

***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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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

Thanks a lot for your comments. Because of the inconsistencies in the way in which the pure QBO response is calculated, 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.

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Minor comments

In the manuscript, the words response and impact are used, but it is not always specified of/on what the authors could maybe prefer anomalies of T/geopotential instead of responses in T... - This has been corrected.

Abstract:

line 3, line 12, line 14, line 17: The abstract is re-structured to incorporate the suggestions given by the reviewer.

Introduction:

line 4-5: Sentence is 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)’

By synchronized, we mean if both the QBO phases of the two eruptions are made to overlap.

line 11-12, line 13: re-written as — ‘Here, the main focus is to see whether the responses of temperature and extratropical circulation, as captured by geopotential height changes, to the radiative forcing caused by the Mt Pinatubo eruption are modulated by the phase of the QBO. Hence, this paper examines the climate impact of the Mt Pinatubo eruption if it had erupted during an approximately opposite QBO phase. We investigate impacts in 30 hPa zonal mean temperature, 30 hPa geopotential height and 2m temperature.’

Section 2:

line 13, line 21, line 23: Modifications are made in the manuscript to define perturbed and unperturbed simulations. The correlation co-efficient value is specified and the methodology used is made more precise.

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line 4: We mean that the amplitudes of the easterly and westerly winds in fig. 1 (a,b) are comparable.

line 7-8: We mean that the zonal mean zonal winds or the QBO phase chosen as the opposite phase can be well denoted by the opposite of the observed QBO phase.

line 9: This is corrected in the manuscript.

line 12: TABLE 1 is taken out.

line 13: Re-written as 'labelled' in the manuscript.

line 15: It is not necessary as the forcing experiments has been modified.

line 15-20: The pure QBO response and the AOQ response is well defined now in the last paragraph of Section 2.

Section 3

line 1: Re-written as 'The first part of this section discusses the responses in temperature and geopotential height at 30 hPa to the QBO phases alone. The second part of this section discusses the combined aerosol+ocean+QBO radiative and dynamical responses under the influence of the El Nino event and also with different QBO phases.'

lines 23-26 and page 9245 lines 1-4: The sentence has been moved to the specific sections.

Section 3.1

The title of this section is modified to read as 'Response of temperature and geopotential at 30 hPa to pure QBO forcing'; as suggested and the pure QBO response is defined.

lines 22-23: The following lines are added to better explain why the temperature anomalies associated with the westerly QBO phase is weaker compared to the east-

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erly phase. This asymmetry between strong cold and weak warm equatorial temperature anomalies at 30 hPa results from the bias in climatological temperature of the reference simulation C_u , 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 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 C_u 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.

lines 22-25: – Fig. 2c represent the climatology and not the difference between 2b and 2a. We cannot calculate a long term climatology from our simulations as our simulation period is just two years. So, here we make use of the two 20 year simulations carried out using MAECHAM4 - CHEM including and excluding a QBO, to calculate the climatological mean differences in the annual cycle (Punge and Giorgetta, 2008).

Section 3.1.2

line 6: The mistake is corrected.

line 19, line 20: — As mentioned before, this section has been modified as the way in which we calculated the pure QBO response has been modified. 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.

Section 3.2.1

This section has been re-phrased.

Line 15, line 24: comparisons are made with figures 2a and 2b.

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line 25: The statistical significance cannot be plotted over the shaded plots using GrADS software, hence, can not be shown. The levels of significance are mentioned in the text.

if conclusions about figure 4 are that the anomalies are a RESULT OF THE COMPLEX INTERACTIONS BETWEEN AEROSOLS, QBO AND SSTs, what is the utility of doing this kind of exercise? — The main idea behind this exercise was to include all the known factors to investigate their combined response to Pinatubo eruption. First of all, such an exercise was never carried out before in the simulation of the climatic impact of volcanic aerosols, either one or the other factors were not considered. And through this exercise it was possible to see that the anomalies are as a result of the interactions between aerosols, QBO and SSTs.

page 9248, line 1. Line has been removed. Additional information on the agreement with Holton and Tan is mentioned.

Section 3.2.2

Could the authors comment on why the HT mechanism is found in the AOQ simulation but not in the pure QBO? (also in the conclusions?) – 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, C_u 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 does 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 in 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

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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 anomalies 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 3.2.3

please refer to the correct figure number of Part I and define what the OCEAN RESPONSE is: – Ocean response is defined in the manuscript and the figures for the same are also shown.

line 15: THE COMBINED EFFECTS DO TO AEROSOLS... ARE SEEN, not clear if the MAIN FEATURES OF THE VOLCANIC WINTER PATTERN are not reproduced by the simulations, what is the interest of looking at the AOQ and AOQbar difference? How are the anomalies in SLP? – As there are only a very few observational cases of large volcanic eruptions in the period for which modern meteorological analyses are available, there is a considerable uncertainty in the reported "observed" volcanic effect on near surface climate. Therefore we find it valuable to obtain from model experiments signals for the prescribed volcanic effects combined in this study with two QBO phases, since the QBO has been permanently present during its observational record. Knowing where near surface climate signals of volcanoes depend on the QBO phase should be helpful for further disentangling the causes for "observed" volcanic signals in the stratosphere and also near the surface (c.f. Thomas (2008) for a detailed discussion of the common features of the anomalies in T2m following Mt Pinatubo, El Chichon and Mt Agung).

Thomas, M. A.: Simulation of the climate impact of Mt. Pinatubo eruption using ECHAM5, Thesis nr. 35, Reports on Earth System Science, MPI-M, 2008.

Conclusions

Conclusion number 2, last sentence: This has been modified due to the change in the forcing experiments of the QBO-alone case.

Conclusion number 3: Conclusion nr. 3 is no. 4 now. Corrections are made as suggested.

Conclusion number 3, lines 24-25: The line has been corrected.

Conclusion 4, please delete OCEAN RESPONSE; ocean response is defined and the figures are also presented in the manuscript.

Conclusion 5: This is moved to conclusion no.3. This point is rephrased as 'Below normal temperature anomalies are observed during the westerly QBO phases in Oct-Nov-Dec months in AOQ and in Nov-Dec in AOQbar. This may be associated with the strengthening of the polar vortex. These anomalies are also seen in the westerly phases in the pure QBO responses, except that the anomalies in the pure responses are weaker.'

Any comment about the ENSO impact on T? Studies (Sassi et al., 2004; Manzini et al., 2006; Chen et al., 2003) have shown that during an El Nino event, the enhancement of vertical propagation and divergence of E-P flux cools the tropics and warms the high latitudes and also, disturbs the polar vortex.

page 9251, line 19: Dynamical response is re-written as '2m winter temperature anomalies'. The observed 2m temperature anomalies in winter is considered as a dynamical response due to the meridional temperature gradient in the lower stratosphere.

Could the authors please add significances in figures 2 and 4?: The signif-

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icances can not be added as the plots are made in GrADS. However, the levels of significances are mentioned in the text.

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