Atmos. Chem. Phys. Discuss., 15, C10714–C10719, 2015
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Atmospheric Chemistry and Physics Discussions
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Interactive comment on "Transport across the tropical tropopause layer and convection" *by* A.-S. Tissier and B. Legras

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Received and published: 21 December 2015

We thank referee #1 for his comments.

Answer to general comment

We do not consider that the issue on transport across the TTL has been settled by our work and we agree with the reviewer that the results are sensitive to the heating rates and there are significant differences among reanalysis in this respect. In order to put the emphasis on this point we have added new calculations based on MERRA which are actually showing large differences with respect to ERA-Interim and JRA-55 in the

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Interactive Discussion
Discussion Paper

vertical distribution of sources. This is due as noticed by the referee to different heating and we show that clouds have a particularly strong effect on MERRA in convective region. See Section 4.4-Sensitivity to the reanalysis and new Figure 9.

The referee also advocate the use of Yang et al. (2010) heating rates calculated from the observed distribution of clouds. Such heating rates are obviously an interesting attempt to understand the effect of clouds onto heating rates. However, the observation are limited and the calculation of Yang et al. (2010) is based on a seasonally averaged distribution of clouds. Radiative transfer is unfortunately a very nonlinear process and does not commute with this type of averaging. There is no reason that the averaged effect of clouds can be accurately represented by the effect of the averaged clouds. This does mean that the calculations based on reanalysis are superior but they cannot be taken *a priori* as inferior.

Figure 1, shown below, shows the vertical profile of heating rates in February and August 2007, between 20S and 20N for the three reanalysis ERA-Interim, JRA-55 and MERRA. This figure compares to Fig. 6 of Bergman et al. (2012). The dispersion of heating rates and heating rate variances in the TTL is clear in this figure. However, none of the analysis displays a change of heating rate distribution over the tropical band between winter and summer that compares with that of Bergman et al. (2012).

The referee mentions that in Bergman et al. (2012) there is a big drop between 65% in winter and 15% in summer of the proportion of backward trajectories reaching a cloud. It seems that this is accompanied by a very strong weakening of the oceanic contribution during summer. We do not find anything similar in our calculations even with the MERRA reanalysis. Such effect is apparently a consequence of using Yang et al. (2010) heating rates. Since the upward flux of the Brewer-Dobson circulation does not vary in such proportion, it would mean a much larger recirculation of extra-tropical stratospheric air during summer to face the lack of fresh air supply from the boundary year with consequences on tracer distribution in the tropical stratosphere which are not supported by any observation to our knowledge.

ACPD
15, C10714–C10719, 2015

It is actually very difficult to compare the calculated heating rates with observations. However, the integrated cloud radiative effect (CRE) of the three reanalysis considered here has been evaluated against CERES observations by Li and Mao (2015) who found that "spatial correlation of CREs and TOA upward radiation fluxes in ERA-Interim is the best among the three reanalyses" in spite of some discrepancies in the global mean CRE. Li and Mao (2015) also notice that all three reanalyses have difficulties to reproduce summer CREs over East Asia, a conclusion also supported by Wang et al. (2014) based on a study of radiation budgets in AMIP-5 models.

Therefore, we are led to conclude that the heating rates and the radiative effect of clouds in the Asian monsoon region are still a puzzle that requires further investigation.

We have added some paragraphs about these matters in our discussion section.

Answer to specific comments

The specific comments are reproduced to ease the reading.

1. ***Page 26240, line 8: It would be useful to explain, however briefly, how any convection (say, in the summer) with a cloud top theta of 348 can make a contribution to transport at 380*** K***. Presumably, some of these 348*** K ***"emitted" parcels move horizontally into a region where the LZRH is less than 348*** K***, and rise upward. It is not clear why the Tibetan high efficiency is a paradox. Based on the distribution of colored arrows, most heating rates in the tropics in the ERA-Interim analysis are positive at the Tibetan mode max of 365*** K ***(even if they are negative at 365*** K ***over Tibet). So, a little horizontal wandering will get the parcel into positive heating rates. Since the parcels are already so high, getting to 380*** K ***should be easier than for parcels that start at a lower theta (convective emission theta). In general, a***

ACPD
15, C10714–C10719, 2015

little more mechanistic explanation of the findings in the figures would be helpful.

