

Interactive comment on “Hydration of the lower stratosphere by ice crystal geysers over land convective systems” by S. Khaykin et al.

S. Khaykin et al.

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We thank the reviewer for his/her thorough attention to the paper and detailed comments. We would also like to acknowledge his/her expertise in the paper's subject. We hope that the detailed answers to these comments and the carefully revised manuscript will clarify some misunderstandings and better reconcile observations with the hypothesis.

"The presentation of observations seems to have been very selective to observations in favor of the hypothesis..."

There has been no selection. All measurements are shown. We fully understand that more flights would be useful but that's all we could perform within a month campaign during the convective monsoon season which started quite late (3rd week of July) in

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2006.

"The suggested evidence in favor of the hypothesis is rather small and often not self consistent..." The evidence is purely experimental, showing H₂O narrow peaks in most of the flights (though not on the first at the beginning of the season) and in one case, above a local convective system, the simultaneous presence of particles. To our knowledge this has never been observed before and thus we think deserves publication. One can certainly discuss the interpretation and we are fully aware that there are still open questions, but we cannot see the reason for not publishing these results.

Answers to detailed comments paragraph by paragraph.

Paragraph 1. "The main convective outflow region of convection is..." It is not obvious that convection, at least fast developing continental convective systems, results in an uplift of the tropopause. There is evidence of the opposite (e.g. lower tropopause around 16 km or even lower above Africa and South America during the convective season compared to 17 -17.5 km in the Western Pacific or signs of lowering of the tropopause during convective compared to non-convective periods [Pommereau and Held, 2007]. The explanation for the latter is that the cold point could be a stratospheric feature of radiative origin which can exist independently of convection (Thuburn and Craig, [2002], Gettelman et al., [2002])

Paragraph 2. "Selective data presentation: In table 2 the authors list observed water vapor enhanced layers, but this table leaves many open questions..."

Enhancement refers indeed to narrow and sharp positive peaks in water vapour mixing ratio (local maxima). Note that there are no negative peaks above the tropopause. The term enhancement means a water vapor increase, but implies nothing about the process involved. Enhancements of 0.2 ppmv are indeed rather small but larger than the 0.1 ppm detection limit of the hygrometer. The enhancements are related to every single profile, therefore have nothing to do with the standard deviation accounting for the variability between the profiles. The enhancements themselves do not say anything

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about their origin. It is only the relation with upwind overshoots, which suggest this explanation.

Paragraph 2. "The term "geyser" evokes the picture, that material is injected well above the tropopause, without significant mixing and without modification of the convective environment."

"Geyser" is a good metaphor for the intrusion-process. Part of the intruding air might fall back in the troposphere, as Referee 1 also suggests, but, providing they are not too large, ice particles will sublime and mix with the environment and stay in the stratosphere. Note that even though the water vapor mixing ratio is enhanced in the layers above the tropopause, it is still orders of magnitude below the tropospheric mixing ratio. The observations are fully compatible with the process predicted by Cloud Resolving Models.

Paragraph 3. "It is very difficult to understand..."

The enhancement at 492 K is indeed a special case, which requires special treatment. Extreme vertical velocity compared to others, absence of relation with an overshoot up wind, coincidence with volcanic aerosols from Soufriere Hills. It is very unlikely that this layer originates from overshooting convection. A discussion of the possible origin of the enhancement at 492 K on 5 August including a reference to possible transport from mid-latitudes has been added. 10-day backward trajectories do not show any indication of that but true zonal transport for the Pacific.

Paragraph 4 "The authors do not mention the possible influence of waves..."

Equatorial Kelvin waves are commonly associated with local cooling of the cold point tropopause, leading to dehydration (e.g. Holton and Gettelman, [2001]), but this was never observed during the campaign. Local ice nucleation by cooling by gravity wave of short wavelength would have required a cooling by some 10 K [Nielsen et al., 2007], never seen in the 4 daily Atmospheric Radiation Station (ARM) soundings performed

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during the campaign. We do not see how waves could enhance the water content in the lowermost stratosphere. A discussion on possible influence of waves has been added.

