

List of Responses

Responses to Farahnaz Khosrawi

Community Comments #1:

Dear Farahnaz Khosrawi:

Thank you for your comments concerning our manuscript. Those comments are all valuable and very helpful for revising and improving our paper, as well as the important guiding significance for our research. We have studied the comments carefully and made corrections which we hope meet with approval.

This is an interesting study, but the authors need to motivate a bit more why it is interesting/important to investigate the seasonal cycle of the QBO. Just stating that this has not done before is, in my opinion, not enough.

Response: Thanks very much for your positive comments. We added why it is interesting/important to investigate the seasonal cycle of the QBO.

- “Serva et al. (2022) found that there are seasonal differences in temperature and SWV in tropical regions. In the northern summer, the temperature at 100 hPa and the WV at 85 hPa reach their peaks, while in winter, they reach their lowest levels (Serva et al., 2022). The QBO is affected by the BD circulation, and it is stronger in northern winter than in summer (Butchart, 2014). Tegtmeier et al. (2020) found that the temperature amplitude of QBO was 2 K in February of northern winter and only 0.9 K in September of summer. Similar questions naturally arise: Does the amplitude of WV QBO also undergo a similar change? What are the differences between winter and summer? The research on the seasonal differences of WV QBO not only deepens the multi-time scale understanding of the stratospheric and tropospheric coupling, but also provides a scientific basis for cross-seasonal climate prediction. This study uses more samples based on the long time series of the QBO signal in SWV and discusses the differences in SWV distribution between different QBO phases and between different seasons. Possible causes of those differences are diagnosed, and the performance of climate models in capturing the QBO signal in WV is also evaluated (Ye et al., 2018; Ziskin et al., 2022).” (L70-81)

Following the description of results was for me quite difficult since there were on one hand too many figures and on the other hand these were not well explained. Starting with Figure 2 it is not stated which data set has been used for the analysis and thus which data set is shown on the figures. I could also find no statement on this in the main text. Are you using here a multi-model mean? Or the SWOOSH data? Or is the analysis based on the reanalysis data?

Response: Thank you for your criticisms. Following Figure 2, we added more discussions this time. The subsequent analysis is based on ERA5 reanalysis.

- “By comparison, it is found that although there are some differences in the SWV QBO between the SWOOSH satellite data and the ERA5 reanalysis data, the ERA5

reanalysis data reproduce the distribution pattern of WV propagation from the lower stratosphere to the upper stratosphere below 10 hPa. Therefore, the long-term data from ERA5 reanalysis can still be used to diagnose the influence and dynamics of WV in the middle and lower stratosphere below 10 hPa. Our subsequent analysis mainly uses ERA5 reanalysis data.” (L175-179)

It should be made more clear which data set has been used for what in your analysis. Also a clear statement/discussion on the uncertainty of these data sets is missing.

Response: Thank you for your suggestion. We have added the comparison of water vapor between the SWOOSH satellite observation data and the ERA5 reanalysis in the data and methods, and introduced the uncertainty of the data.

- “This dataset is a combination of different data sources, including SAGE-II/III/ISS, UARS HALOE, UARS MLS, Aura MLS, ACE-FTS, and OMPS-LP (Davis et al., 2016). The SWOOSH data provide monthly averages, standard deviation, number of observations and average uncertainty on the pressure grid measured by each satellite instrument. SWOOSH also includes combined (multi-instrument) products based on the weighted average of available measurement values. A key aspect of the merged product is that the source records are homogenized to account for inter-satellite biases and to minimize artificial jumps in the record, producing a long-term data record. Since the UARS HALOE observation data began on 19 October 1991, we have used SWOOSH data from 1992 onwards.” (L97-103)
- “In contrast to the troposphere, the WV content within the stratosphere is extremely low.....” (L104-)

Specific comments:

Introduction: Here it should also be discussed that many models have/had problems in simulating QBO and that for that considering waves is important (e.g. Giorgetta et al. 2006). How has this overcome in the CMIP6 model simulations? Which effort has been made so that the models are able to simulate a QBO.

Response: Thanks for your suggestion. We have added this content.

- “However, it remains a challenge to simulate the QBO in general circulation models (GCMs), with only a few GCMs being able to reproduce it. The waves need to be correctly represented to simulate a realistic QBO. Many GCMs still cannot simulate a realistic spectrum of tropical waves because of their low resolution and their deficiencies in the parameterization of small-scale gravity waves forcing (Ricciardulli and Garcia, 2000; Lott et al., 2014). Studies have suggested that an adequately fine vertical resolution (vertical grid spacing of ~500–700 m) of the troposphere and lower stratosphere is also necessary to simulate the QBO due to the forcing of some resolved waves with small vertical wavelength and the need to capture the wind shear (Richter et al., 2014b; Geller et al., 2016). In CMIP5, only five models could generate the QBO internally (Butchart et al., 2018). In CMIP6, at least 15 models now able to simulate realistic QBO-like behavior during the historical period (Richter et al., 2020).” (L49-57)

P3, L65: Here you should provide a motivation why investigating the seasonal cycle of the QBO is important/of interest.

