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Atmospheric Chemistry and Physics
Discussions

Interactive comment on "Impact of tropical land convection on the water vapour budget in the Tropical Tropopause Layer" *by* F. Carminati et al.

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We would like to thank the first referee for his/her rightful comments that helped us to substantially improve the quality of our study. Also, we really appreciated that the referee returned its review ahead of time.

MAJOR COMMENTS:

One main question I have is the uncertainty of the retrievals at 100 hPa and above. Day vs. night water vapor differences from mean values in Figure 6 are very small at levels above 100 hPa, I am wondering how robust is these results.

RESPONSE:

The accuracy of the results presented in our study is naturally of high priority, and all three referees pointed out the very small variability showed in the TTL and the LS. Hence we conducted extra efforts to better determine the significance of the day versus night variations.

"We first considered the MLS averaging kernels (AKs) in the pressure domain of interest. AKs at the equator and at 70°N of each MLS products are provided on the NASA Jet Propulsion Laboratory webpage (https://mls.jpl.nasa.gov/data/ak/). Figure 1 (Fig. 3 in the final manuscript) shows the MLS H2O AKs at equator between 250 and 30 hPa. Dashed black lines represent the 177, 100 and 56 hPa levels. For each level, we colored the corresponding AK that peaks exactly at the pressure of interest. The 177 hPa AK mostly covers the UT with a full-width at half-maximum (FWHM) from 230 to 125 hPa. The 100 hPa AK covers the TTL region from 125 to 80 hPa. Finally, the FWHM of the 56 hPa AK extends from 70 to 45 hPa in the LS. Thus, each of the three highlighted AKs peaks and covers the layer of interest (UT, TTL and LS) with minor overlapping at half maximum. Thereby, we can assume that the three layers are independent in the Optimal Estimation theory since the three AKs cover the region 230-45 hPa with no overlapping at the half-maximum level.

The MLS a priori has also been analysed. MLS a priori is a combination of climatology and operational meteorological data (Livesey and Snyder, 2004) so that for every retrieved H2O profile corresponds an a priori profile. One year of H2O a priori, from January to December 2012, was treated with the same methodology as H2O. Figure 2 (Fig. 4 in the final manuscript) shows the per cent relative difference between daytime and night-time MLS H2O a priori at 177, 100 and 56 hPa in DJF and JJA in the tropics. Globally, the a priori D-N is well below 1% at all levels. Nonetheless, the distribution is not uniform. Localized areas can also reach a D-N close to -2%, as in Southern Brazil at 100 hPa. Tropical lands (e.g. South America and Africa) have a negative or nearly null a priori D-N at all levels. This implies that the positive H2O D-N measured in the TTL and LS is not an artifact generated by the a priori and its amplitude is certainly underestimated. Conversely, in the UT, the negative H2O D-N above continents in DJF and JJA is probably slightly overestimated by at most 2%.

Thus, we showed that H2O measurements at 177, 100 and 56 hPa were independent with respect to each other, and that the a priori does not generate artificial positive values in the D-N above continents. Nonetheless, uncertainties in MLS H2O accuracy and precision (7% and 10%, respectively at 83 hPa) remain to be understood. In the case of our study, it is important to understand the meaning of these uncertainties and consider them separately. On the one hand, the accuracy that can be viewed as a random error is considerably reduced in our study, because, between 2005 and 2012, we average a large number of data (~14,000 profiles in each 10°x10° grid bin for the whole period). On the other hand, the precision, reflecting the systematic error (including biases), is not reducible by averaging the data. However, when the difference between two datasets with the same systematic error is calculated, this systematic error is theoretically removed. Assuming that the daytime and the night-time MLS precisions are similar, we can expect that the systematic error is minimized in the D-N analyses. It is also important to acknowledge that values of a large number of H2O D-N are close to zero. They represent the insignificant cases and produces an underestimation of the D-N amplitude.

We evaluated the number of days when both an H2O average daytime and night-time profile were available (consisting typically of ~6 profiles each) in the African and South American regions, and estimated the percentage for which the D-N was significant. We consider to be significant all |D-N| is greater than 10%. Figure 3 (Table 1 in the final manuscript) shows the percentage of days when the D-N is significant at 177, 100 and 56 hPa in South tropical America. In total, there are 1637 out of 2921 days (2005-2012 period) when both daytime and night-time are available. Among these, about 80% present a significant D-N at 177 hPa, about 50% at 100 hPa and about 10% at 56 hPa, during the convective season (DJF). The statistics are similar in south tropical Africa and their counterpart in the NH (not shown). The small amplitude of D-N in the TTL

and the LS is thus the result of the average of a large number of D-N that are close to zero, but the non-negligible amount of significant cases allows us to safely rely on the sign of the D-N.

