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8, S12198–S12205, 2009

Interactive Comment

Interactive comment on "Implications of Lagrangian transport for coupled chemistry-climate simulations" *by* A. Stenke et al.

A. Stenke et al.

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We thank the reviewer for the helpful comments and have modified the manuscript accordingly. As suggested by the reviewer we have provided some additional material in a supplement. Some of the reviewer's comments refer to technical details of the model. We have not included all details into the paper, but answered the questions in this reply. Below are our specific responses to the comments.

General comments:

- General comment on advection schemes: We are convinced that many models, GCMs or CCMs, would benefit from checking the performance of the applied advection scheme. That's an important point we want to make in our paper. For example, several of the IPCC AR4 models show a wet bias in the extratropical lowermost stratosphere (John and Soden, 2007), comparable to E39C. Schraner et al. (2008) changed the mass fixer and achieved a significantly improved model performance. We have included a short discussion of this issue in the conclusions.

- A quantification of the "badness" of an advection scheme is not possible without a direct comparison with other schemes applying certain test cases which is certainly beyond the scope of the paper. Furthermore, the performance of a transport scheme strongly depends on the tracer, its spatial distribution (occurrence of gradients), and the model resolution. In case of E39C the performance of the semi-Lagrangian scheme was obviously not sufficient. Lagrangian transport works for E39C, but things might look different in other models. However, we believe that other models might also benefit from applying a superior transport algorithm.

- Mass conservation: We have already discussed this problem in detail in Stenke et al. (2008). We tried to provide all information necessary for the understanding of the current paper without repeating results from our previous paper too much.

- CFCs: The CFCs are generally not transported in E39C, neither with the semi-Lagrangian scheme nor with ATTILA. Instead monthly mean CFC concentrations are prescribed depending on latitude and altitude. The prescribed CFC concentrations serve as input for the radiative calculations. However, since CFCs are long-lived GHGs with a nearly uniform mixing ratio, at least in the troposphere, we expect their interactive feedback to dynamics only to be of minor importance. The different treatment of CFCs and N_2O is an inherent part of the chemistry module CHEM (s. Steil et al. (1998)) and not due to ATTILA.

  We have revised the respective paragraph in Sect. 2.2 to clarify this point. Furthermore, we have added a new figure showing the mid-latitude Cly time-series.

Detailed comments:

- Abstract: The text has been re-written following the suggestions of the reviewer.
- p. 18729, l. 14: We totally agree with the reviewer. The comparison of zonal and climatological mean values can only be a first step towards a process-oriented model evaluation. A good agreement with observations does not necessarily mean that all processes are correctly captured in the model. Using standard comparisons with observations, e.g. long-lived tracer distributions, can lead to misinterpretations. We tried to demonstrate this important point with our CH_4 upper boundary sensitivity experiments. Also the study of Müller et al. (2008) is a great example. We have added this reference.
- p. 18730, l. 8,9: As shown in the paper the problems with methane are largely caused by the underrepresented stratospheric methane sink, whereas the Cly problems are caused by the advection scheme. However, we don't think it is useful to extend the discussion in the introduction, especially since Cly and CH_4 are discussed in detail in the results section. As mentioned above we included a figure showing the mid-latitude stratospheric Cly time-series.
- p. 18730, l. 21: A good reference for the diffusiveness of the semi-Lagrangian scheme is the work by Reithmeier and Sausen (2002).

  Without testing different schemes against each other is it hard to say whether another advection scheme, e.g. the Prather scheme, would be an alternative to ATTILA.
- p. 18730, l. 24: A comment has been added to the text.
- p. 18732, l. 17-20: According to our opinion it has to be distinguished between effects of the advection scheme and the general representation of the dynamics

ACPD

8, S12198–S12205, 2009

Interactive Comment

in model. With ATTILA we get clear improvements in modeled tracer distributions and via radiative feedback processes in modeled dynamics, even with a coarse horizontal resolution of T30. However, ATTILA of course does not affect the representation of waves which is limited with T30. Increasing the vertical and horizontal resolution we would expected an improved representation of the overall dynamics as well as an improved performance of the advection scheme (e.g. Roeckner et al., J. Climate, 19, 2006). However, a quantification of both effects seems not to be possible.

- p. 18732, l. 27: We have included a short description of the implemented bromine parameterisation to the supplement.

  Fig. 9: Unfortunately, we can not included an additional line showing the ozone loss without bromine parameterization as suggested by the reviewer, since we don't have a respective model simulation with E39C-A. From model runs testing the parameterization we know that the bromine induced ozone loss amounts approximately 10% of the total chemical ozone loss.

- p. 18733, l. 22: The air parcels are initialized with equal mass which is simply calculated by the total atmospheric mass divided by the number of air parcels. The number of air particles as well as the mass of the air parcels are constant during a model simulation. During advection the air parcels are considered to be isolated. However, in reality, mixing among air parcels occurs. In ATTILA the issue of inter-parcel mixing is addressed by bringing the mass mixing ratio of a species in an air parcel closer to a background mixing ratio $\bar{c}$. For this purpose, the term $(\bar{c} - c)d$ is added to the mixing ratio in an air parcel. The background value $\bar{c}$ is the average mixing ratio of all air parcels within a grid box. d is a constant parameter to control the rate of exchange. This mixing process is also mass conserving.

