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Atmospheric
Chemistry
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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

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We thank the referee for a thorough and thoughtful reading of the original manuscript. In what follows we address these comments and remarks (the referee's comments are cited in italics; unless stated otherwise, we will refer to the original manuscript for any changes made).

Main comments:

Data and method

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The authors necessarily consider and discuss various sources of uncertainties in their trajectory calculations. They are particularly aware of the uncertainty resulting from sub-grid cloud processes in ECMWF calculation of all-sky heating rates. The trajectory launch frequency (4 days here) is likely to be an important point which is investigated by the authors and eventually ruled out by sensitivity tests (p18168).

Some aspects of the method may however deserve to be addressed or clarified. The first one deals with the period chosen which is of 1.5 year (from January 2005 to 30 June 2006). Why not having focused only on the year 2005 since the chosen period encompasses 2 winter seasons (JF), 2 springs (MAM), and only 1 summer (JJA) and 1 fall (SON)? Indeed, one may think about a problem of too much weight attributed to the winter and spring events in your statistics. Also, the results section (section 3, p18173, l13) does not seem to take into account the half year of 2006 (like Fig.1 anyway). Could you explain this discrepancy?

In this paper we consider only those CS-TTL trajectories that are detrained during 2005. These CS-TTL trajectories constitute 65-66% of the CS-TTL ensemble. This ensemble is obtained for both all-sky and clear-sky conditions by launching trajectories during 2005 and the first half of 2006. The remaining CS-TTL trajectories have either detrained during 2004 or 2006 and are discarded.

We use the CS-TTL trajectories that are detrained during 2005 to determine the sources of convection for 2005. In order that all of these sources are equally sampled, we set the launch period to cover the period between the 1st of January 2005 and the 30th June 2006 (Note that the latter date should actually correspond to the 31st of Dec+200 days=19th July but is shorter by 19 days. This slip will only have a small effect on the tails of the transit-time histograms for some December sources. Otherwise, the effect is negligible and not worth mentioning in the text).

The above information is now added in the first paragraph in sec. 2.1 (where the methodology for obtaining the trajectories is described) as well as that of sec. 3 (where the sources are obtained). We hope that this makes the methodology clearer and eliminates the apparent discrepancy.

Another point is the 200-day back trajectory integration time which is a long and rather uncommon duration for trajectories used for TST studies. Such a long integration time might be problematic when mixing processes are discarded, a limitation of Lagrangian methods which is well-known anyway. Fueglistaler et al. (JGR, 2004) and Fueglistaler et al. (JGR, 2005) have used trajectory durations of 60 and 90 days (at maximum) respectively. Have the authors made some investigations using shorter integration times closer to other studies available in the literature to especially ensure that the mapping of trajectory-cloud intersections (Fig. 3), the distributions of cloud top brightness temperatures (Fig. 6) and potential temperature levels of trajectory-convection encounter (Fig. 8) are conserved? If not, I would recommend this sensitivity test at least for one of these 3 figures.

By launching a large number of parcels over a long period of time and assuming ergodic properties of mixing, the proportion of parcels located in a given region at 100 or 70hPa that have originated from convection within a time t<T (i.e., the CS-TTL trajectory ensemble) provide information about the influence of convection for species with life-time shorter or equal to T. In Figs. 9 and 10 we show that the distributions of first-entry and transit times are peaked but at the same time they are wide, particularly the transit-time distribution that has a long tail extending to 200 days. Because of mixing, this tail is, for times larger than 90 days, the same for all source regions. The existence of a long tail in the transit times implies that their mean value may be large and very different from the value corresponding to the peak or the median. An important point that we make here is that this mean value is not meaningful and is very sensitive to the length of the trajectories and that the full distribution should be considered instead.

We chose T to be 200 days because VSLS are less than 200 days but also as a compromise value that samples the exchanges between tropical and extra-tropical lower stratosphere which are much faster than the times associated with the deep Brewer-

Dobson circulation.

