Reviewer 1

Summary

In this study, the authors focus the possible impact of the ENSO on the QBO cycle using the observations and the model simulations from GISS E2.2. However, the modulation of the QBO cycle by the El Nino and La Nina is not consistent among the model configurations. The authors concluded that the model physics are important to simulate the impact of the ENSO on the QBO period. In general, the authors well explored the possible impact of ENSO on the QBO period. However, I also found some relevant concerns, which should be well addressed. Therefore, I suggest a major revision at the present time.

Thank you very much for your constructive criticisms. We will address your comments point by point as below.

Major comments

1. The relationship between the ENSO and QBO should be well reviewed in the introduction. The possible impact of ENSO on the QBO amplitude and phase should mentioned.

The second paragraph in the introduction contains the following sentences: "Remarkably, an observational study conducted by Taguchi (2010) demonstrated that the downward propagation of the QBO tends to speed up during El Niño and slow down during La Niña while the amplitude of the QBO tends to be smaller during El Niño and larger during La Niña, respectively. Using radiosonde data from 10 near-equatorial stations distributed along the Equator, Yuan et al. (2014) found that the ENSO modulation of the QBO period is more robust than that of the QBO amplitude."

Thus, the manuscript had already adequately addressed the issue with regard to "The possible impact of ENSO on the QBO amplitude and phase…".

Further, ENSO and QBO phase coincidence should also be mentioned. Before 1980s, El Nino tends to appear during EQBO, and La Nina tends to appear during WQBO. After 1980s, El Nino tends to appear during WQBO, and La Nina tends to appear during EQBO (DOI: 10.1175/JCLI-D-19-0087.1; 10.1175/JCLI-D-20-0024.1).

We have changed "The QBO and the ENSO defy linear relationships (Angell, 1986; Xu, 1992; Garfinkel and Hartmann, 2007)." into "The QBO and the ENSO defy linear relationships (Angell, 1986; Xu, 1992; Hu et al., 2012) as highlighted by that fact that while the QBO and ENSO indices are negatively and positively correlated before and after 1980s, respectively (Garfinkel and Hartmann, 2007; Domeisen et al., 2019; Rao et al., 2020c) they are virtually uncorrelated over the longer periods from 1953 to recent times (Garfinkel and Hartmann, 2007; Geller et al., 2016b, see their Figure 5 for details)

2. Previous studies also found that the relationship between ENSO and QBO is not universal among models (DOI: 10.1175/JCLI-D-20-0024.1). This paper only emphasizes the possible impact of ENSO on the QBO, is there a possibility that the QBO can impact the ENSO occurrence and amplitude.

Concerning the QBO influence on the atmospheric circulation in boreal winter, Fig. 13 in DOI: 10.1175/JCLI-D-20-0024.1 shows that none of the CMIP5/6 models can fully capture the physical processes that show up in the JRA reanalysis. Each model is flawed in one way or another.

We are actively investigating those issues right now. Aside from a handful of papers (e.g., Gray et al., 1992) we are unaware of prior studies on whether/how the QBO exerts influence over the occurrence or amplitude of the ENSO.

3. Further, this paper is too long and too dispersal and include too many contents. This paper is not aimed to evaluate the model configurations. However, the comparison between AMIP and CMIP simulations and that between SP and AP physics accounts for a large portion of the paper. I suggest to remove the experiments that fail to reproduce the impact of ENSO on the QBO period. Including those results that do not simulate a significant difference between the QBO periods during El Nino and La Nina, the paper is not convinced at all.

We have removed the Coupled-OMA-AP ensemble to streamline the paper.

There exists no model that is capable of realistically simulating the impact of ENSO on the QBO period with all relevant physical processes being simulated correctly. To reflect this reality, we have changed the title of the manuscript from "ENSO Modulation of the QBO Periods in GISS E2.2 Models" into "Exploring the ENSO Modulation of the QBO Periods with GISS E2.2 Models".

Here are some of our perspectives on why we need to include both the SP and AP models:

(1) In Table 2, the first member of the Coupled–NINT–SP ensemble simulates a reasonable difference in the mean QBO period between El Nino and La Nina episodes. However, the difference is not statistically significant. In parallel, the second member of the Coupled–NINT–AP ensemble shown in Table 2 simulates a smaller difference in the mean QBO period between El Nino and La Nina episodes. However, this difference is statistically significant. Why?
Fig. 14 in the preprint demonstrates that the first member of the Coupled–NINT–SP ensemble simulate more realistic variability of SSTs while the second member of the Coupled–NINT–AP ensemble fails to capture the variability of SSTs on decadal/interdecadal scales. Thus, the ratio of the ENSO signal to non-ENSO noise from the latter run is unrealistically large, underlying why the smaller difference in the mean QBO period simulated by Coupled–NINT–AP between El Nino and La Nina episodes is statistically significant.

(2) Table 2 also shows that the Coupled–NINT–AP ensemble runs generally simulate larger differences in the mean QBO period between El Nino and La Nina episodes than the Coupled–NINT–SP ensemble runs. Does this mean that the Coupled–NINT–AP model is better than Coupled–NINT–SP? On the one hand, the answer is "No" because Fig. 8 and Fig. 9 show that the ENSO amplitude simulated by Coupled–NINT–SP is much more realistic than that simulated by Coupled–NINT–AP.
On the other hand, the answer is "Yes" because Fig. 13 shows that the OLR amplitude associated with the ENSO from Coupled–NINT–AP is much more realistic than that from Coupled–NINT–SP.

