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Atmospheric Chemistry and Physics Discussions

Interactive comment on "A multi-model study of impacts of climate change on surface ozone in Europe" *by* J. Langner et al.

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We are very grateful for the valuable comments and questions posed by Anonymous Referee #1. Below we address the general and specific comments raised. Minor comments will be accounted for in a revised version of the manuscript.

General comments

While 10 years are modelled for the present and future situation, these 10 years are averaged and only mean difference are discussed in the paper. These 10-years simulation offer a good opportunity to assess the statistical significance of the O3 changes discussed in the paper, hence increasing the robustness of the conclusions. First, some changes discussed in the paper are small, it is important to explain whether

these changes exceed the interannual variability observed for the control period before discussion further the implication for climate and air quality interlinkages. Second, it is mentioned that some models appear less sensitive to climate than others, but no quantitative elements are given to estimate their inter-annual variability. The conclusions regarding the respective sensitivity of the models would benefit from using an appropriate statistical measure of the significance.

Response - We acknowledge that the statistical significance is an important issue. In new versions of Fig. 5-7 we have added this by only plotting results that are significant at the 95% level with respect to interannual variability in the model output. These new figures appear as Fig. 1-3 in this response. These figures and all other results presented in this response are based on revised model runs for the EMEP and SILAM models using the most recent model versions. This has resulted in minor changes in the EMEP model results while the change is larger for the SILAM model.

Biogenic emissions and boundary conditions constitute two major sources of potential discrepancies in the modelling setup. These factors are well documented in the paper, but these elements are fragmented and a synthesis in a dedicated paragraph would be useful. For example it is mentioned that a set of boundary conditions was provided but, in the description of the models, it appears that a number of exceptions applies. A single paragraph explaining that in a more synthetic way would be useful. Similarly, it is not easy to find out what is being done for biogenic emissions. For example it would be very useful to add monthly isoprene emissions on the seasonal cycle of daily mean O3 for each model (Figure 2). Biogenic emissions are often pointed out as a major driver of projected O3 changes under climate scenarios in Europe. I think a dedicated paragraph in the discussion would be relevant, especially since one of the models involved has zero biogenic emissions. If such a hypothesis could be considered to yield satisfactory results, it would be relevant to highlight it more prominently in the conclusions.

Response - The information on the handling of the boundary conditions is compiled in

section 2.3 of the paper, in a revised version we will improve the wording according to the suggestion by the reviewer. The following clarifications can also be added to that description:

The vertical discretization differs between the different models. The EnvClimA, EMEP, SILAM and MATCH models use vertically interpolated lateral chemical boundary conditions calculated by the DEHM model. In EMEP, SILAM and MATCH the data from DEHM is also used to set boundary conditions at the top boundary while EnvClimA includes both the troposphere and the lower and middle stratosphere and therefore treat transport of stratospheric ozone to the troposphere internally.

In Table 1 in the paper we have provided domain-averaged emissions of isoprene. The differences between the models are substantial, which is also highlighted in the Abstract. The seasonal variation of the isoprene emissions in each model is given in Fig. 4 in this response. As can be seen the seasonality of emissions are quite similar with highest emissions in July except for MATCH which have the highest emissions in August.

In this paper, and in previously published works, several processes potentially leading to increases of O3 are mentioned but the investigation of O3 decrease is overlooked. “Reaction with water vapor” is pointed out, for example for the decrease over the Mediterranean modelled with MATCH (P4917L9) but such a statement does not constitute an evidence. No possible explanation is given to explain the decrease over the N-E part of the domain in MATCH and EMEP (P4917L23). The ensemble gathered in the present study constitutes a unique opportunity to isolate underlying processes and more substantive grounds should be sought after.

Response - The climate projection used shows an increase in summer precipitation in large parts of northern Europe extending also over Poland and Germany between the periods 2000-2009 and 2040-2949 while precipitation generally decreases in southern Europe. Connected to this is also summer total cloudiness increase in northern Europe

and decrease in southern Europe with the same spatial pattern as for precipitation. Changes in relative humidity at the surface also show a similar pattern but in addition relative humidity also generally increases over the oceans including the Mediterranean.