Finally, unlike the distribution of transit-times, the convective source characteristics as well as the first-entry times, should not be different when the trajectory length varies from 60 to 200 days. Indeed this is the case. In particular, results shown in Figs. 3, 5, 6, 8 and 9 remain practically identical when the trajectory length is cut to 60 days. This lack of sensitivity is noted in the text.

Latitude range
The 50N-50S latitude range used to initialise the trajectories is wide and encompasses midlatitude transport features. I still do not get why the authors have not selected a narrower latitude range, I mean more restricted to tropical latitudes such as 30N-30S (which still encompass the influence of the Asian Monsoon). The paper focuses on TTL transport and it seems more interesting to analyze your nice statistics obtained from the tropical latitude range, especially concerning the remaining "free" trajectories likely to be significantly influenced by midlatitude to tropics transport (trajectories not influenced by tropical deep convection) when computed over a latitudinal area as wide as 50N-50S. This may allow the reader to better compare the convectively-influenced trajectories and the "free" trajectories with transport features mainly inherent to the tropics. Can the authors provide some of their statistics over this restricted latitude range to ensure that these new results compare well with the 50N- 50S results? Also, I see that Fig.3 maps only the 30N-30S area which is in line with the above-mentioned point. This raises the following question. Has the transport distribution calculation method (Section 3.1.1) been really applied to the 50N-50S (there is a doubt from the choice of 30N-30S on Fig.3)? Fig.11 is plotted over 50N-50S and it would be worth to map the same latitude range for uniformity of Fig. 3 and 11.

We focus on TTL convective sources which is why for most of the time (aside from boreal summer) we only consider cloud encounters between 30S and 30N (in practice though less than 5% of the trajectories encounter clouds at higher latitudes). We could have indeed chosen the same latitudinal range to initialize the trajectories. We instead chose the 50N-50S range as we were also interested in the meridional transport that takes place in the upper TTL and the lower extratropical stratosphere which is partly responsible for the long tails observed in the transit-time distributions in Figs. 9(c) and 10 (see above discussion about the length of the trajectories).

It is important to note that the choice of latitudes for the launch is made independently of the restriction of latitudes for the sources. It is also important to note that Figs. 3 and 11 are normalized differently. For the sources, the normalization is based on the expected number of trajectories that would encounter a cloud within a given grid-box, if all regions were acting as sources of equal strength uniformly during 2005. Conversely, in Fig. 10, the normalization denotes the expected number of CS-TTL trajectories that would be found within a grid-box if all CS-TTL trajectories had encountered a convective source with equal probability during the last 200 days (the length of the trajectory). The first normalization serves to highlight the relative importance of different sources during 2005. The second normalization serves to highlight which parts of the upper TTL/lower stratosphere are most influenced by convection and what is the corresponding range of ages/transit-times of the tracers originating from convection. Since the normalizations in Fig. 3 and 11 are different, a comparison between Figs. 3 and 11 can only be made on the spatial features in each of the figures e.g. Fig. 3 (top,left) shares similar patterns to Fig. 10 (top,left). To clarify potential confusion, text referring to the choice of normalization is modified in the 1st par. of 3.1.1. and 2nd par. of 3.3.

Notice that the choice of 50N and 50S for the launch boundaries allows us to see that the transit times to the extratropical destinations are in the upper 60-200 days range (bottom panel, Fig. 11) while the tropical destinations are populated by shorter transit times (top two panels, Fig. 11).

We now describe how the statistics may change when considering a smaller range of latitudes for the launch. In particular we focus only on those CS-TTL trajectories launched between 30N and 30S. As was the case for the shorter trajectories, this choice of latitudes does not lead to different results about sources than the 50N-50S choice of launch: the distribution of sources (horizontal,vertical), their localization or the cumulative distributions of the brightness temperatures that the trajectories have encountered are the same for both ranges of latitude. So are the first-entry distributions shown in Figs. 9(a-b). The only difference appears in the distributions of transit-times, shown in Fig. 9(c) and 10. For the 30N-30S latitude range, the tail decays faster than for the 50N-50S latitude range (see supporting figure) which is in agreement with Fig. 11.

