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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Variability of residence time in the Tropical Tropopause Layer during Northern Hemisphere winter" *by* K. Krüger et al.

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We would like to thank the two anonymous reviewers for their useful comments and suggestions, which help to clarify and improve our paper.

Combined answers to reviewer 1 and 2 general remarks:

As suggested by reviewer 1 we will add a discussion section in the current paper addressing the variability of transit times, possible long-term changes and the effects of latent heating and mixing on transit times. Previous conclusions regarding possible long-term changes are shifted to the discussion now (see detailed comments below). The discussion will consist of the following points:

1) We will discuss the uncertainties of the radiative heating and hence residence time,

which were provided by the first study by Krüger et al., 2008 (K08). As we have already included a detailed case study in K08, we feel that repeating the details of this case study in the current paper is redundant. However, we agree with the reviewer that the results of the case study are of general interest for the readers, and therefore we will summarize the most important findings (based on Fig. 1 and 2 from K08) in our new paper including the effects of the temperature bias and uncertainties in the ozone fields.

2) We will discuss the effects of mixing and latent heat, which are not included in our current study. These effects are addressed by Fueglistaler et al., 2009, who found a residual term of up to 0.1 K/day around the 360K layer in the tropics and by Ploeger et al., 2009, who derived 10% longer residence times for the 370K-400K when including mixing and latent heating.

3) The effects of ECMWF cirrus clouds on our trajectory calculations were investigated by our companion studies by Immler et al., 2007 and Immler et al., 2008, which will be mentioned. Cirrus clouds are resolved in the ECMWF cloud input fields, which we are using.

4) Previous derived transit times from other observational estimates as suggested by the reviewer are added in the discussion section as well. However, the suggested reference by Andrews et al., 1999 is restricted to tropical layers between 390 and 460K and Boering et al 1994 does not provide transit times for the TTL.

5) The uncertainty for the 360-380 K in contrast to the 380-400K layers i.e., the role of latent heating and mixing for the 360-380K is addressed in the new discussion section now.

Detailed comments to reviewer 2:

L7-17: The abstract is changed according to the three suggestions.

p12598 l24: changed to "due to their potential for depleting stratospheric ozone".

p12598 l26: 'bromocarbons', plural is added.

p12599 l4: now added ˆˆ: “where especially the maritime continent during NH winter season plays a dominant role (ˆNewell and Gould-Stewart (1981)ˆ, Holton and Gettelman, 2001, ˆBonazzola and Haynes 2004, Fueglistaler et al 2004ˆ).”

p12599 l20: Changed to ˆˆ: However, K08 found that differences in the density ˆof LCP trajectories that reach the stratosphereˆ, the distribution of diabatic ascent and in the residence time between the LCP and 400K are all large.

p12600: “To confirm – Q is simply Delta Theta/ residence time (for each trajectory)? So for 360K-380K and similar layers the statistics of Q is completely determined by the statistics of residence time (and vice versa)?” Yes this is the common procedure, the info is added for clarification.

p12601 l18: 'tilde' = zonal mean is added in the ms now.

p12602 l8: Figure 1, 1962-2001 vs 1992-2001 averages: The mentioned contradiction is already published in Krüger et al 2008 and a detailed discussion and possible reasons for it (less wave driving in the early to mid 1990s, strong El Nino 1997/98) are given in K08. The LCP temperature and Q differences between 1962-2001 and 1962-1991 are very small compared to the 1992-2001 average. Thus showing the 1962-1991 period won't change the results. The LCP temperature for the 1992-2001 (and 2000-2004) average shows a distinct difference to periods before. This is also in line with other papers comparing ERA40 temperatures (100hPa) with independent data sets (e.g. Fueglistaler and Haynes 2005; Dhomse et al 2008). As our focus lies on interannaual variability and not on trends, we do think that we can use the pre-satellite era of ERA40 data. (Note in contrast to other reanalyses the data inhomogeneities of EAR40 are pronounced during the satellite era compared to the pre-satellite era.) However, we will rewrite the sentence to: “The other two time periods reflect the results shown previously by K08.”

p12605 l24: changed to “might“.

p12606 l12: See comments above. The quality of ERA40 temperatures are discussed in detail by K08 and Fueglistaler and Haynes 2005 which we will refer to. ERA40 temperature in the tropical tropopause (100hPa) have a cold bias in the beginning of the 1980s (e.g. Fueglistaler et al 2005, Dhomse et al 2008), which might have caused this one outlier in fig. 3 and fig 4 (DJF 1982/83). This information is now added in the figure description and in the discussion section.

Figure 4: The requested details are added accordingly.

p12606 l26: changed to (new ˆˆ): “Figure 4b reveals the maximum anticorrelation between the subtropical wave driving ˆ(divF averaged between 10-20° S/ N)ˆ at 133 hPa and tau_360 K−400 K.” Figure 4 refers to the results by Randel et al 2008 as is clearly stated in the ms (p12607 line 5-7).

p12606 l27: “This paragraph seems rambling and unfocussed.” For a hopefully better clarification: A convergence (divF<0) means that we have enhanced wave driving e.g. the mean flow is getting decelerated which leads to an acceleration of the BDC, stronger upwelling in the TTL, hence a shorter residence time in the TTL! According to this a stronger vertical EP flux (EP flux _z) leads to enhanced wave propagation e.g. wave driving, the mean flow is getting decelerated, which leads to an acceleration of the BDC, stronger upwelling in the TTL, hence a shorter residence time in the TTL! The shown anticorrelation between the EP flux quantities and the residence time for Fig. 4 b is therefore correct.

p12608 l14: “I don't really see why the trend towards shorter residence times should correspond straightforwardly to the trend in LCP tropopause height.... Why 'tropospherically induced'? ...” When the tropical tropopause height increases (above 360K) (Seidel et al and others, LCP theta in figure 1 this study), we can expect a higher cloud top/convection top hence the altitude range of tropospheric influences increases (above 360K), hence the vertical velocities can increase (also above 360K), hence the residence time have to shorten between 360-380K and 360-400K. As it is a hypothesis it will be shifted to the discussion section.

p12608 l26: 'maximum density of LCP trajectories' needs explanation – see previous comment on this. What exactly are 'LCP trajectories'? added ˆˆ: "coinciding with the maximum density of LCP crossing points of trajectories ˆthat reach the stratosphereˆ."

References:

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