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.

F. Carminati et al.

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We are grateful to the second referee whose comments helped us make a clearer analysis. His/her suggestions to estimate the impact of the a priori and averaging kernels brought, among others, further evidences that strengthen our results.

MAJOR COMMENTS:

1. Like the first referee, I have some questions regarding uncertainties and the robustness of the results at higher levels (especially at 56 hPa). The differences shown in Fig. 2 and Fig. 6 are quite small, while the MLS retrievals for each layer are somewhat dependent on the water vapour profile at other levels. This dependence on other layers can be positive (in phase) or negative (out of phase). Have you been able to confirm

that the diurnal cycles at these higher levels are not artifacts of the averaging kernel dependence on the diurnal cycle at lower levels? Are there any systematic day–night differences in the a priori profiles that might propagate into the retrievals? I recommend including a discussion of these issues in the revised manuscript.

RESPONSE:

All referees have justly raised questions regarding MLS uncertainties, specifically at low-pressure levels. This study presents a picture of the difference between the daytime and the night-time H_2O content, at large scale in the whole tropics first, and in restricted areas in a second time, which, indeed deals with very small variations. In order to address this issue and assess our observations, we proceeded with a three-step analysis. First, we studied the MLS averaging kernels and showed that the averaging kernels giving the maximum information at the 177, 100 and 56 hPa levels were not only almost independent but also representative of the UT, TTL and LS, respectively. In a second time, we treated one year of H_2O a priori (2012) with the same methodology than the H_2O mixing ratio and calculated the D-N of the a priori. It resulted that although the a priori does slightly vary, its D-N is most often negative or close to zero, so that it cannot be responsible of an artificial positive signal in the H_2O mixing ratio D-N as showed in Figs. 2, 6 and 7 (in the final manuscript) above continents at 100 and 56 hPa. Finally, we estimated the percentage of days among the whole dataset for which the D-N was without ambiguity significant (limit set to 10%). We showed that the D-N is significant about 80% of the time at 177 hPa, ∼50% at 100 hPa and ∼10% at 56 hPa during the summertime when the convection is the strongest. For further details, please refer to the response addressed to the referee #1. As recommended, we dedicated a new section in the discussion of the revised manuscript to the analysis of the uncertainties.

MAJOR COMMENTS:

2. I recommend slightly refocusing Section 3 ("Water vapour seasonal variations over

land areas") to emphasize covariability in water vapour, temperature and IWC. One option would be to replace the current Figs. 4 and 5 with composite time–height seasonal cycles of (a) day–night differences (in MLS water vapour, temperature and IWC) and (b) anomalies from the climatological mean (in MLS water vapour, temperature and IWC). It might be helpful to include the western Pacific region in these plots for additional context. By relating the annual and diurnal cycles of water vapour, temperature and IWC, you may be able to make clearer arguments regarding the importance of overshooting convection relative to other TTL processes at different times of year and over different regions. This approach would allow you to replace at least the top row of plots in Figs. 6 and A1, and might enable a more detailed look at your argument regarding the effects of El Niño/La Niña.

RESPONSE:

The suggestion to emphasize the co-variability of H2O, temperature and IWC can help to clarify our arguments. Also, we agree with the integration of the western Pacific in the main text and therefore modified the figures accordingly. However, we think that the addition of the D-Ns and anomalies time-height figures of temperature and IWC would add a large volume of information that we do not consider as indispensable. We preferred another approach, which consist in adding the annual mean daytime and night-time temperature and IWC anomalies alongside those of H2O. This anomaly gives information on the daytime and on the night-time separately, and keeps the information on the sign and amplitude of the D-N. Figures 1 (Fig. 10 in the final manuscript) show the H2O and temperature day and night anomalies.

This part of the discussion has been revised as follows: "Fig. 10 shows the seasonal variations of daytime and night-time anomalies for H2O mixing ratio and temperature over the same areas as in Fig. 9. In the UT (177 hPa), a strong night-time moistening in summer (October-March) over South America and Africa is in phase with the diurnal cycle of convection. The upper tropospheric night-time moistening is weaker above the maritime continent and nearly absent in the western Pacific. The TTL (100 hPa)

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in the summer is characterized by a daytime moistening above the two land convective regions, whereas anomalies show a night-time moistening in winter, and slight or insignificant night-time moistening during the whole year over the oceanic areas. The picture is very similar at 56 hPa in the LS, where daytime hydration is also observed above the two continents in the summer, and absent everywhere else where the night-time is maximum. Not shown in this figure, a daytime moistening characterises the layer near the Cold Point tropopause (centered on 82 hPa) above oceanic areas.

