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Atmospheric Chemistry and Physics
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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Authors' reply to Referee #2

We express our gratitude to the reviewer for the fair and constructive suggestions.

* From the introduction and the abstract is unclear which are the mechanisms that control water vapor concentrations in the tropical lower stratosphere. The authors either refer to in-mixing and overshooting (L23-24, L87-88) or to slow ascent and overshooting (L57-59). I suggest that the authors rephrase these sentences to make clear that there are 3 main mechanisms (slow ascent by the Brewer-Dobson circulation, in-mixing

from the extratropics and overshooting convection). Dehydration along the slow ascent determines the mean concentrations and seasonality of tropical lower stratospheric water vapor, on top of which interesting hydration features can be observed as a signature of overshooting convection and in-mixing. The latter are the subject of the present study.

The introduction has been modified in accordance with the suggestions. The second paragraph of the introduction lists all three transport processes relevant from the TTL water: "There are three transport processes controlling the water vapour abundance in the TTL, thereby setting the global stratospheric water budget: (1) slow ascent in the upward branch of Brewer-Dobson circulation leading to dehydration of air passing through the coldest regions of the TTL (2) fast cross-tropopause vertical transport (convective overshooting), and (3) quasi-horizontal transport from the extra-tropics (in-mixing). The dehydration ("freeze-drying") along the slow ascent or advection occurs primarily in the Western Pacific and Maritime continent ("cold trap" hypothesis) – a region of large-scale slow ascent and cold TTL anomaly (Holton and Gettelman, 2001), where the Cold Point Tropopause (CPT) temperatures experience minimum during austral summer (Gettelman and Forster, 2002)."

Then, all three processes are discussed in terms of their effect on water. Third paragraph now starts with: "While the dehydration process followed by upward and poleward transport of dry air is generally deemed to be of primary importance for the mean stratospheric water concentration and seasonality, the effect of overshooting convection on the TTL water vapour (dehydration versus moistening and the net effect) is under debate for many years. . ."

Forth paragraph ends with: ". . .Based on the transport model simulations, the effect of in-mixing on stratospheric water is expected to be limited due to a small latitudinal gradient of this trace gas, although this inference has not been yet verified observationally." Fifth paragraph starts with: "Transport processes influencing the TTL composition, be that slow ascent, fast overshooting or horizontal in-mixing have been mainly studied using trajectory and mesoscale modeling, whereas in situ observational evidence, indispensable to constrain the models, is lacking. . .”

Second line of the abstract has been modified: “. . .to evaluate the processes controlling affecting the stratospheric water budget. . .”

* L180: Why are two different Lagrangian transport models used/needed?

CLaMS runs on ERA-Int, whereas HYSPLIT can run on both ERA-Int and GDAS analyses. We compared the radiosonde wind velocity/direction profiles (Fig. R1) with those of ERA-Int and GDAS and found that the latter agrees with the measurements better than the one of ERA-Int (particularly at the level, where backward trajectories were initialized). The correct information on the wind is essential for trajectories, especially at such a small spatial scale. The backward trajectories computed using ERA-Int do not allow for matching the air mass location in space and time with any convective cell upwind. Of course, trajectory tracking of short-lived convective cells that are smaller than the model grid is prone to error, however the results obtained with GDAS fields are fully consistent with the observations exploited. This is why it was decided to use HYSPLIT+GDAS for the overshoot tracking.

* L 182: The HYSPLIT model is a CTM that uses GDAS winds to compute the trajectories (as CLaMS uses ERA-Interim), rather than being just “initialized” by GDAS.

The word “initialized” was replaced by “fed”.

âĂć P3 L189-190: How is “the (diabatic) vertical velocity deduced from the forecast total diabatic heating rate”? I would think these two are the same thing. âĂć We followed the notation of Andrews et al. (1987), their Eq. 3.1.3e) here: If the heating rate is denoted J, the cross-isentropic vertical velocity dθ/dt is related to it via dθ/dt = J*(θ/T*c_p), where θ is potential temperature, T - temperature and c_p the specific heat capacity at constant pressure. We cite the Andrews et al., 1987 reference now in the revised version.

* L239: It would be good to mention the origin of the overall methane distribution, as it is done for water vapor and aerosols. The following sentences have been included into Sect. 3.2: “For this reason the extratropical stratosphere contains more water vapour and less methane.” Sect. 3.3: “A notable anticorrelation between the water and methane is expectable since photochemical oxidation of methane in the stratosphere yields water vapour.”

* L247-250: Does the filament result from a Rossby wave breaking event?

Yes, there is a Rossby wave breaking event occurring over South America around the 13 March, represented the in ERA-Interim PV distribution (not shown), which causes the observed filament.

We added a remark on that to the draft: line 247ff: “. The ERA-int wind fields in Fig. 3 show an enhanced meridional wind component above the Southern Atlantic, related to a Rossby wave breaking event (as suggested by ERA-int potential vorticity fields, not shown), which supplies humid high-latitude air up to. . .”

* L330: “... at 4 levels corresponding to the hydrated layers vertical extent and spaced vertically by 50 m”. Do you mean 4 levels within each of the 2 hydrated layers identified (404 K and 386 K)?

