Dear Dr. Jöckel,

Thank you very much for your time serving as an editor for my manuscript acp-2015-594. I have just completed the uploading the 2nd revised manuscript on the Copernicus web site.

The following revisions have been made in response to the reviewer comment dated 15 Feb 2016.

Comment: Line 116: "... the diabatic ascent is driven by radiative heating, ..." The broadly accepted consensus is that the upwelling is dynamically forced, and the radiative heating is a result, not the cause of the upwelling.

Reply: The sentence is revised as follows:
Up in the TTL, on the other hand, the diabatic ascent is associated with the dynamically driven relaxational radiative heating. The seasonal migration with respect to latitude is much smaller than that in the troposphere because the dynamical field generated by the thermal forcing at the bottom boundary retains relatively high symmetry with respect to the equator.

Comment: Line 250ff: The decomposition into average mixing ratio, and probability, of a grid cell "j" is straightforward. The product of the two is of course the contribution of grid cell "j" to the total entry mixing ratio. However, the interpretation of changes in the product of these two terms is not straightforward. For example:

Line 262ff: "it is interesting to note the increase of E(LCP e j) despite the decrease in SMR(LCP e j) ..." Why do you write "despite"? First, we should know how the SMR in this region changed compared to the tropical average - if it has cooled compared to the tropical average, we actually would expect that the probability P(...) is increasing (this is one of the key results of Fueglistaler and Haynes [2005]).

Reply: The use of "despite" refers to the simple-minded expectation from Eulerian view that the water entry will decrease in response to the widespread cooling (decrease in SMR(LCP e j)) in the TTL. The sentence is revised as follows:
it is interesting to see the increase of E(LCP e j) simultaneous with the decrease in SMR(LCP e j) over the central Pacific.

Comment: How would you interpret the following scenario: In period "before", grid cell "j" is very warm, and 0 trajectories experience their last saturation in that cell, i.e. P(j)=0. Hence the contribution E(..) is 0. Now, in period "after", grid cell "j" has cooled more than all other locations and is now the coldest location. Correspondingly, a very large fraction of trajectories experience their last saturation there, and P(j) * SMR(j) > 0. Now you take the difference: E(j)_after - E(j)_before which is greater than 0.

Reply: Our interpretation on the above example is that the contribution from cell "j" increased in the period "after" as the mathematics shows. As P(j)=0 in the period "before", there was no contribution of cell "j" to the ST water. On the other hand, the contribution from cell "j" increased from zero to some positive definite as P(j)>0 in the period "after" whatever the value SMR(j) might be.

Comment: If I understand your interpretation of Figure 7 (Line 264: "In this sense, it is not appropriate to attribute the cooling over the western and central Pacific to the drop ..."), you would then say that grid cell "j" has NOT contributed to the decrease in [H2O]entry?

Reply: Yes, we should say that grid cell "j" has NOT contributed to the decrease in [H2O]entry simply because E(j) has increased. Our standpoint here is that we have to discriminate P(j) against SMR(j), even if the cooling (decrease in SMR(j)) tends to accompany increase in P(j) as was shown by Fueglistaler and Haynes (2005).

Comment: The following statements (Line 265 ff) are also difficult to follow, I have difficulties understanding to which plot and which area exactly you refer; I don't know whether labels and/or "arrows" in the figures are possible, but it would help if you would refer to Figure-X/Panel-Y for each statement, so the reader can better follow your interpretation.

Reply: The sentence is revised as follows:
The similarity in the spatial distributions between P(LCP e j) (Fig. 5) and E(LCP e j) (Fig. 7) in the corresponding period, especially that between the location of maxima over the Bay of Bengal and Malay Peninsula (warm colors in panels (a) and (b)) together with the post 2000 decrease over there and the western tropical Pacific (dark blue in panel (c)), suggests that the relocation of LCPs (change in P(LCP e j) is a leading factor that has caused the drop in [H2O]_e in September 2000.

The differential file for confirmation of the above revision is attached. I would be grateful if you find the manuscript suitable for publication in ACP. Thank you very much in advance.

Best regards,

Fumio Hasebe

caution of this method, see, for example, the pioneering studies by Fueglistaler et al. (2004) and Bonazzola and Haynes (2004).

2.2 Selection of trajectories relevant to TTL dehydration

The meridional projections of the backward trajectories extracted from those initialized on 15 January 1999 are shown in Fig. 1. The top and bottom diagrams are the same except that pressure (top) and potential temperature (bottom) are taken as the ordinate. The asterisks in red indicate the location of the LCP while those in green are the termination point of trajectory calculations ($90\,\mathrm{days}$ before initialization at the longest). In case the backward extension of the trajectories hit the surface of the earth, the calculations are terminated at that point, and those portions of the trajectories immediately before the surface collision are used for the analysis. The migration of air parcels depicted in the trajectories is roughly categorized into three major branches: quasi-isentropic advection in the TTL and the lower stratosphere (LS), vertical displacement in the troposphere due to diabatic motion resolvable in grid-scale velocity field, and quasi-isentropic migration in the troposphere. We can see many air parcels are traced back to the troposphere representing the tropical troposphere-to-stratosphere transport (TST), while some portion of the trajectories remain in the LS and/or reach the tropical $400\,\mathrm{K}$ surface by taking the sideways without making excursions in the TTL. All non-TST trajectories are removed from the following analysis to focus our discussion on the modulation of $[\mathrm{H_2O}]_\mathrm{e}$. For the sake of clarity, the TST particles in the present study are defined as a subset of those particles traceable down to $340\,\mathrm{K}$ having recorded LCP in the TTL. For the application of this LCP condition to our trajectories, we introduce the Lagrangian definition of the TTL to assure internal consistency of the analysis.