This study aims to be a qualitative analysis of the H2O variability, because, even if MLS was able to measure the finest variation, it does not sample at the maximum of convection, but rather an initial state (at 13:30 LT at the beginning of the convection cycle) and a final state (at 01:30 LT toward the end of the cycle). Therefore, we can only conjecture what happen in-between."

MINOR COMMENTS:

1. P33056, L10, This is a quite long sentence. Might be helpful to break into a few shorter sentences. Why TTL is defined as 121-68 hPa? Does full oceanic areas share the same diurnal cycle as maritime continents?

RESPONSE:

It is right that the TTL has not been defined yet. Also, land and ocean have a different cycle. As suggested we broke and reformulated the sentences as follows: "In the tropical upper troposphere (177 hPa), continents, including the maritime continent, present the night-time (01:30 Local Time) peak in the water vapour mixing ratio characteristic of the H2O diurnal cycle above tropical land. The western Pacific region, governed by the tropical oceanic diurnal cycle, has a daytime maximum (13:30 Local Time). In the TTL (100 hPa) and tropical lower stratosphere (56 hPa), South America and Africa differs from maritime continent and western Pacific displaying a daytime maximum of H2O."

MINOR COMMENTS:

2. P33056, L15, the amplitude of water vapor diurnal cycle larger does not directly indicate a stronger convection. Water vapor variations due to the convective detrainment may also depend on the surrounding ambient water vapor concentration (how dry it is).

What if the southern LS is dryer?

RESPONSE:

A climatology of the relative humidity background shows that there are few or no differences at least in the UT between our 8 boxes. (For further details please refer to the response to referee #2 minor comment number 19.) In addition, the amplitude of the difference between the daytime and the night-time H2O concentration is compared in relative terms (day versus night, with respect to the daytime) so that even if one hemisphere was drier than the other, the relative amplitude remains an adequate tool to compare Northern and Southern hemisphere. Note that, a greater amplitude in the Southern hemisphere than in the Northern in the temperature diurnal cycle induced by convection was reported by Khaykin et al. (2013), as mentioned in section 2.4. Nonetheless, it is right that the largest differences between Northern and Southern tropics are observed in the UT and, to a lesser extent in the TTL, so we modified the sentence as follows: "In addition, the relative amplitude between day and night is found to be systematically higher by 5–10% in the south tropical UT and 1-3% in the TTL than in the northern tropics during their respective summer, indicative of a more vigorous convective intensity in the southern tropics."

MINOR COMMENTS:

3. P33059, L20, please mention that the boxes used in this study are shown in Figure 2.

RESPONSE:

The Fig. 2 (in the final manuscript) is updated and the text modified as follows: "We also focused on restricted areas of the north tropical and the south tropical South America, Africa, maritime continent (where the convection was shown to be most intense by Liu and Zipser, 2005) and Western Pacific (see Fig. 2)."

MINOR COMMENTS:

4. P33061, L1-3, Would the definition of the TTL change your conclusions? Note that 121-68 hPa basically include the upper troposphere and lower stratosphere. With low vertical resolution, this is > 6 km depth.

RESPONSE:

An exact definition of the TTL is not clearly established, mostly because the TTL does not present the same characteristics (depth, processes involved or entry level) depending if studied in maritime area or in continental area. Some defines it as the upper tropospheric layer under influence of the LS plus the lower stratospheric layer under influence of the UT. It is thus not surprising that what we defined as TTL (121-68 hPa) include what could be seen as the upper part of the UT and the lower part of the LS. In this study we chose the layers for which the D-N demonstrates a change in variability and then in the processes involved. As seen in Figs. 6 and 7 (in the final manuscript) the D-N behavior is different to those in the UT and in the LS between 121 and 68 hPa. Finally, we showed that the AKs peaking at 177, 100 and 56 hPa are not overlapping at their half-maximum. The three layers are thus independent.

