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Interactive Comment

Interactive comment on "Seasonal and inter-annual variations in Troposphere-to-Stratosphere Transport from the Tropical Tropopause Layer" *by* J. G. Levine et al.

J. G. Levine et al.

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Responses to Referee 3

We would like to thank the referee for his/her comments. We believe the paper has been improved in the process of responding to them.

Responses to main comments

1. Given the page number cited (503) we assume that the reference to Figure 9 is a typo and the referee is referring to Figure 8. We can see that we did not make it clear that we are trying a cautious, probabilistic approach in motivating a link between Gaussian and Lagrangian frameworks of tropical motion with rather simple diagnostics.

We think that the transformed-Eulerian mean (TEM) quantities, as opposed to heating rates, are the best measures with which to interpret our kinematic trajectories, on the grounds that the latter may be artificially smooth. It is less than straightforward to evaluate the TEM measures reliably with 6 hourly data [see the ERA-40 Atlas (http://www.ecmwf.int/publications/library/do/references/show?id=86620; pages 166-167) for meridional streamfunction estimates for the four seasons]. However, the isentropic mass-weighted meridional circulation/streamfunction from ERA-40 resembles well the TEM circulation [Juckes et al., 1994]. Unsurprisingly the streamfunction does not contradict the seasonality of v_bar in the tropical belt at 150hPa. In DJF, positive values are found around the Equator at 360K, indicating a circulation cell towards the North Pole. In MAM, the streamfunction is close to zero in this area and changes sign for JJA and SON. The negative values in JJA and SON are indicative of a circulation cell towards the South Pole. The seasonality in v_bar, as illustrated in Figure 8b, is more pronounced than that apparent from the streamfunction, owing to the averaging of v_bar over a selective range of longitudes and the interannual variability of the streamfunction (roughly 10-20% in this region).

Through Figure 8, we intend to remind the reader that there is a complex annual cycle in the large scale circulation and that the region of maximum ascent changes position (in latitude) relative to the region of strongest meridional motion. We also note that Eulerian zonal mean vertical velocities around the equator are not expected to differ significantly from the residual mean vertical velocities as defined in the TEM formalism [Garcia et al., 2007].

In light of the referee’s comments, we have revised much of section 4.2, including the main points made above. We have also removed what was Figure 8a.

Garcia, R. R., Marsh, D. R., Kinnison, D. E., Boville, B. A., and Sassi, F., Simulation of secular trends in the middle atmosphere, 1950-2003, J. Geophys. Res., 112, doi:10.1029/2006JD007485, 2007.

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Juckes, M. N., James, I. N., and Blackburn, M., The influence of Antarctica on the momentum budget of the southern extratropics, Q. J. R. Meteorol. Soc., 120, pp 1017-1044, 1994.

2. We have not filtered out air parcels undergoing shallow TST on the basis that this could be important in determining the chemical composition of the lowermost stratosphere. To make clear to the reader that our calculations include shallow TST, we have added a note to this effect in the last paragraph of section 2. Here, we have also included the fractions of air parcels we identify as undergoing TST that spend 9 days or more in the stratosphere, both in total (i.e. integrated over a four-week period) and upon first entering the stratosphere, based on a small sample of trajectories (those calculated in January and July 2001). We have also noted in the final paragraph of section 4.1 that our findings, regarding the seasonality of TST, may be influenced by the inclusion of air parcels undergoing shallow TST.

Responses to other comments and suggestions

1. We have removed the sentence contrasting the homogeneity of TST (including transport into the ELS) with transport to the overworld predominantly from the region of the TTL above the West Pacific. We have also added a sentence to the first paragraph of section 3.6 noting that previous studies have identified the region of the TTL above the West Pacific as the predominant region for dehydration and the preferred origin of air reaching the overworld.

2. We have not added a comment as suggested. As in our earlier study [Levine et al., 2007], we use a global, Eulerian model (driven by ECMWF analyses) to locate the tropopause and identify if, and where, each air parcel enters the stratosphere. At each timestep, in each model column, we identify the grid box that contains the tropopause. Only the trajectories that enter the region above this box (i.e. traverse the entire box containing the tropopause) are identified as undergoing TST. We do not therefore expect our quantification of TST (in the tropics) to be sensitive to modest

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changes in the height of the cold-point tropopause.

Levine, J. G., Braesicke, P., Harris, N. R. P., Savage, N. H., and Pyle, J. A.: Pathways and timescales for troposphere-to-stratosphere transport via the tropical tropopause layer and their relevance for very short lived substances, J. Geophys. Res., 112, doi:10.1029/2005JD006940, 2007.

3. We have only explored TST subject to the dynamical and WMO definitions of the tropopause. However, in our earlier study [Levine et al., 2007], we did explore TST on longer (and shorter) timescales in a single-release tracer experiment lasting twelve months. In an additional paragraph, inserted before the final paragraph of the Method section, we have explained why we chose to investigate TST over periods of four weeks and noted that, based on the results of the fore-mentioned experiment, our top level result - most TST from the TTL comprises transport into the ELS (c.f. the overworld) - holds true on timescales up to at least twelve months.

4. We have not changed Figure 2 as suggested, for two reasons: the small variations in the fractions of air parcels entering the stratosphere in the tropics and at higher latitudes could make it difficult for the reader to pick out the variations in the distribution of TST between the NH and SH; and, through Figure 2, we are attempting to convey a different, albeit simple, point – the vast majority of air parcels undergoing TST from the TTL enter the stratosphere in the subtropics. However, we have changed what was Figure 4 (now Figure 3) so as it illustrates the hemispheric distribution of TST in the extratropics (subtropics + higher latitudes) as opposed to TST at all latitudes (including the tropics). We have also reversed the order of sections 3.3 and 3.4 as suggested to improve the flow of the paper.

5. We have changed the figure captions to Figure 5 (previously Figure 3) and Figure 7.

6. See revised section 4.2.

7. We have not changed the text re the inferred transport barriers associated with

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PV gradients, as we do not believe it is suggestive of a hard and fast relationship between the strength of transport barrier and the magnitude of the PV gradient. We have changed the last sentence of section 4.2 to emphasise the need for modelling transport at higher spatial resolution.

Interactive comment on Atmos. Chem. Phys. Discuss., 8, 489, 2008.