Response: The research significance has been added to the Introduction.

- “Serva et al. (2022) found that there are seasonal differences in temperature and SWV in tropical regions. In the northern summer, the temperature at 100 hPa and the WV at 85 hPa reach their peaks, while in winter, they reach their lowest levels (Serva et al., 2022). The QBO is affected by the BD circulation, and it is stronger in northern winter than in summer (Butchart, 2014). Tegtmeier et al. (2020) found that the temperature amplitude of QBO was 2 K in February of northern winter and only 0.9 K in September of summer. Similar questions naturally arise: Does the amplitude of WV QBO also undergo a similar change? What are the differences between winter and summer? The research on the seasonal differences of WV QBO not only deepens the multi-time scale understanding of the stratospheric and tropospheric coupling, but also provides a scientific basis for cross-seasonal climate prediction. This study uses more samples based on the long time series of the QBO signal in SWV and discusses the differences in SWV distribution between different QBO phases and between different seasons. Possible causes of those differences are diagnosed, and the performance of climate models in capturing the QBO signal in WV is also evaluated (Ye et al., 2018; Ziskin et al., 2022).” (L70-81)

P3, L83-87: Add a few more sentence on the SWOOSH data set itself and the quality of this data set. Have all e.g. biases been removed? How have the satellite data sets been merged and what is the advantage of using this merged data set instead of using one or several satellite data sets separately?

Response: Added.

- “SWOOSH also includes combined (multi-instrument) products based on the weighted average of available measurement values. A key aspect of the merged product is that the source records are homogenized to account for inter-satellite biases and to minimize artificial jumps in the record, producing a long-term data record.” (L100-102)

P5, L137: What do these differences mean for your study? Which data set is more realistic? The SWOOSH QBO or the reanalysis QBO? What are the known uncertainties of these data sets?

Response: Here, water vapor below 10 hPa is displayed, and detailed descriptions of ERA5 and SWOOSH are provided.

- “In terms of data and methods, we compared ERA5 reanalysis with SWOOSH satellite monitoring data and found that ERA5 reanalysis data could reproduce the distribution pattern of SWV (Fig. 1). ERA5 reanalysis can well display the QBO signal of SWV below 10 hPa.....” (L164-)

- “Compared to the SWOOSH satellite observation data, the ERA5 reanalysis data provides a longer time span, which provides more samples for revealing the effect of QBO on SWV. There remains uncertainty regarding the performance of ERA5 reanalysis data in depicting SWV.....” (L104-)

P5, L124: In Figure 2 the QBO from ERA5 and SWOOSH is shown but then the QBO is analysed in detail but without stating which data set has been used.

Response: In the newly revised manuscript, the water vapor QBO shown by ERA5 and SWOOSH were analyzed respectively.

- “Figure 2 shows the evolution of SWV anomalies in the tropics over the past 60 years for the ERA5 reanalysis and 30 years for the SWOOSH data.” (L168-169)

Figure 2-10: Which data set has been analysed?

Response: Figure 2-10 used ERA5 reanalysis data.

- “Our subsequent analysis mainly uses ERA5 reanalysis data.....” (L178-)

P7, Figure 3: In the figure it is written “q”. If the specific humidity is shown here this should be clearly stated or if you have calculated from q the water vapour mixing ratio then you should write in the figure legend and on the axis “H₂O”.

Response: Changed to H₂O in Fig.4. (L210)

P11, L263: Leads to cold “temperatures”? Please be more clear.

Response: Added:

- “Namely, when an air mass descends, it is compressed, its volume decreases, its internal energy increases, and its temperature rises. This phenomenon is called adiabatic heating. Conversely, during ascent, adiabatic cooling occurs.” (L317-319)

Figures: 14 figures are too much. I would suggest to put some of the figures in an appendix and focus in the main text of the manuscript on the most important figures.

Response: Changed. Thanks for your suggestion. We have moved some figures from the main manuscript to the supplementary materials, leaving 11 figures in the main text.

Technical corrections:

P7, L162: shows weak -> shows a weak

Response: Corrected.

P7, Figure 3 caption: “Figure. 3” should be “Figure 3.” Note, this needs to be corrected also for all other figures, too.

Response: All the figure captions have been changed.

P8, L179: un der -> under

Response: It has been removed in the latest revised version.

P9, L206: 100hPa -> 100 hPa

Response: Changed. (L229)

P10, L223: warm -> warms

Response: Changed. (246)

P13, L299: in tropics -> in the tropics

Response: It has been removed in the latest revised version.

References:

Giorgetta, M. A., Manzini, E., Roeckner, E., Esch, M., and Bengtsson, L.: Climatology and forcing of the quasi-biennial oscillation in the MAECHAM5 model, J. Clim., 19, 3882–3901, 2006.

Response: Learned and cited this reference.