Response to Reviewer 1

Overview

We thank the reviewers for their helpful comments on our study. Based on their comments, the manuscript has been substantially improved since its initial submission. We briefly summarise the improvements here in an overview, before responding to the reviewer's specific comments.

The key improvements to the paper include, but are not limited to:

- A new section investigating equatorial waves, in response to comments by reviewers #2 and #3. This includes (a) new analyses of Kelvin wave variance during the QBO disruption (b) new analyses of the symmetric and antisymmetric power spectra, and (c) a consideration of the equivalent depth h_e and vertical wavelength L_z of Kelvin waves. These results help to clarify equatorial wave processes during the disruption, are consistent with our existing material and other studies, and have improved and expanded the scope of the our study.
- Statistical tests which have been applied to our results, including to the comparison of Aeolus with ERA5 and radiosonde measurements, and to our calculation of the equivalent depth.
- A more comprehensive description of important Aeolus and ERA5 biases which might influence the results in this study, with additional information on these for the reader's benefit.

We now respond to the specific comments by reviewer 1 below.

Reviewer 1

This study provides a good investigation of the ability of the Aeolus data to contribute to the understanding of the QBO dynamics. To this end, Aeolus observational data from various range-bin settings were compared with ERA5 reanalyses and high-quality radiosonde observations. The results and discussions highlight both opportunities and limitations of the Aeolus DWL mission. The manuscript is well written, concise, and includes appropriate figures. I recommend publication after the following minor issues and suggestions are resolved or considered.

We thank the reviewer for this overview and recommendation.

2. Data and Methods *I think the order of the data description could be changed. In the subsection about the radiosonde data, there is already written about Aeolus measurement geometry, overflights and a special Aeolus setting. It would be easier for the reader to understand this if he/she has learned about Aeolus before.*

Agreed, the order of the sections has been updated.

2.2. Aeolus: *Somewhere it should be mentioned that Aeolus is a polar orbiting satellite.*

Agreed, we have mentioned this in the text.

Line 72: Please consider making two sentences out of this (The satellite's orbit is sun-synchronous with 15.6 orbits each day and a repeat cycle of 7 days. For the duration of the observing period in this study there is a close overpass to the site of the Singapore rawinsonde station between 22:55 and 23:00 UTC every Wednesday.)

We agree and we have changed the text to match the reviewer's suggestion.

Consider offering the reader a reference for more detailed information about the Aeolus data products and processing (e.g., Reitebuch et al., 2018 and Tan et al. 2008).

We have added the suggested references to the manuscript, and have also included the L2B Algorithm Theoretical Basis Document (Rennie et al., 2020) as well for the reader's reference.

Are there important changes between Baseline 11 and Baseline 14 that the reader should know about?

It is not expected that there will be any major differences in these baselines that would affect our results here. However, we have added details of the Baseline 13 parameterisation which particularly improves Rayleigh cloudy winds, and the Baseline 14 correction which addresses a seasonal ascending/descending node bias. We only mention these details for information for the reader, and because we refer to both improvements later in the manuscript. We think it is important to mention that different processing baselines are available for the Aeolus dataset, and that future users should note which version they are using.

What are random error sources that could affect the data quality during the analyzed period?

The main sources of random error that could affect the Aeolus data quality are (a) signal photon shot noise, which arises from fluctuations in the number of arriving photons from the expected average and (b) unwanted electronic noise, which is caused by other electronic components in the detection chain of the instrument. Both act to decrease the signal-to-noise ratio (SNR) and/or broaden the spectral width of the backscattered signal. Wind errors for single-point Aeolus measurements are found to be typically around 5 to 9 ms^{-1} in this study and in previous literature (e.g. Rennie et al. [2021], Martin et al. [2021] and Lux et al. [2022]), although note that aggregated wind measurements from multiple points can be much more accurate. This information regarding sources of random error has been added to the manuscript.

Please add a sentence as to why only Rayleigh winds are considered. In the upper troposphere in the tropics, I would expect good quality Mie winds at cloud top level or within thin clouds.

We have added a sentence to explain that this was done to simplify the processing of the analysis at the start of the study, and we have mentioned that including Mie winds in future studies could be useful for the reasons the reviewer has given.

2.3. ERA5

Consider including the formula how to calculate ERA5 HLOS wind.

We have added the formula as suggested by the reviewer.

Please provide some information on the quality of the ERA5 data in the upper troposphere/lower stratosphere. NWP models typically have large uncertainties at these altitudes that could potentially affect the results(?).

We have added a paragraph providing information on some of the relevant biases in ERA5 which may affect its representation of the QBO and/or comparisons made in the upper troposphere/lower stratosphere, and have justified the usage of ERA5 for our study. We have also quantified some of the uncertainty in reanalysis winds at these altitudes, citing Kawatani et al. [2016] which discusses uncertainties in tropical zonal winds in different atmospheric reanalyses (excluding ERA5), and citing Healy et al. [2020], which shows root-mean-square zonal wind differences between GNSS-RO and ERA5 of up to 5 ms^{-1} at 30 hPa.

3. Results

3.1. Aeolus observations of the QBO disruption

Line 168: repeating information (see Line 129)

Yes, we have removed this sentence and modified the sentence at Line 129.

3.2. Validation against reanalysis and radiosondes

Line 208: I'm not totally convinced, that ERA5 stratospheric wind errors are that small (due to large model errors at these levels). E.g., the warm bias is mentioned later in the text, what makes this statement slightly doubtful.

We agree with the reviewer that ERA5 stratospheric wind errors may be comparable to the HLOS error from Aeolus. We have corrected the text to clarify this, and we also include additional references to Kawatani et al. [2016] and Healy et al. [2020]. We suggest that much of the tropopause bias seen in Fig. 4b is a result of biases in ERA5, rather than solely being a consequence of biases in Aeolus. This is particularly likely since a bias is also seen between ERA5 and the radiosonde, as reviewer #3 points out.

