Climate change and future ozone concentrations in high resolution over Europe

Varotsos K.V., Protonotariou A.P., Giannakopoulos C., Tombrou M.

In this study a methodology is developed that applies the ozone concentration change signal from a global climate-chemical modeling system with a coarse horizontal resolution to a finer resolution. To this aim simulations with two different configurations of the GEOS-CHEM chemical transport model are conducted a) driven from the GISS III general circulation model (4^ox 5^o) for a present (1999–2001) and a future (2049–2051) period and b) driven by assimilated meteorological data (GEOS, 0.5^o x 0.667^o) for the year 2005. Results indicate highest increases between the future and the reference period in the north west and the south west Europe for both the average mean (~ 5 ppb) and average daily maximum ozone concentrations (~ 10 ppb) whereas the highest decreases (~ 4-6 ppb) are shown in the south East Europe for the same statistical targets. Moreover, these results are of the same sign to the results of the global climate-chemical modelling system in the North-west and the South-east Europe. Nevertheless changes in the GISS/GEOS-CHEM between the future and the present climate are in the range of ± 2 ppb and ± 3 ppb for the average mean and the average daily maximum ozone concentrations respectively.

Varotsos K.V.[1,2*], Protonotariou A.P.[1], Giannakopoulos C.[2], Tombrou M.[1]

1 Division of Environmental Physics and Meteorology, Department of Physics, National and Kapodistrian University of Athens, Greece
2 Institute for Environmental Research and Sustainable Development, National Observatory of Athens, Greece

***corresponding author e-mail: kvarotso@phys.uoa.gr**

1 Introduction

Global Climate Models (GCMs) are widely applied to project long term climate and air-quality trends (Giannakopoulos et al. 2009, Varotsos et al. 2013). However, their coarse resolution is a limiting factor to provide reliable projections at areas with heterogeneity and/or complex terrain. To overcome this problem as well as to integrate the useful information from climate/air quality global models to regional or local scales, various methods described by the term “downscalling" have been developed. Downscalling the output of a global model can be performed either with the use of a nested high-resolution Regional Climate Model (RCM) (dynamical downscalling) or through equations to convert global scale output to regional/local scale conditions (statistical downscalling).

However both methodologies are subject to limitations. For instance, most of the dynamical studies regarding the future projections of ozone under the influence of climate change focusing on Europe have a 50 km horizontal resolution and when a finer resolution is applied, they are confined to smaller domains. Apart from the computational cost, other challenges also arise with dynamical downscaling such as consistency in the physics and chemistry between the parent GCM and RCM (Jacob and Winner 2009). Although statistical downscalling is less computational expensive, its main limitation arises from the fact that the statistical relationships are based on historical data and there is no guarantee that the past observed relationships between different variables will exhibit the same characteristics in the future. The objective of this study is to develop a methodology in order to apply the ozone concentration change signal from a global climate-chemical modelling system with a coarse horizontal resolution to a finer resolution over Europe.

2 Methodology and Simulations

2.1 Methodology

The GEOS-CHEM chemical transport model driven by meteorological fields from the NASA/GISS III GCM is used to investigate ozone air quality in Europe under present and future climate as well as to obtain the signal in the changes of ozone concentrations in Europe between the future and the present climate. The horizontal resolution is 4^{o}x5^{o} (Fig. 1a) with 23 vertical levels extending up to 0.02hPa. In addition simulations with the GEOS-CHEM driven by assimilated meteorological data from the Goddard Earth Observing System (GEOS) of the NASA Global Modelling and Assimilation Office for the year 2005 are performed. The horizontal resolution is 0.5^{o} x 0.667^{o} (Fig. 1b) with 30 vertical levels up to 0.01 hPa.

To obtain the future daily ozone concentrations in the highest resolution (under the A1B GHG emissions scenario) we calculate the ratios of the daily ozone concentrations between the nested GEOS-CHEM and the present climate simulation which in return are applied to the future climate simulation. In particular, for each grid box located within a grid box of the GISS/GEOS-CHEM, the day to day ozone concentration ratios are obtained for both the daily mean and daily maximum ozone concentrations which are thereafter implemented in a similar way to future simulation of the GISS/GEOS-CHEM. To our knowledge the methodology presented in this study has not been used or evaluated in earlier studies. It should be noted here that the different time slices used in this study, 1999-2001 for the GISS/GEOS-CHEM and 2005 for the GEOS-CHEM are due to the lack of meteorological data to drive simulations for the year 2000 for the GEOS-CHEM.