Temperature anomalies are more variable in the UT, characterized by a summer daytime cooling, followed by a winter daytime warming in both South America and maritime continent, and the opposite in Africa and western Pacific. The continent-oceanic dichotomy, absent in the UT, appears in the TTL. The temperature presents a year-long daytime warming (of larger amplitude in summer) over South America and Africa. However, maritime continent and western Pacific have both warming and cooling with very little amplitude. In the LS, a daytime cooling (of larger amplitude in October-March) is shown in all areas. Only in Africa, during JJA, the daytime is warming, most likely under the influence of the underneath layer. Note that the anomaly in DJF (± 0.25 K) is very consistent with the results published by Khaykin et al. (2013, Fig. 1).

IWC anomalies [not shown in the manuscript] are characterized by a year-long positive feature in daytime (and negative in night-time) in continental areas (± 0.3 mg.m-3) at all levels, and the opposite in western Pacific (± 0.15 mg.m-3). Only the maritime continent presents both features with a positive nigh-time in December, January and April, but with a very small amplitude (mostly less than ± 0.05 mg.m-3).

At 100 hPa, the night-time moistening above oceanic areas during the whole year, as well as continental regions in the winter, is consistent with the negative D-N observed at the same level for insignificantly convective cases [please refer to response referee #1, Fig. 4]. This is attributed to a horizontal advection from neighbouring areas. In the summer, however, the continental daytime moistening during the convective season requires a hydration process. The only known mechanism compatible for hydrating this

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layer is the convective overshooting of ice crystals, sublimating in the next day until the next cycle of convection.

At 56 hPa, the daytime continental hydration cannot be attributed to the direct injection of ice crystals, which caps, on average, at 82 hPa [please refer to response to referee #1, Fig.4]. The positive D-N, however, is consistent with the temperature diurnal cycle as presented by Khaykin et al. (2013), and attributed to non-migrating tides and convective updraft of adiabatically cooled air, of maximum amplitude in the LS. H_2O potentially turns into ice with the afternoon temperature drop, and then sublimates the next morning when the temperature rises. Note that it is possible that the information captured by the AK peaking at 56 hPa comes from the 70-60 hPa region, where colder temperature than that found at 56 hPa would favour this process. Remarkably, the geographical extension of the brightness temperature diurnal cycle over the ocean westward of South America and Africa revealed by Yang and Slingo (2001) and attributed to the propagation of gravity waves, can explain the positive D-N observed in Fig. 2 over the same places. "

MAJOR COMMENTS:

I cannot identify these ENSO effects in the current figures (see minor comment below); perhaps showing difference plots relative to the composite annual cycle would highlight the differences you are reporting? Relative to the current manuscript, this change would eliminate the annual cycle in water vapour (shown many times previously) and the interannual variability (only currently used with respect to the impact of ENSO phase).

RESPONSE:

In order to highlight the perturbation in the D-N linked to ENSO, we computed the D-N yearly average. Figure 3 shows the yearly averaged D-N at 177 and 100 hPa for (top row, from left to right) North tropical America, Africa, maritime continent and western Pacific, and (bottom row) their southern counterparts. The most striking impact of

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ENSOs is in South tropical America where the mean D-N in the UT (TTL) drops (rise) after the 06-07 event and rises (drops) again only after the 09-10 event. The South tropical maritime continent follows an almost similar pattern while South tropical Africa and Western Pacific show the opposite. The ENSO effect in the northern tropic is not as much apparent as in the southern but roughly seems to show an opposite variation, except for western Pacific.

