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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 #2. Below we address the general and specific comments raised. Technical comments will be accounted for in a revised version of the manuscript.

General comments

The current work presents simulations of 5 climate-chemistry models (4 off-line coupled and 1 online) over Europe aiming to investigate the impact of climate change on surface ozone. The control time slice of the study is selected to be 2000-2009 and the future time slice 2040-2049 (A1B scenario). Anthropogenic emissions are kept constant for the control and future simulation in order to isolate the impact of climate

change on air quality. The paper addresses the scientific question of climate-air quality interactions, which is an interesting topic, well within the scope of the journal. However, there are some issues in the methodology followed, the presentation and the discussion of the material, requiring major revisions prior to publication. The most important issues raised are described below in detail.

Specific comments

The interesting part of this work is the presentation of results of five different models, which are harmonized to the most possible extent, in order to assess the variability in surface ozone predictions. The same i) meteorological forcing (ECHAM5/RCA3) ii) boundaries (DEHM/6 hourly) iii) anthropogenic emissions (RCP4.5) iv) domain set up (0.44) are applied in the EMEP, SILAM and MATCH models. Comparison of these 3 model results shows the sensitivity of simulated surface ozone on the internal model parameterizations.

The DEHM model is configured in a coarser resolution (150 Km) and is forced directly by the GCM ECHAM5. The differences in the meteorological forcing and the spatial resolution between DEHM and EMEP/SILAM/MATCH and their impact on surface ozone are discussed in the current manuscript.

EnvClimA is the only on-line model in this study, which is set up in a fine (50 km) and has the advantage of taking into account feedbacks of climate-chemistry interaction in each time-step. The major drawback in the application of EnvClimA model is the absence of biogenic emissions (BE), which is known to be an important ozone precursor. The absence of BE in the simulations, introduces an error in the calculation of present time surface ozone and ignores the part of surface ozone future changes related to the climate-depended BE. I doubt that EnvClimA results represent valid surface ozone concentrations of the present decade, even if the summer bias appears to be below 10% (Table 3). Can the authors make an estimation of the impact of the BE-omission on background surface O3? How do they explain such a low O3 bias in summer? I am

rather critical in including EnvClimA results in the calculation of the ensemble mean (Fig 5 and 6). In some studies (Meleux et al, 2007, Atmos Environ a.o.) isoprene was identified as the most important chemical factor in O3 sensitivity in view of climate change. Ito et al, 2009, JGR, provides a very detailed description of the impact of BVOCs on surface ozone with relation to temperature changes. The EnvClimA results could be discussed as a results of an experiment without considering the impact of BE.

Response - Results from EnvClimA were not included in the calculation of the ensemble mean in Fig. 5-7. Only the SILAM, EMEP and MATCH models were included. This is stated on page 4917 and 4918 but could be added also in the figure captions.

In the EnvClimA simulation we considered the isoprene emissions from forest/grass fires. However these emissions are small compared to the biogenic emissions simulated by the other models, 125 Gg/year. EnvClimA is online coupled with the MEGAN biogenic emission model. Comparison between observed and modeled ozone concentrations using full isoprene and half biogenic isoprene emissions indicate that half isoprene emissions from MEGAN gives ozone concentrations closer to the observed value. It was therefore decided to omit the biogenic isoprene emission in EnvClimA until a more satisfactory way of including them have been found.

All 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.

2.2 Emission data

It is mentioned that all models use the same anthropogenic emissions (page 5, lines 4-10). However, in each model description there seems to be a different way of implementing anthropogenic emissions. It would be nice, if the authors could clarify if the emission annual average –or something else – is the same for all models and the temporal disaggregation differs. In DEHM anthropogenic emissions are distributed with height, including monthly-weekly-daily cycles (please clarify whether you mean daily or

hourly). In DMI-EnvClimA it is mentioned that daily and diurnal variations are not prescribed in the emission inventory (page 9, line 1). In EMEP/MSC-W emissions seem to be available only as area ground level sources (page 9, line 19) without any elevation and no diurnal variability. In SILAM emissions are disaggregated on a monthly, daily and hourly basis and are distributed with height. In MATCH information on anthropogenic emissions is missing. Authors should definitely add some information. Table 1. It would be nice if you could compare your biogenic emission totals with others found in literature from previous studies, as well as their increase in the future decade.

