI values against the solar UVI measurements of the NOA network has been studied. Comparing the results of the 10 stations during the summer period of 2013 with the cloud-corrected UVI forecast values (Figure 4), a quite good agreement is observed between measurements and forecast. Small biases (Lefkochori) indicate measurement calibration differences, while in about 5% UVI forecast underestimates the real cloud coverage, resulting in an overestimation of UVI values (UVI difference more than 1).

In addition, for the same grids, the OMI UVI overpass data have been compared with the forecast UVI model including the cloud forecasts (Figure 5). The results show an agreement between the two datasets. For cloudless cases, there are differences in the order of ±1 UVI that are due to the forecasted and OMI retrieved total column ozone and also the aerosol variability which is included in the forecast model only as a climatological monthly mean.
Fig. 4. Correlation of measurements from 10 NOA stations and UVI 1-day forecast values (10:30 UTC), for the summer period of 2013.

Fig. 5. UVI difference of forecasted and OMI retrieved values for the summer of 2013 including the cloud estimation.

For cloudy conditions and on about 30% of the cases, UVI differences show a larger scatter mostly due to the different approach of the cloud estimation introduced in the forecast and in the satellite UV retrieval algorithms.

4 Conclusions

Solar UV index forecasts, including cloud forecasts, provided by NOA have been assessed using ground based instrumentation and satellite retrievals. The results showed a good agreement of the compared datasets.

Acknowledgments

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References

Aerosol effect on atmospheric heating rate profiles using vertically resolved satellite aerosol data

Korras-Carraca M.B., Pappas V., Matsoukas C., Hatzianastassiou N., Vardavas I.

The vertical profile of aerosol direct radiative effect (DRE) is computed using a deterministic spectral radiative transfer model, using vertically resolved aerosol optical properties from the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) database. From this, atmospheric heating/cooling rate profiles due to aerosols are derived. The model computations are performed on a monthly, 2.5°x2.5° latitude-longitude resolution and in 40 vertical layers from the ground level up to 50 mb, for a period of 3 complete years (2007-2009). In this study, we focus on areas of special interest, namely the Arabian Peninsula, Southern Africa, and China, in order to investigate the effect of different type of aerosols, both natural and anthropogenic (desert dust, biomass burning, urban/industrial), on the vertical profile of heating rates. Our results reveal an aerosol heating effect, which strongly depends on height. Maximum values are observed over the Arabian Peninsula.

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1 Introduction

Atmospheric aerosols, both natural and anthropogenic, can cause climate change through their direct, indirect, and semi-direct effects on the radiative energy budget of the earth-atmosphere system. In general, aerosols cause cooling of the surface and the planet, while they warm the atmosphere due to scattering and absorption of incoming solar radiation. The importance of vertically resolved direct radiative effect (DRE) and heating/cooling effects of aerosols is large, because they result in a modification of the lapse rate and the atmospheric dynamics, increasing the atmospheric stability, consequently weakening the convection, and eventually suppressing cloud formation (Ackerman et al. 2000). Despite this, large uncertainties still lie with their magnitudes. In order to be able to quantify them throughout the atmosphere, a detailed vertical profile of the aerosol effect is required. Such data were made available recently by the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) on board the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) satellite. CALIOP is the first polarization lidar to fly in space after LITE and has been acquiring unique observations of aerosols and clouds since June 2006 (Winker et al. 2007). In the present study we investigate the aerosol heating rate profiles in three regions with high aerosol load contributed by different types of both natural and anthropogenic aerosol particles. These regions are the Arabian Peninsula (desert dust), Southern Africa (mainly biomass burning aerosols), and China (urban/industrial anthropogenic aerosols).

2 Model description and the input Data

2.1 The model

The vertical profile of aerosol direct radiative effect is computed using a deterministic spectral radiative transfer model (Hatzianastassiou et al. 2007) developed from a radiative-convective model (Vardavas and Carver, 1984). The model computations are performed on a monthly, 2.5°x2.5° resolution, for 118 wavelengths ranging from 0.20 μm to 1 μm and at 10 intervals between 1 and 10 μm. For each wavelength and spectral interval, a set of monochromatic radiative flux transfer equations is solved for an absorbing/multiple-scattering atmosphere using the Delta-Eddington method.

