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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Decadal regional air quality simulations over Europe in present climate: near surface ozone sensitivity to external meteorological forcing" *by* E. Katragkou et al.

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We would like to thank Dr Kaminski for the detailed comments.

Our response follows:

COMMENT: The authors should have presented scientific justification for using these models. Are these models compatible? Why was the WRF/Chem model not used in place of RegCM3 and CAMx?

RESPONSE: RegCM3 is a well established regional climate model. Long simulations of RegCM3 were carried out within the framework of the EU project ENSEMBLES

both using ERA-40 data for the period 1961-2000 and ECHAM (IPCC A1B scenario) through the period 1951 to 2100. Our scope within the framework of the EU project CECILIA was to take advantage of the RegCM3 data produced within ENSEMBLES to force a well established air quality model such as CAMx in 4 decadal simulations. Hence the whole experimental setup of air quality simulations with CAMx in CECILIA was designed to be forced by RegCM3. A similar approach has been also used by Meloux et al. (Atmos. Environ., 41 (35), pp. 7577-7587, 2007) where they used RegCM3 and CHIMERE (instead of CAMx). WRF/Chem model is computationally much more expensive than our set-up which took a few months to complete the 4 decadal simulations. Furthermore, as far as we know, WRF/Chem has not been used so far in long climatic air-quality simulations.

COMMENT: According to the last paragraph on page 10679 (line 25), the model top was set at 6.5 km, where "boundary conditions were kept constant, corresponding to a clean atmosphere". Whereas such an assumption may seem suitable for studies involving primary pollutant dispersion on local and short time scales, it is hardly justifiable for ozone in the context of a continental-scale climatic study. There is an abundant body of research in which the issues of stratospheric ozone intrusions, upper troposphere - lower troposphere exchange and the role of large-scale transport of ozone precursors in the upper troposphere are addressed. These processes cannot be considered as negligible and must not be excluded from a modelling system. Given the fact that the "uppermost layer is 1.2 km deep", one might well suspect that the model actually describes not much more than just the boundary layer which, in the context of a climatic study, seems to be a gross simplification and misunderstanding.

RESPONSE: We have to clarify that the experimental design of the RegCM3/CAMx simulations with four decadal simulations (two in the present decade 1991-2000 with ERA-40 and ECHAM and two in the future decades 2041-2050 and 2091-2100) was to investigate the sensitivity of future air quality to the effect of a climate change projection (under A1b in our case) in a regional scale. Mind also that our emissions were constant, set to the EMEP 2000 for all four decadal simulations. The purpose of the above mentioned simulations was not to establish a state of the art modeling system for understanding the present time ozone variability in regional scale over Europe in climatic time scales. In that aspect there is ongoing work in our group where present time decadal simulations of the RegCM3/CAMx system considers chemical boundary conditions from a global CTM (chemistry transport model) and varying year by year EMEP emissions. Climate change may impact air quality in different ways by affecting atmospheric processes such as a) circulation changes, b) boundary layer ventilation, c) deposition, d) convection distribution, e) clouds, radiation and reaction rates, and f) stratosphere troposphere exchange. Climate change may further impact air quality by affecting natural emissions through the changes in land use, temperature and radiation fields. Climate change may also impact the anthropogenic emissions by modifying the energy needs. So in general it is clear the complexity in which climate change may affect regional air quality. In our experimental design the climate change impact on future anthropogenic emissions (ozone precursors) and land use is not considered (both taken constant in present and future decadal simulations). It is also true that our regional simulations do not consider the impact of the upper troposphere/lower stratosphere interactions and the intercontinental transport of pollution as the top and lateral chemical boundary conditions were kept constant with no seasonal variation and annual variability, identical for both decadal simulations in the set up of this study. Of course there are a few of limitations to be noted with respect to the chemical boundaries of the air quality simulations in this modelling set up. It is known from global studies (e.g. Stevenson et al., JGR, 2006, ensemble of 10 models) that stratospheric flux to the troposphere is an important contribution to the global ozone budget and that in future projections upper tropospheric ozone will rise, especially in the Northern Hemisphere, which is related to an increased influx from the stratosphere. However, in these global studies the effect of stratospheric influx to the surface ozone (the focus in our study) is rather small. Furthermore it has been clearly concluded from the recent IPCC/TEAP 2005 and Scientific Assessment of Ozone Depletion report (2006)

