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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Simulation of the climate impact of Mt. Pinatubo eruption using ECHAM5 – Part 2: Sensitivity to the phase of the QBO" *by* M. A. Thomas et al.

M. A. Thomas et al.

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Answers to the comments of Anonymous Referee #1

We would like to thank the reviewer for very constructive and informative comments that have led to the improvement of the manuscript. Please find below the responses to your comments.

General comments:

Thank you for your comments. As mentioned by the reviewer, the inconsistencies in the way in which the pure QBO response is calculated is duly noted and in the paper the anomalies in the pure QBO response is re-calculated as the difference of the prescribed QBO simulation under climatological SST as boundary conditions from the climatological SST run. Hence,the text has been modified accordingly. Apart from this the abstract has been re-written to be more precise.

Minor comments:

Abstract - Line 1-3, Line 11-12: The abstract has been re-written to make it more precise and the points raised by the reviewer are incorporated.

Introduction:

Line 2: changes are made.

Line 11: The references Labitzke, 1987 and Labitzke and Van Loon, 1988 are added.

The references Chattopadhyay and Bhatla 2002 and Mukherjee et al 1985 (line 15) on Indian summer monsoon are placed together.

The paragraph on the significant differences between the tropical and extratropical QBO response are re-written as “ The QBO also plays an important role in the distribution of chemical constituents like ozone, water vapor and methane and aerosols in the tropics (Trepte et al., 1992; Trepte et al., 1993; Baldwin et al., 2001). This distribution of chemical constituents is facilitated by the planetary wave activity in the extratropics. For example, the planetary wave activity is much less in the easterly phase of the QBO compared to the westerly phase, which means that the aerosols are trapped in the equatorial belt during the easterly phase of QBO and are dispersed during the westerly phase (Trepte et al., 1993).

Line 4: re-written as 'Lidar observations of the stratospheric aerosol layer from the NH mid latitudes show that Mt. Pinatubo (1991) and El Chichon (1982) have the same volcanic aerosol decay rate of 12 months for about three years when the QBO phases of these two eruptions are synchronized (Jaeger, 2005)'

Line 8-13: Sentence in the abstract is modified.

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Line: 18-20 The references Scaife et al and Untch et al. are added

Model, datasets used and experimental set up: ———————————————————-

Line 8, Line 10-11 : changes are made.

Line 18: This line has been re-written as 'In the vertical, the core domain extends over the levels from 70 hPa to 10 hPa. The nudging rate is 1/10 days. This means that the nudging interferes with the dynamics in this well defined domain only on time scales of 10 days and longer.'

Why don't you simply use the opposite signal for the QBO phase during the Pinatubo eruption? There must be some more background behind it why are you carrying out such a complicated approach? The aim is to understand how the circulation anomalies observed after the Mt. Pinatubo eruption changed if the QBO had been in an approximately opposite phase, under the constraint that this phase has all the realistic features known from the observational record of the QBO. This excludes simple approaches, like reversing the sign of the observed QBO phase of June 1991 onward, or reversing the sign of the zonal wind anomaly of the observed QBO phase of June 1991 onward. Such simple approaches would result in unrealistic amplitudes and/or unrealistic decent rates and durations of the "reverse" QBO jets. Hence we chose the approach to select another period from the QBO record starting at the same time of the year (month of June) and having maximum anti-correlation in the considered time window.

Line 28: The anti correlation is -0.86. This is added in the manuscript.

Section 3.1: The calculation of the anomalies is more precisely mentioned in this section. Line 26: "colder by up to -1.5K" : This is seen in the tropics. Line has been re-written as 'However, the temperature response associated with the westerly phase of the QBO in Figures 2 (a,b) is comparatively weaker. This asymmetry between strong cold and weak warm equatorial temperature anomalies at 30 hPa results from the bias

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in climatological temperature of the reference simulation Cu, which misses the long term net effects of the QBO (Punge and Giorgetta, 2008). The climatological mean differences in the annual cycle of lower stratospheric temperature at 30 hPa between two 20-year model simulations including and excluding the QBO are shown in Fig. 2(c). It can be clearly seen that the stratospheric temperature climatology at 30 hPa in the tropics is colder by up to -1.5 K in the model without a QBO than with a QBO (Punge and Giorgetta, 2008). This explains why the positive temperature anomalies with respect to the control simulation Cu excluding the QBO, as shown in Figure 2a and 2b, are weaker than observed positive temperature anomalies with respect to the observed climatology, which includes the QBO."