Response - We will clarify and harmonise the description on how emissions were treated in the different models in a revised version of the manuscript. All models except EnvClimA employed, monthly, daily and hourly cycles. The specification for the model runs stipulated that the same annual anthropogenic emissions from the RCP4.5 should be used. The process for ingesting the data is however model specific. In Table 1 in the supplement we report the annual emissions coming out from the different models. Due to technical limitations it has not been possible to extract these numbers from SILAM and EnvClimA. As can be seen the annual numbers for DEHM, EMEP and MATCH agree to within 3.7%.

In the revised version of the paper we will extend the discussion on the biogenic emissions in the present and in previous studies.

2.3 Boundary conditions

Could you please specify whether the top chemical boundaries include transport of stratospheric ozone to the troposphere?

Response - Two of the models, DEHM, and EnvClimA, include both the troposphere and the lower and middle stratosphere and therefore treat transport of stratospheric ozone to the troposphere internally. EMEP, SILAM and MATCH use top chemical boundary conditions from the DEHM model and therefore reflect the stratosphere-troposphere exchange simulated by this model.

2.4 Model description

It is important that all models cite their previous validation work, so that the reader can be informed in detail about the performance of each modeling system, its strengths and weaknesses and its ability to serve as a useful tool for climate-air quality interactions. This ability is usually based on acceptable model performance.

Response - We agree with this comment and will add relevant references in a revised version of the manuscript. We will also take in to account the additional suggestions made by the referee on section 2.4.

2.5 Model set up

Page 11, Line 15. ".. and the same ozone precursor emissions. . ." I don't think this statement is correct, since biogenic emissions are O3 precursor emissions and are different in every modeling system as shown in Table 1.

Response - We agree. This should be corrected to "anthropogenic ozone precursor emissions".

Page 11, Line 18. "..the same anthropogenic emission data from RCP4.5" Please clarify that although annual averages (or else?) are identical for all models, the emission implementation is different for each model, since the temporal disaggregation and the emission heights are different, and this is expected to have an impact on the final surface ozone concentrations.

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

3.1 Comparison to observations

Page 11, Line 30 The observations should definitely be calculated for the same timeslice as model calculations i.e. 2000-2009. The EMEP data are available.

Response - We do not think that this is a obligatory requirement since we are not using meteorological data constrained by observations for driving the CTM simulations. We

cannot expect the meteorology used to drive the CTMs to be in phase with the real meteorology. In choosing the observations we have rather tried to center the observation period around the year for which the emission data is valid i.e. 2000.

Page 12, Line 19-26 The discussion on the correlation is not sufficient. How should these numbers be interpreted? Explain why the spatial correlation is better in summer and better for the EnvClimA model.

Response - The gradients in ozone concentrations across Europe are larger during summer due to a stronger photochemical activity resulting in higher concentrations in continental and southern Europe. The models seem to capture a substantial part of these gradients and the spatial correlation therefore improves for the summer season. The EnvClimA model has the highest spatial correlation but also has the largest bias and RMSE (see Table 2 in this response) of the high resolution models for daily max. EnvClimA seems to capture the gradients to a large extent but underestimate concentrations in the northern half of the model domain substantially, especially for daily max.

All statistics are presented as averages over all EMEP stations and this does not give a very clear idea of what is happening. Most importantly, biases may cancel each other, providing a good average score which however, does not represent the truth. It is important that the scores are presented over each station (see e.g. Fig 4 and 5 of Zanis et al., 2011, Evaluation of near surface ozone in air quality simulations forced by a regional climate model over Europe for the period 1991-2000, Atmos Environ).