2.2 The GISS/GEOS-CHEM climate-chemical modelling system

For the purposes of this study two scenario simulations with the GISS/GEOS are performed: a) present day climate and emissions (hereafter SCEN_1) and (b) future climate following the IPCC SRES A1B scenario (Nakicenovic and Swart 2000) and present day anthropogenic emissions (hereafter SCEN_2). The base year anthropogenic emissions inventory used in this study is 2000. The model's inventory among other includes natural emissions of ozone precursors such as NMVOCs from vegetation and NOx from soil and lightning which are computed within the model and are allowed to vary with the meteorological variables. NMVOCs vary only with temperature and solar radiation. The simulations performed here cover two 3-year time slices: 1999-2001 for the present day climate and 2049-2051 for future climate. The results presented are 3-year averages (2000 and 2050, respectively).

2.3 The GEOS-CHEM chemical modelling system

In order to apply the nested-grid configuration, first a 2-yr (2004-2005) global simulation with GEOS-CHEM is performed. As 1-yr spin up is suggested, hourly boundary conditions (BCs) are saved around the nesting domain of Europe during the second run-year. The BCs are then implemented around the European domain for the nested-grid simulation.
All results presented in this study are calculated over the period April 1 - September 30 since highest ozone concentrations usually occur during this period.

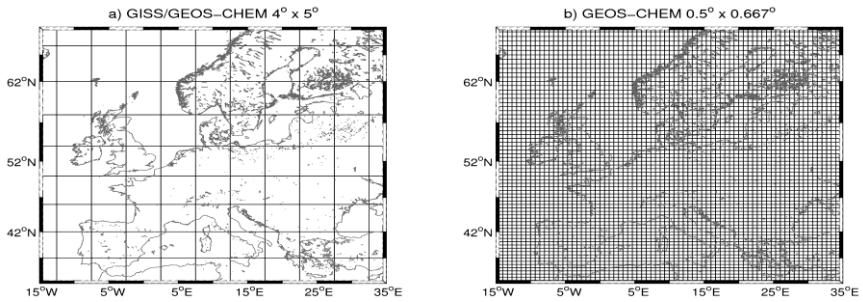

Fig. 1. Horizontal resolution of the two different configurations of the GEOS-CHEM a) GISS/GEOS-CHEM (4^{o}x5^{o}) and b) GEOS-CHEM (0.5^{o}x0.667^{o}).

3. Results

3.1 The GISS/GEOS-CHEM simulations

Fig. 2 shows results of the average mean ozone concentrations during April–September under the present climate and present emissions (SCEN_1) as well as the changes between SCEN_2 and SCEN_1. It is evident that the impact of climate change on its own leads to an increase of less than 2 ppb in western and central Europe whereas decreases are also evident for most of the remaining areas with the highest (about 2 ppb) found in southeastern Europe (Italy, Greece). The aforementioned increases are a combination of higher temperatures, solar radiation and mixing depths. In addition, ozone increases due to increases of isoprene biogenic emissions associated with the temperature increases as well as lower PAN stability (Varotsos et al. 2013). The highest decreases are shown in the Northern and Southeast Europe. In Northern Europe the changes are associated with decreases in snow cover leading to increases in the dry deposition of ozone as well as the decrease in solar radiation leading to weaker photochemical ozone production. In the South East Europe (Italy and Greece) which are areas mostly covered by water, reflecting relative clean areas, in the GISS/GEOS-CHEM

the decreases are associated with the increase of water vapor overseas which tends to decrease the lifetime of ozone as well as the increased wind speeds in the 2050 climate (Varotsos et al., 2013). Average daily maximum ozone concentration changes follow a similar pattern, with the highest changes reaching up to 3 ppb (not shown).

It should be noted here that changes in ozone concentrations between SCEN_2 and SCEN_1, especially in the northwest Europe, could be linked to changes in circulation patterns. For instance, Leibensperger et al. (2008) found a significant relationship between the reduction in the frequency of the mid-latitude cyclones and the increase of the days with stagnant conditions (which favor the ozone pollution episodes) in the Eastern U.S. However, the investigation of this relationship in Europe is beyond the purposes of this study.