Another difference is the number of ‘free’ parcels. As expected, for the 30N-30S latitude range, the number of ‘free’ parcels is smaller. In particular, for trajectories launched at 100hPa, the percentage of parcels that are free is 8-10% for all-sky conditions and 16% for clear-sky conditions. The corresponding percentages obtained from trajectories launched at 70hPa are 26% for all-sky and 35% for clear-sky conditions (to be compared with Table 1).

Pressure and potential temperature coordinates

All over the manuscript the authors specify two levels of pressure (100 and 70 hPa) on which are released the backward trajectories while most of the convection/long-range transport are discussed in terms of potential temperatures. This is a bit surprising and misleading since most of the time trajectory studies either focus on pressure or pot.temp. coordinates mainly depending on the studied processes, i.e. diabatic or quasi-horizontal transport (see Hegglin et al., GRL, 2005 for instance). The simultaneous use of pressure and potential temperature values leads to some kind of ambiguity. Please explain this choice of initialization on pressure levels rather than typical potential temperature levels in your simulation and specify the range of potential temperature values corresponding to 100 hPa and 70 hPa.

The choice of launch on iso-pressure surfaces is conventional and is motivated by the fact that most satellite retrievals and aircraft measurements are made on isobaric sources. There are other theoretical reasons that would tend to launch parcels on isentropic surfaces. However, as far as the convective sources as concerned, we believe the general conclusions will still hold if we had chosen, say, the 380K surface instead of the 100hPa surface. What is important is that, at their launch, trajectories lie either in the upper TTL or in the extratropical lower (but not lowermost) stratosphere. Their backward-in-time transfer to the troposphere is thus controlled by the TTL which they have to cross in order to encounter a source of convection (recall that any encounters with clouds are set to take place within the tropical troposphere - sec. 2.2).

It may indeed be instructive to include the range of potential temperatures for these surfaces constrained within latitudes 50S and 50N. Their mean potential temperature in the tropics is designated in Fig. 1. We have now added the following information in the 1st paragraph of sec. 2.1:

"On these surfaces, the potential temperatures vary between low values at the equator that depend on the season - the mean January (July) potential temperature is 380K (385K) for the 100hPa surface and 430K (415K) for the 70hPa surface - and larger values at the poleward boundaries that are weakly affected by the season (the mean potential temperature is 420K on the 100hPa surface and 465K on the 70hPa surface).."

Trajectory wording

The reader may be misled when the authors state about the initial and final positions of the back trajectories. In some cases, this is clearly mentioned but not anywhere in the manuscript. For instance, when the authors write "trajectories end up" (p18172, l22) I guess this is not equivalent to the locations where back trajectories are released but the final position of the trajectory backward in time. Also in Table 1 caption, "initial locations in the extratropics" refer to locations where the trajectories are released backward in time. So please clarify these points in the manuscript where wording referring to start/end or initial/final features of the 200-day backward trajectories may be doubtful.

The term 'initial' refers always to the location of parcels at the start time of the backward trajectory. We have found two instances where this term was used inconsistently and they have been corrected. The term ‘final’, which is admittedly confusing when combined with ‘initial’, is no longer used and we use the term ‘destination’ alone to denote the location of the parcels reached when the trajectories are considered in the forward direction. The words ‘end’ and ‘start’ are always associated with ‘back trajectories’.

Minor comments and technical points:

Fig.8 and Fig.11 and text: *I think the term “histogram” is not appropriate. Distribution may be more convenient.*

Histogram is the correct term to describe Figs. 8, 9, 10 and 11 (see also vertical axis in these Figs). However, a distribution is readily obtained from a histogram by taking into account the bin size. A confusion was, however, present as, in the text, we refer to these histograms as distributions. This confusion has now been rectified.

P18166, l23: *“radiative heating rates” is written in italic.*

We have chosen italic to emphasize that the heating rates are radiative and not total diabatic.