The reasons for reduced O3 concentrations in northern Europe have not been considered in detail but both cloudiness and precipitation increase in northern Europe in the climate projection and time periods used, leading to increased scavenging of ozone precursors and less solar radiation for driving the photochemistry in these areas. Increased relative humidity in the Mediterranean are co-located with the decrease in ozone simulated with MATCH giving some support for the hypothesis that reaction with water vapor could be part of the explanation.

Specific comments

P4903, para 2: Although the focus of the paper is on O3, the impact of PM on climate should be mentioned in the overview of climate and air quality interlinkages in this introductory paragraph.

Response - This will be included in a revised version of the manuscript.

P4903, para 3: It is suggested that online coupled models will contribute decreasing the uncertainties in the projections. While these models will certainly offer a more satisfactory representation of the processes involved, it is anticipatory to suggest that uncertainties will be reduced.

Response - We will rephrase this part in a revised version of the manuscript.

P4905L26: in addition to the estimate of the difference in temperature between 2000 and 2040, the absolute bias (if any) of the climate control simulation for the present day should be given.

Response - The mean absolute error for temperature and precipitation over land areas for June-August for the period 1961-1990 is 1.05 K and 38.9% respectively when comparing to observations (Kjellström et al., 2011). The corresponding biases when

forcing RCA3 with ERA40 on the boundaries are 0.60 K and 41.3%.

P4906L12: Is the landuse identical for all models? Difference landuses would presumably influence biogenic emissions.

Response - The participating models use their own landuse classification together with their own dry deposition velocities and formulations for biogenic emissions. Details about the respective set-up should mainly be sought in the given references to the respective models.

P4907L10: Since aerosols are not addressed in the paper, and excluded from the inventory of anthropogenic emission, it is not clear why secondary inorganic aerosols are included the boundary conditions.

Response - Secondary inorganic aerosols were included in the boundary conditions in order to enable also a future study of nitrogen deposition this will be clarified in the revised version of the manuscript.

P4908L5: Using annual mean values in the boundary conditions for DEHM seems contradictory with the monthly values mentioned in Section 2.3. Would it be possible to confirm this apparent contradiction?

Response - We agree that the text is not well formulated. We will improve this in a revised version of the manuscript. With regard to handling of the chemical boundary data from DEHM it is the EnvClimA model that differs in using monthly values. The other three models used 6-hourly data from DEHM. EnvClimA was run on a larger model domain than EMEP, SILAM and MATCH and monthly values were therefore considered to be sufficient.

P4909L16-18: The similarity of DMI-EnvClimA and Enviro-Hirlam are explicated, but not the differences. It would be interesting to explain briefly what makes EnvClimA more appropriate for climate studies.

Response - The Enviro-Hirlam is based on the HIRLAM numerical weather prediction

(NWP) model and is used as a chemical weather forecast model (short-term simulation), while the EnvClimA model is used as a climate-chemistry model framework for regional climate applications (climate projection taking into account the chemistry feedback). EnvClimA is based on the Regional Climate Model (RegCM), developed at the Abdus Salam International Centre for Theoretical Physics (ICTP). RegCM was built for long-term climate simulations, and does not include, in comparison with HIRLAM, the NWP rerunning and data assimilation routines and is optimized for continuous long-term climate runs. Thus, this version of the model was computationally faster and more efficient for climate studies. The Enviro-Hirlam online coupled ACT-NWP model was built mostly for research purposes and short-term forecasting on meteorological time scale. It was built on the base of the HIRLAM NWP model and keeps the forecasting mode run routines (with the model restart each 24 hours for the next forecasting period) and data assimilation.

P4909L10-24: The added value of EnvClimA compared to RegCM should be more explicit. At this stage, I understand that the dynamical core is that of RegCM, while chemistry/aerosol processes and feedback with the dynamic are modified. If correct, could this be stated more clearly in the text?

Response - The dynamical core of EnvClimA is that of RegCM, while the chemistry/aerosol processes and feedback with the dynamics are realized like in Enviro-HIRLAM. However, the latest version of the RegCM (RegCM4) includes also a similar gas-phase chemistry scheme. There are a few differences between the EnvClimA and RegCM4-CHEM such as:

1) The photolysis rates are calculated by different methods

2) The cloud treatment of the photolysis rates in EnvClimA is different from RegCM4-CHEM

3) The Pre-processor of emissions and chemical boundary conditions treatment are different

4) Ozone feedback is not taken into account in RegCM4-CHEM yet, but it is considered in EnvClimA.

