27 July 2016

Manuscript Title: *Evaluation of Water Vapour Assimilation in the Tropical Upper Troposphere and Lower Stratosphere by a Chemical Transport Model* **by Payra et al.**

RESPONSES TO THE REVIEWERS

We would like to thank the reviewers for their insightful comments that were helpful in improving substantially the presentation and contents of the revised manuscript. We hope we have addressed appropriately all issues raised by the reviewers. The reviewers' comments are repeated below in blue and our responses appear in black.

We have inserted this sentence in the acknowledgments:

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We finally would like to thank the two anonymous
reviewers to their fruitful comments.
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The following changes have been made in the revised manuscript.

Anonymous Referee #2

1) This paper explores the possibility of assimilating MLS H2O into analyses and generally shows improvements that can be gained by doing so. I am mostly satisfied with the analysis but one thing I did not understand was the difference between the background runs and those that assimilated MLS. It seems like the background was also assimilating MLS data in some way also. It was not clear exactly what the background run is. If this can be clarified, then the paper is publishable in my opinion.

→ We understand the confusion between background and analysis, that was present when reading the first version of the manuscript. This major comment was very consistent with the comment 1) from the Reviewer#1. We have already replied to this point (first item of the reply to the comment 1) from the Reviewer#1) by detailing the formulation of the assimilation method in a variational point of view, highlighting the cost function J, separated into the background cost function J_b and the observation cost function J_o.

Minor points

2) page 2 line 40 change assess to assessment of
→ Done

3) page 3 line 41 change Southern to South
→ Done

4) page 4 line 48 change earth's to Earth's
→ Done

5) page 4 line 50 change in form of to as
→ Done

6) page 4 line 53 change gas to gases
→ Done

7) page 4 line 58 earth to Earth
→ Done

8) page 4 lines 63-65. Specialized models seem to capture TTL water vapor well (e.g. Lagrangian trajectory type models). The challenge is why GCMs and Analyses seem to do so poorly when I would presume they have the same physics.
→ Global GCM and CTM are generally 3D Eulerian or semi-Lagrangian models, either free running or assimilating data. Although those models allow complex dynamical, radiative, and chemical interactions, they typically present coarse horizontal and vertical resolutions (~9km/137 levels at ECMWF). Also, cloud microphysics and vertical transport are known weaknesses and active areas of research and development. As a result, short scale/short term variability of temperature and humidity, cloud, and severe convection are often misrepresented in the TTL.

In advanced models, the implementation of semi-Lagrangian scheme has been used to estimate the Lagrangian transport of model variables such as temperature and humidity. Nevertheless, semi-Lagrangian transport lacks the full Lagrangian skills, which conserves advected quantities (Mote and O'Neill, 2000).

Fueglistaler et al. (2005) and Fueglistaler and Haynes (2005) showed that a synoptic-scale full Lagrangian model can reproduce the long term variability of H_2O in the TTL and LS. However, in a more recent study, Dessler et al. (2007) suggested that this apparent correct representation of H_2O resulted from compensating errors in the over simplified model (e.g. lack of saturation or convective transport of ice). Accounting for the convective ice lofting in Fueglistaler's model, the authors obtained an improved simulation of the H_2O isotopologue HDO in the TTL without degrading that of H_2O. Those results demonstrate the need for a better representation of subgrid scale non-hydrostatic processes in order to realistically simulate the variability of H_2O in the TTL and LS.

The simulation of short scale/short term variability (convective/hourly scales) of H_2O and temperature associated with deep overshooting convection requires the high resolution of cloud resolving models. Those models allow the analysis of the impact of convective transport, mixing, and/or microphysics by reproducing both timing and structure of severe convective events (Chemel et al., 2009; Hassim and Lane, 2010). However, with an horizontal resolution of 1 km or less (Chemel et al., 2009), such simulations are computationally expensive and limited to small areas.

Chemel, C., Russo, M.R., Pyle, J.A., Sokhi, R.S. and Schiller, C., 2009. Quantifying the imprint of a severe hector thunderstorm during

ACTIVE/SCOUT-O3 onto the water content in the upper troposphere/lower stratosphere. Monthly weather review, 137(8), pp.2493-2514.

Dessler, A.E., Hanisco, T.F. and Fueglistaler, S., 2007. Effects of convective ice lofting on H2O and HDO in the tropical tropopause layer. Journal of Geophysical Research: Atmospheres, 112(D18).

Fueglistaler, S., Bonazzola, M., Haynes, P.H. and Peter, T., 2005. Stratospheric water vapor predicted from the Lagrangian temperature history of air entering the stratosphere in the tropics. Journal of Geophysical Research: Atmospheres, 110(D8).

Fueglistaler, S. and Haynes, P.H., 2005. Control of interannual and longer□term variability of stratospheric water vapor. Journal of Geophysical Research: Atmospheres, 110(D24).