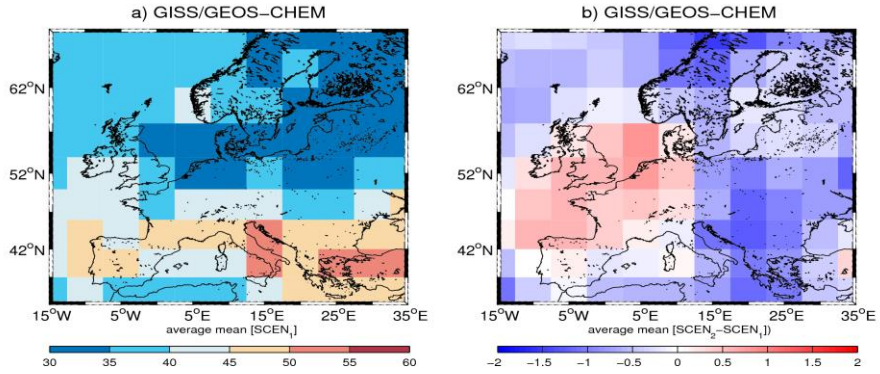

Fig. 2. GISS/GEOS-CHEM April-September average mean ozone concentrations for a) SCEN_1 (1999-2001) and (b) SCEN_2-SCEN_1 (2049-2051)-(1999-2001).

3.2 High resolution results

In this section, results of the average mean (Fig. 3a) and the average daily maximum ozone concentrations (Fig. 3c) for 2005 (April-September) as well as the changes between the perturbed ozone concentrations (based on the SCEN_2 simulation, 2049-2051) and the reference period for the same statistical targets are shown (Fig. 3b and 3d respectively). It should be noted here that changes have been examined for statistical significance using the bootstrap 95th percentile confidence intervals (not shown); moreover changes in the range of ± 1 ppb in both Figs. 3b and 3d are not found statistically significant. The averaged ratios of the average mean and the average daily maximum ozone concentrations (between the nested-grid and SCEN_1 simulations) are higher than unit at most of the areas of the study domain (the highest are seen in the Mediterranean) with the exception of the area of the British Isles where the ratios are below one (not shown). From Figs. 3b it is evident that the changes in the high resolution grid between the perturbed ozone concentrations and the reference period are mostly driven from the signal obtained by the GISS/GEOS-CHEM simulations. Similar to Fig. 2b the highest increases are seen in north west Europe (Northern U.K and the Benelux area, ~ 5ppb) and the south West Europe (western Iberina penisula, ~ 5ppb) whereas the highest decreases are evident in the Southeastern Europe (Italy and Greece ~ 4-6 ppb). Regarding the average daily maximum changes, the highest increases (8-10 ppb), are evident in the west coast of the Iberian peninsula. Lower increases are shown in Nothern Italy and and in NorthWest Europe (4-6 ppb) whereas the highest decreases are seen in the Southeastern Europe (Italy and Greece ~ 4-6 ppb).

