Atmos. Chem. Phys. Discuss.,
doi:10.5194/acp-2016-588-AC2, 2016

Atmospheric Chemistry and Physics
Open Access
Discussions

Interactive comment on "Evidence of horizontal and vertical transport of water in the Southern Hemisphere Tropical Tropopause Layer (TTL) from high-resolution balloon observations" *by* Sergey M. Khaykin et al.

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Received and published: 2 September 2016

Authors' reply to referee #3

We thank the Referee #3 for a positive evaluation and pertinent remarks.

L51: I don't think the TTL extends down to 12 km. The base of the TTL is typically defined as being 14 km (see Fueglistaler et al 2009).

The sentence has been corrected: "Extending between the main level of convective outflow (∼14 km) and the maximum level reachable by convection (18 - 19 km), the

TTL. . ."

L169: What is the Livesey reference? I don't see it in the references section.

The reference has been added into the reference section.

L186: GDAS acronym needs to be defined

GDAS acronym is actually defined in L182

L252: I assume you mean 17 March, not 17 August?

Yes, we certainly meant 17 March, not August.

L287-288: There are different ways to define overshooting, and I'm not sure if LRT is the most appropriate boundary for talking about WV. Wouldn't the cold point tropopause be most appropriate? Some further discussion here to justify the choice of LRT seems appropriate.

The cold point tropopause (CPT) would indeed be a more appropriate boundary for overshooting hydration in case if the air is close to saturation at the CPT level (as is often the case above e.g. Maritime continent/Western Pacific). In that case, the extra moisture injected into subsaturated environment below CPT would eventually freeze out as it rises through the CPT. However in our case the entire TTL is nowhere near the saturation (see Fig. 4c updated), therefore all the water injected above LZRH (∼360 K for clear-sky conditions) should further rise above the TTL thereby moistening the stratosphere. Essentially, in our case whatever level above 360 K is considered as a boundary for overshoot, the conclusion regarding the hydration of the stratosphere would remain unchanged. The LRT was chosen as a boundary for overshoot as a compromise between the classical definition of convective overshoot (above LNB) and the one that is more appropriate for stratospheric hydration (above CPT). This choice also facilitates the discussion of radar observations of convective cells reaching above 16 km and termed "overshooting cells". The following paragraph has been included into Sect. 4.5 "Hydration process" "It should be kept in mind that subsaturation of air at and above the level of detrainment is a prerequisite for hydration of the stratosphere through overshooting. If the TTL above the level of detrainment is close to saturation, the stratospheric hydration is possible only if the humid air is injected above the temperature minimum (CPT), otherwise any amount of additional water in excess of the minimum saturation would freeze out as it rises into the stratosphere. Furthermore, if TTL is initially supersaturated, an overshoot can lead to dehydration as the excess vapour condenses on the ice crystals (Jensen et al., 2007). In a generalized case, an overshoot must surpass the CPT level to ultimately hydrate the stratosphere, however if CPT is well below the saturation - as is the case here - any overshoot above the level of zero radiative heating (LZRH, ~360 K, Fueglistaler et al., 2009) can potentially hydrate the stratosphere. In the case of 13 March sounding CPT is found at 387 K (17.3 km), which is slightly above the lower humid layer (386 K) but well below the upper humid layer (404 K)."

L353: Remove comma after "locations"

Correction applied.

Paragraph starting on L369: This paragraph confused me. Overall, I just don't see what the point is that is trying to be made here. Also, what does negative 13 m/s mean in this context?

Although the vector of falling rain drops within a storm has 3 components (u, v, w, corresponding to the east/west, north/south and vertical components, respectively), a single Doppler radar can only measure the radial component of the three-dimensional movement of rain drops (three Doppler radars, positioned at the corners of a triangle, would be required to resolve the three-dimensional air flow correctly). Negative radial velocities indicate that the radial component of the three-dimensional movement of rain drops is towards the radar, while positive velocities represent movement along the radial away from the radar (this follows the same convention as used in astronomy for the movement of stars). In order to calculate the true outflow velocity, the vectors

of the ambient air flow and storm motion have to be taken into consideration (vector calculation). In this case, both vectors were in the same direction, while the storm motion was negligible, hence the ambient flow of 3 m/s was subtracted from the radial flow of 13 m/s, resulting in a net flow component towards the radar of -10 m/s. The paragraph has been modified: "The radial velocity cross-sections for both cells (not shown) obtained from the IPMet Doppler radar suggest that the outflow from both cells into their anvils exceeded -13 m/s (negative radial velocities indicate that the radial component of the three-dimensional movement of rain drops is towards the radar)."

Sentence starting line 379: The 'cooling signature' is not very obvious to me in Fig. 4. Perhaps it would be more obvious if an 'unperturbed' temperature profile were available. I'm not sure if there is one (perhaps from a nearby radiosonde), but if so it would help. As is, this is not very convincing.

Unfortunately an "unperturbed" temperature profile is not available: the nearest GPS radio occultation measurements are too far away in space or in time to be used for that purpose. The cooling signatures are indeed not very prominent, however they are discernible and appear in all the three panels of Fig. 4, precisely at the hydrated layer. A cooling is expected to follow an overshoot: there are a number of observational studies reporting local cooling of the lower stratosphere from convective injections of adiabatically cooled air with cooling amplitude from 2 K to 10 K. In our case the cooling amplitude is only about 1 K, which is consistent with a relatively small amplitude of hydration and a very limited size and lifetime of the overshooting cell. The sentence in line 379 has been modified: "Small cooling features (~ -1 K) corresponding to the hydrated layer at 404 K are discernible in Fig. 4..."

Sentence starting on line 381: You say that the ice has sublimated, but it also could have precipitated.

Indeed, one can not rule out that a part of the ice crystals have sedimented before sublimating. The corresponding sentence has been modified: "Apparently, the ice detrained from convective updrafts has fully sublimated (or partly precipitated) before the plume was sampled.”

Line 389: You mention a dip in ozone in the data from Africa. Were ozone data available from these flights? If so, that would seem to be an important piece of information to include.

Unfortunately the ozone soundings were not conducted during the campaign.

Sentence starting L458: So in-mixing and overshooting signatures are similar, at least in terms of WV/aerosol. But what about ozone? It seems as though ozone would allow one to fingerprint' these two processes, since extratropical overworld ozone would have a high value, whereas overshooting would bring up ozone poor air.

Indeed, one should expect higher ozone in the layer affected by in-mixing. This is confirmed by CLaMS simulation of the ozone fields (not shown). The overshooting is expected to bring up ozone-poor air, but in this case we do not have an observational evidence for that and can not really develop this argument.

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