Response - We will add the observed station values in a revised Fig 3 and 4. These figures are included as Fig 1 and 2 in this response.

The discussion of the evaluation findings should be extended and thorough. It would be nice if, besides a measure of bias, a measure of the overall error, a measure of temporal correlation and a measure of the amplitude of variation (e.g. m/Î£ the ratio of the standard deviation of model to the standard deviation of the observation) is

also included. All results should be discussed in view of calculated metrics, avoiding qualitative expressions ("considerably", "slight positive bias").

Response - We have added the root mean square error in the statistical evaluation as a measure of the overall error. A revised version of Table 3 is given as Table 2 in the supplement. In the revised version of the manuscript we will also limit our usage of subjective expressions.

Page 12, line 31. "All models show a clear seasonal variation in line with observation" I don't quite agree with this statement. The authors should calculate temporal correlations between each model and the observations (after extending the EMEP observations to 2000-2009). Which model performs better and why? The discrepancies should be discussed thoroughly. It would be nice if you could mention the countries which are taken into account when dividing into the 4 sub-domains (NW, NS, SW, SE).

Response - Temporal correlations will be included in the revised version of Table 3 as shown in Table 2 of this response. All models have temporal correlations that are higher than 0.93 for SW and SE stations. EnvClimA has lower correlations than the other models for NW and NE. This is related to the shifted spring time peak in ozone in EnvClimA. The stations included in each sub-area are shown in Fig 3. in this response where locations are colour coded.

3.3 Climatically induced changes in ozone concentrations

It is important that each modeling team calculates the statistical significance of the future surface ozone changes and discusses the results (similar work has been performed in Andersson and Engardt, 2010, JGR; Katragkou et al., 2011, JGR). Recent studies show that the changes in surface ozone, especially in the first half of the century, are not statistically significant for a great part of the European domain. Since the surface ozone changes are investigated with respect to climate change it would be nice to see how key-meteorological parameters (temperature-solar radiation) change in the future decades. What is the temperature change according to the regional cli-

mate model? What is the pattern of changes in solar radiation? Are there any changes in the circulation patterns seen, affecting changes in ozone? What seems to be the driving factor of surface ozone change? What is the added value of the online model?

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. 4-6 in this response.

The changes in temperature at two meter level, precipitation, sunshine duration and relative humidity between the periods 2000-2009 and 2040-2049 simulated for the summer period (AMJJAS) are shown in Fig. 7 in this response.

Conclusions

The conclusions reached are very generic and qualitative. Authors must provide evaluation statistics (suggestions on evaluation metrics described above) for each model and highlight current problems in model behavior as well as suggestions for improvement. They should provide concrete ranges of O3 sensitivity among different models and discuss their significance.

Response - The conclusions on model evaluation and sensitivity to climat changes for ozone concentrations will be expanded in the revised version of the paper using the additional evaluation statisitics and plots of significant surface ozone changes provided in this response.

It is mentioned (page 3, line28) that "The inclusion of one CCM gives the possibility to analyze the importance of feedbacks of changes in ozone on meteorology". Could the authors summarize the importance of these feedbacks based on their analysis?

Response - In the lower troposphere the direct radiative forcing contribution from increasing tropospheric O3 is estimated to be less than 0.2 W/m2 on average, resulting in a relatively small warming effect (see e.g. MEGAPOLI, 2011). This forcing can be

a bit stronger over regions with higher amounts of O3 in the troposphere. Additionally, the tropospheric O3 is also the source of OH, which controls the abundance and distribution of other GHGs like methane and hydrochlorofluorocarbons. The importance of feedbacks of changes in ozone on meteorology and climate is a special subject of current studies now with further specific numerical experiments by EnsClimA with and without feedbacks. These expected results will be described in a separate paper when the study is finalized.

References

MEGAPOLI, 2011: MEGAPOLI Project Final Report, Chapter 1: "Final publishable summary report". DMI, Copenhagen, September 2011, http://megapoli.dmi.dk/publ/MEGAPOLI_FinalReport_Part1.pdf

Please also note the supplement to this comment:
http://www.atmos-chem-phys-discuss.net/12/C6051/2012/acpd-12-C6051-2012-supplement.pdf

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Interactive comment on Atmos. Chem. Phys. Discuss., 12, 4901, 2012.

