

## ***Interactive comment on “Quantifying transport into the Arctic lowermost stratosphere” by A. Werner et al.***

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### **to Anonymous Referee 1:**

*"p1412: Discuss the implications using a fixed threshold of 400K as boundary condition, since vertical gradients occur also inside the vortex."*

In section 2, the referee refers to, only the ideal tracer is described which does not implicate such a problem. Nevertheless, I do agree with the referee, that there are strong vertical gradients in the vortex region, furthermore horizontal inhomogenities have to be considered. However, this is accounted for with a variable boundary condition in the vortex region and additionally a rather large error margins (discussed in section 4 and see subsections 4.2 and 4.3). The sensitivity of the mass balance system to these

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errors has been evaluated in the sensitivity study that has been described in section 5.2.

*"You motivate the 400K on p.1410,l.26, which seems to be reasonable. Note that the associated mixing ratios at 400 K also are rather variable over different years particularly over the Arctic. How does this add to the fractions which you obtain? Are the numbers typical or what is the expected range between different years?"*

The year-to-year variability has not been regarded in this study but as a matter of fact, I have raised the question for the representativeness of these results myself at the end of the conclusion. However, in the conclusions it has been mentioned (p.1428), that this variability has an influence on the composition of the arctic LMS. To what extent can hardly be derived as this was the first time using in-situ observations. Comparisons with previous studies using model data are difficult, as derived fractions (i.e Günther et al, 2008) are based upon different definitions.

However, i.e. Günther et al.(2008) or Grooß et al. (2008) the winter 2002/2003 exhibited some extensive mixing across the vortex edge above 400 K and a rather dynamic winter after mid January and thus an exceptional winter. Nevertheless, their derived numbers for the impact of vortex air to mid-latitude O3 depletion in this winter are in agreement with earlier studies of other winters, implying that the numbers are in a typical range. I have inserted this remark in the conclusions.

*"Note that the extreme profiles are taken in this approach (the low N2O and high N2O cases). How representative are these also in terms for other NH-regions or other winters than 2003?"*

Tracer measurements have of the winter 2003 have been compared to SPURT data and Polaris data and show a good agreement, though different regions and different years were sampled. Furthermore, the data span a rather large equivalent latitude

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(see Fig. 10) over a time span of several weeks. Thus, the measurements should be representative for a typical LMS in the northern hemisphere.

Nevertheless, as mentioned in the conclusion the shown results are valid for the European northern hemisphere in the winter 2003. that the results given here are representative for the examined winter 2003 and for the European NH.

*"If you weight the fractions for all your data (not only using the 'extreme' N<sub>2</sub>O-profiles) on a given Theta-interval, how representative are these compared to the total amount of data?"*

I do not know wether I properly understand your question. What do you mean by all your data? I hope this will answer your question:

I used all tracer data to solve the equation system, not only the N<sub>2</sub>O data. Only results are shown for data following the upper and lower envelope of the N<sub>2</sub>O profile. Fractions for those data filling the space between the extremes profiles lie somewhere between the fraction of the upper envelope profile and the lower envelope profile.

I slightly revised the description how the data were separated in order to clarify this point.

*"Concerning particularly H<sub>2</sub>O, which is mentioned as being the major constraint for the tropospheric fraction: How do different tropospheric source regions impact the results (e.g. tropical and extratropical tropopause)? Do you assume pure isentropic mixing from the tropopause to higher latitudes below Theta=380K? Since H<sub>2</sub>O is temperature dependent, you would underestimate the tropospheric fraction e.g. at Theta = 360K if a significant amount of tropospheric air from the tropics originating at 380K were included in the air parcel. Is this included in the error?"*

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Yes, a cross-isentropic transport would indeed lead to a underestimation in this case. However, the error bars for the tropospheric boundary function (Fig. 6 plus p.1419, l. 16-18) are rather large, especially in the theta interval where the vertical gradient of the H<sub>2</sub>O trop. boundary function is strong. Thus, cross-isentropic transport over a vertical distance of a view K is accounted for. An error of 10ppm for H<sub>2</sub>O in theta levels between 300K-340K, accounts for a vertical error of almost  $\pm 20$ K.

This is a good point and the above given explanation was inserted in the respective section!

*"Please add some uncertainties estimates to the numbers in the abstract".*

Ok, uncertainties are in the range of  $\pm 15\%$  and have been added to the abstract.

*"p1409,114-16: deeper into the stratosphere, deeper than? Please specify."*

Relatively young tropospheric influence can detected up to 450 K in the so-called tropically controlled transition region (Rosenlof et al., 1997). But in case of transport processes through the extra tropical tropopause the respective tropospheric air masses will certainly not be detected above 380 K. I have re-formulated the sentence.

*"p1412,111/121: What does the abbreviations QR and QL stand for?"*

QR and LQ - Algorithms are the established names for the below given matrix decomposition and not really an abbreviation. I still think a more detailed description is not necessary as the referring cites were given in the paper.

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QR: Here a Matrix  $A(n \times m)$  can be written as, i.e.  $A = Q * R$ , where  $Q$  is the quadratic  $n \times n$  matrix and  $R$  the upper right triangular  $n \times m$  matrix. LQ:  $A = L * Q$ , here the  $L$  is the lower (left) triangular ( $n \times m$ ) matrix.

*"1414: I18: Do you mean  $\Delta\theta < -10K$ ? I guess so (see I.22)."*

Yes! Changed this in the paper.

*"1414: I16. The ozone variability is of course small with respect to stratospheric variability, but how large is it compared to tropopause variability or typical latitudinal gradient along the tropopause?"*

The tropospheric  $O_3$  values are in the range of 0 - 100 ppb (IPPC), the value along the 400K isentrope can vary by nearly 2 ppm, thus a factor 20 compared to the tropospheric variability. I am, however, not sure whether this answers your question?

*"1415: I10: How does this fit to the findings of Engel et al, 2006, or more recently Hegglin and Shepherd, 2007 who report significant changing influence from overworld air above  $\theta=380K$  from autumn to winter? Maybe you could mention some typical ranges for your tracers or a range of variability at 400K."*

Of course due to ongoing descent of air from above 380 K there is a seasonal change of air masses between autumn and winter. But comparisons of several in-situ measurements of the regarded tracers (as described in the paper p.1415, I.8) at 400 K in the mid-latitudes (well southward of the vortex edge!) in autumn and winter show relatively small differences in the mixing ratio for  $2O_2$ :4%, CFC-11: 9%,  $CH_4$ : 3%, For

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the more sensitive tracers like O3 (35%) or H-1211 (12%) this change is more severe. Nevertheless, the inter-seasonal variability is of the same magnitude (average of the January O3 data: 614 ppb  $\pm$  200 ppb, H-1211: 3.28 ppt  $\pm$ 0.3 ppt). Thus the this boundary is described with a constant mixing ratio considering the variability (temporal and spatial) with a very conservatively estimated error (see p.1415,l.22,23 and Table 1 on p. 1436).

I added some numbers to the mentioned paragraph.

*"Fig.4 : Mention green symbols in the caption Fig.8/9 : Please indicate more clearly the different date of the underlying data (e.g. as plot title), it is difficult to find in the tiny legend."*

I agree! Green symbols will be mentioned; Fig. 8/9 will be plotted in a new version.

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