

Comments to the author:

In your response and revision you seem to have resolved the primary concern of Reviewer 1 regarding the depiction on the Figures of regions where signals are statistically significant. My impression is also that you have addressed most of the comments of Reviewer 2. Therefore I do not see it as appropriate to request further comments from the Reviewers regarding your revision. However there are a number of minor points, mostly arising out of comments from Reviewer 2, that I request that you address before publication. (Please provide with your revised paper a brief set of responses that make it clear which of these points you have addressed and which you have not, with brief justification for the latter.)

We thank the editor very much for the further comments and suggestions. We have addressed the points of 2, 4, 5 and 6 as the editor suggested. For points 1 and 3 regarding to the QBO definition, we have considered the problem carefully and we would like to solve the problem as follows: 1) describe the definition of the QBO index used in this study clearly in Section 2.4 and explain the reason of the choice; 2) remove the construction like 'QBOE (westerly at 50hPa); 3) discuss the results of using the PC2 (in effect the wind direction at 50 hPa) as the QBO index in Section 4. Then we think that the audience will not be confused with the results shown in this study and can also compare the results to previous studies.

More details of the revision can be found in the revised manuscript as well as the point-to-point response as follows. The comments are shown in black and our replies are marked in blue.

1) A legitimate concern of Reviewer 2 was that your definition of QBOW vs QBOE (in effect the wind direction at 20hPa) would cause confusion since the vast majority of papers on this topic define QBOW vs QBOE by the wind direction at 50hPa. You have addressed this, as suggested by the referee but writing 'QBOE (westerly around 50hPa)' etc. But have you considered the simpler approach of simply swapping your definition of QBOW and QBOE? You can explain that the phase is defined by the EOF and that your definition is equivalent to using the sign of the wind direction at 50Pa (or some other nearby pressure level if you want to be more exact).

We thank the editor for the good suggestion. However, as the editor noticed in point 3, the QBO index used in this study is not simply the opposite of the zonal winds at 50 hPa/70 hPa in the tropics (with a correlation of -0.18/-0.62). Therefore, a swapping of the QBOW and QBOE is not equivalent to using the sign of the wind direction at 50 hPa/70 hPa. We will describe our solution to this problem in the response to point 3.

2) Contours: you are in Figs 9-12 now using contours to show QBOE means. That is fine. But please can you note the contour interval used explicitly in the each of the relevant Figure captions. (The interval can be deduced, but it would be helpful for the reader if it was simply given.)

We thank the reviewer for the good comment. We have added the contour interval in the figure captions in Figures 9-12 as suggested.

3) Further issue regarding QBO phase: As I note above, you have used the construction 'QBOE (westerly at 50hPa)' -- and I have suggested an alternative to that -- but then in your long response to Reviewer 2 regarding Figure 12 you say 'The QBO index used in this study (with a correlation of 0.99 to the U at 20 hPa) is not simply the opposite of the zonal winds at 50hPa in the tropics (with a correlation of -0.18)'. So this suggests that the 'QBOE (westerly at 50hPa)' construction is simply misleading, in which case you should not be using it and you need to find some other way of expressing the relation of your definition of QBO phase to others that have commonly been used, with the wind at 50hPa being the most common. I might ask why you chose this particular definition of the QBO -- I don't believe that you explain that. Certainly the use of different definitions of the QBO in different papers is potentially confusing and what is important is that the choice of the definition is justified (perhaps the signals are weaker when other definitions are used) and there is some effort to explain how the choice affects the relation of the results to those presented in other papers on this topic. At present you seem to have decided on a way (suggested by Reviewer 2) to state the relation of your own definition of QBO phase to the definition that is most often used by others (wind direction at 50hPa) but then you are saying that this statement is not a valid one.

We agree with the editor that the construction like 'QBOE (westerly at 50hPa) is misleading. As described in Section 2.4, our choice of the QBO index is due to 2 reasons: 1) PC1 (in effect the wind direction at 20 hPa) is close to the middle stratosphere (~10 hPa), where the ozone mixing ratios are highest; 2) The sample size of QBOW and QBOE is nearly equal to each other, while the QBOW size is usually much larger than the QBOE size using PC2 (Fig. 1). After careful consideration, we would like to solve the problem as follows: 1) describe the definition of the QBO index used in this study clearly in Section 2.4 and explain the reason of the choice; 2) remove the construction like 'QBOE (westerly at 50hPa); 3) discuss the results of using the PC2 (in effect the wind direction at 50 hPa) as the QBO index in Section 4. Then we think that the audience will not be confused with the results shown in this study and can also compare the results to previous studies.