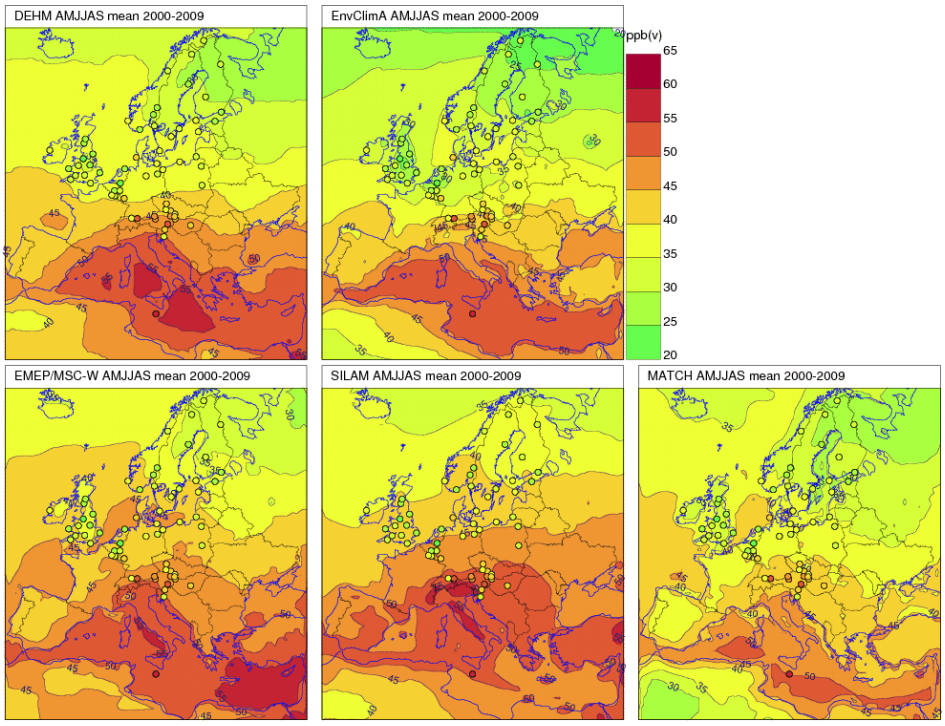

Fig. 1. Simulated Apr-Sep O3 concentration at the lowest model level for the period 2000-2009. Circles indicate the observed values at the stations used in the model evaluation given in Table 2. Units ppb(v).