Paragraph 4. "Although ozone is measured..."

The paper focuses on water vapour observations, the ozone and particles measurements are involved only for better describing the special case of 23 August high local convective activity. The particles observed on that day are shown to likely originate from a fresh injection 0.5-1 h before, sublimating rapidly before being sedimented. The drop in ozone at 16.2 km in Fig 5 is consistent with a mixing of 20 percents tropospheric ozone poor air. That at 18 km would also be consistent with a mixing of 3 percents. There may be other explanations for such ozone drops (e.g. meridional transport though the trajectories do not show this) but we think it is worth noting that they could be very consistent with an injection of tropospheric air at the altitude where the particles and the enhanced water vapour layers are observed. The discussion on the possible origin of the ozone dips has been worked into the paper. The scale of Fig. 5 has been enlarged for better showing the ozone profile.

Paragraph 5. "Bottom of page 3: The statement about "little use of water vapor observations..."

The key point here is the vertical resolution of the satellite observations, which is by far insufficient for studies of such kind. The text has been modified.

Paragraph 6. "Page 4: Enhanced moisture layers above the tropopause is not unique to continental convection..."

We are not aware of similar observations over oceanic areas. To our knowledge, particles like ours as well as water vapour layers have been observed above continental convective systems only [Kelly et al, 1993; Nielsen et al., 2007; Chaboureau et al., 2007; Corti et al., 2008]

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Paragraph 7. "Page 4: Here, the authors state, that the presence of moist layers in the lower stratosphere..."

We agree that this statement has rather week basis at that point. The sentence has been modified.

Paragraph 7. "Meridional transport and impact of waves might play a role as well, but are not discussed..."

As mentioned above the 10 days backward trajectories available do not reveal meridional transport but almost zonal transport from the Pacific at these levels. As far as the effect of waves might be concerned, we do not see how waves could enhance the lower stratospheric water vapour. A short discussion on possible influence of waves and meridional transport has been added into the paper.

Paragraph 8. "The cloud resolving models, to which the authors refer..."

Enhanced water vapour air is included by Brewer-Dobson circulation and is obviously the reason for the observed H₂O maximum at 24-25 km.

Paragraph 9. "Figure 6: It is difficult to reconcile the figure inset..."

There were a number of storms and squall lines developing in the Niamey area during that afternoon. We agree that shown in Fig 6 was not the best choice, which indeed would have resulted in an overshoot displaced west of the sonde at the time of the measurements. We have looked carefully at all radar pictures during that evening. The radar image in Figure 6 taken at 16:51 UT has been replaced with theby a cloud top image taken at 20:31 UT corresponding better to the observations. The wind direction and speed measured by the sonde, identical during its ascent and descent, show that the observations would be compatible with an injection by that cloud 30-60 minutes before before.

Paragraph 10. "Compared to Aura/MLS observations, the data of the authors..."

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The discussion on the discrepancies/agreement with the other data sets and possible sources of uncertainty has been improved. As far as Geophysica aircraft measurements are concerned, during SCOUT-AMMA campaign the aircraft did climb up to 450 K (19 km) and measurements up to this level were obtained. Although the usefulness of an indirect comparison may be limited, the main point is that independent measurements by the FISH hygrometer onboard Geophysica consistently showed very similar values at the minimum of water vapour at 19 km.

Paragraph 11. "The authors state that the parallel micro-SLDA water vapor data..."

The water vapor data from micro-SLDA was referenced in order to prove that the observed fine structure in the lowermost stratosphere is reproduced by two independent hygrometers thus confirming it. This confirmation appears to be most important in the context of the paper. The systematic discrepancy is a totally different issue. However, the reference to the micro-SLDA data has been deleted.

Paragraph 12. "The authors observe up to 177 RHi inside clouds..."