The radiative transfer model is taking into account the scattering and absorption of solar radiation by clouds (low, middle, high), aerosols, and the reflection from the Earth’s surface. In the ultraviolet–visible part of the spectral range the model considers Rayleigh scattering and ozone absorption, while in the near-infrared it takes into account absorption by water vapor, carbon dioxide, and methane.

The aerosol direct radiative effect is computed in 40 atmospheric layers from the surface up to 50 mb as follows:

\[ \Delta F = F - F_{\text{no aerosol}} \]

where \( F \) and \( F_{\text{no aerosol}} \) are the net radiative fluxes with and without aerosols, respectively. The heating rates (dT/dt) within each layer are calculated using the equation:

\[ \frac{dT}{dt} = \frac{g}{c} \frac{\Delta F}{\Delta P} \]

where \( \Delta F \) is the aerosol effect on radiation flux, \( c \) is the specific heat of air, \( g \) is the standard gravity, and \( \Delta P \) is the pressure change across the layer.
2.2 The input data

In the present study CALIOP Level 2-Version 3 Layer Aerosol Optical Depth (AOD) at 532 nm data are used, for a period of 3 complete years (2007-2009). These data are provided on a 5 km horizontal resolution and in up to 8 vertical layers. The original hourly CALIOP AOD data have been quality controlled using these with Cloud Aerosol Discrimination (CAD) score of -50 and less. We regridded the CALIOP AOD to our radiation transfer model horizontal (2.5°x2.5°) and vertical (40 layers) resolutions and averaged them on a monthly scale (temporal resolution of our model). The detailed spectral resolution of aerosol optical properties (optical depth, asymmetry parameter and single scattering albedo) are taken from the Global Aerosol Data Set (GADS, Koepke et al. 1997). The required cloud data (cloud amount, optical depth and top pressure) given for 15 cloud types (low, middle and high) are taken from the International Satellite Cloud Climatology Project (ISCCP). The model input data include also vertical temperature and humidity profiles (from NCEP/NCAR global reanalysis project), surface albedo and ozone concentration (from TIROS Operational Vertical Sounder).

3 Results

Fig. 1. The three selected regions (Arabian Peninsula, Southern Africa and China) for which the heating rates profile are presented.

According to our model results, aerosols are causing a warming of the atmosphere. Similar results were reported also by Nakajima (Nakajima, T.: A System for evaluating the Earth Radiation Budget from the EarthCARE Satellite, CALIPSO, CloudSat, EarthCARE Joint Workshop, Paris, 18-22 June 2012). These heating effects strongly depend on altitude. They are small near the surface (down to 0.08-0.09 K/day), exhibiting a rapid increase with altitude, reaching their maximum values at the height of around 1-2 km above ground level (agl) and then they decrease becoming practically zero above 6 km agl. The heating rate profiles are in agreement with the vertical profiles of aerosol optical depth (not shown here), with maximum values in the layers where AOD is largest. The aerosol heating effect is stronger (up to 0.28 K/day at the height of 1.1 km agl) in the mainly affected by desert dust Arabian Peninsula. The strong heating effect over this region can be attributed primarily to large AOD values. Moreover, the multiple scattering occurring over the highly reflective desert surface results in an overall positive radiative effect, as it has been shown in previous studies (Hatzianastassiou et al. 2007). Over China (affected by anthropogenetic urban / industrial aerosols) and Southern Africa (strongly affected by extensive biomass burning during the dry season), the aerosol effects on heating rates are somewhat lower (with maximum values around 0.18 and 0.17 K/day, respectively).
Fig. 2. (a) Mean (2007-2009) values of the aerosol effect on atmospheric heating rates over the Arabian Peninsula (green line), China (black) and Southern Africa (red) and (b) Mean difference between profiles of the aerosol effect on heating rates during clear-sky and all-sky conditions.