Fig. 3 will not be added in the manuscript but the paragraph p33068, l7-25 has been rephrased as follows: "The El Niño and La Niña events do not appear in the Figs. 6 and 7 (a and b) because the FFT filter removes inter-annual variations. However, by influencing the tropical circulation, these events indirectly perturb the D-N and anomaly amplitudes. The ENSO events of 2006-07 and 2009-10 (Su and Jiang, 2013) match both the upper tropospheric (TTL) strengthening (weakening) followed by the weakening (reinforcing) of both D-N and anomaly amplitudes over south tropical South America and maritime continent, as well as the opposite effect above south tropical Africa and western Pacific. The ENSO 2009-10 was the strongest, displaying the warmest sea surface temperatures in the Pacific since 1980, followed by a strong La Niña event the next summer (Lee and McPhaden, 2010; Kim et al., 2011). As shown by Su and Jiang (2013), the ENSO 2006-07, (an Eastern Pacific event), resulted in a weakening of the Walker circulation, while the stronger ENSO 2009-10, (a central Pacific event), resulted in an eastward displacement of the Walker cell and a strengthening of the Hadley cell. The authors found a 5% increase of high cirrus clouds (at 100 hPa) in South America along with a 30% drop above the Pacific in 2009-10. Amplitude changes in H_2O D-N and anomalies in the southern tropics (Figs. 6 a and b) are consistent with the Su and Jiang (2013) observations during the El Niño events, further underlying the convective origin of water vapour variations in the TTL and in the stratosphere. In the northern tropics (Figs. 7a and b), these modulations are approximately out-of-phase with respect to the southern tropics; yet, they do not coincide as much as in the south to the ESNO years, meaning that other perturbations probably affect the convection. "

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MAJOR COMMENTS:

3. I would like to see more in the discussion regarding how seasonal changes in the diurnal cycle of UT/TTL water vapour relate to seasonal changes in the properties of convection (particularly overshooting convection) based on previously published work (e.g., TRMM, CloudSat, etc.), as well as what (if anything) the results imply for the importance of overshooting convection to global stratospheric humidity.

RESPONSE:

As suggested, we introduced studies based on TRMM and CloudSat-CALIPSO that show good agreement with the results presented in our study. The following paragraph has been added in the discussion.

"The seasonal changes in the H2O D-N (i.e., summertime maximum amplitude, negative in the UT, positive in the TTL and LS) closely follow the distribution of overshooting convection seasonal cycle as measured from the Tropical Rainfall Measuring Mission (TRMM) (Liu and Zipser, 2005). The authors showed that in DJF (JJA), OPFs were essentially found between 0 and 20°S (0 and 20°N), while March-May and September-November are transition periods during which the convective systems move from South to North and conversely, so that the maximum of convection is found at the equator. Also, Iwasaki et al. (2010) confirmed that the overshoot samples are not rare at the tropical belt scale, and induce a potential impact on the stratospheric hydration. The number of events penetrating the 380-K potential temperature level in the TTL, as measured by CALIPSO, is approximately 7.10ˆ6 events per year in the tropical belt (20°N-20°S). A hydration of about 100 tons of H2O per event was calculated using a combination of CloutSat and CALIOP data. Their results showed more cases during the day than during the night, and more cases over land than over the ocean. No discussion is made about the impact of the time of overpass, which may alter the statistics in some regions, but the results are qualitatively in agreement and compatible with this study."

MAJOR COMMENTS:

4. The text of the manuscript requires substantial editing. In particular, there are a number of sentences that could be reworded or split to improve clarity and readability. It may be helpful to engage the services of a professional editing service prior to submitting a revised manuscript.

RESPONSE:

Several persons of competence have edited the manuscript that we believe to be now of high English standard.

MINOR COMMENTS:

1) p.33057, l.7-8 : Sherwood (2000) showed that vertical motion derived from sounding data over the "stratospheric fountain" region is actually downward; see also Hartmann et al. (2001) for an explanation of how radiative cooling can exist at the tropopause in this region despite cold temperatures.

RESPONSE:

It is right, both Sherwood and Hartmann demonstrate the subsidence of air masses near convective centers. But when the air mass is no more cooled by the underlying anvil, the upward dynamic prevail anew. Nevertheless, the sentence has been rephrased as follows: "The long known convective area in the Western Pacific, referred to as 'stratospheric fountain' (Newell and Gould-Stewart, 1981), has been the focus of numerous field campaigns."

MINOR COMMENTS:

2) p.33057, l.25-26 : If possible, you should refer back to the TROPICO campaign in the discussion or conclusions. How has this study helped to inform or provide a baseline for TROPICO?