We are not intending to take a position in the supersaturation debate; it certainly falls beyond the paper's scope. A brief discussion on possible sources of errors has been added.

Paragraph 13. "Page 9 discusses the difference between satellite observations and..."

We agree that the structure of the profiles alone and the variability does not say anything about the origin of these structures. Our conclusions on a possible hydration by overshooting ice particles are not coming from the existence of the H₂O layers but from their connection with overshoots. The discussion on other possible origins of moist layers has been improved.

Paragraph 14. "Vertical mixing time scales are..."

We believe that a clear relation between humid layers and overshoots upwind along the backward trajectories found for 70 percents of the layers makes substantiated state-

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ment on the origin of those layers, especially since other origins appear very unlikely.

Paragraph 15. "The quantitative determination of an overshooting event in MSG is problematic..."

We can not determine if an overshoot reached a certain level in the lower stratosphere. The only way to do this is a radar like that of TRMM showing frequent overshoot over Africa (Zipser, 2006) but from which there no coincident data are available. However the brightness temperature difference method allows detecting an overshoot (not just convection). The method is based on the observation of the difference between cloud top emission at two wavelengths, 6.2 μm and 10.8 μm , the first being sensitive to the water vapour emission at higher temperature in the lower stratosphere above the cloud in contrast to the adiabatically cooled turret.

Paragraph 16. "The authors state that supersaturation in cloud free air is frequently observed..."

Supersaturation in cloud-free conditions was observed only in a narrow altitude layers on 3 and 5 August. The text has been corrected.

Paragraph 17. "The discussion about the updraft velocity in the convective events is speculative..."

We are not aware of a better method for estimating the updraft velocity. All we have is the method proposed by Vonnegut and Moore, consistent with vertical velocities of up to 60 m/s captured by CRM models. We are only providing the estimates without making a strong statement based onfrom them.

Paragraph 18. "The authors state that for 30 percents of the elevated water vapor events..."

The discussion on other possible origins of moist layers, for which no overshoots were identified, has been improved.

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Paragraph 19. "The statement that these events are particularly abundant over Africa..."

This statement is based on the TRMM radar observations, showing that overshooting events are indeed more frequent over Africa (Zipser, 2006).

Paragraph 20. "No attempt to generalize this particular synoptic situation..."

We do not see a way to generalize this particular synoptic situation but we do know from Zipser, [2006] that overshooting events are particularly abundant and extreme over Western Africa.

Paragraph 21. "The ozone profile in figure 5 has been shifted by 50 seconds..."

The response time of the ECC ozone sondes depends on the temperature of the solution [Bethan et al., 1996]. The commonly reported response times are 40-50 seconds [Borchi et al., 2007; SPARC, 1998; Johnson et al., 2002], which make the measurements during the fast descent unreliable. The effect of this slow response on the ascent measurements at 5-6 m/s is not only to shift the signal in altitude, but also to smooth the profile. Therefore the observed dip in ozone could actually be even deeper and wider.

Paragraph 22. "The comment about the Laser Backscatter Sonde data on the 23rd (page 12)..."

The comment has been removed.

Paragraph 23. "The last paragraph of section 4.2 is highly speculative..."

The last paragraph of section 4.2 has been corrected. Dips in the ozone layer are not the artifact, since the time lag correction is not excessive as said above.

Paragraph 24. "In the concluding remarks the water vapor enhanced layers are placed up to 450 K..."

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The text has been corrected to remove this contradiction. The discussion about the layer at 492 K has been improved.

Paragraph 25. "The last section of the concluding remarks states..."

Indeed, the mechanism proposed in the paper could only be considered as an option for explaining observed features. The statement has been corrected.

Paragraph 26. "A claim as in the last sentence of the manuscript..."

The text says "Ice geyser hydration across the tropopause may be a significant factor, controlling water vapour in the stratosphere on a global scale." This is not a claim but a conjecture. The concluding remarks section has been rewritten.

Interactive comment on Atmos. Chem. Phys. Discuss., 8, 15463, 2008.

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