Setting cloud amount equal to zero (clear-sky conditions), we find that the aerosol effect is larger, mainly over China (increase of heating rates up to 0.09 K/day compared with all-sky conditions), as shown in Fig. 2 (b). This indicates that clouds cause a decrease of aerosol heating effect over the studied regions. The lower heating rates under all-sky conditions can be attributed to the decrease of downwelling radiative fluxes under cloudy conditions and the presence of the larger fraction of aerosol load below clouds.

The aerosol effect on the atmospheric heating rates also exhibits a strong seasonal cycle as shown in Fig. 3, which is in agreement with the AOD intra-annual variation. Over the Arabian Peninsula, the heating rates are greater in April and especially in July (maximum values up to 0.38 K/day), when they are also reaching greater heights. These can be attributed to the seasonal cycle of desert-dust activity over the Arabian Peninsula, which is low during the winter, grows stronger in March–April, and increases to a maximum in June and July (Prospero et al. 2002). Over China, atmospheric heating rates due to aerosols reach their maximum values during July and October (up to 0.24, 0.26 K/day). It is worth noting that in April, while the heating rates are generally lower, aerosol heating effects are observed as high as 10 km agl. Over Southern Africa the heating rates are strongest during the austral winter (dry season), when the aerosol loading is greatest and consists mainly of highly absorbing biomass burning particles (heating rates up to 0.29 K/day in July). In October, atmospheric heating rates are also large (up to 0.20 K/day) with the maximum values observed higher than in the other months. The minimum values are seen in January and April.

Fig. 3. Aerosol effect under all-sky conditions on the Atmospheric Heating Rates over (a) the Arabian Peninsula, (b) China and (c) Southern Africa for the mid-seasonal months of January (black), April (red), July (green), and October (blue).
4 Conclusions

A deterministic spectral radiative transfer model was used to compute the atmospheric heating rate profiles due to aerosols under clear- and all-sky conditions above three regions with different type of aerosols, both natural and anthropogenic (Arabian Peninsula, China, and Southern Africa) using vertically resolved aerosol data from CALIOP and cloud properties from ISCCP. According to our results:

- Aerosols are causing a heating of the atmosphere, with the heating rates strongly depending on height.
- On mean annual level, the strongest heating effects are observed over the Arabian Peninsula (up to 0.28 K/day).
- The presence of clouds results in a decrease of aerosol heating effects, mainly over China.
- The heating rates exhibit a clear seasonal cycle with maximum values during spring and mainly summer over the Arabian Peninsula, during summer and autumn over China and during the austral winter in Southern Africa, in agreement with the seasonal distribution of AOD.

It should be noted that the aforementioned results can be influenced by the uncertainties of the CALIOP instrument itself, the retrieval errors due to all the assumptions made in the inversion process (Omar et al. 2013), and to sampling errors due to the spatial and temporal sparseness of CALIOP Level 2 data.

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Aerosol forcing efficiency from the FORTH radiative transfer model with CALIOP AOD vertical profiles

Korras-Carraca M.B., Pappas V., Matsoukas C., Hatzianastassiou N., Vardavas I.

The FORTH radiative transfer model is run globally with vertically resolved aerosol optical depth (AOD) profiles provided by the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) on board satellite Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO). Our 3-year period of interest is 2007-2009, with CALIOP Level 2-Version 3 Layer data being used. For our all-sky runs, we employ cloud properties from the International Satellite Cloud Climatology Project (ISCCP). The derived direct radiative effect divided by the AOD gives the aerosol radiative forcing efficiency (ARFE), a function mainly of the single scattering albedo of the aerosol and the reflectance of the underlying surface or clouds. ARFE describes how effectively aerosols are warming or cooling each location and facilitate future projections in various AOD scenarios. We produce monthly, 2.5°x2.5° maps of the annual and seasonal behavior of the ARFE globally, which highlight the dependence of ARFE on clouds, aerosol type and surface albedo. Moreover, the contribution of the above-cloud aerosol fraction to the total ARFE, produced by the AOD over the whole atmospheric column, is examined. We demonstrate that in many cases the bulk of the aerosol radiative forcing is attributed to the aerosol fraction above the clouds, despite the significant fraction of aerosol load below the clouds.

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