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Atmospheric
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Discussions

Interactive comment on “Severe ozone air pollution in the Persian Gulf region” *by* J. Lelieveld et al.

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We are grateful to referee #2 for the thoughtful and constructive comments that we generally agree with and will take into account in the revised manuscript.

1. The average midpoint of the lowest layer is at 30 m altitude (terrain following sigma-coordinates) and the lower 1.5 kilometer of the model (up to 857 hPa) is represented by 5 layers. We will add this information to the manuscript.

2. The O3s tracer is set to O3 throughout the stratosphere, i.e. and follows the transport and destruction processes of O3 in the troposphere, however, it is not recycled through NOx chemistry (including titration by NO and recycling into O3). This has been introduced in this version of the model by Jöckel et al. (2006) based on earlier work of

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our group, and described in more detail in several references, going back to Roelofs and Lelieveld in Tellus (1997). If O3s re-enters the stratosphere it is re-initialized at stratospheric values.

3. A more detailed description and a discussion of how well the ECHAM model represents stratosphere-troposphere exchange (STE) processes and its dependence on resolution can be found in Kentarchos et al. (2000), and references therein. STE is forced by the large-scale dynamics (wave forcing) which is well resolved by the model at T42. Further improvements are reported by Giorgetta et al. (2006) who increased the vertical resolution of the model, as used in the present study. Sensitivity simulations, as presented by Kentarchos et a. (2000) indicate that at higher horizontal resolution (i.e. T63) the STE flux may be about 10% larger than at T42, whereas further resolution increases (i.e. T106) do not lead to significant further STE flux changes. Kentarchos et al. reported excellent agreement of the representation of tropopause folding events as compared to ECMWF analyses.

4. We refer to a number of papers in a special issue of ACP about the EMAC model (see http://www.atmos-chem-phys.net/special_issue22.html). We will add a brief discussion of salient features to the revised manuscript.

5. The database for anthropogenic emissions used is EDGAR 3.2 (fast track). In general one can say that emissions of ozone precursors, notably of NOx, are fairly well constrained for Europe and the USA, but not for many other regions including the Middle East. The EDGAR 3.2 data set (see http://www.mnp.nl/edgar/) is not accompanied by information about individual source categories. We will check the database and provide information about the NOx source categories and contrast the Middle East with California in the revised manuscript. At present we are performing a study of the global NOx emissions based on SCIAMACHY satellite observations of NO2, and the preliminary results for the Middle East indicate that they are underestimated in EDGAR 3.2. We will report about this work in a separate publication. We have referred to Van der A et al (2008) in which NO2 trends, including over the Middle East, are being reported.

6. We shall provide lat/lon coordinates in the revised manuscript whenever the locations are mentioned for the first time.

7. We agree, and this is actually how we have performed the comparison of model results with TES data, for which information about averaging kernels has been provided by our colleagues at NASA JPL. We will explain this in more detail in the revision.

8. We will consider including NOx to the figure and see how much information can be added. However, it will be difficult to derive how much of the ambient NOx mixing ratios has been released from PAN and how much has been emitted locally.

9. We concur that it is actually quite likely that the EDGAR 3.2 database underestimates emissions in megacities in East Asia. This database refers to the year 2000 and will miss (2006). This will be subject of a separate publication (see point 5) and we consider the Asian emissions and consequent air pollution as not within the scope of the present study.

10. Even though near-surface circulation patterns may be similar in November compared to the summer, the intensity of photochemically active radiation, cloudiness and the removal of air pollutants by precipitation differ strongly, leading to a lower efficiency of ozone formation.

11. We show the important role of STE, but nevertheless emphasize that the pollution problem is caused by anthropogenic emissions. We have not performed tracer studies, which are rather difficult for ozone. This requires that all NOx related substances (incl. reservoir gases) are tagged simultaneously, which is a big effort and slows down the model (as e.g. done in Lelieveld and Dentener, 2000). It has furthermore been shown that the results of O3 tagging agree well with switching on/off emissions. For the contribution from South Asia, being rather small at the surface in the Mediterranean region and the Middle East, we refer to earlier work by our group (Lelieveld et al., 2002; Traub et al., 2003; Lawrence et al., 2003). For the significant contribution by lightning we refer to Li et al. (2002) whose model has a similar lightning source as our model.

Rather than presenting background information, which is difficult to define, we provide the results of a model run without anthropogenic emissions (Figure 9). As far as we know the region has not adopted air quality standards. Therefore we are mentioning the EU air quality standards which apply to the countries closest to the Middle East. We are reluctant to provide recommendations about achieving air quality standards based on a course-grid global model simulation. We rather limit ourselves to identifying the problem and recommending additional studies based on observations and regional air quality modeling. We will emphasize this more strongly in the revised manuscript.

12. We will analyze and explain the STE hotspot over the eastern Mediterranean and Middle East, and transport processes, including subsidence and mixing toward the surface, in more detail in the revised manuscript. For this we will additionally use and refer to the article by Sprenger et al., GJR 108 (2003), in which ECMWF analyses are used.

13. This is a good point that we will bring out more prominently in the revised manuscript. However, as mentioned also in the reply to point 11, we should be cautious not to over-interpret our course-grid model results in terms of air pollution control strategies. Nevertheless it seems justified to emphasize more strongly that the relatively high background levels indicate that local control options are limited. Considering the growth of NOx emissions in the Middle East, as indicated by the satellite analysis of Van der A. et al (2008), it will be important to emphasize that further emission increases in the region in future should be prevented.

14. We have investigated the inter-annual variability in the long-term run presented by Jöckel et. (2006), as mentioned in the last section. From these results it appears that the ozone maximum over the Gulf is a recurrent and robust feature although some of the details may vary. Again we are reluctant to over-interpret regional features based or global model results. A trend analysis will be more useful in using a 45-year model run (since 1958), using time-varying emissions, which we are currently performing. It is unlikely that these results will become available for the present manuscript, but we

will certainly take up the recommendation by ref #2 and look into this aspect in greater detail. This will also be a more appropriate model output dataset to study ozone tendencies associated with the Asian monsoon and the North Atlantic Oscillation, although from previous studies we have learned that the NAO influence is largely limited to the western Mediterranean region. A link with the monsoon is possible, as discussed also by Rodwell and Hoskins (2001).

We thank referee #2 for the list of corrections, which we will include into the revised manuscript.

New references:

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Roelofs, G.J., and J. Lelieveld, Model study of the influence of cross-tropopause O3 transports on tropospheric O3 levels, Tellus, 49B, 38-55, 1997.

Lawrence, M. G., P. J. Rasch, R. von Kuhlmann, J. Williams, H. Fischer, M. de Reus, J. Lelieveld, P. J. Crutzen, M. Schultz, P. Stier, H. Huntrieser, J. Heland, A. Stohl, C. Forster, H. Elbern, H. Jakobs, and R. R. Dickerson, Global chemical weather forecasts for field campaign planning: predictions and observations of large-scale features during MINOS, CONTRACE, and INDOEX, Atmos. Chem. Phys., 3, 267-289, 2003

Sprenger, M., and H. Wernli, A northern hemispheric climatology of cross-tropopause exchange for the ERA15 time period (1979-1993), J. Geophys. Res., 108, 8521, doi:10.1029/2002JD002636, 2003.

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