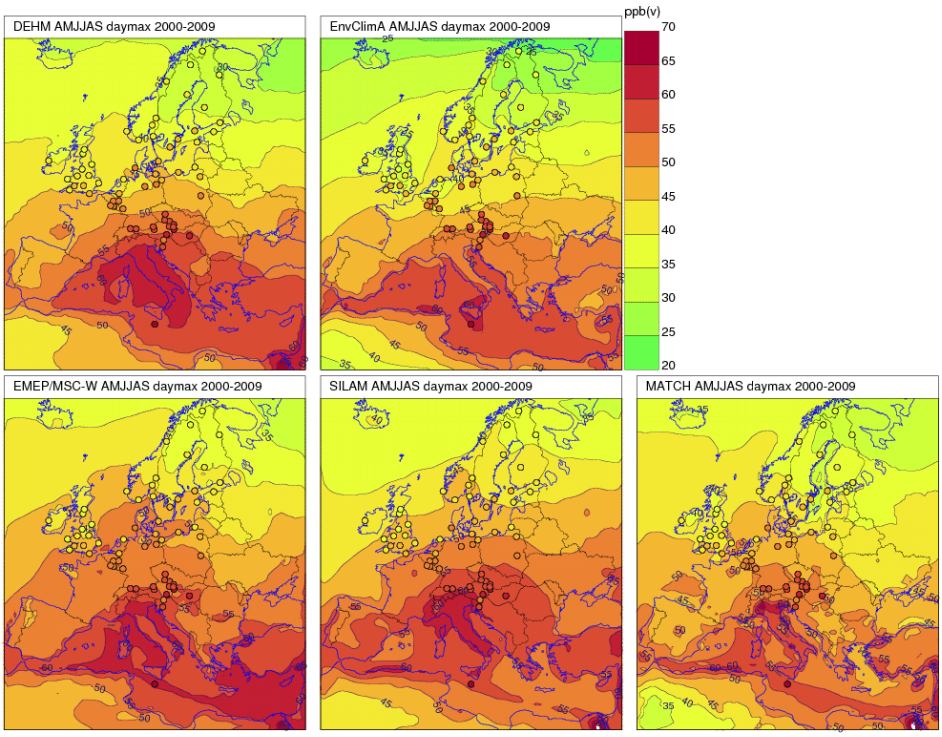

Fig. 2. Simulated Apr-Sep daily maximum O3 at the lowest model level for the reference period,. Circles indicate the observed values at the stations used in the model evaluation given in Table 2. Units ppb(v)

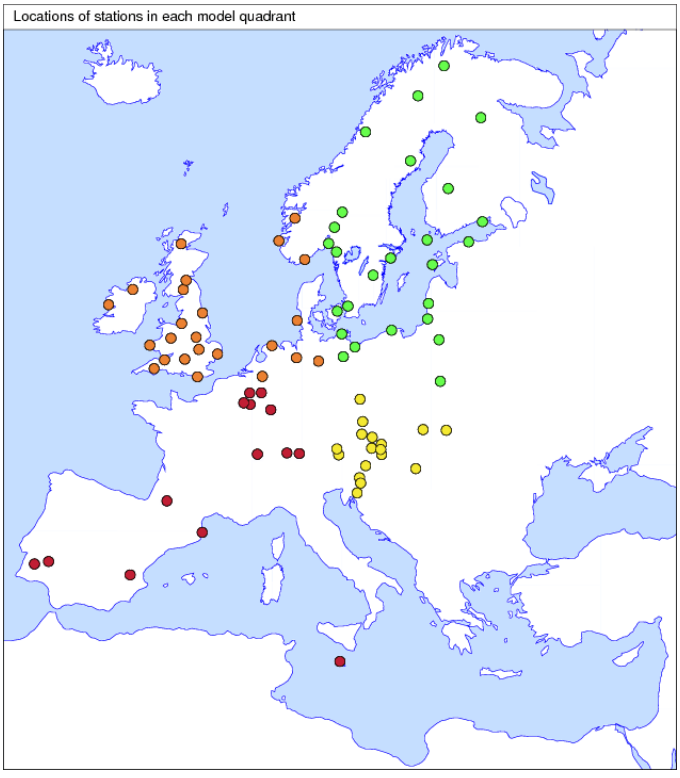

Fig. 3. Colour coded locations of the stations in each model quadrant used to derive the seasonal variation plots in Fig. 2 in the paper.