P4914L20: The low bias of O3 of EnvClimA in winter is attributed to the feedback of O3 on climate while no evidence is given to support this statement. It is not clear how O3 will influence regional climate in winter. This item should be discussed more in depth pointing towards specific underlying processes and giving quantitative evidence.

Response - The O3 feedback on climate can be stronger over regions with higher amounts of O3, however it is smaller than feedbacks of the main long-lived GHGs especially during winter seasons. However, the main reason of the low bias of O3 of EnvClimA in winter (especially over north regions) is attributed to the specifics of the RegCM climate model with underestimation of temperatures over Northern regions and more accurate representation of climate characteristics over southern regions leading to a reduced O3 bias.

P4915 para 3: EMEP is the only model to exhibit a local minimum in June-July that is also seen in the observations. It would be useful to discuss further this feature and explain why the other models fail to capture it. In order to provide a quantitative support to the discussion of this paragraph, the authors could consider adding a correlation coefficient computed from the monthly time series to Table 3.

Response - This minima in the EMEP results is rather the gap between two maxima – that associated with the springtime peak of ozone seen across much of the continent (as discussed by P. Monks, Atmos. Env., 2000) and the later summertime peak arising from increased Europe-scale photochemistry. It is not clear why the EMEP model differes from the others in this respect. This point was also noted in Colette et al., (ACP, 2011).

P4918L11: why is the 95th percentile of hourly O3 chosen while there are alternative indicators that make a consensus in terms of impacts of O3 on ecosystems and human health (AOT, SOMO)?

Response - The 95-percentile was chosen to represent changes in the higher ozone concentrations rather than illustrating changes in metrics customary used for assessing impacts on ecosystem and human health. Note that neither of daily mean concentration during summer (Fig.5) and average of daily maximum concentration during summer (Fig.6) represent a metric directly related to EU legislation.

P4919L1-8: The first paragraph of the discussion is largely irrelevant since only model projections using similar forcing (scenario and target year) should be compared.

Response - We agree and will remove this sentence in a revised version of the manuscript.

P4920L15: The sensitivity of temperature to model resolution, and, in turn, the impact on biogenic emission is not supported by quantitative grounds in the paper and should therefore not appear as one of the findings of the study. Presumably, the underlying biogenic emission model can also play an important role here.

Response - To support our argument we have added plots of the simulated temperature change from the ECHAM5 and from the downscaling with RCA3 in Fig 5 in this response.

References

Colette, A.; Granier, C.; Hodnebrog, &O. Jakobs, H.; Maurizi, A.; Nyiri, A.; Bessagnet, B.; D'Angiola, A.; D'Isidoro, M.; Gauss, M.; Meleux, F.; Memmesheimer, M.; Mieville, A.; Roul, L.; Russo, F.; Solberg, S.; Stordal, F. & Tampieri, F. Air quality trends in Europe over the past decade: a first multi-model assessment Atmos. Chem. Physics, 2011, 11, 11657-11678

Kjellström, E., Nikulin, G., Hansson, U., Strandberg, G., and Ullerstig, A.: 21st century changes in the European climate: uncertainties derived from an ensemble of regional climate model simulations, Tellus 63A, 24–40, doi:10.1111/j.1600-0870.2010.00475.x, 2011.

Monks, P. A review of the observations and origins of the spring ozone maximum Atmos. Environ., 2000, 34, 3545-3561

