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Atmospheric Chemistry and Physics Discussions

Interactive comment on "A Lagrangian view of convective sources for transport of air across the Tropical Tropopause Layer: distribution, times and the radiative influence of clouds" *by* A. Tzella and B. Legras

Anonymous Referee #1

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The paper by A. Tzella and B. Legras presents a diabatic back trajectory study for transport across the Tropical Tropopause Layer (TTL) from the point of detrainment from deep tropical convection into the upper TTL. Main results are the distribution of convective sources for tropical upward transport and its seasonal dependence and degree of localisation, as well as time-scales for transport. The paper is well written and makes a valuable contribution to research in this key region of the atmosphere, improving our understanding of the interaction of high-reaching tropospheric convection with the upwelling branch of the stratospheric Brewer-Dobson (BD) circulation.

However, the readability of the paper could be improved and the authors ought to be more careful with their discussion at some points. I therefore recommend publication of the paper in ACP after the following major and minor comments have been adressed.

Note, that I refer to papers using the same citations as in the paper by A. Tzella and B. Legras. Papers which are not cited yet are given at the end of the review.

Major comments:

1. In many parts of the paper the readability could be improved. First, the wording concerning the back trajectories has to be clear and unambiguous. An example where this is not the case is the use of the terms 'initial' and 'final' in this context, with final at one point denoting the last (end) time, at another point the first (start) time of back trajectories (see specific comments below). Second, too much numbers (e.g., percentages) are presented in the text. The main message could be strengthened if only the important ones would appear in the text. Third, I had the feeling that some percentages appearing in the text are not consistent with the figures (see my specific comments below).

2. An integration period of 200 days is a rather long time for a pure trajectory study, a simulation which neglects any kind of mixing process in the atmosphere. Of course, this is a general problem for any kind of pure trajectory analysis and nevertheless the results of the paper are valuable and worth publishing. However, in particular the estimate of the proportion of 'free' trajectories (trajectories not originating at convective sources during 200 days of backward integration) seems problematic to me. Table 1 shows that the proportion of those free trajectories which end in the extratropics is rather small (1–6% in the annual mean). I think there is a much larger fraction of trajectories which are transported across extratropical regions for many days during the backward integration period and nev-

ertheless finally end in a tropical convective source. As these trajectories may encounter regions of strong flow deformations (subtropical jets) for long times, they are likely to be influenced by mixing and will represent extratropical stratospheric rather than tropical cloud air. Hence, I think that the fraction of in-mixed extratropical air is larger than the stated 1–6%. Moreover, these annual mean values are not reflecting the strong seasonality in extratropical–tropical exchange and are therefore misleading. Even a small percentage of extratropical (in-mixed) air has the potential to influence the mean tropical mixing ratio of a tracer, if the horizontal gradient in the species' mixing ratio is large enough. E.g., the impact of horizontal in-mixing from the extratropics on the annual cycle of ozone in the TTL was recently shown to be important (Konopka et al., 2009). The authors should, at least, thoroughly discuss these points.

Minor comments:

General:

1. In my opinion, the most interesting results of the paper concern the distribution of convective sources and their degree of localisation, rather than the time-scales of transport. For the time-scales of upward transport there already exist a large number of estimates in the literature. Moreover, Ploeger et al. (2010) have recently shown that these time-scales depend very sensitively on the particular trajectory method (e.g., the choice of vertical velocities). I would therefore recommend to focus more on the convective source distributions as the main results, at least in abstract and conclusions.

2. I'm unsure about the restriction to radiative heating rates (see also my specific comment below). Of course, in cloud-free air the latent heat contribution should be negligible. However, the residual heating (the sum of latent heat exchange, turbulent and diffusive heating) in ERA-Interim can be positive in the deep tropics up to 380 K in the annual mean (see e.g., Fueglistaler et al., 2009b) and it is not possible to separate the residual heat component into the individual terms. Therefore, important (non latent) heating terms could be neglected by restricting to all-sky radiation only.

   The motivation to use both all-sky and clear-sky heating rates is, in my opinion, to derive an estimate for the uncertainty in vertical transport, due to radiative effects of clouds. Wouldn't it be even better to run a third set of trajectories using total heating rates to take also the uncertainty due to the residual heating terms into account? And why did you include the ± 5K brightness temperature offset only for the all-sky trajectories?

3. Why did you consider the annual mean for the year 2005 for some results and

the average over 2005 and half of 2006 for other results? I would prefer annual mean estimates for 2005 for all results.

Specific and technical:

P18162, L13: '... conditions, in order to ...'

P18162, L24: What do you mean by 'apparent at small time-scales'? I think there are significant differences in the transit time distributions, e.g. between the summer and winter cases in Fig. 11a.

P18164, L18: '..., if the air remains ...'

P18165, L12: '... European Centre for Medium-range Weather Forecasts ...'

P18166, L3: '... resulting in a total ...'

P18166, L6: 'The lifetimes of VSLS are by definition ...'

P18166, L9: '... in an isentropic coordinate system (diabatic trajectories) with ...' I would introduce 'diabatic' already here.

P18166, L18: This sentence needs clarification and rephrasing: It is true that the difference in dispersion between kinematic and diabatic trajectories is less prominent in ERA-Interim than e.g. in ERA-40, as shown by (Monge-Sanz et al., 2007; Liu et al., 2010). However, there are differences with the vertical dispersion higher for kinematic compared to diabatic trajectories causing significant differences in recontructions of ozone in the TTL (compare, Ploeger et al., 2011).