Yes, we meant 4 levels within each of the 3 hydrated layers.

* L345-348: Reanalysis winds are given on a 1 or 0.5 degree grid (so there are only 1 to 4 wind values within the box in Fig. 7). Is there a chance that faster subgrid-scale winds exist around the convection, and thus the in situ measurements could be affected by other overshooting towers?

The GDAS fields are given on 0.5 degree grid, so there are 4 values within the boxes. It is certainly possible that the sub-grid scale winds, particularly around strong convection may largely differ from those available from the reanalysis. However for the other cells to be linked with the detected hydration layers, the average wind velocity between the second closest cell (near Botucatu, Fig. 5) and the balloon must have been at least twice as strong. In Sect. 3.4 we state that “the two small overshooting cells of 13 March, closest to the measurement location are the most likely sources of the hydrated layers.”, which leaves some room for consideration of the more distant cells. In any case the conclusion is unaffected. The following sentence has been placed in the end of Sect. 4.3: “That said we cannot entirely rule out the contribution from other convective cells because faster subgrid-scale winds, unresolved by the reanalysis, may exist around the strong convection.”

* Fig. 3 It’s hard to see where the arrows are pointing.

The arrows’ heads have been thickened.

* Fig. 4: indicate whether the sampling time is local time or UTC time?

The sampling time indicated is UTC, this has been included in the caption.

* Fig. 5 caption: "Black arrows indicate [...]" and the UTC of the radar measurement. Also, indicate what are the dark and light blue lines.

Caption has been modified: “Black arrows tag the overshooting cells potentially responsible for the hydrated layers shown in Fig. 4 with indication of the UTC of their detection by radar. . . . Blue lines indicate the balloon trajectories (FLASH-B dark blue, Pico-SDLA light blue). “

Technical corrections * L201: Was reaching → reached * L250: hundreds kilometers → hundred kilometers * L305: Fig. 6 → Fig. 5 * L336: has reached → reached * L442: totally → completely

All technical corrections have been implemented.

Figures 1-2. Comparison of vertical profiles of wind direction (1) and speed (2) obtained in the FLASH/RS92 sounding on 13 March 2012 and provided by GDAS and ERA-Interim reanalyses. Dashed lines denote the levels where hydration signatures were

found.

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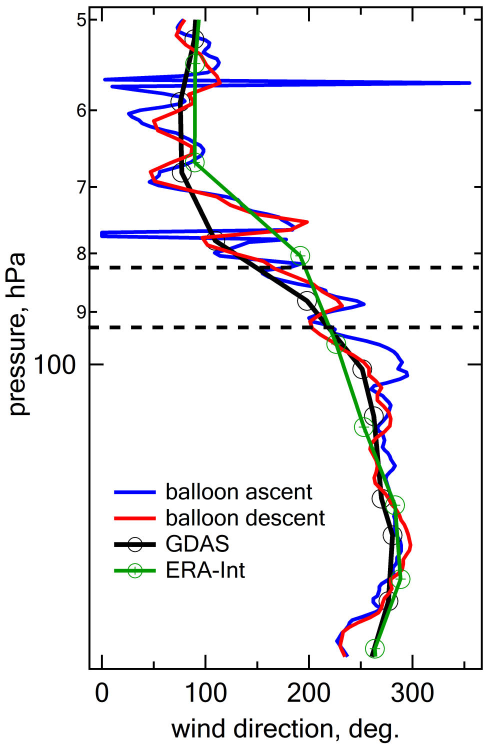
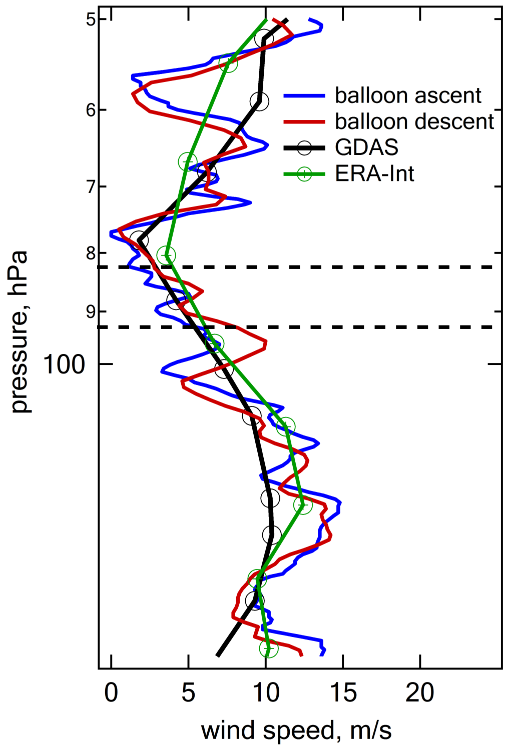


5
6
7
8
9
100
pressure, hPa
balloon ascent
balloon descent
GDAS
ERA-Int
0
100
200
300
wind direction, deg.

Fig. 1.



5
6
7
8
9
100
pressure, hPa
balloon ascent
balloon descent
GDAS
ERA-Int
0
5
10
15
20
wind speed, m/s

Fig. 2.