that the stratosphere-troposphere dynamical coupling is a key issue for future climate change and ozone recovery but large uncertainties exist especially in vertical wave propagation from troposphere to stratosphere and stratospheric dynamics for future climate. The vertical wave propagation from the troposphere to stratosphere drives the meridional Brewer-Dobson circulation in the stratosphere which in turn drives the Stratosphere-Troposphere Exchange (Stohl et al., JGR, 2003). Taking into account a) the large existing uncertainties in STE in future climate and b) the fact that from previous global simulations the effect of stratospheric influx to surface ozone is rather small we decided in the framework of our experimental design in regional scale to consider constant top chemical boundary conditions for present and future thus reducing the "degrees of freedom" in our climate change sensitivity study of surface regional air quality. As far as it concerns the effect of intercontinental transport of pollution towards Europe, Li et al. (2002) showed that the effects of North America and Asia anthropogenic emissions on European surface ozone is in average over summer 1997 around 2-3 ppbv for the largest part of Europe. This is rather small compared to the effect of the European emissions on European surface ozone which is more than 20 ppbv. Nevertheless in order to address the point for the effect of top and lateral boundary conditions on surface ozone we carried out a sensitivity study by modifying the top and lateral boundary concentrations of ozone. In a new paragraph entitled "Sensitivity to chemical boundary conditions" we discuss more in detail the role of chemical boundaries in our modelling system and the limitations from our modelling set-up as well as the results of the sensitivity study.

COMMENT: Furthermore, photolysis rates used in CAMx are pre-calculated by the TUV radiative transfer model (Madronich, 1989) and stored in a multi-dimensional lookup table by surface albedo, total ozone column, haze turbidity, altitude, and zenith angle. (CAMx v5.00 User's Guide, March 2009. Same method was used in the presented version 4.40). It should be clear that ozone column abundance is above the model top and thus has to be prescribed for each chemical time step, or at least on a monthly basis, and for each year of simulations. The authors have not addressed how the column ozone was determined by the model for the past conditions and how it could be calculated/ prescribed for future climate simulations.

RESPONSE: Global ozone column was obtained on a monthly basis from the Ozone Monitoring Instrument (OMI) platform. The data are on-line available for use http://jwocky.gsfc.nasa.gov/. Since there is no discussion about future simulations in the current paper, the issue does not need to be discussed in the manuscript.

COMMENT: Notwithstanding the apparent lack of references, a very simplistic description of climate simulations and modelling tools that served as a basis for the presented study, the authors have attempted to establish the credibility (page 10678, starting on line 11) of the constructed modelling system by stating that "The wider scope of this work is to investigate the credibility of our modeling system which is driven by the ECHAM5 general circulation model (GCM) in order to further use it for future scenarios including climate change." As in any complex interaction, the overall value of a system is determined by its weakest component. Thus, it seems the presented system does not offer much credibility.

RESPONSE: The sentence "The wider scope.." seems to confuse the reader about what was the target of this work and misleads to comments irrelevant to the aim of this paper. It was removed and replaced with: Comparing present GCM-driven climate simulations with reanalysis-driven simulations, we learn how sensitive are the CAMx air quality simulations to the different meteorological forcing of the perfect boundary conditions experiment and the control experiment which is a valuable information for understanding the air quality simulations in the future climate. The common strategy in climate studies is to validate a model with what we say "perfect boundary conditions" experiments. The ERA40/RegCM3/CAMx is such a perfect boundary conditions experiment with the ERA-40 reanalysis meteorological fields constraining RegCM3 simulation for the period 1991-2000. The ECHAM5/RegCM3/CAMx simulation of the present decade 1991-2000 is the "control" experiment which is the suitable simulation (or in other words the basis) to estimate the future climate

change impacts by comparison with the ECHAM5/RegCM3/CAMx simulations in the future decades thus counterbalancing internal model errors in present and future of the GCM runs (in our case ECHAM5). Of course, we are also interested to know, what are the differences between the "perfect boundary conditions" experiment and the control experiment and that was the purpose of this work. It should be clearly stated that the differences between ERA40/RegCM3/CAMx and ECHAM5/RegCM3/CAMx arise from the differences between ERA40 and ECHAM5 fields so in other words how close is ECHAM5 to the reanalysis fields. The differences between ERA40/RegCM3/CAMx and ECHAM5/RegCM3/CAMx DO NOT SHOW that our modelling strategy (GCM/RCM/AQM) is inappropriate and inconsistent! It is reasonable that ECHAM5 and ERA40 have differences. These differences are transferred in RegCM3 simulations which in turn determine the meteorology of CAMx. We investigate in our work how sensitive are our CAMx results on different meteorological forcing. The presented system is already used in several previous studies concerning climate and air quality studies. Several references were added in the revised manuscript, and so the question about the "credibility" is addressed. Furthermore a paragraph entitled evaluation of the modeling system was added in the manuscript, including results from calculation of bias and error from the comparison between measurements of surface ozone available from the EMEP database and results of the model simulations.