P18167, L2ff: See my general comment above, concerning the use of radiative heating rates.

P18167, L7: '... kinds of clouds ...'

P16167, L26: I wouldn't use the term 'barrier for transport', as this barrier exists only if important terms in the heating budget are neglected (only radiation considered). As shown by Ploeger et al. (2010), including the residual heating term (latent heat release, turbulent and diffusive heating) yields positive vertical velocities (upward motion) throughout the mean tropical velocity profile.

P18168, L7ff: Why is the motion of those trajectories, which remain around their launch level for some time, 'spurious' if this motion is consistent with the wind fields and we trust the reanalysis data? And how does this impact your results? The following paragraph needs clarification.

P18168, L26: The term 'CS-TTL' is unprecise, as you include also extratropical air (latitudinal boundaries $\pm 50°$). A few more words could be helpful.

P18171, L25: '... is a run ...'

P18171, L25: I would say '... two sets of trajectories ...', as the number of different simulations you consider is four (ALLSKY-$\Delta T0$, ...).

P18172, L9ff: I don't see where the numbers 17-30% and 40% come from (see my major comment). Of course, the proportion of CS-TTL trajectories encountering a convective source within the last 90 days is non-negligible, as already the proportion encountering a source within the last 40 days was found to be ≥ 40% (previous sentence, Fig. 2) and is therefore non-negligible. In my opinion, the 90 days proportion should be larger than the 40 days proportion, as the last 40 days are included in the last 90 days. And even more so for 200 days, as this is the whole trajectory length. Therefore, the 200 day proportion should be the total CS-TTL proportion of 79-80% (ALLSKY).

P18172, L20: '... originates ...'

P18173, L2: That tropical upwelling slows down around the LZH, causing longer trajectory transit times in that region, was already mentioned by (e.g., Fueglistaler et al., 2004; Ploeger et al., 2010).

P18173, L9: I think, 'final destination' here refers to the last time in forward time (of the backward trajectories) - what you termed 'initial' before (e.g., in the caption of Table 1.; there, 'final' refers to the last time in backward time). I'm slightly confused about the use of 'final', 'initial', ... also at other points (see my general major comment).

P18174, L11ff: I would rephrase the sentence to improve readability: 'We resolve the source distribution ... in order to obtain meaningful statistics.'

P18174, L19ff: What do these proportions refer to? Their sum is $27{+}27{+}22{+}23 = 99$% for ALLSKY and even larger than 100% for CLRSKY.

P18175, L5: I would define the geographical locations only once in the caption of Fig. 3, and just refer to it here.

P18176, L3: Why is the daily variability larger for clear-sky compared to all-sky conditions? Is it so, because horizontal transport around the LZH is more important for clear-sky, due to the slower vertical transport in that region?

P18177, L22: I don't see the 'lack of seasonal differences'. The fraction of CS-TTL parcels varies between 27 (DJF) and 22% (JJA), see Table 2, so seasonal differences are about 20%.

P18179, L20: '... the deeper the convective sources, the less localised they are and the more efficiently they are sampled', to clarify what 'efficiently' here means.

P18179, L21ff: 'In particular, ...' – I don't understand the point here.

P18180, L8: '... for a sufficiently large number ...'

P18180, L16ff: I wouldn't present all percentages in the text, to improve readability.

P18181, L10: 'A similar two-peak behaviour ...'

P18183, L8: '... clear- and all-sky ...'

P18184, L1: 'The distributions ...'

P18184, L7: 'Note again ...' – rephrase this sentence.

P18184, L12: The sentence starts with 'Figure 10 shows ...' and ends with '(see Fig. 10)' - keep only one.

P18184, L24: Did you check the influence of the monsoon, e.g. by checking that a large fraction of parcels circles around the anticyclone?

P18186, L21: '... diabatic back trajectory ...'

P18187, L27: '... advantages compared to ...'

Table 4/caption: '... the focus is on the four ...'. I would end the caption at '... surface.'.

Figure 1: I would write the indices (a) and (b) on top of the figures (better say 'main convective outflow' instead of 'mean ...').

Figure 2/caption: '(thick lines)'

Figure 3: Why are the clear-sky distributions more patchy? Is it just due to less CS-TTL trajectories causing worse statistics?

Figure 5/caption: '... trajectories uniformly randomly distributed ...'

Figure 8: What is the bin size for the histograms?

Figure 10/caption: '... also shown is the corresponding ...'

Figure 11/caption: '... summer (dashed) ...', '... (in black)', '... different ranges of ...'

Figure 11: I find it interesting that the peak of the histograms shifts from the deep tropics to the subtropics and extratropics with increasing transit time. I would mention this behaviour in the text.

References:

Konopka, P., Grooß, J.-U., Ploeger, F., and Müller, R., Annual cycle of horizontal in-mixing into the lower tropical stratosphere, *J. Geophys. Res.*, *114*, (D19111), 2009.

Monge-Sanz, B. M., Chipperfield, M. P., Simmons, A. J. and Uppala, S. M., Mean age of air and transport in a CTM: Comparison of different ECMWF analyses, *Geophys. Res. Lett.*, *34*, (L04801), 2007.

Ploeger, F., Fueglistaler, S., Guenther, G., Grooß, J.-U., Konopka, P., Liu, S., Müller, R., Ravegnani, F., Schiller, C., Ulanovsky, A., and Riese, M., Insight from ozone and water vapour on transport in the tropical tropopause layer (TTL), *Atmos. Chem. Phys.*, *11*, 407–419, 2011.

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