RESPONSE:

The following paragraph has been added to the conclusion: "TRO-pico's objectives are to evaluate to what extent the overshooting convection and involved processes contribute to the stratospheric water vapour entry. Light and medium size balloons were launched as part of two field campaigns (2012 and 2013) held during the convective period in Bauru, Sao Paulo state, Brazil. Flights carrying Pico-SDLA (Durry et al., 2008) and Flash-B (Yushkov et al., 1998) hygrometers were launched early morning and late evening while radiosondes were launched up to 4 times a day during the most convective period. The measurements, still under analysis, are matched with space-borne and model data. Then, to evaluate the local results obtained in Bauru with respect to larger scale, comparisons with climatologies will be necessary. Although seasonal and annual variation of H2O has been extensively studied, few studies were devoted to the geographical and temporal variability of its diurnal cycle in the TTL. With this study, we aim to deliver a comprehensible landmark for TRO-pico as well as future research debating the impact on H2O of the continental tropical convection. "

MINOR COMMENTS:

3) p.33058, l.3 : I'm not sure that I would say that water vapour is a "source of" photo-chemical reactions – it's a source of OH and a key player in stratospheric photochem-istry.

RESPONSE:

It has been rephrased as follows: "Being the most powerful greenhouse gas and play-ing an important role in the UT, TTL and LS chemistry as one of the main sources of OH radicals, [. . .]"

MINOR COMMENTS:

4) p.33058, l.13-14 : The wording of the beginning of this sentence ("If the process is well-captured by cloud-resolving models") is confusing. I think that you mean "Although this process is well-captured in cloud-resolving models" – is this correct?

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RESPONSE:

It is correct, the sentence has been corrected.

MINOR COMMENTS:

5) p.33061, l.2-4 : How different is this qualitative definition of the TTL from the defi-nition based on MLS pressure levels? The locations of the LZRH and CP change by region – are the results in any of the study regions sensitive to the definition of the TTL?

RESPONSE:

There is no major difference between the MLS pressure-based and the qualitative def-inition, nor are our results sensitive to it. Nonetheless, a comprehensive definition of the pressure range that we consider to be the TTL is needed for the clarity of the study.

MINOR COMMENTS:

6) p.33061, l.8 : AURA is not an acronym – it should be replaced with Aura.âĂĺ

RESPONSE:

It has been corrected.

MINOR COMMENTS:

7) p.33061, l.15 : The wording of this sentence is difficult to follow. Is it that the precision varies from 40% at 220 hPa to 6% at 31 hPa and the accuracy ranges from 25% at 220 hPa to 4% at 31 hPa. Should these values be preceded by $\pm$?

RESPONSE:

The sentence has been replaced by: "The precision ranges from 40% at 215 hPa to 6% at 46 hPa, and the accuracy from 25% at 215 hPa to 4% at 46 hPa, for a vertical resolution of 2.5-to-3.2 km."

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MINOR COMMENTS:

8) p.33061, l.23 : v3.3 is biased relative to v2.2 – does this bias represent an improvement in MLS estimates of IWC? Is it clear at this point which version is more accurate?

RESPONSE:

We compared both versions and no significant difference was observed in the D-N at 177 and 100 hPa.

MINOR COMMENTS:

9) p.33063, l.4-5 : The 100 hPa day–night differences only appear to be out of phase with the 177 hPa differences over portions of south tropical South America and south tropical Africa, and over Africa the region that is out of phase doesn't line up with the largest signal at 177 hPa. Over other regions (and during JJA), the variations seem to be small or in phase with the UT.

RESPONSE:

It is right. Variations in-phase or out of phase but not lining up with the maximum D-N amplitude at 177 hPa are the result of competing possesses: 1) a D-N variability induced by the convection (e.g. negative in the UT and positive in the TTL), and 2) a variability largely impacted by horizontal transport (negative in the lower TTL and positive around 80 hPa, similar to what is observed above oceanic areas). Figures 6 and 7 (in the final manuscript) result then from the average of very convective days when the first case is predominant and days when the convection is weak or inexistent, giving weight to the second case. Figure 8 (in the final manuscript) shows the D-N for the most convective days only (when the |D-N| at 177 hPa is greater than 20%) compared to non-convective days (|D-N| at 177 hPa less than 5%). In the case of the most convective days, the D-N sign present a clear opposition of phase between UT and TTL with a good alignment with respect to the maximum amplitude at 177 hPa.

MINOR COMMENTS:

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10) p.33063, l.11-14 : Are relative humidities sufficiently high at 56 hPa in this region to support a diurnal cycle in thin cirrus / sublimation?