This report serves as a stepping stone to further model improvements which will in turn provide more insights into how the ENSO modulates the QBO.

4. The paper should provide a section named "Data and method" or something like. Without a data description and experiment introduction, this paper reads weird and readers fail to find the experimental setup.

Done as suggested.

Other comments

1. L30, L43-45: There are too many papers concerning the possible impact of ENSO and QBO on the climate (DOI: 10.1175/JCLI-D-19-0663.1; 10.1029/2020GL089149; 10.1175/JCLI-D-20-0960.1). I suggest to include more recent publication in the citations.

Done as suggested.

2. L59-60: There are also some studies that focus on the possible impact of the QBO on ENSO. The authors should present some review.

Concerning the possible impact of the QBO on ENSO, the preprint has adequately cited three papers: Gray et al. (1992), Huang et al., (2012), and Hansen et al. (2016).

3. L145-146: The ENSO amplitude in observations and CMIP models are not identical (DOI: 10.3878/AOSL20140055). If you use the same criterion, will the results be not convincing.

DOI: 10.3878/AOSL20140055 investigated the frequency and amplitude of cold tongue and warm pool ENSO events in CMIP5 models. Since most CMIP5 models simulated a smaller ENSO amplitude as compared with the observation, it was wise for its authors to define an ENSO event by using the criterion of whether a selected index (i.e., Niño3 index or ENSO Modoki index) was greater than 0.5 or less than -0.5 times its standard deviation. That being said, the frequency of simulated ENSO Modoki was inflated artificially and understandably in DOI: 10.3878/AOSL20140055 (refer to their Figure 2(c) and Figure 2(d)).
Zhao and Sun (2022) pointed out that most of the CMIP6 models have an amplitude comparable to or even greater than that is seen in observations (see their Fig. 1). Now we can afford to use the realistic, thus better, criterion.

4. L153-154: Other studies also performed the EOF analysis for the QBO wind profiles (See Figure 3 in Rao and Ren 2018CD, doi: 10.1007/s00382-017-3998-x).

This reference couldn't be added because it doesn't include the information that two leading pairs of empirical orthogonal functions (EOFs) and principal components (PCs) account for more than 90% of the vertical structure variance".

5. L168: Here is programming language. I suggest to use the science language: φ =atan(PC2/PC1)

According to Wikipedia, atan2 is a well-grounded mathematical function. Specifically speaking, the webpage points out that atan2 ranges from $-\pi$ to π while arctan ranges from $-\pi/2$ to $\pi/2$, which is the very reason why we have adopted atan2.

6. L233: You should provide a detailed introduction for the calculation steps in a method section.

Done as suggested.

7. L254: modulates of => modelate (remove "of")

Corrected.

8. L259: Section 3.1, and 3.2: Should move to a method section.

Done as suggested.

9. L404-406: I also download historical runs from the GISS-E2 models for CMIP6. But I did not see the spontaneous QBO. Is the model in this paper same configured as for CMIP6?

E2.1 and E2.2 are two CMIP6 models that were optimized for the lower and middle atmosphere, respectively. E2.1 has only 40 vertical layers up to 0.1 hPa, thus cannot simulate the QBO. Note that the outputs of E2.1 were submitted to the CMIP6 archive earlier than those of E2.2. You had probably downloaded the CMIP6 historical runs simulated by the E2.1 models before we uploaded the E2.2 outputs to ESGF.

10. Section 4.1: Should move to the method section.

Done as suggested.

11. L439-441: Can you explain why the relationship is not stable?

We have added a paragraph immediately before the last paragraph in the manuscript to explain it.

12. L475: help => helps

Corrected.

13. L495-497: Please also see Domeisen et al. 2019 (RG) and references therein.

Done as suggested.

14. L531-532: Most CMIP models simulate a smaller ENSO amplitude as compared with the observations (DOI: 10.3878/AOSL20140055). This model is different and simulate a stronger ENSO.

DOI: 10.3878/AOSL20140055 studied the CMIP5 models, most of which simulate a smaller ENSO amplitude as compared with the observations. Concerning the CMIP6 models, Zhao and Sun (2022) revealed that most of the models have an amplitude comparable to or even greater than that is seen in observations (see their Fig. 1). We agree with you that the E2.2 model simulates a stronger ENSO.

15. L588-593: This paragraph describes the ERA5 reanalysis and should be moved to the method section.

Done as suggested.

16. L597: during in => during

Corrected.

17. L605-606: This sentence repeats many times. You can provide a section describing the data and methods. There is no need to repeat the methods time by time.

Done as suggested.

18. L732-735: The ENSO amplitude has so larger a bias. To what extent can we trust the results?

We have removed the Coupled–OMA–AP runs from the manuscript.

19. L743, Figure 14: This figure is redundant and fail to connect with the topic of this study.

This figure is closely connected with the topic of this study, showing that whether the ENSO can significantly and realistically modulate the QBO period is dependent on whether the spectra of SSTs are properly simulated. Figure 14 indicates the ratio of the ENSO signal to the non-ENSO noises. Note that erstwhile Figure 14 has become Figure 13 now.

20. L760: Do you mean that none of the results are robust in this study? I also did not see that the QBOi also explore the ENSO modulation of the QBO cycle.

We have added a sentence to explain why our results are robust.

I also did not see that the QBOi also explore the ENSO modulation of the QBO cycle.

Please take a look at the following website:
https://users.ox.ac.uk/~astr0092/Experiments.html#widget2
and refer to Kawatani et al. (2019).

References

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