Figure R1 shows the influences of QBO (QBOW-QBOE, using PC2 as the QBO index to indicate U at 50 hPa) on global total column ozone (TCO) in different seasons based on MSR2 data 1979-2020. In general, there are also some zonally asymmetric features in the differences of TCO between QBOW and QBOE phases and the magnitude of the anomalies are comparable to that shown in Figure 3 in the main text. In DJF, the QBO signals using PC2 are opposite in sign with that using PC1 in the Northern Hemisphere (NH), while the zonal asymmetry is not that obvious. In MAM, the TCO anomalies are all negative in most of areas in the mid-to-high latitudes of the NH no matter which QBO index is used. In JJA, the PC2 related TCO anomalies are in the same sign with the PC1 related anomalies in the NH, but opposite in sign with the PC1 related anomalies in the Tropics and the Southern Hemisphere (SH). In SON, the zonal asymmetry of the PC2 related TCO anomalies is more obvious in the SH but less significant in the NH compared with PC1. It is very interesting that there are significant differences in the QBO related signals while using QBO index at different levels. We would like to leave these questions, e.g., why the PC2 related TCO anomalies are more zonal asymmetry during SON in the SH but less zonal asymmetry

during DJF in the NH, as open questions and try to find an explanation in future studies. We have added Figure R1 in the Supplement and discussed about the results in Section 4 in the revised manuscript.

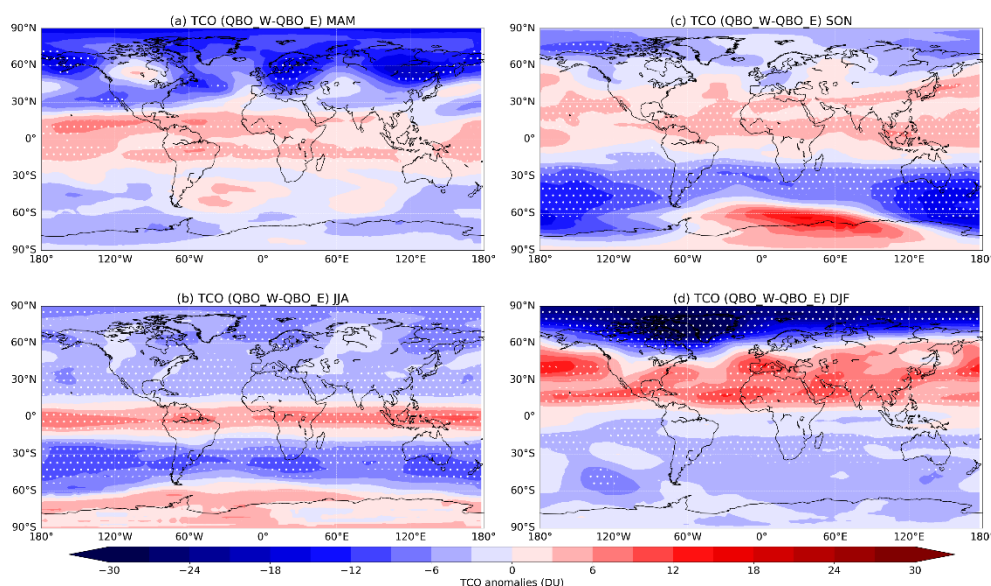


Figure R1. Influences of QBO (QBOW-QBOE, using PC2 as the QBO index to indicate U at 50 hPa) on global total column ozone (TCO) in different seasons based on MSR2 data 1979-2020. (a) MAM. (b) JJA. (c) SON. (d) DJF. Stippled areas indicate results that are statistically significant over the 95% level, using the two-tailed Student's t-test.

4) Period of analysis: Reviewer 2 asked that the period of the analysis be given in the abstract -- your response is that is not possible because there are three different periods of analysis corresponding to three different data types. But surely it is perfectly possible to state that in one sentence in the abstract.

Thanks. We have added a sentence for the period of analysis in the abstract.

5) There is an error in equation (1) -- there should not be a 'z' subscript on the capital Theta '.

We are really sorry for the mistake and thank the editor for the correction. We have corrected the equation in the revised manuscript.

6) Please give the length of the model integrations (I think 1979-2020) in the text in Section 2.4.

Sorry for the missing information. The model simulations were integrated from 1955 to 2099. We have added this information to the revised manuscript.