RESPONSE:

This argument has been removed from section 2.2. The origin of the positive D-N observed above continental regions in the LS is now discussed in the section 4.3 of the discussion (see response to major comment 2). It is attributed to the temperature variability induced by convection, although it is possible that the information captured by the kernel peaking at 56 hPa comes from the 70-60 hPa region, where the temperature is colder than at 56 hPa.

MINOR COMMENTS:

11) p.33064, l.17-19 : Is the amplitude of the diurnal cycle in temperature quantitatively consistent with the diurnal variation of H2O, or only qualitatively? More specifically, can the amplitude of the diurnal cycle in temperature fully account for the amplitude of the diurnal cycle in water vapour? Does the MLS temperature data agree with COSMIC in sign / magnitude?

RESPONSE:

As already mentioned, MLS does not sample the atmosphere at the maximum of convection, and then cannot estimate the maximum of the diurnal amplitude of temperature. Nonetheless, at 01:30 and 13:30 LT the MLS night-time and daytime temperature anomalies (Figure 1) are of ± 0.25 K, positive at night and negative at day, which is very consistent with the COSMIC data in magnitude and sign (about ± 0.2 K, Khaykin et al., 2013).

L17-19 have been rephrased as follows:

"Khaykin et al. (2013) estimated the temperature diurnal cycle from the COSMIC satellites GPS Radio Occultation measurements. At the MLS sampling time, the temperature measured by COSMIC had not reached its maximal amplitude but did show its

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premises, with a ∼0.2 K cooling (warming) at 13:30 LT (01:30 LT), in agreement both in sign and magnitude with the temperature measured by MLS. At 100 hPa, the COSMIC temperature diurnal cycle is consistent with the positive continental signature of H2O D-N (see Fig. 2) in contrast to oceanic areas where the D-N is insignificant."

MINOR COMMENTS:

12) p.33064, l.21 : Does "such event" refer to the diurnal cycle of COSMIC temperature? Please clarify.

RESPONSE:

The sentence has been modified as follows:

"In JJA in the northern tropics, late afternoon cooling is limited to Central Africa and does not appear elsewhere."

MINOR COMMENTS:

13) p.33066, l.19 : The vertical location of the hygropause appears to vary substantially by season.

RESPONSE:

It has been modified as follows:

"The driest hygropause is observed from January to May at about 80 hPa in the four regions."

MINOR COMMENTS:

14) p.33067, l.8-10 : It's difficult to tell from the figure whether the vertical propagation of the TTL summer maximum is any faster than the vertical propagation of the TTL winter minimum (also, shouldn't these be "winter maximum" and "summer minimum" since Fig. 4 shows the southern hemisphere?).

RESPONSE:

The confusing sentence has been removed.

MINOR COMMENTS:

15) p.33067, l.23 : "6% weaker"; "3% weaker" – are these relative or absolute differences? Specifying the amplitude or maxima/minima (e.g., "xx% relative to yy% in the southern hemisphere") may help to avoid confusion here.

RESPONSE:

We agree with the referee and replaced l.23 and l.27 by:

"However, the D-N features (middle panels Figs. 7a and b) are significantly different: in the UT, a weaker night-time maximum humidity is displayed (-17% relative to -25% in the southern tropics), and in the TTL, above South America and Africa, a weaker daytime maximum is displayed (1.5% relative to 4% in the southern tropics). [...] The monthly mean anomalies are similar to those of the SH, although of lesser amplitude in the UT (±8-18% relative to ±18-28% in the southern tropic)."

MINOR COMMENTS:

16) p.33068, l.4-25 : I can't clearly identify the weakening/strengthening of the amplitude in the UT/TTL that is supposed to be related to ENSO in these figures. It looks like the amplitude in the TTL strengthens in both 2008–2009 and 2009–2010, while the amplitude in the UT weakens in both years. . .

RESPONSE:

Please refer to the response of the major comment number 2.

MINOR COMMENTS:

17) p.33069, l.10 : No sign of diurnal variation in what? Water vapor? Tropopause temperature/vertical location? Please clarify.