- p. 18735, l. 20: According to our knowledge it is not possible to observe this sim-

ACPD

8, S12198–S12205, 2009

Interactive Comment

ulated cooling directly. Using the heating rates provided by Kirchner et al. (1999) the lower stratospheric temperature response in E39C after a volcanic eruption was significantly larger than observed by MSU (s. Dameris et al.(2005), Fig. 12). With the heating rates provided by Stenchikov the simulated temperatures in the lower stratosphere are in good agreement with MSU observations (s. Figure S1 in the supplement).

- p. 18736, l. 16-24: We agree with the referee that the upper boundary conditions for Cly and NOy are essential for our model simulations and that the model results somehow depend on the information provided by the 2D model of Brühl and Crutzen (1993). Indeed there is no detailed description of this 2D model published. In order to provide some more information about the upper boundary, especially for Cly, we have extended the description of the upper boundary conditions a little bit. Furthermore, we have added the temporal evolution of the Cly upper boundary values.

  We agree with the reviewer that an additional upper boundary condition for water vapor would be a logical consequence. At the moment a consistent parameterisation of chemical processes in the upper stratosphere (i.e. photolysis of N_2O, CFCs, methane oxidation) for the next model generation based on ECHAM5/MESSy with a 5 hPa model top is under development.

  With respect to the referee's comment concerning the different treatment of CFCs and N_2O in the model we think that a further discussion of this issue is far beyond the scope of the paper. The treatment of CFCs and N_2O is an inherent part of the chemistry module CHEM. The details have already been published in Steil et al. (1998). The treatment of the upper boundary conditions as well as the formulation of the chemistry code are the same in E39C and E39C-A, only the advection of the chemical trace species has been changed.

- p. 18738, l. 23: We agree with the referee, the text was incorrect and has been

ACPD

8, S12198–S12205, 2009

changed.

- p. 18742-18743: So far we have performed the shown sensitivity experiments using an upper boundary conditions for methane. According to our opinion the boundary condition is somehow incomplete since it does not consider water vapor production.

  For a further discussion of the upper boundary condition for methane we have added a figure to the supplement comparing the simulated methane values at 10 hPa with HALOE observations. The modeled methane values are only slightly higher than the HALOE measurements (s. Fig. S2), i.e. the methane excess in the polar vortex at 50 hPa is not caused by an incorrect upper boundary. Furthermore, we included a figure showing the horizontal methane distribution in the polar vortex at 50 hPa for both model versions to the supplement (s. Fig. S3).

  The information of the upper boundary conditions is communicated to the Lagrangian air parcels by simply overwriting the respective mixing ratios on the air parcels when they reach the uppermost model level. A short explanation has been added to the text.

- p. 18744, l. 25: As mentioned above we have added the Cly upper boundary values to the polar Cly time-series, and we have included the Cly trend for northern mid-lats.

- p. 18746, l. 6 / l. 8, 9: Our discussion of Fig. 7 and 8 seems to be somehow misleading and unprecise. We have change the respective paragraph, distinguishing between the different seasons and geographical regions. Futhermore, we have added figures of total column ozone for both model versions in the supplement.

- p. 18746, Fig. 8 and 9: As discussed in Hein et al. (2000) E39C shows an exceptional high chlorine activation over Antarctica in mid-winter at the 30 hPa level, higher than in 50 hPa. The high level of chlorine activation in E39C may be

ACPD

8, S12198–S12205, 2009

Interactive Comment

attributed to the cold bias in the model's Antarctic stratosphere which is most pronounced at 30 hPa and results in a too strong formation of PSCs.

Fig. 8: We have added observed ozone profiles for the South Pole. This comparison shows that E39C-A does a better job concerning the altitude of the ozone minimum. However, the polar ozone loss is still underestimated in E39C-A.

Fig. 9: We have included ozone anomalies based on the observed ozone time-series by Fioletov et al. (2002).

- p. 18747, l. 18: Reithmeier and Sausen (2002) have already shown that ATTILA is able to maintain steeper meridional tracer gradients. They compared the horizontal distribution of Rn at 100 hPa between ATTILA and the semi-Lagrangian scheme, with the semi-Lagrangian scheme showing a smaller meridional gradient.
- p. 18748, l. 14: As mentioned above we have added the mid-latitude stratospheric Cly time-series.
- p. 18748, l. 27: The respective paragraph has been re-written.

Minor points:

- p. 18730, l. 25: 'simulated' removed
- p. 18731, l. 9: 'CLAMS' replaced by 'CLaMS', reference added
- p. 18731, l. 14: sentence re-written
- p. 18734, l. 25: 'blended' replaced by 'merged'
- p. 18737, l. 14: sentence re-written

ACPD

8, S12198–S12205, 2009

- p. 18738, l. 1: ’dynamical variability’
- p. 18738, l. 15: footnote added
- p. 18743, l. 18: Some more discussion has been included.
- p. 18744, l. 4: ’descent’ replaced by ’descend’
- p. 18747, l. 3: ’upgraded’ replaced by ’improved’
- p. 18747, l. 19: sentence re-written, reference ’Stenke et al., 2008’ added
- p. 18749, l. 2: ’reasons’ replaced by ’causes’

Interactive comment on Atmos. Chem. Phys. Discuss., 8, 18727, 2008.