The motion of air parcels ascending in the tropical troposphere is characterized by rapid convective up-lift that accompanies latitudinal migration associated with the seasonal displacement of the Inter-Tropical Convergence Zone. Up in the TTL, on the other hand, the diabatic ascent is ~~driven by radiative heating, in which the~~ associated with the dynamically driven relaxational radiative heating. The seasonal migration with respect to latitude is much smaller than that in the troposphere because the dynamical field generated by the thermal forcing at the bottom boundary retains relatively high symmetry with respect to the equator. By translating these features into the characteristics of trajectories, we derive a definition of the TTL in a Lagrangian fashion.

Figure 2 on the top illustrates the vertical distribution of the proportion of trajectories categorized on a daily basis as "fast" ascending air parcels. The required rate for the fast ascent is empirically set to more than $0.2\,\mathrm{K}$ in potential temperature within 1 time step ($30\,\mathrm{min}$), that is, the condition for $\theta\,\mathrm{K}$ isentrope is met if the air parcel crosses $\theta\,\mathrm{K}$ surface from below $\theta - 0.1\,\mathrm{K}$ to above $\theta + 0.1\,\mathrm{K}$ in $30\,\mathrm{min}$. We can see that the proportion of the fast diabatic ascent thus defined takes maximum at around $340\,\mathrm{K}$ in the troposphere and minimum at around $355\,\mathrm{K}$. The proportion of such "fast" air parcels reduces above the level of main outflow and rapidly goes to near zero toward the level

Figure 7 shows the horizontal distribution of $E(\mathrm{LCP} \in j)$. This corresponds to the projection of $[H_2O]_e$ onto each bin. We can see that the September values of $[H_2O]_e$ are mostly projected to the Bay of Bengal and Malay Peninsula before the drop (Fig. 7(a)). The contribution from this core area remains dominant during the posterior period (Fig. 7(b)). While the reduction of $[H_2O]_e$ cannot be free from the general cooling (lowering of SMR(LCP$\in j$)) in posterior years over most of the tropics (Fig. 6), it is interesting to ~~note~~ see the increase of $E(\mathrm{LCP} \in j)$ ~~despite~~ simultaneous with the decrease in SMR(LCP$\in j$) over the central Pacific. This is because the increase of $P(\mathrm{LCP} \in j)$ more than compensate for the decrease of SMR(LCP$\in j$) over there. In this sense, it is not appropriate to attribute the cooling over the western and the central Pacific to the drop in $[H_2O]_e$. The similarity in the spatial distributions ~~of~~ between $P(\mathrm{LCP} \in j)$ (Fig. 5) and $E(\mathrm{LCP} \in j)$ (Fig. 7) in the corresponding period, especially that ~~of~~ between the location of maxima over the Bay of Bengal and Malay Peninsula (warm colors in panels (a) and (b)) together with the post 2000 decrease over there and the western tropical Pacific ~~,~~ (dark blue in panel (c)), suggests that the relocation of LCPs (change in $P(\mathrm{LCP} \in j)$) is a leading factor that has caused the drop in $[H_2O]_e$ in September 2000.

The resultant changes could be interpreted as the composite of two components: (i) the decrease over the Bay of Bengal and (ii) the decrease over the equatorial western Pacific and the increase over the central Pacific almost symmetric with respect to the equator extending to the subtropical latitudes of both hemispheres. The former is supplemented by slight decrease widespread along the 10° N zonal belt with the exception around 150° E and the central Pacific. These features will be related to the eastward expansion of the anticyclonic circulation around the Tibetan high, while the latter is suggestive of some response to the thermal forcing from the equatorial ocean.

4 Discussion

4.1 Maxima of $[H_2O]_e$ in 1998

We have seen in Fig. 3 that the time series of $[H_2O]_e$ shows maxima in January through June 1998. We excluded these months from our analysis in Sect. 3 because of the influences of strong El Niño. The values of $[H_2O]_e$ in November and December 1997 are larger than those in 1998, which may suggest possible influence of El Niño also in these months. Actually Fueglistaler and Haynes (2005) demonstrated in their Fig. 2 that the trajectory model shows large increase of lower-stratospheric water ($[H_2O]_{T400}$ which takes non-TST trajectories into account in addition to $[H_2O]_e$) associated with El Niño and that the increase is accompanied by the eastward shift of the high density region of LCP. The reason why we regard these facts as little related to the drop of $[H_2O]_e$ in 2000 is briefly discussed here.

For exploration of the reason of such anomalies, the horizontal distributions of LCP are shown for those initialized in February 1997, 1998 and 1999 in Fig. 8. The distributions in February 2000, 2001 and 2002 (not shown) are similar to those of 1997 and 1999. The LCPs in February are commonly