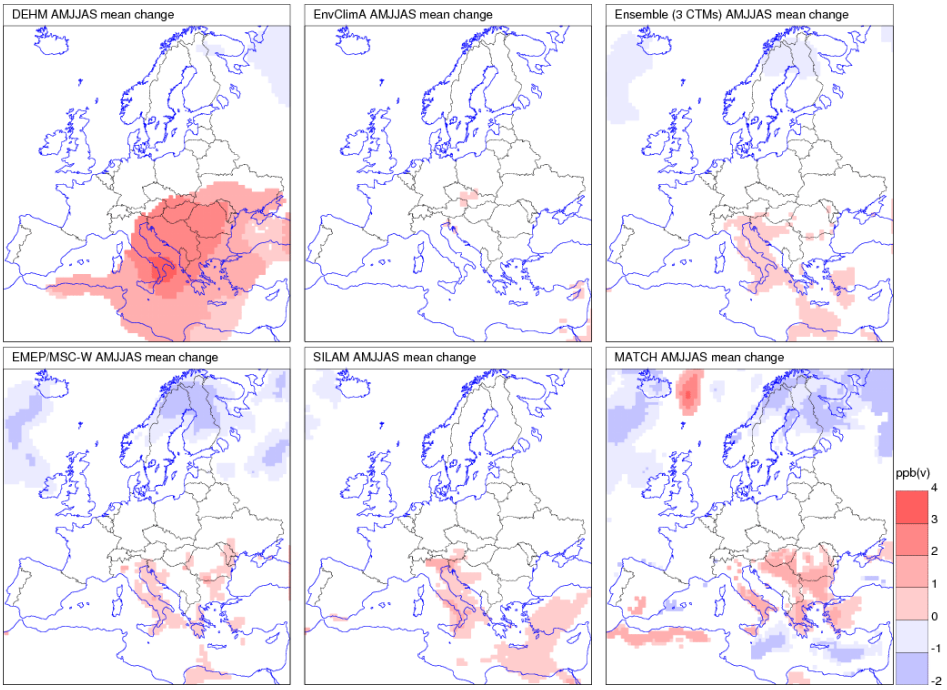

Fig. 4. Simulated Apr–Sep change in O3 concentration at the first model level. Results statistically significant at the 95% level with regard to interannual variability are plotted. Units ppb(v).

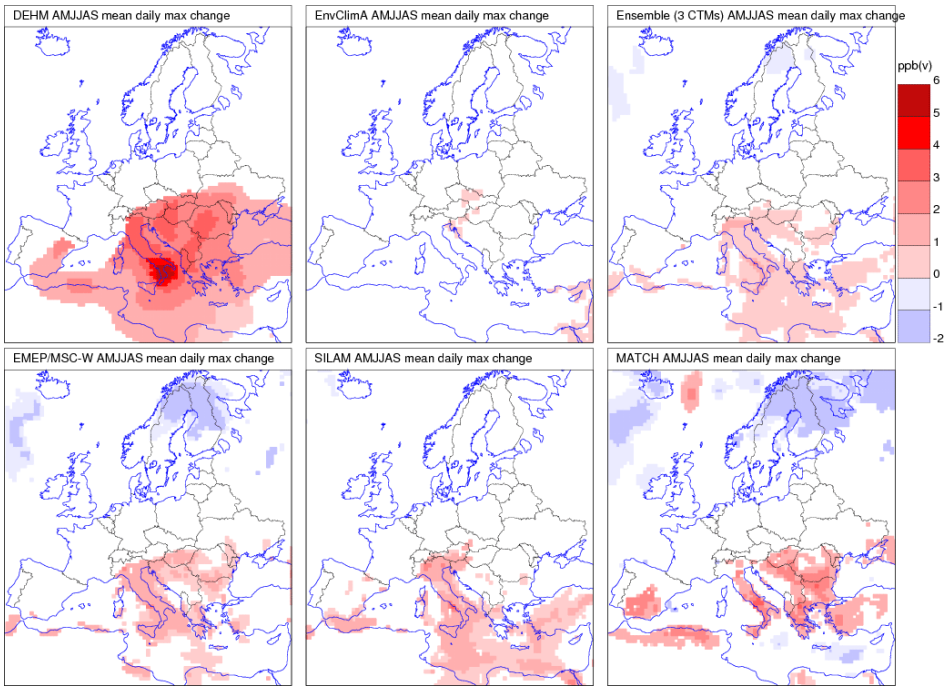

Fig. 5. Simulated Apr–Sep change in daily maximum O3 concentration at the first model level. Results statistically significant at the 95% level with regard to interannual variability are plotted. Units ppb(v