RESPONSE:

The paragraph has been modified as follows:

"As explained in section 2.4 and also suggested by Danielsen (1982), the late afternoon cooling by injection of adiabatic cooled air from overshooting convective systems is a well-understood feature which may have two implications: 1) drying by condensation at temperatures below saturation either at, or below, the Cold Point tropopause (Danielsen, 1982; Sherwood and Dessler, 2001), and/or 2) moistening by the subsequent sublimation of ice crystals injected in the TTL by overshooting convection. The first option would explain the positive D-N signal in the extremely dry tropopause region above the maritime continent and western Pacific. This results from the heating rate cycle of cirrus clouds formed by condensation because of the low temperature (Hartmann et al., 2001; Corti et al., 2006). However, the wetter TTL in continental areas requires a hydrating process that the first scheme does not provide. "

MINOR COMMENTS:

18) p.33069, l.19-22 : I don't follow the two implications here. My understanding is that the two possible effects should be (1) drying by condensation occurring because of the relatively low temperatures in cold overshooting air, or (2) moistening by the subsequent sublimation of ice crystals injected by overshooting convection.

RESPONSE:

This point is also answered in the previous response.

MINOR COMMENTS:

19) p.33070, l.12-13 : Does a greater efficiency of moistening necessarily mean more intense convection? How does the background RH compare among these regions? By many measures (lightning, radar reflectivity), convection over south tropical Africa is more intense than convection over south tropical South America, especially during DJF (e.g., Petersen and Rutledge, 2001). If the amplitude of the diurnal cycle in water vapour is entirely attributable to the intensity of overshooting convection, how is this

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consistent with the amplitude being greater over south tropical South America than over south tropical Africa?

RESPONSE:

Our observations are consistent with the Yang and Slingo (2000) mean brightness temperature (BT) climatology. They show that the mean BT are 1) lowest in DJF in the southern tropic with respect to the northern tropic in JJA, and 2) South America presents lower BT (in DJF) than Africa. Also note that in the northern tropic in JJA, Africa has lower BT than South America.

Regarding the relative humidity (RH), the Gettelman et al., 2006, climatology shows that, at least in the UT, the RH is similar ($\sim$ 60-70%) in the northern and southern tropics in JJA and DJF, respectively, in the areas of interest of this study. A more efficient convection would lead to a wetter UT in convective season and consequently larger gradient in the monthly mean anomaly. South tropical America UT anomaly amplitude is indeed greater than in south tropical Africa and, although weaker than in the south, north tropical Africa anomaly amplitude is greater than north tropical Americas', in agreement with Yang and Slingo (2000) BTs.

We agree that a larger sampling would result in a better characterization of the impact of convection, but the fact that MLS samples the different tropical regions at the same local time already allows drawing conclusions.

The paragraph has been modified as follows:

"The H2O mixing ratio, D-N, and anomalies show marked seasonal variations in the eight regions. However, the upper tropospheric D-Ns are of systematically larger amplitude above land areas, particularly in the southern tropics. Another typical feature of these areas is the positive D-N at the bottom of the TTL and up to 82 hPa during the most convective season, in contrast to oceanic areas that display a positive D-N near the tropopause at 82 hPa.

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The main differences between these areas are their convection characteristics, with late afternoon maximum intensity over tropical land and weak diurnal change over ocean. Moreover, the stronger signal in the south tropical summer, particularly above South America, indicates a much more intense convection than in the northern tropics. These observations are consistent with the Yang and Slingo (2000) mean brightness temperature climatology showing the lowest brightness temperatures, synonymous of colder cloud top, in the southern tropics in DJF and more precisely over South America. Also, this North-South difference in D-N amplitude cannot be, at least in the UT, attributed to a gradient in the relative humidity (RH). In South America, Africa, maritime continent and western Pacific, north and south tropical RHs are comparable during their respective summer (Gettelman et al., 2006).

In the TTL and LS, the variability of the anomaly in all areas, which remains unchanged regardless of the strength of the convection in the UT, is consistent with the seasonal variability of the Cold Point temperature. This indicates that in the TTL and above, the continental convection does not affect H2O seasonal variability, even though, it strongly impacts its diurnal cycle. "

MINOR COMMENTS:

20) p.33070, l.16–18 : What do these results mean, if anything, regarding the global impact of deep continental convection in the TTL/LS? For instance, Fig. 6 suggests that the amplitude of the diurnal cycle over the convective regions is very small (less than 5%) relative to the amplitude of the typical seasonal cycle in the TTL/LS; on the other hand, MLS may substantially underrepresent the diurnal cycle in water vapour at these levels (cf. Fig. 1). Do you feel comfortable making any statements about this at this point?