P18169, l17-21: *In this case, when a cloud top has been encountered backward in time, please clarify if the trajectory is stopped or still integrated up to 200 days to derive further convection source areas. It seems that (on the opposite to the above-mentioned Fueglistaler et al. papers), but not explicitly mentioned, you let all your back trajectories run to the end of the 200-day period unless I have missed something important in your manuscript.*

All trajectories are followed backward-in-time for 200 days as described in sec. 2.1. In order to determine which of these trajectories belong to the CS-TTL ensembles we use the criteria described in sec. 2.2. Once a trajectory satisfies these criteria it is then cut at the first time (in backward time) at which the trajectory’s temperature is larger than the cloud top temperature. The remaining part of the trajectory is discarded.

To clarify this point we have now added at the end of this paragraph: “The remaining part of the trajectory is thereafter ignored."

P18170, l29: *"Less" instead of "least".* OK

P18172, l9-10: *This sentence is unclear to me. I do not get the same percentage numbers unless you also consider here parcels released at 70hPa?*

The percentage numbers correspond to the percentage of CS-TTL parcels (and not all parcels) that have encountered a convective source between 90 and 200 days ago. Note that the English has now slightly changed as before it was confusing. It is hopefully now clear that these proportions correspond to Fig. 2 and they necessarily need to be less than 50%.

P18174, l19-21: *Do these percentage values correspond to an all-area average for a given season? Please clarify.*

Indeed this is the case. The corresponding discussion is now in a separate paragraph that does not involve the source density that may have been one possible source of confusion. Also, the percentage description is now left for Table 1 in the revised manuscript. The text now reads:

"For both ALLSKY-ΔT0 and CLRSKY-ΔT0, we find that trajectories are detrained almost uniformly all along 2005 with a slight preference for the boreal winter and spring seasons (see Table 1 for results obtained from the ALLSKY-ΔT0 ensemble)."

P18175, l7: *It is not clear whether or not these percentage values correspond to maximum values. Please specify.*

The values listed correspond to the percentage of CS-TTL trajectories detrained during sometime in 2005 within different key regions whose geographical limits are defined in Fig. 3. In Table 3, we show the percentages corresponding to all 5 considered regions, obtained from the ALLSKY-DT0 ensemble. Note that the sum of these percentages is 94% because some CS-TTL trajectories have detrained outside these regions. From Table 3 it is clear that half of the CS-TTL trajectories have detrained within the southern

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Asian-Pacific region. A smaller percentage corresponds to clear-sky conditions.

The text has now been modified to clarify these percentages.

P18175, l28: *Fig.4 needs some clarification. Does it correspond to an all-area average? Why do the authors so low probability values? Is it because the normalisation method described in 3.1.1 is applied all over the 50N-50S latitude range?*

Fig. 4 is now removed because sec. 3.1.2 and the relevant figure (Fig. 5) covers the point made by Fig. 4. In particular, in sec. 3.1.2. it is shown that the source distribution obtained under clear-sky conditions is more localized in space-time than the corresponding source obtained under all-sky conditions. It is thus not particularly surprising that the percentage of CS-TTL trajectories, calculated as a function of the day they are detrained, is higher for clear-sky than for all-sky conditions. The percentages are low on a daily basis but their sum over the whole year is 100%.

P18177, l11: *“Less” instead of “least”.*

We are here referring to the source distribution that is the least localized so we think this is the appropriate description.

P18182, l4: *Please specify “forward in time” in the caption of Table 5 and Fig. 9 to avoid confusion (see trajectory wording main comment above).* OK

P18182, l16-17:*I am a bit confused here. Are you sure it is 370K and not 380K? I do not get the same time values.*

Yes, we are sure. These values are also consistent with Fig. 9. Are you using the same method to obtain these values?

