

Atmos. Chem. Phys. Discuss., referee comment RC2  
<https://doi.org/10.5194/acp-2022-177-RC2>, 2022  
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## Comment on acp-2022-177

Anonymous Referee #2

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Referee comment on "The effect of ash, water vapor, and heterogeneous chemistry on the evolution of a Pinatubo-size volcanic cloud" by Mohamed Abdelkader et al., Atmos. Chem. Phys. Discuss., <https://doi.org/10.5194/acp-2022-177-RC2>, 2022

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Review of "The effect of ash, water vapor, and heterogeneous chemistry on the evolution of a Pinatubo-size volcanic cloud" by Abdelkader et al.

In this study, the effects of varying injection parameters and heterogeneous chemistry are modelled for the Pinatubo 1991 eruption. For this, the coupled chemistry climate model EMAC is run with prescribed Sea Surface Temperature and nudged Quasi-Biennial Oscillation. Model experiments are compared with available limited observations and reanalysis data. The study is of scientific interest and includes novel aspects. It may be publishable after considering the following general and minor comments carefully.

General comments:

This study follows previous model work from some of the co-authors. In Osipov et al 2020 & 2021 and Stenchikov et al 2021, the effects of interactive SO<sub>2</sub> and photolysis rates (next to volcanic ash) were simulated for the Toba super eruption and the Pinatubo eruption using the EMAC and WRF models, respectively. Why were these effects not taken into account in this study as well? The ratio and consequences of the missing effects need to be explained and discussed. Also why choosing a different EMAC model set-up as in Osipov et al 2020/2021 or is it the same one?

The authors run 5 ensemble members for each of their experiments. Which atmospheric initial conditions were chosen and how large is the spread among the different ensemble members? Please give some background and discuss the variability of the SAOD response and its effects at northern high latitudes as observed and modeled for the Pinatubo eruption (Toohey et al, 2014).

Why was the latitudinal band 3s10-25km experiment chosen? The motivation for this is rather vague. There is a bunch of other model studies, f.e., Dhomse et al (2014) and Mills et al (2016) next to Brühl et al (2015).

Stratospheric temperature response: Here it would be rather helpful to show the results from the other experiments. Suddenly the 20 km 12 Mt injection SO<sub>2</sub> scenario comes up as a best analogy, but what do the others experiments show? As the MERRA2 reanalysis is based on a model as well, what do observations show for Pinatubo (cf. Labitzke and McCormick, 1992)?

Overall, it would be interesting to see some of the results (SO<sub>2</sub>, SO<sub>4</sub>, SAOD, R<sub>eff</sub>, and stratospheric temperature) for all experiments, which would certainly lengthen the manuscript. Thus, I leave it up to the authors to decide but I think it would be very helpful for a better understanding and model intercomparison.

The abstract and conclusions need some overall take home messages i) on the overall study conclusion, and ii) from the set of model experiments: Which model experiment fits best with observations?

The paper is sometimes a bit lengthy and could be cut at certain points; see suggestions below.

Minor comments:

Abstract:

"The volcanic cloud interacts with tropopause and stratopause,... coupled with the ozone cycle." This sentence needs to be revised (science and grammar).

Pls add an overall conclusion wrt to the SO<sub>2</sub>, ash and water vapour injection impacts.

Pls add an overall model vs observation conclusion. Which model experiment is the closest to the Pinatubo observations within the EMAC model world?

Introduction:

"Volcanic activity is a major natural cause of climate variation..." Pls correct as not all volcanic activity is climate relevant. You are referring to major explosive volcanic eruptions reaching stratospheric levels only.

Graft et al 1995 > Graf et al 1995

>>Volcanic<< Explosivity Index

dacitic magma: Explain dacitic and relate it to your research work here.

A positive phase of the Arctic Oscillation is not simulated by recent CMIP models. See the more recent studies by Driscoll et al (2012); Charlton-Perez et al (2013); Toohey et al (2014); Bittner et al (2016a/b), and following work. This statement has to be updated with more recent research work and model results.

Line 36: Over which time period erupted Pinatubo?

"...and has been neglected in many previous studies (Niemeier et al 2009; Oman et al 2006)." Pls cite also more recent papers here.