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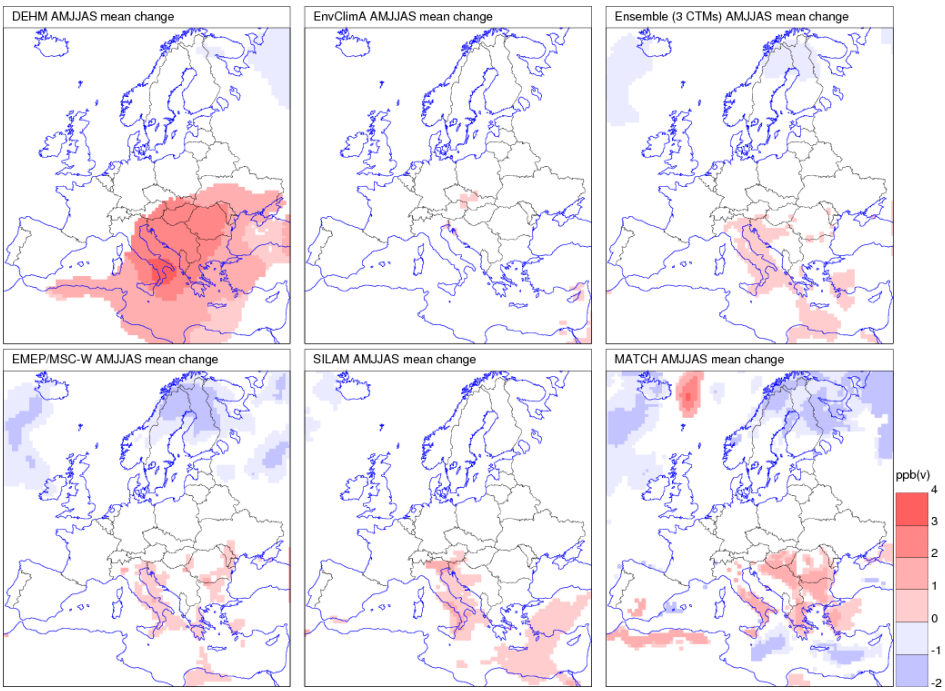

Fig. 1. Simulated April–September change in O3 concentration at the first model level. Results statistically significant at the 95% level with regard to interannual variability are plotted. Units ppb(v).

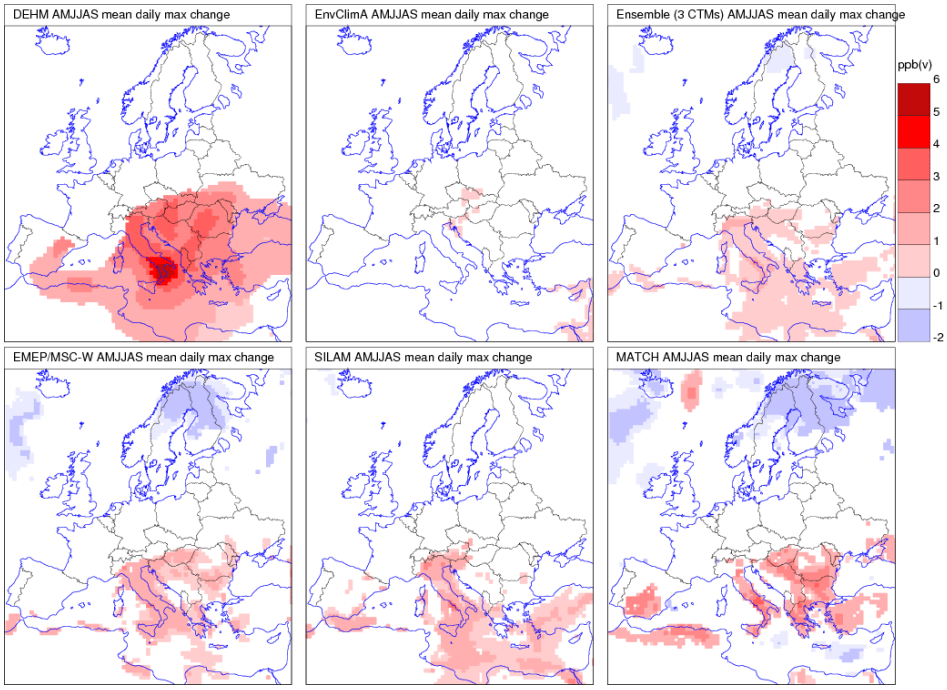

Fig. 2. Simulated Apr–Sep change in daily max O3 concentration at the first model level. Results statistically significant at the 95% level with regard to interannual variability are plotted. Units ppb(v).

