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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Quantifying tracer transport in the tropical lower stratosphere using WACCM" *by* M. Abalos et al.

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We thank the referee for thoughtful suggestions on the manuscript and answer below to the specific comments and technical corrections.

Specific comments:

1) Variability linked to upwelling in p/theta-coordinates

The difference between the 'upwelling' on pressure coordinates and the 'upwelling' on isentropes could be highlighted at some point in the paper. In isentropic coordinates the upwelling is purely diabatic, which is not true in p-coordinates. At some points, the wording (like e.g., '...component of variability tied to upwelling is removed in isentropic

coordinates...', p13261/l7, also p13264/l9), could be misleading. What is removed is the variability linked to the 'adiabatic part of upwelling'. The fact that the remaining part of the variability (linked to the diabatic part of upwelling) is much smaller shows that a large part of variability linked to upwelling is related to the relative movement of pressure and -surfaces. We agree and we have changed the wording to make this clear in the manuscript (page 13261, line 7 and page 13264, line 9).

2) Horizontal transport impact on 400/440K

The discussion of isentropic (quasi-horizontal) ozone transport at different altitudes (400 and 440K) suggests that the impact of this transport on tropical ozone is, at least, equally important on 440K than on 400K, which I think is not true (Figure 9 even suggests a stronger impact at 440K). First, at 440K ozone concentrations are much higher than at 400K and I guess the 6ppbv/day at 400K in summer will have a stronger impact on tropical ozone than the 12ppbv/day at 440K in winter (in Fig. 9). Wouldn't the relative tendency (relative to the tropical mean concentration) be a more appropriate measure for this impact in Fig. 9 (similar to Fig. 7)? Furthermore, there is a seasonal movement of subtropical transport barriers (which is discussed later), with transport barriers more polewards during summer than winter. Consequently, the horizontal transport effects (e.g., Fig. 9) reach deeper into the tropics at 400K compared to 440K. Overall, I think horizontal transport affects tropical ozone much more significantly at 400K than at 440K, and this could be made clearer.

» We agree, and we have changed Figure 9 to show relative contribution of isentropic transport relative to the annual mean concentration at each level and latitude (i.e., in %/day, as in Fig. 7) instead of the contribution to the absolute ozone tendency (ppbv/day).

P13246, L22: ...highlighting cross-isentropic mean advection as the main term in the balance, I would add: 'at higher levels (2km above the tropopause)'. Near the tropopause hor. transport causes the summer ozone maximum (as you discuss later).

» In this sentence we state that cross-isentropic mean advection is the main term in the balance (in terms of the magnitude, not amplitude of the annual cycle), and this is true also at the lower levels. We have clarified this in the manuscript.

P13251, L13: Can you speculate about the reasons for the temperature/tropopause bias in WACCM, and about related biases in tropical upwelling?

» We have performed comparisons of the time-mean and annual cycle amplitude vertical structures of temperature and tracers in our WACCM simulation with output from a high-vertical resolution version of WACCM which was available to us after submitting the manuscript. The results suggest that the limited vertical resolution plays an important role in producing the observed bias in the tropopause height. We have added some comments on this in Section 5 (Summary and Discussion). Nevertheless, the vertical shift could also be partly associated with biases in the magnitude of upwelling in the model.

P13255, L10: For ozone, eddy transport makes a substantial contribution in NH subtropics.

» This is right, and we have corrected the sentence in the manuscript.

P13255, L15: For ozone, the largest contribution due to advection occurs slightly below the region of maximum vertical gradients. Is this an indication that horizontal advection is not totally negligible (the maximum meridional gradients occur slightly below)?

» This is right: at levels close to the tropopause (below $\sim$70 hPa) the meridional advection makes a non-negligible contribution to the total advective transport of ozone (in contrast with upper levels where upwelling dominates). The relatively large poleward velocities near the tropopause (i.e. the shallow branch of the Brewer-Dobson circulation) have an enhanced effect decreasing ozone at these levels because they coincide with stronger meridional gradients (as seen in the bottom-left panel). Figure A1 also shows that the contribution of horizontal advection near the tropopause is larger than

at higher levels. We have included this in the manuscript.

P13257, L6ff: Figure A1 shows a clear summer maximum also in the advective horizontal transport contribution.

» The peak in horizontal transport in Fig. A1a is negligible compared to the other terms in the balance. There is a somewhat more relevant peak in the isentropic advective transport (Fig. A1b), which could play a role in the reduced ozone seasonality observed at 440 K.

P13259, L10ff: The fact that hor. transport of ozone occurs mainly at levels around the tropopause is consistent with Konopka et al. (2009,2010) and Ploeger et al. (2012). E.g., Fig. 4/5 of Ploeger et al. (2012) show the main effect of hor. transport related to the Asian monsoon between about 370-420K.

» OK, we have added this (page 13262, line 20).

P13260, L26ff: How does Fig. 13 look if the tendencies are taken from the isentropic formulation of the continuity equation?

» On isentropic coordinates the sub-seasonal fluctuations in the tracer tendencies are best correlated with eddy isentropic transport for ozone, while for CO the correlations for cross-and isentropic transport are comparable. This is explicitly mentioned in page 13261, lines 6-11.

Technical corrections:

P13247, L18: 'separating' better than limiting?

» We agree and have changed it.

P13247, L23: I think Rosenlof et al. (1997) argue that rapid horizontal transport extends up to 450K.

» Yes, we have changed it.

P13248, L25: ...in upwelling, in turn resulting from variations in wave driving.

» We added this.

P13254, L14: Perhaps mention that r is the horizontal gradient.

» The divergence operator here is applied to the dimensions y and z.

P13257, L2ff: ...Fig. A1.

» Changed.

P13258, L2: There is a summer maximum in isentropic transport still at 420K, coinciding with the ozone tendency maximum.

» As mentioned above, Figure 1Ab shows a small seasonality in advection along the isentropes at all levels. However, in this sentence we emphasize the transition in the net isentropic transport from a clear summer peak near the tropopause to a smaller seasonality at higher levels seen in Figures 8 and 9.

P13259, L11: ...lower stratosphere (around 70hPa).

» OK, it has been added.

P13262, L7: ...higher levels around 70hPa.

» OK, it has been added.

P13264, L6: . . .correlated with temperature for O3. . ..

» It has been changed.

Fig. 7 caption: Are there any dashed: negative contours in the figure. We have changed Figure 7 to make the dashed contours more clearly distinguishable.

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