The LZRH is a mean value but it fluctuates a lot when taking into account the temporal and spatial variation of the cloudy component of the heating rate. Therefore parcels launched at 348 K can sample occasionnaly positive heating rates and a small proportion of them can make it to cross the LZRH above which it is much easier to reach the 380 K surface. See also point 3 below. We have two other articles in preparation where the mechanistic explanation will be more developped.

2. ***Figure 5: I understand the comparison between the backward trajectories for the two different satellite cloud altitude treatments (1 km offset), but am confused by the drastic difference in the forward trajectories. With lower clouds, it takes longer for emitted parcels to get to 380K, so is it a matter of integration time in the forward direction? 3 months (backward trajectories) is still enough time for parcels from either the low or high cloud case to mostly (80 plus %) get to 380*** **K*. More explanation is needed here*

   It is not only a matter of integration time. While the proportion of backward trajectories reaching a cloud does not change, they do it a to a restricted set of clouds and over a slightly longer time. Regarding the forward trajectories, the situation is different: many trajectories launched from the lower clouds are never able to move up and they descend in the trosposphere.

3. ***I assume the LZRH in Figure 3 for the different sources represents a mean LZRH for the locations of convection in that season and region (AML, SAP...). Might be good to make this clear. The LZRH must jump around a lot, because a lot of convective systems in the AML in DJF (for example) with cloud tops much less than 359*** **K** ***contribute to air at 380*** **K*.***

   It is true that the LZRH calculated over 3-hour interval jumps a lot but the mean is nevertheless relevant. We have added a sensitivity test where the heating rate

ACPD

15, C10714–C10719, 2015

is replaced by its moving monthly average. The transit properties are only very weakly affected by this transformation, therefore indicating that the horizontal motion is the main mechanism through which Lagrangian parcels sample the variations of heating rates. The caption of Figure 3 is modified for more clarity : "The arrows on the upper axes indicate the corresponding LZRH levels" → "the corresponding mean LZRH levels over the season and 2005–2008."

4. ***There is no reference to the results of section 5 in the abstract that I can see.***

   The results from this section are now mentioned in the abstract.

References

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Li, Jian-Dong and Mao, Jiang-Yu: A preliminary evaluation of global and East Asian cloud radiative effects in reanalyses, Atmospheric and Oceanic Science Letters, 8, 100–106, 10.3878/AOSL20140093, 2015.

Wang, F., Yang, S., and Wu, T.: Radiation budget biases in AMIP5 models over the East Asian monsoon region, Journal of Geophysical Research: Atmospheres, 119, 13,400–13,426, 10.1002/2014JD022243, 2014.

Yang, Q., Fu, Q., and Hu, Y.: Radiative impacts of clouds in the tropical tropopause layer, Journal of Geophysical Research, 115, 10.1029/2009JD012393, 2010.

Please also note the supplement to this comment:
http://www.atmos-chem-phys-discuss.net/15/C10714/2015/acpd-15-C10714-2015-supplement.pdf

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ACPD

15, C10714–C10719, 2015

ACPD
15, C10714–C10719, 2015

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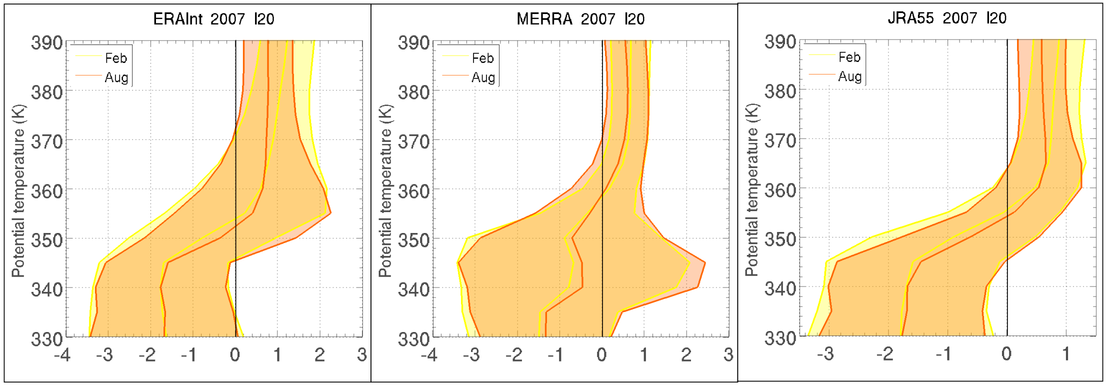

Fig. 1.

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