MINOR COMMENTS:

5. P33062, 14, both MAM and SON are active seasons for deep overshooting convection in tropics (Liu and Zipser 2005).

RESPONSE:

It is right that Liu and Zipser (2005) showed a semi-annual cycle in the convective season. In our study however, we point out the importance to differentiate the most convective periods in the NH and the SH. The strong negative D-N in the UT (Fig. 2 in the final manuscript), the IWC occurrences (Fig. 5 in the final manuscript) and the H2O concentration (top panel Figs. 6 and 7 in the final manuscript), show areas of intense convection well established in the South between 0 and 20°S (North, between 0 and 20°N) in DJF (JJA). MAM and SON are transition periods during which the convective systems move South to North and conversely, so that the maximum of convection is found at the equator. Extended seasons (DJFM and JJAS) have been studied (not shown) but no significant differences with DJF and JJA were found.

MINOR COMMENTS:

6. P33065, L1-5, I am wondering about this speculation. It is proven that the stronger convection happens over the regions with dry air aloft combined with the low level jet of moist air, such as Argentina and SE US. Central Africa and Amazon convection have very different convective intensity properties. Regarding the explanation of CAPE, I am wondering if there is any study to support this statement.

RESPONSE:

Rosenfeld et al. (2008) hypothesis is theoretical and, to our knowledge, has not been assessed. However, Ackerman et al. (2000) and Koren et al. (2004) demonstrated the role of carbon-based aerosols in the inhibition of convective development. The sentence has been modified as follows: "As proposed by Khaykin et al. (2013), the larger aerosol concentration in the northern tropics might reduce the Convective Available Potential Energy (CAPE). This idea was first suggested by Rosenfeld et al. (2008) who developed a conceptual model to address the question of the relationship between aerosols, cloud microphysics, and radiative properties. Their results show that at moderate cloud condensation nuclei (CCN) aerosol concentration, the CAPE is enhanced until a maximum is reached to a concentration of ~1200 cm-3. Beyond this limit, larger CCN concentration has the opposite impact, preventing rainout in tropical clouds and inhibiting the convection. To our knowledge, no published study assesses this hypothesis. Nonetheless, it was demonstrated that carbon-based solar-absorbing aerosols with large optical thickness (such as soot) warm the planetary boundary layer, making it more stable and inhibiting the development of convective clouds (Ackerman et al., 2000; Koren et al., 2004)."

MINOR COMMENTS:

7. P33067, L10, are you implying that the TTL could be up to 68 hPa? Or this should be said the convection impact stops at 68 hPa.

RESPONSE:

This is right, given the D-N variability and the anomaly vertical propagation, we estimate the top of the TTL somewhere between 82 and 68 hPa (corresponding to the MLS retrieval layers). More information is however needed to determine whether or not deep convections have a direct impact up to the top of the TTL. We come back to this point in the discussion, please see the response to the comment #9.

MINOR COMMENTS:

8. P33071, L5, Bottom panels shows the “anomaly” of the water vapor mixing ratio.

RESPONSE:

It is right. However the entire paragraph has been modified. Please refer to the response of the major comment number 2 of the referee #2

MINOR COMMENTS:

9. P33071, at 171, there is not much day vs. night water vapor variation in winter. Then why there is opposite day vs. night water vapor variation at 100 hPa in winter, when there is no deep convection? Could this be related to the diurnal tide? Also the amplitude of water vapor variation is very small. I worry about the error bar is greater than the signal at this level and above.

RESPONSE:

