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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Variability in upwelling across the tropical tropopause and correlations with tracers in the lower stratosphere" *by* M. Abalos et al.

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We acknowledge the Anonymous Referee #2 for useful critics and comments on the manuscript.

Overall, we agree with the referee in that, while being clearly beyond the scope of this paper to resolve the cause of the conflicting results in the literature regarding the main driver of the ozone seasonality above the tropical tropopause, it would be certainly beneficial to further address this issue in the manuscript. Therefore, we have extended the discussion for the reviewed version of the manuscript, providing the reader some hints on the possible reasons for the discrepancy and thus pointing out the specific

needs for future research on this issue (starting on line 26, page 18835).

In addition to the changes made in the manuscript and the responses to the minor comments below, in the following paragraphs we shortly address some specific points raised by the referee in the general comments.

"The authors use the TEM formalism to show that there are statistically significant correlations between tropical upwelling and ozone and temperature variability on time scales from 10 days or so up to seasonal. However, correlation does not prove causation."

We certainly agree with the referee that correlation does not prove causation in general. However, in the case under consideration, the significant correlations between tropical upwelling and tracer tendencies are accompanied by an underlying simple physical mechanism (i.e. upwelling acting on a large background vertical gradient can induce a local change in the tracer concentration). From our point of view the combination of significant correlations and a plausible physical explanation strongly suggests the causal origin of the correlations.

"The Ploeger et al. paper has essentially raised the bar on understanding the variability of ozone in the lower tropical stratosphere. I don't think that the current paper advances our understanding any further since the end result is essentially the same as Randel et al. (2007)".

We would like to highlight the novel contributions of the present work in response to this comment. Our results are, in fact, consistent with the conclusions in Randel et al. (2007), who argue that the vertical structure and timing of the seasonal cycle in ozone can be explained by the effect of tropical upwelling on the large vertical gradients observed in these tracers. However, we do believe that the present paper contributes to the advance in the understanding of ozone variability in the lower tropical stratosphere. In this work, tracer vertical advection is obtained from carefully computed tropical upwelling, which is proven to be reliable by the good agreement among three independent

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estimates. We then examine the full tracer budget analysis, which has not been done before. Finally, the variability in ozone is shown to be directly related to the variability in tropical upwelling, both on seasonal and sub-seasonal timescales. This constitutes new observational evidence of the role of upwelling in forcing temporal variations in tracer concentration in this region.

“Does the TEM analysis effectively separate advection and mixing?”

In the present study it is most important to isolate the effect of vertical advection from other transport terms. There is no obvious reason for us why the TEM analysis should not separate vertical advection from quasi-isentropic mixing in this region. In fact, the vertical component of the TEM residual circulation is primarily associated to the zonal mean upward transport, and it has been shown to be a good representation of the Lagrangian vertical tracer transport (e.g. Shepherd, 2007 and references therein).

“What effect does the use of pressure vs. potential temperature coordinates have on the analysis?”

We are aware that this could be one of the reasons for the mentioned discrepancy, and this issue is discussed in the extended version of section 4 (Summary and discussion). See also the response to the Anonymous Referee #3.

Minor comments:

"Pg. 18826, lines 8-10: There is good agreement between wm and wq at 100 and 70 hPa, but not so much at 80 hPa. Any explanation for why this might be the case?"

Figure 5 shows that the eddy term in the thermodynamic balance is largest at 80 hPa and, given that this term is not included in the calculations of wQ*, this leads to larger uncertainties at this level. However, although the magnitude and seasonality of wQ* differs from that of wm*, the overall variability is not significantly affected, so that the linear correlations are still high at this level (see Figure 4). This is explained in lines 13-20 on page 18825 and lines 1-4 on page 18828.

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Interactive Comment

"Pg. 18832: The correlations shown in Fig. 10b may be statistically significant but with values of 0.7 and lower this means the upwelling is explaining less than half of the tracer variance. And less than a quarter of the variance is explained at 80 hPa and below. Is this consistent with upwelling being the primary controlling mechanism of ozone variability in the lower tropical stratosphere?"

We agree with the referee that the correlations imply less than 50% of tracer tendency variance explained by upwelling, and hence it is not correct to state that tropical upwelling is the dominant control mechanism of sub-seasonal tracer variability in the lower stratosphere. We have included a new sentence to explicitly clarify this issue (on line 5, page 18834). On the other hand, the fact that the correlations in Figure 10b are lower below 70 hPa is expected, given the smaller vertical gradient in ozone at these lower levels, and this is indicated in the manuscript. We modified the sentence starting on line 5, page 18834 accordingly, to make the wording more accurate: Before: "Overall, [. . .] are strong evidence that sub-seasonal variations in upwelling are a primary mechanism for [. . .]". Now: "Overall, [. . .] are strong evidence that sub-seasonal variations in upwelling make an important contribution to [. . .], in particular at the levels where vertical gradients are stronger."

"Pg. 18833: Again in Fig. 11a the correlation may be significant but there is a lot of spread around the linear correlation. Just over a third of variance is explained at this level by the correlation. It would be at least good to mention this."

In this case the percentage of explained variance is not a particularly relevant measure, since we are not implying causality between the temperature and the tracer tendencies. Hence we consider the linear correlation a more indicative parameter in order to describe the spread in the scatter plots.

"Pg. 18834, line 18: "primarily" should be "primary"."

We agree and we will change it the reviewed version of the manuscript.

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References

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Shepherd, T. G.: Transport in the Middle Atmosphere, Journal of the Meteorological Society of Japan, 85, 165–191, 2007.

Interactive comment on Atmos. Chem. Phys. Discuss., 12, 18817, 2012.