RESPONSE:

As it is rightly underlined, for many aspects, MLS underestimates the H2O variability at all levels because not in phase with its largest magnitude. This is the reason why

we adopted a quantitative approach and try to determine the nature of the involved processes (hydrating or dehydration), their origins and mechanisms, and not how much water is injected or removed from a given layer. MLS samplings offer what we could define as an initial and a final state (before/after convection) of H2O, so we can only hypothesize how it evolved in-between. However, our analyses gather enough clues to present reliable conclusions.

MINOR COMMENTS:

21) p.33071, l.18-21 : Is there any indication from previous work that ice crystals from overshooting convection can moisten the atmosphere at 56 hPa? At the very least, it needs to be shown that these diurnal cycles are not artifacts of the retrieval (e.g., averaging kernel, a priori profiles, covariability with temperature).

RESPONSE:

Please refer to responses to major comments 1 and 2.

MINOR COMMENTS:

22) p.33072, l.15-19 : This argument regarding the diurnal cycle of water vapour at 56 hPa over the Asian monsoon region requires further discussion and support. Is there any published evidence of cirrus clouds at this altitude (e.g., SAGE II, CALIPSO)?

RESPONSE:

Asian and Central American monsoon regions are at the edge of the tropics and characterized by complex convective systems of different origins and characteristics relative to those occurring deeper in the tropics and analyzed in the present study. The convective aspects of the monsoon, especially the Asian one, has been extensively studied, and although the methodology developed in our study is applicable to those regions, it would require a whole new analysis that could be developed in a different paper.

In order to clarify the observations relative to monsoon regions, the following paragraph

has been added to the discussion:

"In the Asian and Central American monsoon regions, we noticed at 56 hPa a positive D-N signal in JJA, in absence of strong night-time moistening in the UT. This atypical feature potentially results from the influence of the adjacent seas; namely, Gulf of Mexico and Caribbean Sea for the Central America monsoon region, and South China Sea and Bay of Bengal for the Asian monsoon region. Yang and Slingo (2000) showed that in these regions, both brightness temperature and precipitation diurnal cycle are shifted by about 10-12 hours from sea to land with a sharp transition. Since we average H2O in a 10ĚŽx10ĚŽ grid, both land and ocean are combined in these areas, resulting in a composite land-ocean convection cycle, which explains the absence of a strong signal in the UT. Unlike the maritime continent where land and ocean are also combined, Asian and Central America monsoon regions present the continental convection signature in the LS (e.g. positive D-N). Although the methodology developed in our study is applicable to monsoon regions, it would require a dedicated analysis beyond the scope of this study. "

MINOR COMMENTS:

23) p.33072, l.25 : Should "daytime" at the end of this line be "nighttime"?

RESPONSE:

The paragraph has been replaced by:

"The convective origin of the TTL and LS hydration is confirmed by the humidity and temperature daytime and night-time seasonal variations over the various land tropical regions. The TTL daytime moistening by sublimation of up-drafted ice crystals up to 82 hPa, and the LS daytime moistening associated to the temperature cycle induced by convection, are characteristics of summertime south tropical land. Similar patterns, but of lesser intensity, are found in north tropical land, suggesting that convective overshoots are less frequent or less vigorous in the northern tropics. In com-

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parison, oceanic locations present a daytime maximum water vapour at the tropopause level consistent with the cirrus daily cycle of radiative heating origin."

MINOR COMMENTS:

24) p.33073, l.5-16 : As mentioned above, I recommend integrating this appendix with the main text of the manuscript.

RESPONSE:

We integrated the western Pacific to the main text.

âĂČ REFERENCES:

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FIGURE CAPTIONS:

Figure 1. Monthly daytime H2O (red solid line), night-time H2O (red dotted line), daytime temperature (green solid line) and night-time temperature (green dotted line) anomalies, calculated for each month as the difference between the monthly average daytime (night-time) and the monthly average, for the 2005-2012 period, at 177, 100 and 56 hPa in South tropical America (top left) and South tropical Africa (top right), South tropical maritime continent (bottom left) and South tropical western Pacific (bottom right).

Figure 2. Same as Fig. 1 but for IWC at 100 hPa.