Main results of section 3.1.2: ——————————-

As mentioned in the beginning, the pure QBO response in the paper is now shown as the difference of the unperturbed prescribed QBO run (in both observed and opposite phases) under climatological SST as boundary conditions from the control run climatology, Cu for the pure QBO responses. As can be seen the northern polar vortex is very sensitive to the boundary conditions and that the vortex is inherently non-linear. In the new set, the model simulations do not show a clear Holton and Tan mechanism. The vortex is centered over northern N. America in fig. 3(a) and no signal is seen in fig. 3(d) when the QBO is in its westerly phase in both the cases. However, a vortex centered over parts of northern N. America, Greenland and N. Atlantic is seen is fig. 3 (b) and a much warmer vortex is seen in fig. 3(c) in the easterly QBO phases. The differences in the geopotential height anomalies in fig. 3(b) and 3(c) , in the easterly phases of QBO can be explained by the zonal mean zonal winds. It can be seen that in the first winter (Fig. 1(b)), the QBO is in its easterly phase between 50 and 15 hPa and westerly phases below 50 hPa and above 15 hPa. This may result in more wave mean flow interaction in the high latitudes, resulting in a higher temperature and higher geopotential. But, the wind profiles are different in the second winter. The text has been modified accordingly. But, if we look into the stratospheric temperature anoma-

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lies in boreal winter in the high latitudes, we can see cooling in the westerly phases of the QBO which can be related to the strengthening of the polar vortex. But the cooling signal becomes weaker while averaging over the entire winter season (refer figs. 2(a) and 2(b)). However, the cooling is much weaker in the westerly QBO phase when the observed phase is prescribed.

Section 3.2: ———— Line 6: change order of appearance of the two plots first the opposite phase of the QBO Fig 4a and the observed QBO phase 4b. - The order is changed in the manuscript.

Line 3 and 23: the levels of significance are mentioned in the text. Unfortunately, I could not plot the levels of significance on top of a shaded plot using GrADS software.

Line 14: Change to "lower temperatures": changes are made.

Section 3.2: The model results in section 3.2 are consistent and are not in contradiction with the QBO phases. Why should these experiments differ incl. the aerosol effects? There is one difference that for these plots, you subtracted the AOQ simulation from the control runs with clim SSTs. Maybe this is something you should also do for the "pure QBO runs" but then you can not distinguish anymore between the QBO an the obsSST forcing. -Concerning the temperature in the equatorial stratosphere we already explain that Cu does not include the "net effects" of the QBO on the climatology of temperature. The same applies to the climatology of the wind in the extratropical stratosphere. We must expect that Cu is biased compared to an experiment including the QBO, which would conceptually be closer to an observed climatology. If a long control simulation is used including a QBO as reference, lets say Cqu, one would expect to find a difference dQ:=CQu-Cu in temperature, wind or geopotential, which would be significant in some places. This dQ then represents the net effect of the QBO variations on the climatology of the analysed variables. In your current Fig.2c you see for example that also in high latitudes in Nov-Dec there are net effects. One would have to subtract this net effect of Fig.2c from Fig.2a and 2b to get a signal that conceptually is more comparable to

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observed high latitude temperature signals. The same would apply to Fig4a and 4b. And would be instructive for the interpretation of the geopotential signals. This is to highlight why we cannot expect exactly what is known from observations, where the climatology always includes the QBO.

Conclusions: ——————

Some of the conclusions had to be re-written due to the change in the design of the pure QBO experiment.

3.: The conclusion has been re-written as 'Similarly, the simulated vortex is weak and shifted over northern Europe in the combined AOQ response irrespective of the QBO phases in the first winters. This may be because of the increased vertical wave activity during El Nino winters making the vortex much weaker. However, the model simulates a strong polar vortex during the second winter when the QBO is in its westerly phase in the AOQ experiment.

Conclusion no.3 is no. 4 in the new manuscript.

Information on the contour intervals are given in the caption of each figure.

4.: "The dynamical response" see comment on paper part I: re-phrased as 2m temperature response.

5.: Change to "Lower temperatures"

Line 21: change to "poleward of 60N"

Line 22: double the: All the above suggestions have been incorporated.

Table and figures: ——————

Table 1 does not become quiet clear as table 2 in part I: The table is removed from the revised manuscript.

Figures 1, 4 and 6: plot the figures from 90S to 90N, add the contour intervals: The

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contour intervals and the latitudinal extend of the figures are added in the caption.

Figure 2: Add the QBO phases by a horizontal line as in Fig. 4.:The QBO phases are marked in the revised manuscript.

c) How is the net QBO plot calculated? Details are missing!: The net QBO effect is calculated as the climatological mean differences in the annual cycle of lower stratospheric temperature at 30 hPa between two 20 year model simulations including and excluding the QBO. This is added in the text. Unfortunately, these two model simulations are not taken from the experiments mentioned in this paper. More details on these two simulations can be found in the referred paper (Punge and Giorgetta, 2008). The reference is given.

Figure 3: Plots are shown from 20N to 90N? Three different shadings for 90, 95 and 99% significances can't be seen on the plots.

Plots are shown from 10N to 90N.

Figure 5 has irregular contour intervals, please give informations: Additional information is given in the caption.

Figure 6: Starts in 20S? Give informations and extend to 90N: The latitudinal extend is from 15S-90N and this information is added.

Interactive comment on Atmos. Chem. Phys. Discuss., 8, 9239, 2008.