COMMENT/ ECHAM5: Simulations have no corresponding reference. The authors should have informed the reader about the horizontal and vertical grids and parameterizations selected in performing climate simulations with the selected model. Was there an ocean model connected to the ECHAM5 model?

RESPONSE:Horizontal and vertical grids: We stated already that the RegCM grid has 50 km horizontal resolution. Concerning ECHAM: There are 18 vertical levels spaced more closely together near the surface. Model top is at 50 hPa. There was no ocean model connected to RegCM, the SSTs were prescribed from the ECHAM model (ECHAM was run fully coupled). RegCM is not derived from the ECHAM model, but it is standard practice to couple different RCM/GCM pairs (this is the whole purpose of the ENSEMBLES project). Boundary conditions were updated every 6 hours and are relaxed into the domain using a method from Davies and Turner (1977). There were 12 grid points in the boundary. The forcing data are provided on pressure levels, and they are interpolated vertically (to sigma levels) and horizontally to the RegCM grid. The required fields (which are standard for any RCM) are temperature, humidity, geopotential height, u and v wind components, surface pressure, surface temperature, also orography and land use for the initial conditions/domain.

COMMENT/ ERA40: There is no proper reference to the ERA40 dataset. The only passing comment on page 10680 line 23 ": : :ERA40 reanalysis project is a global atmospheric analysis of observations and satellite data streams: : :" is simplistic and inaccurate. For clarity and completeness the authors should have stated resolutions (horizontal and vertical) and a list of available fields should have been provided. In addition, it is not clear to the reader what are the differences between ERA40 and ECHAM5 datasets used for input to RegCM3.

RESPONSE:The difference between ECHAM and ERA40 is clearly stated in the manuscript: ECHAM5 is a global circulation model and ERA40 is a reanalysis data set. The missing reference to the ERA40 dataset and the GCM ECHAM was added in the revised manuscript. The reader can find all needed info in these publications.

COMMENT/ RegCM3: Simulations have no corresponding reference. The authors should have informed the reader about the horizontal and vertical grids and parameterizations selected in performing climate simulations with the selected model and its scientific compatibility and relationship to ECHAM5. Was there an ocean model connected to the regional climate model?

RESPONSE:Several references were added to the revised manuscript to inform the reader about previous modeling work with the models ECHAM, RegCM and CAMx. There was no ocean model connected to RegCM.

COMMENT/ Nesting of models: What were the nesting time intervals for ECHAM5 to RegCM3, ERA40 to RegCM3 and RegCM3 to CAMx? In addition, a list of levels and fields used for nesting, together with the nesting methods including the extent of the nesting band should have been provided.

RegCM receives lateral boundaries from ECHAM and ERA40 reanalysis in the two decadal simulations on a 6 hourly basis. CAMx is off-line coupled to RegCM on a 6 hourly basis. The meteorological variables that are passed to CAMx are described in the revised manuscript.

COMMENT: Authors should explain and further clarify statements on page 10679 lines 11 to 20. It is hard to imagine that the CAMx model would require fields not available from a regional climate model - from an advanced atmospheric model.The sentence on line 17 on page 10679 is surely an error: "Pressure and geopotential height is obtained using the hydrostatic formula: : :". Why and how would one be able to recalculate pressure and geopotential from the hydrostatic equation? After all, these fields are produced by RegCM3. The authors should have stated which fields from RegCM3 were used as input to CAMx.

RESPONSE:These lines were removed and they are replaced by the fields which are used as input to CAMx, as suggested by Dr. Kaminski.

Technical/Editorial comment: It appears that the Technical Editor missed a reference to a publication in preparation (Tegoulias et al. 2009) that should have been included as a footnote and not in the list of references. It is rather unfortunate that a large part of this paper hinges on the non-existent publication which was referenced 3 times.

RESPONSE: The reference Tegoulias et al., 2009 was removed from the revised manuscript. A new paragraph entitled “Evaluation of the modeling system” covers the evaluation work performed for the chemical model CAMx.

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