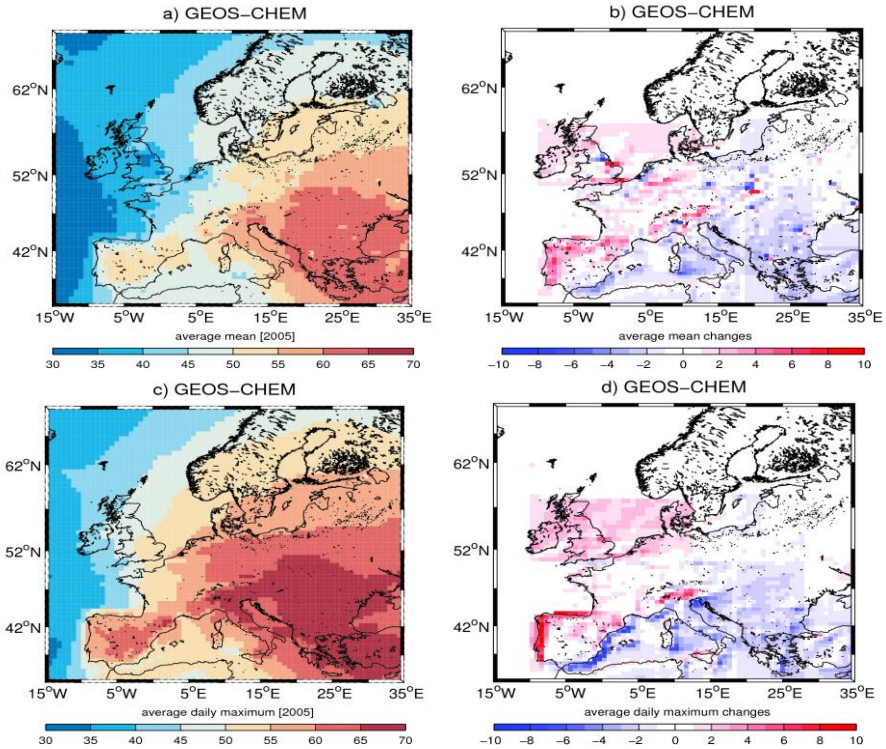

Fig. 3 Top row, GEOS-CHEM April-September results for a) the average mean ozone concentrations and b) the changes between the perturbed (based on the SCEN_2, 2049-2051) and the reference period for the same statistical target. Bottom row GEOS-CHEM April-September results for c) the average daily maximum ozone concentrations and d) the changes between the perturbed (based on the SCEN_2, 2049-2051) and the reference period for the same statistical target.

4 Conclusions

In this study we developed a statistical methodology to apply the ozone concentration change signal from a global climate-chemical modelling system with a coarse horizontal resolution to a finer resolution over Europe. Simulations were conducted with the GEOS-CHEM driven a) by meteorological fields from the NASA/GISS III GCM for a present (1999-2001) and a future (2049-2051) 3-year period and b) by assimilated meteorological data from the Goddard Earth Observing System (GEOS) of the NASA Global Modelling and Assimilation Office for the year 2005. To obtain the future daily ozone concentrations (under the A1B GHG emissions scenario) on the finer grid we employed a straightforward methodology based on the ratios of the daily ozone concentrations between the nested GEOS-CHEM and the global climate simulations. Results indicated highest increases between the future and the reference period in the north-west and the south-west Europe for both the average mean (~ 5ppb) and average daily maximum ozone concentrations (~ 10 ppb) whereas the highest decreases (~ 4-6 ppb) are shown in the south East Europe for the same statistical targets. Note that the decreases found in the south East Europe are in contrast to the increases found in an earlier published study (Katragkou et al. 2011). The discrepancies in the results can be attributed mostly to the different modelling systems used to examine climate change impacts on ozone concentrations.

Acknowledgments 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: Heracleitus II. Investing in knowledge society through the European Social Fund.

References

Giannakopoulos C, Le Sager P, Bindi M, Moriondo M, Kostopoulou E, and Goodess CM (2009) Climatic changes and associated impacts in the Mediterranean resulting from a 2 °C global warming, Global and Planetary Change, 68(3), 209–224, doi:10.1016/j.gloplacha.2009.06.001.

Jacob DJ, Winner DA (2009) Effect of climate change on air quality. Atmos Environ,51-63, doi:10.1016/ j.atmosenv.2008.09.051.

Katragkou E, Zanis P, Kioutsioukis I, Tegoulias I, Melas D, Krüger BC, and Coppola E (2011) Future climate change impacts on summer surface ozone from regional climate-air quality simulations over Europe, J. Geophys. Res., 116, 14 PP., doi:201110.1029/2011JD015899.

Leibensperger EM, Mickley LJ, and Jacob DJ (2008) Sensitivity of US air quality to mid-latitude cyclone frequency and implications of 1980–2006 climate change, Atmos. Chem. Phys. Discuss., 8(3), 12253–12282, doi:10.5194/acpd-8-12253-2008.

Nakicenovic N, Swart R (2000) Special report on emissions scenarios (SRES) A special report of IPCC Working Group III. Cambridge University Press, Cambridge, UK.

Varotsos KV, Giannakopoulos C, and Tombrou M (2013) Assessment of the Impacts of Climate Change on European Ozone Levels, Water Air Soil Pollut, 224(6), 1–13, doi:10.1007/s11270-013.