Hassim, M.E.E. and Lane, T.P., 2010. A model study on the influence of overshooting convection on TTL water vapour. Atmospheric Chemistry and Physics, 10(20), pp.9833-9849.

Mote, P. and O'Neill, A. eds., 2000. Numerical modeling of the global atmosphere in the climate system (Vol. 550). Springer Science & Business Media.

9) page 5 line 76 change such as to such as those. Also IPCC International Panel on Climate Change.
→ Done

10) page 5 line 80 change Heggling to Hegglin
→ Done

11) page 6 line 112 change 60 hybrid to 60 vertical hybrid
→ Done

12) page 6 line 114 change beyond to above
→ Done

13) page 8 line 155 change order that to order to that
→ Done

14) page 11 line 226 change upper stratosphere to mesosphere
→ Done

15) page 12 line 250 The tropopause generally varies between 100 and 83 hPa. Could consider interpolating the values between the two levels to the TP.
→ Indeed, the tropical tropopause pressure can vary between 120 and 80 hPa (see e.g. Carminati et al., 2014), depending on the season, the latitude, and also the longitude considered. But this is not the scope of our paper. The 3 layers we mention (following the approach presented in Carminati et al., 2014) are considered 1) to provide independent pieces of information relative to the observations and 2) to be, on a climatological point on view, representative of 3

different vertical layers in the TTL: UT, TP and LS. Consequently, our approach is to keep the information within the three independent layers and not to interpolate the H_2O values to the TP, whose actual value and definition are multiple.

16) page 12 line 265 change on the rejection to the rejection
→ Done

17) page 13 line 275 change MIPAS run to MIPAS operates.
→ We preferred using the term “MIPAS operated”.

18) Page 14 line 302 change the South of to South (2 places)
→ Done

19) page 17 line 385 It is curious that using the MLS AK made things worse.
→ We have already replied in detail to this particular point in the comment 18) from the Reviewer#1.

20) page 18 line 406 do you mean assimilation run rather than free run?
→ In order to avoid misinterpretation (see also the comment 20) from Reviewer#1), we have rephrased the sentence into:

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On 1 December 2011 at 00:00 UTC, we perform a free
model simulation (without assimilating MLS
observations) that is initialized by the obtained
analysis state.
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21) page 20 line 461 Why should ARPEGE represent the true H_2O?
→ You are right, ARPEGE cannot be considered as the truth but as the reference in the Upper Troposphere. We changed the term accordingly, also in the abstract and in the conclusions.

22) page 20 line 464 change constraint to constrain
→ Done

23) page 20 line 469 change continents to continent
→ Done

24) page 21 line 474 change constraint to constrains
→ Done

25) page 21 line 483 change cannot cope with to allows unrestricted
→ Done, see also the comment 24) from Reviewer#1

26) page 22 line 500 change constraint to constrain
→ Done

27) page 24 line 560 change to assess the to an assessment of the
→ Done

28) page 25 lines 582–589 Instead of comparing Jan to Feb where the latter had some missing days as a data sampling, you could repeat the January with 4 days of data removed.

→ You are, in theory, perfectly right. But you have to remember that, in our study, we have performed a long run starting on 1st August 2011 and ending on 28 February 2012 in an operational mode. That is to say we have used all the MLS data available over this period and processed them according to the assimilation method and parameters presented in the paper in one single run. The sensitivity study related to the improvement of MLS data quality (V4 vs. V3) is also performed in an operational mode from 1st August 2011 to 28 February 2012. Consequently, the only possibility we had to perform a sensitivity study when considering periods with no measurements was to focus on a month with a lack of measurements as in February 2012.

29) page 26 line 600 change Southern to South

→ Done

30) page 26 line 619 change the Southern American to South America

→ Done

31) page 28 line 660 change prevent to assess the to prevent the assessment of

→ Done

In conclusion, we have inserted 4 new references in the revised manuscript:

El Amraoui, L., Attié, J.-L., Ricaud, P., Lahoz, W. A., Piacentini, A., Peuch, V.-H., Warner, J. X., Abida, R., Barré, J., and Zbinden, R.: Tropospheric CO vertical profiles deduced from total columns using data assimilation: methodology and validation, Atmos. Meas. Tech., 7, 3035-3057, doi:10.5194/amt-7-3035-2014, 2014.

Ide, K., Courtier, P., Ghil, M., and Lorenc, A.: Unified notation for data assimilation: Operational, sequential and variational. J. Meteor. Soc. Japan, 75, 181–189, 1997.

Intergovernmental Panel on Climate Change, Working Group I: The Physical Science Basis, 2.5.6 Tropospheric Water Vapour from Anthropogenic Sources, Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.), Cambridge University Press, 2007.

Smith, R. N. B.: A scheme for predicting layer clouds and their water content in a general circulation model. Q. J. R. Meteorol. Soc., 116, 435-460, 1990.