From line 49 onwards:

Pls clarify and disentangle observational versus model studies here. Right now, the paragraph mixes both although having quite different reasons for the spread and uncertainties.

Timmreck et al (2018) gives an uncertainty of 10-20 Mt SO<sub>2</sub> injection into the stratosphere for the Pinatubo eruption based on available observations and model work, which should be referred to here. Then the details before can be shortened.

Line 76-77: Fig. 1 is nice to have but you can also just refer to McCormick et al (1995); Robock (2000); Timmreck (2012); and Zhu et al 2020. There is nothing new you add here, or? Next, there are also processes displayed you do not address or mention (c.f. ocean circulation and biogeochemistry).

Line 95 >: The difference to Stenchikov et al 2021 is mentioned partly, but it still lacks that SO<sub>2</sub> heating is not included next to online photolysis rates of volcanic aerosols in your study. Pls try to explain what you do in contrast to Stenchikov et al 2021 and Osipov et al 2020 and 2021 and why. This list is not complete yet.

2 Data:

How good is the MERRA2 assimilation product for the Pinatubo? Pls check the new S-RIP 2022 report. Pls compare with observations f.e Labitzke and McCormick, 1992.

Line 196: " sulphate represents by the soluble mode" grammar correct?

3 Model:

Line 164-167: I assume you also take into account natural and anthropogenic surface halogen emissions as background (such as CHBr<sub>3</sub>, CH<sub>2</sub>Br<sub>2</sub>, CH<sub>3</sub>Br, CFCs, halons)?

3.4 Section: Pls clarify

-AEROPT: EMAC module?

-RAD: EMAC module?

-Fouquart and Bonnel (1980) part of EMAC?

-RRTM part of EMAC?

-SO<sub>2</sub> is not radiative active in this (EMAC) model study but it is included in EMAC used by Osipov et al 2020 and 2021, why not here? Pls explain the ratio and the effects of neglecting it.

4 Experimental Setup:

Line 251: Why choosing different injecting heights? This is not really motivated and explained in the introduction.

Line 256: 3s10-25km: So the injection layer is 22.5-27.5 km or ...?

Line 265: "Based on different atmospheric initial conditions" Which are?

Results:

Line 296: "The cloud height is essential..." Do you mean injection height? This whole sentence needs an overall rewording to make scientifically sense.

Line 301: "lofting driven by radiative heating of volcanic debris" So what is the effect of the missing SO<sub>2</sub> radiative heating in your results? (see also Osipov et al 2020/2021; Stenchikov et al 2021)

Line 305-306 and ff manuscript:

Why not continuing with model experiment 3s10-25km if it shows such a good comparison with observations? The ratio for this is missing.

Line 385: Stenchikov et al 2021 and Osipov et al 2020&2021 included online photolysis rates (of volcanic aerosols) in addition in contrast to your study here, nor?

Section 5.1.5 and Figure 6:

Can you show O<sub>3</sub> as well which would be interesting to see and to understand and interpret the stratospheric temperature response in Fig. 15?

Section 5.6:

Pls compare also with observations cf. Labitzke and McCormick (1992).

## Conclusions:

Line 594-596: "Because of the coarse resolution...similar to other global models...too fast aerosol poleward transport..." This statement comes as a surprise. Can you pls elaborate a bit more on this and give references to it: Toohey et al (2014) simulates the effects of different Pinatubo aerosol forcing fields in MPI-ESM based on observations and MAECHAM5HAM model simulations (for 17 Mt SO<sub>2</sub> injections representing different states of the NH polar vortex and thus aerosol transport and SAOD at high latitudes).

## Figures:

-The figures in the pdf file seem to have some problems. At same pages, letters are missing cf. Page 38 y-axes labels on the right side, and Fig. 9 titles, etc.

-Numbers at the legends are often unreadable cf. Fig. 6. This has to be checked and revised for all figures.

-Figure captions need to explain the shown figures, which is often not the case, f.e. SPARC in Fig. 3 is missing etc.

Fig. 4 and elsewhere: Pls show meridional sections from 90N to 90S.

Fig. 5: SAGEII vs SAGE/ASAP ?

Fig. 6: Ozone should be shown here as well.

Fig. 8 and elsewhere: AOD, AO, vs SAOD is written, pls homogenize.

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