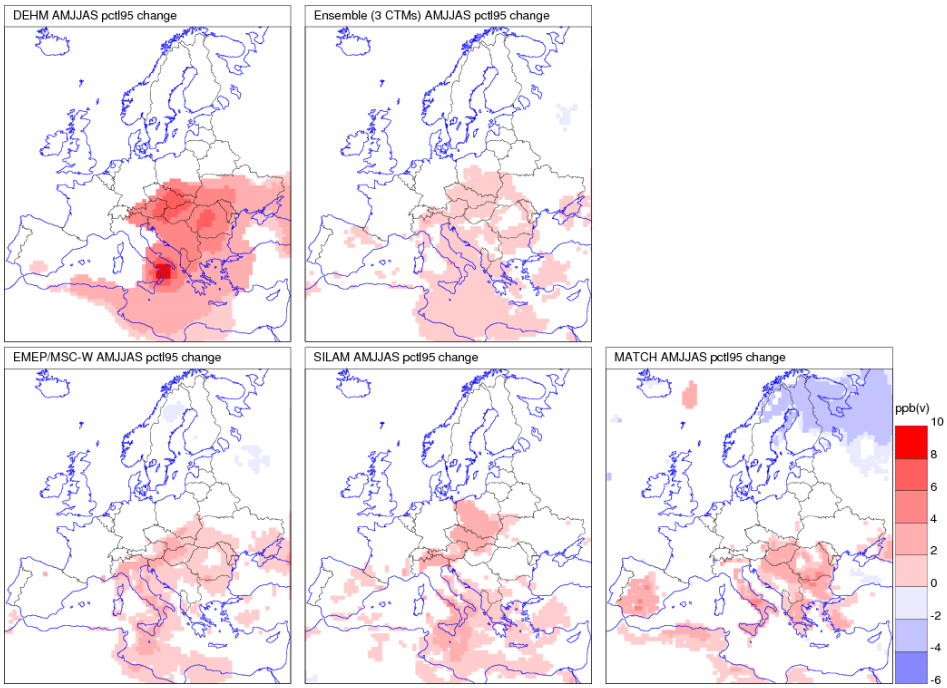

Fig. 6. Simulated Apr–Sep change in 95-percentile O3 concentration at the first model level. Results statistically significant at the 95% level with regard to interannual variability are plotted. Units ppb(v

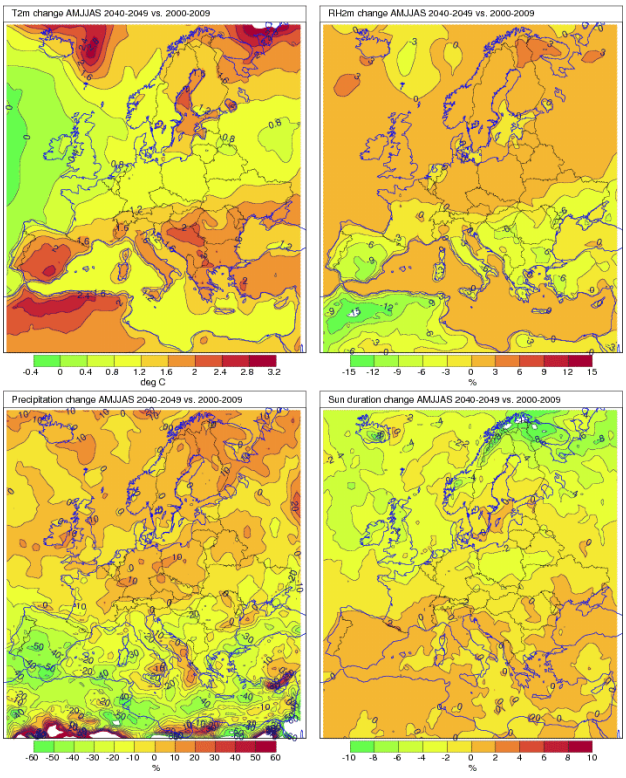

Fig. 7. Simulated April–September change 2000–2009 to 2040–2049 in two meter temperature, precipitation, sunshine duration and relative humidity at two meter simulated by RCA3. Units °C and %.