Figure 3. (Top) Yearly average in ppmv of the filtered D-N at 177 and 100 hPa above (from left to right) North tropical America, Africa, maritime continent and western Pacific. (Bottom) Same as top but for South tropical America, Africa, maritime continent and western Pacific.
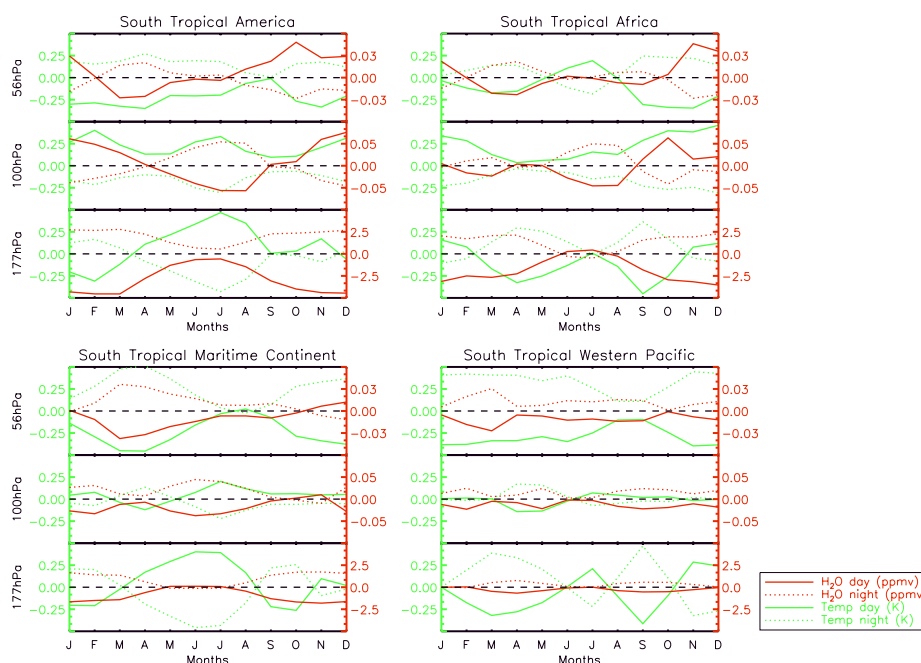
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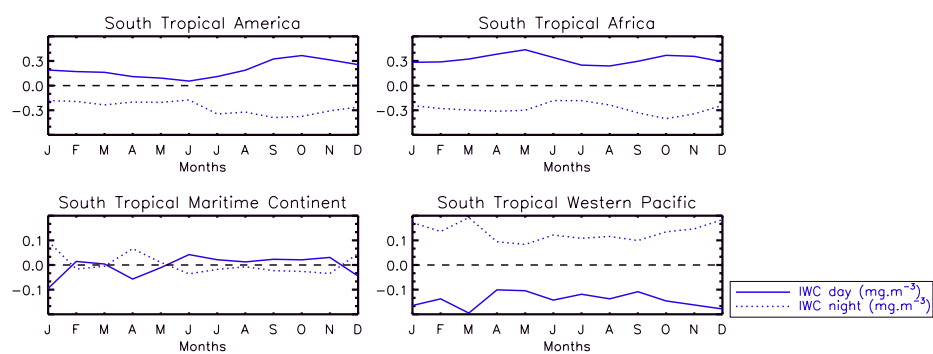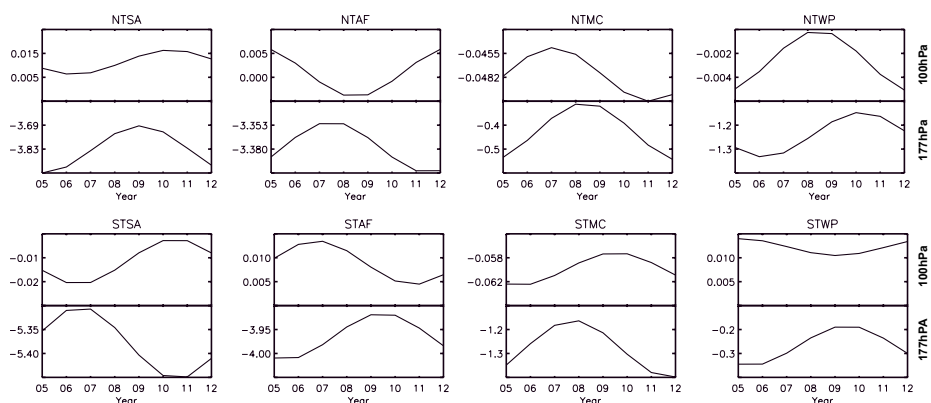**Fig. 1.** Please refer to Figure Captions

Fig. 2. Please refer to Figure Captions

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Fig. 3. Please refer to Figure Captions