Actually, the day and night anomalies are of the same sign in winter at 177 and 100 hPa, and was attributed to the condensation-sublimation diurnal cycle related to the radiative heating rate cycle of cirrus clouds. Nevertheless, we completed the analysis by implementing a filter based on the D-N significance. As showed in Fig. 3, not all the available D-N (on a daily base) are significant. From about 50% in summer, the statistics drop to 15-25% in winter at 100 hPa. We analysed the D-Ns for which |D-N| at 177 hPa is greater or equal to 20%, which we consider as significantly convective cases. Also, we assume to be insignificantly convective cases the D-Ns for which |D-N| at 177 hPa is less than 5%. We mainly focus on strong convective tropical land areas: South America and Africa. Results for the southern tropics are showed in Figure 4 (Fig. 8 in the final manuscript). "For significantly convective cases, the D-N in the UT in south tropical America and Africa is similar to that of Fig. 6a (the larger amplitude results with the selection of the most significant cases). However, the pattern is different in the TTL. In both areas, we observe a year-long positive layer between 121 and 100 hPa, extending up to 82 hPa in summer. Another positive layer is found between 56 and 46 hPa in the LS, also similar to that of Fig. 6a. For insignificantly convective cases, we assume that the convection is not responsible for the variability above 177 hPa. We observe a D-N distribution in the TTL similar to that of oceanic areas in Fig. 6b. A negative layer, at approximately 121–100 hPa, is surmounted by a positive D-N extending from 100 to 68 hPa, with maxima at 82 hPa coincident in time and pressure with the temperature minimum. Characterized by a strong negative D-N, the variability at the bottom of the TTL can only result from advection from outside the box. However, the transport must occur on short timescale (a few hours) from the source to the box, suggesting an origin from neighbouring convective areas; otherwise, mixing would progressively eliminate the difference between the day and night. In the LS, the negative D-N between 46 and 56 hPa also suggests possible advection from neighbouring regions.

Overall, transport by advection produces D-N in opposition of phase with respect to that of convective origin, resulting in an underestimation in the 121–100 hPa pressure range and an overestimation in the 82 – 68 hPa layer of the D-N as represented in Fig. 6a. Similar results are obtained in the northern tropics with less amplitude. Over oceanic areas, the D-N in the TTL is similar in amplitude and sign both for significantly and insignificantly convective cases, and presents the same characteristics than in Fig. 6b."

MINOR COMMENTS:

10. P33073, why do not showing this in the main text? I think the result over the western Pacific is compensating the rest results and it should be shown as Figure 7, if not combined into Figure 6. Also, please be specific on how you define the region.

RESPONSE:

The western Pacific is now integrated in the main text so that Figures 6 and 7 (in the final manuscript) are divided in two sub-figures: a) South America and Africa and b) maritime continent and western Pacific.

REFERENCES:

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FIGURE CAPTIONS:

Figure 1: MLS H_2O averaging kernels from 250 hPa to 30 hPa. Dashed lines represent the 177, 100 and 56 hPa levels. The red, green and blue kernels are the kernels peaking at 177, 100 and 56 hPa, respectively.

Figure 2: Same as Fig. 2 (in the manuscript) but for the MLS H_2O a priori in 2012.

Figure 3: Relative number of days in south tropical America for which the |D-N| is

greater than 10% with respect to all the days when both an average daytime and night time were available (1639 days) between 2005 and 2012.

Figure 4: Relative filtered H2O D-N over south tropical South America (left) and south tropical Africa (right) considering significantly convective cases (|D-N| at 177 hPa greater than 20%) (Top) and insignificantly convective cases (|D-N| at 177 hPa less than 5%) (Bottom).

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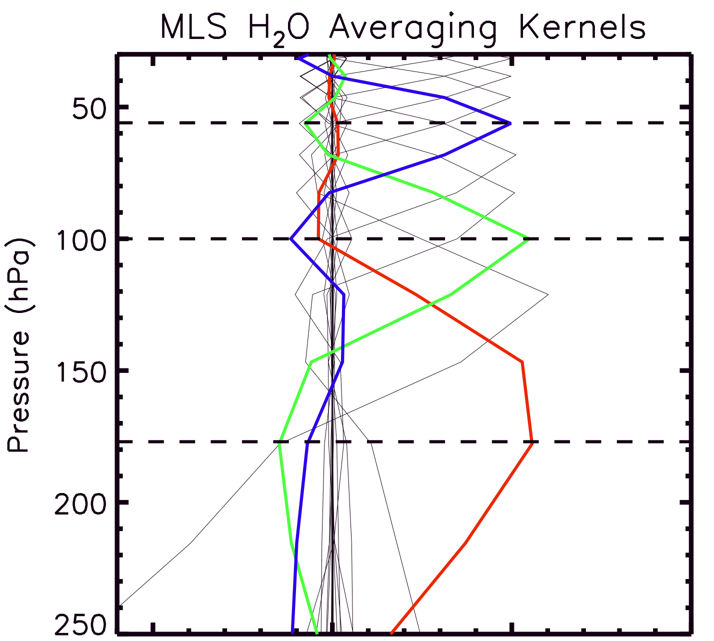