P18183, l1: *“. . .for clear-sky conditions”. Refer to Table 5.* OK

P18183, l6-8:*This sentence is misleading. Do the authors mean all-sky LZH? Otherwise this statement is confusing (maybe except for the JJA season) because as mentioned in the introduction 345-355K are the main levels for maximum convection* *outflow and C-LZH is about 360K and A-LZH is about 355K.*

The mean potential temperature at which CS-TTL parcels detrain is related but not equal to the level of maximum convective outflow. In the all-sky case, the potential temperature at which CS-TTL parcels detrain is at 354K while in the clear-sky case, the corresponding mean is at 359K (see Table 4). At the same time, the mean A-LZH is at 354K and that of C-LZH is at 359K (results obtained from the EI dataset). Therefore, for both all-sky and clear-sky conditions, the mean potential temperature at which CS-TTL parcels detrain coincides with the LZH (this is also noted in the 2nd par. in sec. 3.1.5).

P18184, l4:*"2005" instead of "2004" I suppose.*

Some of the CS-TTL trajectories that were launched during 2005 have encountered a source of convection during 2004. It is also true that some of the CS-TTL trajectories that were launched during 2006 have encountered a source of convection during the same year. Both this sets of trajectories are not considered in the results section 3. For as discussed above, our focus lies on those CS-TTL trajectories that were detrained during 2005.

P18185, l24, p18186, l1, l5: *Are these percentage values obtained by geographical integration? Please clarify.*

For each regime in Fig. 11, we determine the percentage of CS-TTL trajectories with transit times within the range of values associated with each regime. The same percentage values can be obtained by geographical integration.

Interactive comment on Atmos. Chem. Phys. Discuss., 11, 18161, 2011.

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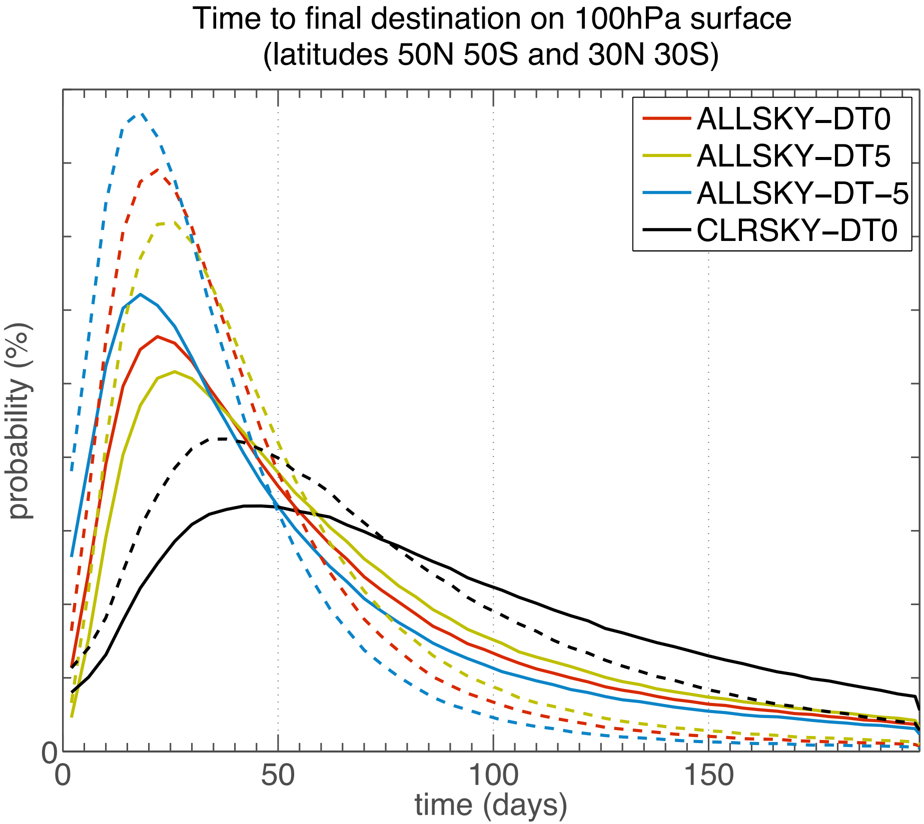

Fig. 1. Fig 9(c) but this time modified to include results obtained with CS-TTL trajectories launched between 30N-30S (dashed lines).

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