Line 235/236: Is there any conjecture about this height dependence of the Aeolus bias?

We have expanded our discussion of the height dependence of the Aeolus bias to give two citations of validation papers which show a similar morphology to the bias structure found in our study. We also suggest that this height dependence is related to the vertical wind shear which maximises at the same altitude, with the following addition: "Given the high vertical wind shear at these altitudes, as noted by Houchi et al. [2010], it is likely that the apparent dipole in this bias is related to local wind shear effects. On the one hand, Aeolus, through its long horizontal accumulation of measurements which form each wind profile, has the capacity to capture localised wind shear that the radiosonde might miss. On the other hand, radiosondes provide a better vertical resolution and can accurately capture regions of high wind shear, but only at the location where the radiosonde is taking measurements."

3.3 Equatorial waves during the QBO disruption

Please add a reference about the wave filtering method that is used here.

We have added the following references to justify using the Gaussian band-pass filter in this study to highlight the Kelvin waves: Holton [1973], Polo et al. [2008], Roundy and Kiladis [2006], Blaauw and Žagar [2018].

Figure 6: What are the thick horizontal gray lines (early January 2020 and around March 2020)? I can't find a description in the caption or the text.

The gray lines are data gaps. The figure caption has been updated to add this information.

Introduction/Discussion

Regarding the current state of Aeolus research consider adding the reference Martin et al., 2023 (https://doi.org/10.5194/wcd-4-249-2023) about the impact of assimilating Aeolus observations on QBO (with and without QBO RBS) and ENSO in 2020 in the Introduction or Discussion

Yes, this is a relevant reference, particularly since it discusses the QBO 2020 RBS. We have added it to the discussion.

Technical stuff

I believe the EGU guidelines say that there should be a space in between for the unit ms^{-1}.

Thanks, this has been fixed in the text.

Sometimes you use 2019/2020, sometimes 2019-2020 or 2019-20. Please make this consistent.

We have changed all instances to 2019/2020 for consistency.

Line 83: please change 2,000 m –> 2.000 m

This value is meant to be 2000 m rather than 2 m, so we have left this unchanged.

Line 84: please write out the abbreviation UTLS once

We have added this to the text.

Line 105: please write out the abbreviation ECMWF once

We have added this to the text.

Line 155: please write out the abbreviation GNSS-RO once

We have added this to the text.

Line 272: please write out the abbreviation OLR once

We have added this to the text.

Line 358: abbreviation DWL is already defined in Line 174

Yes, we have removed this from the text.

References

M. Blaauw and N. Žagar. Multivariate analysis of kelvin wave seasonal variability in ecmwf l91 analyses. *Atmospheric Chemistry and Physics*, 18(11):8313–8330, 2018. doi: 10.5194/acp-18-8313-2018.

S. B. Healy, I. Polichtchouk, and A. Horányi. Monthly and zonally averaged zonal wind information in the equatorial stratosphere provided by gnss radio occultation. *Quarterly Journal of the Royal Meteorological Society*, 146(732):3612–3621, 2020. doi: 10.1002/qj.3870.

J. R. Holton. On the frequency distribution of atmospheric kelvin waves. *Journal of Atmospheric Sciences*, 30(3):499–501, 1973. doi: 10.1175/1520-0469(1973)030<0499:OTFDOA>2.0.CO;2.

K. Houchi, A. Stoffelen, G. J. Marseille, and J. De Kloe. Comparison of wind and wind shear climatologies derived from high-resolution radiosondes and the ecmwf model. *Journal of Geophysical Research: Atmospheres*, 115(D22), 2010. doi: 10.1029/2009JD013196.

Y. Kawatani, K. Hamilton, K. Miyazaki, M. Fujiwara, and J.A. Anstey. Representation of the tropical stratospheric zonal wind in global atmospheric reanalyses. *Atmospheric Chemistry and Physics*, 16(11):6681–6699, 2016. doi: 10.5194/acp-16-6681-2016.

O. Lux, B. Witschas, A. Geiß, C. Lemmerz, F. Weiler, U. Marksteiner, S. Rahm, A. Schäfler, and O. Reitebuch. Quality control and error assessment of the aeolus l2b wind results from the joint aeolus tropical atlantic campaign. *Atmospheric Measurement Techniques*, 15(21):6467–6488, 2022. doi: 10.5194/amt-15-6467-2022.

A. Martin, M. Weissmann, O. Reitebuch, M. Rennie, A. Geiß, and A. Cress. Validation of aeolus winds using radiosonde observations and numerical weather prediction model equivalents. *Atmospheric Measurement Techniques*, 14(3):2167–2183, 2021. doi: 10.5194/amt-14-2167-2021.

I. Polo, A. Lazar, B. Rodriguez-Fonseca, and S. Arnault. Oceanic kelvin waves and tropical atlantic intraseasonal variability: 1. kelvin wave characterization. *Journal of Geophysical Research: Oceans*, 113(C7), 2008. doi: 10.1029/2007JC004495.

M. P. Rennie, L. Isaksen, F. Weiler, J. de Kloe, T. Kanitz, and O. Reitebuch. The impact of aeolus wind retrievals on ecmwf global weather forecasts. *Quarterly Journal of the Royal Meteorological Society*, 147(740):3555–3586, 2021. doi: 10.1002/qj.4142.

P. E. Roundy and G. N. Kiladis. Observed relationships between oceanic kelvin waves and atmospheric forcing. *Journal of Climate*, 19(20):5253–5272, 2006. doi: 10.1175/JCLI3893.1.