Fig. 1. Please see Figure Captions

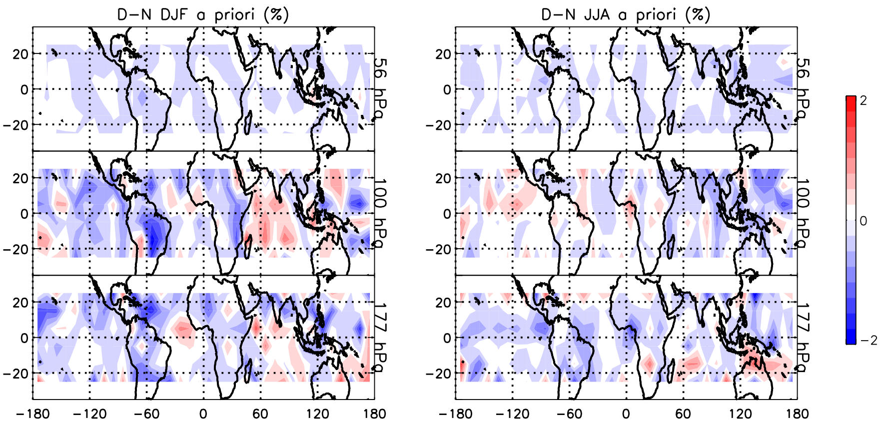

Fig. 2. Please see Figure Captions

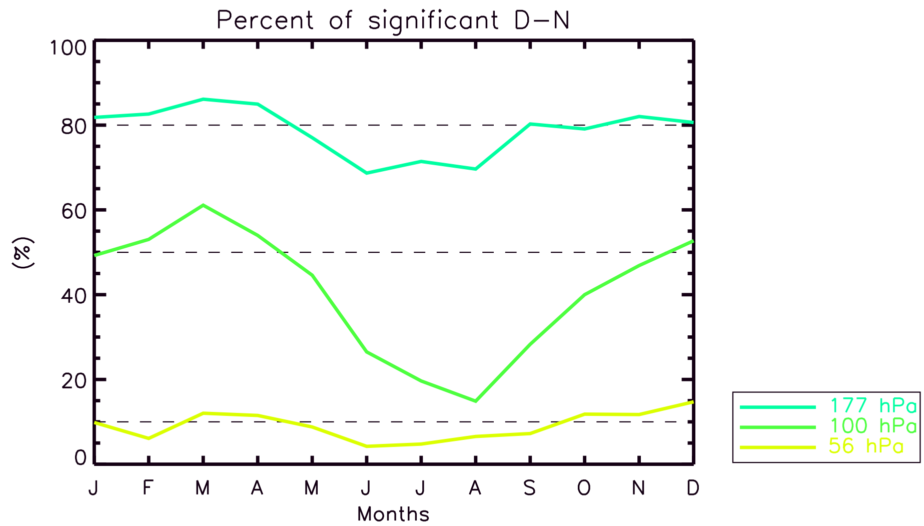

Fig. 3. Please see Figure Captions

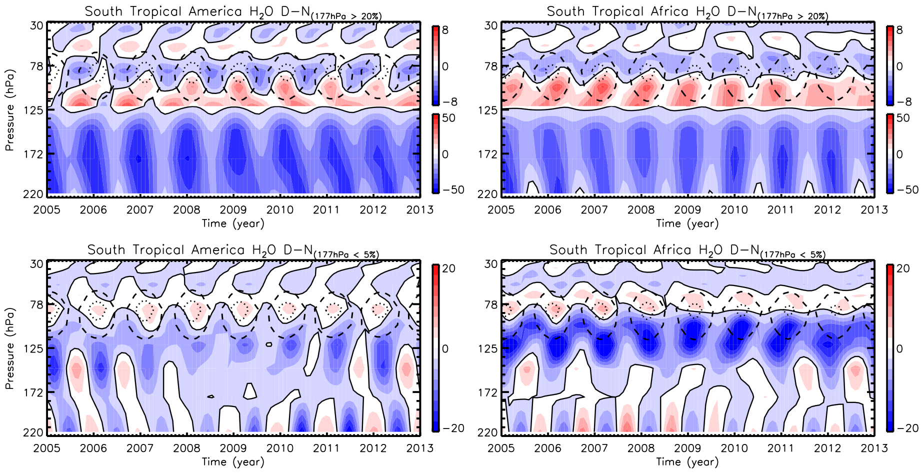

Fig. 4. Please see Figure Captions