

# Answer to Reviewers Comments for “Response of stratospheric water vapor and ozone to the unusual timing of El Niño and QBO disruption in 2015–2016” by Mohamadou Diallo et al.

Dear Editor-in-Chief, Karen Rosenlof,

We are submitting our revised article titled “Response of stratospheric water vapor and ozone to the unusual timing of El Niño and QBO disruption in 2015–2016”. We thank the two Reviewers for their detailed and well thought-out comments, which helped to significantly improve the paper. We have made substantial changes to the manuscript in order to thoroughly address the Reviewers’ suggestions and comments. Main changes concern:

- an additional new figure 5 describing the fraction of variance of the deseasonalized time series that’s captured by QBO and ENSO in the manuscript as suggested by Reviewer #2
- adding a new paragraph in the discussion as suggested by Reviewer #2
- rephrasing of certain paragraphs in order to clarify the manuscript.

With these changes, we are convinced that the paper is highly relevant for a wide-ranging journal like *Atmospheric Chemistry and Physics*. Please see below our answers point by point to all reviewers comments and suggestions.

Reviewers comments are in bold, followed by our respective replies. Changes in the manuscript are in blue, allowing them to be tracked easily.

Kind regards,

Mohamadou Diallo (on behalf of the co-authors)

## Reviewer #1 (Comments to Author):

### Specific comments:

1. **Page 4, lines 14-15: How accurate are ERA-Interim temperatures in the tropical tropopause layer? Could you please address this?**

We thank Reviewer 1 for her/his instructive suggestion for discussing the accuracy of ERA-I temperatures in the tropical tropopause layer (TTL). ERA-Interim, especially since the 2000s, lies in the middle of all reanalyses in a multi-reanalysis comparison (Long et al. 2017) and is one of the best-performing reanalyses currently available. The assimilation of Global Positioning System radio occultation data since December 2006 have reduced the ERA-Interim cold temperature bias compared with radiosondes in the tropopause layer and the lower stratosphere (Poli et al. 2010). ERA-Interim tropical tropopause temperatures have been shown to compare very well against aircraft measurements in the TTL region over the eastern tropical Pacific (Ueyama et al. 2014). By comparing the ERA-Interim reanalysis with PreConcordiasi balloon observations, Podglajen et al. (2014) find fairly good agreement, with a weak positive bias of 0.6 K and a standard deviation of 1.8 K. These previous studies provide confidence in the use of ERA-Interim temperatures. We have added a discussion about this aspect at Page 5, Lines 7-14.

2. **Page 4, line 16: the simplified dehydration scheme in CLaMS may be an oversimplification of the microphysical processes that occur in the tropical tropopause layer, controlling water entering the stratosphere. For instance, supersaturation is common in the upper troposphere. Also, stratospheric entry-level value of water vapor is strongly dependent on temperature (see my point 1.1). How do we know that the processes that control stratospheric water are properly represented by the reanalysis meteorology (ERA-Interim) in combination with the CLaMS transport model? Admittedly, the remarkable similarity of Figures 4 and 5 lends confidence to the CLaMS model, but one should be careful about interpretation because of the MLS vertical resolution of 2.5 to 3 km for H<sub>2</sub>O. Is this vertical resolution similar to the model, or mismatched with the model?**

We agree with the reviewer that the simplified dehydration scheme in CLaMS may not capture all details about the microphysical processes that occur in the tropical tropopause layer, controlling water entering the stratosphere. Using a trajectory model driven by ERA-Interim and in-situ observations for temperature intercomparison, Schoeberl et al. (2012) show that even small temperature differences between

reanalyses and observations can still induce significant differences in the associated water vapor saturation mixing ratio. However, the CLaMS water vapor anomaly agrees extremely well with time series of MLS-HALOE and Boulder water vapor anomalies as shown in Tao et al. (2015). The climatological tape recorder from CLaMS water vapor has also been compared with MLS (Tao et al. 2015). They find remarkably good agreement between CLaMS and MLS in terms of mean vertical structure and the slow upward phase propagation. This good agreement between CLaMS and observations (Ploeger et al. 2013, Tao et al. 2015, Lossow et al. 2018) gives good confidence in the CLaMS water vapor reconstruction from the large-scale perspective. As pointed out by the reviewer, the remarkable similarity of Figures 4 and 5 is a good example. For the wind and temperature fields, CLaMS uses the native ERA-I vertical resolution, therefore, has higher vertical resolution than MLS. The mean vertical resolution of air parcels in CLaMS Lagrangian model is about 400m near the tropopause. We have added a discussion about this aspect at page 4-5, Lines 34,1-4 and page 5, Lines 14-19. We have also acknowledged the possible effect of the MLS vertical resolution of 2.5 to 3 km for H<sub>2</sub>O at page 7, lines 27-30 and in next question.

3. **Page 6, lines 26-28: given the MLS vertical resolution, how do you separate tropospheric water vapor anomalies from stratospheric anomalies?**

Concerning the MLS vertical resolution, there is not much we can do about it as we use the latest version 4.2, which is provided to users by the MLS team and used in the previous studies (Tweedy et al. 2017; Avery et al. 2017). However, we discussed in the early manuscript (page 7, line 27-30) the possible effect of the smearing arising from the 2.5-3 km vertical resolution of the MLS water vapor measurements on the positive anomalies near the tropopause region.

4. **In your conclusion, page 10, lines 30-32, you conclude that your "results suggest that the interplay of ENSO events and QBO phases will be crucial for the control of the lower stratospheric water vapor and ozone budget under changing future climate . . ." Do you address the separate impact of future changing tropopause height/tropopause temperature on stratospheric water?**

In this last sentence of the conclusion, we speculate based on current knowledge in the literature and findings that the interplay will be crucial for the control of the lower stratospheric water vapor and ozone budget under changing future climate. In a changing future climate with a projection of a decreasing lower stratospheric QBO amplitude (Kawatani et al. 2013) combined with increasing frequency of El Niño-like conditions (Cai et al. 2014), the interplay will change with ENSO, hence likely controlling the lower stratospheric trace gas variability more strongly in the future. It is clear that ENSO impacts both tropopause height/tropopause temperature. Future analysis is needed using CCMs/GCM sensitivity runs to diagnose and separate the impact of future changing tropopause height/tropopause temperature on stratospheric water. We have added more details at Page 11-12, last lines in sect. 7.

**Technical corrections (minor):**

1. **2.1) Page 3, line 11: I do not like the word "unprecedented" because you actually mean to say "previously unobserved". ENSO, QBO and stratospheric water vapor have only been monitored during the era of satellite observations. A similar interplay between ENSO and QBO could have occurred in the historic or even geologic record.**

We have rephrased it.

2. **Page 8, line 27: I recommend that you replace "unprecedented changes" with "changes larger than previously observed".**

We have rephrased it.

3. **Figure 1: Please define the horizontal black lines in the Figure 1 caption. Are these Pressures?**

Thanks for the remark. Yes these black lines indicate isobars lines. We have defined the horizontal black lines now in the captions.

4. **Figures 1,2,3,4,5: I recommend that you label the x-axis with "year".**

We have now labelled the x-axis with "year" in these figures.