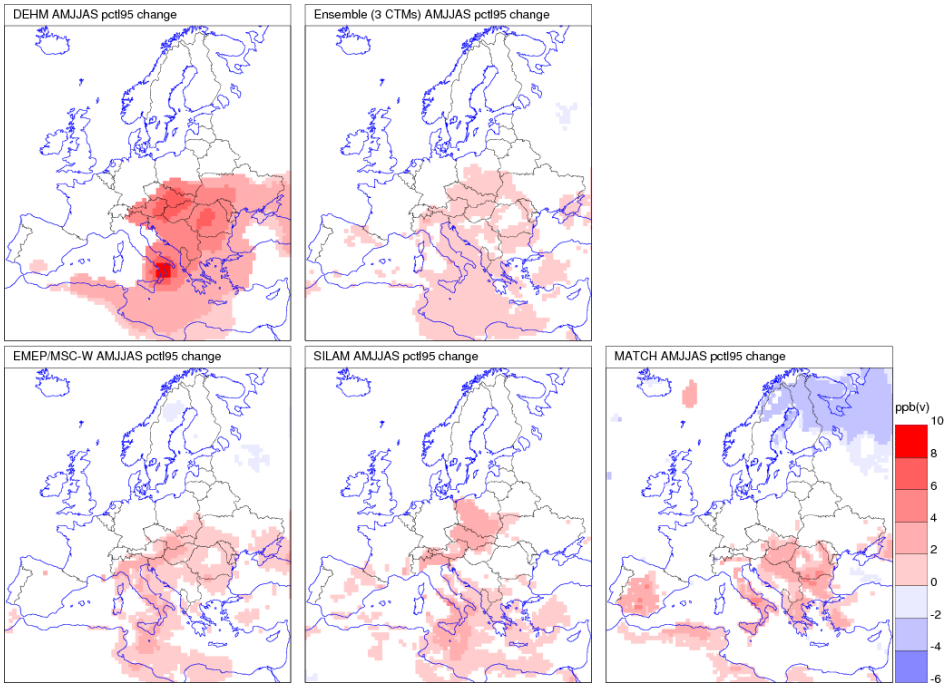

Fig. 3. Simulated Apr–Sep change in 95-percentile O3 concentration at the first model level. Results statistically significant at the 95% level with regard to interannual variability are plotted. Units ppb(v

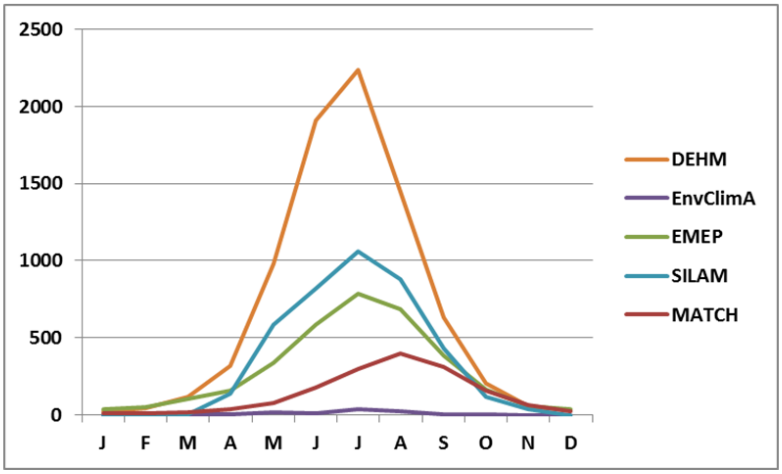

Fig. 4. Simulated seasonal variation in Isoprene emissions as an average for 2000–2009. Units Gg/month.

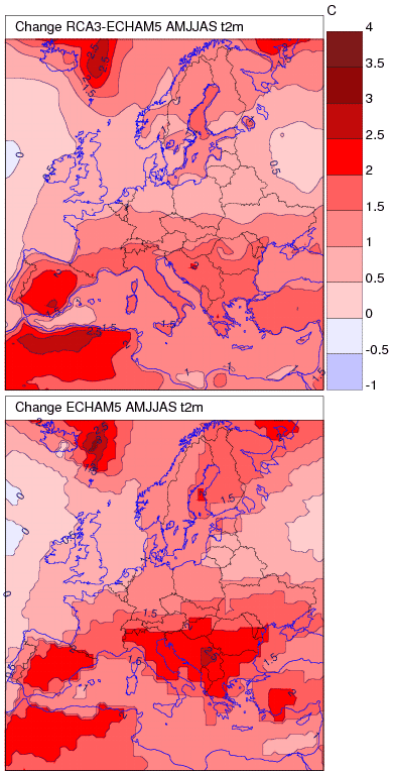

Fig. 5. Temperature change between the periods 2000-2009 and 2040-2049 simulated with ECHAM5 (bottom) and downscaling of the same simulation with RCA3 (top). Units: °C.