Authors' Response to the Editor of

Volcanic Aerosol Modification of the Stratospheric Circulation in E3SMv2 Part I: Wave-Mean Flow Interaction

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EC: ***Editor Comment***, AR: Author Response, ☐ Manuscript Text

We thank the editor for the careful reading of our manuscript and the useful feedback. This document contains our responses to comments 1, 3, 4, 6, and 8. Comments 2, 5, and 7 were minor corrections that have been implemented per the editor suggestion, and are not commented upon. Each comment below appears as a editor comment (EC) followed by an author response (AR). Closed boxes show text from the manuscript. Red text with strikethrough represents deleted text, and blue text with wavy underlining represents new text.

Comment 1

EC: ***L2-4: this statement doesn't sound accurate. Even if the volcano eruptions initially happen in the tropics, much of the sulfate is transported to the midlatitude and polar regions during the gas-to-particle conversion and coagulation processes. Please state it clearly if you refer to a specific volcano during its initial eruption time.***

AR: We were not referring to a specific eruption when we wrote this sentence, but indeed we were referring to the initial period of a few months to a year post-eruption. This is the time period during which our statement that "the primary effect of volcanic aerosols is to heat the tropical stratosphere" is true, and also the time period over which accelerations to the winter vortex region are typically observed and discussed in the literature (and in our paper). The abstract has been tweaked to be more clear about this:

> ...This wind response has been reproduced in some (but not all) simulated eruption studies. As the primary effect of volcanic aerosols during the initial post-eruption period is to heat the tropical stratosphere, the midlatitude zonal wind response is often explained as thermal wind effect. ...

Comment 3 & 4

EC: ***L135-136: the description of how the prognostic aerosol scheme converts SO2 gas to sulfate aerosol and how the volcanic sulfate aerosol is represented in the MAM4 scheme needs improvement. Also, the MAM4 scheme in standard E3SMv2 (Wang et al., 2020), where all aerosol components appear in the coarse mode, is different from the original MAM4 (Liu et al., 2016). Please adds a bit more clarification on how the stratospheric sulfate in represented in the E3SMv2-SPA model version.***

EC: ***L143-144: please add a reference for the specifics of the Mt. Pinatubo emissions.***

AR: We thank the editor for the correction on the citation for MAM4 in E3SMv2. We have added some more precise language about the specific MAM4 implementation being used in E3SMv2-SPA, and included a reference for the SO2 emissions dataset in use. The new information added comes from Brown et al. (2024), which describes E3SMv2-SPA. Rather than repeat all of the details which are presented in that paper, and are beyond the scope of the present work, we've also added a more explicit citation to Section 2 of Brown et al. (2024), where the stratospheric modifications made to MAM4 are described in detail.

> The numerical experiments utilized for this study were conducted in a custom version of the Energy Exascale Earth System Model version 2 (E3SMv2; Golaz et al. (2022)) called E3SMv2-SPA, described in Brown et al. (2024). While E3SMv2 describes volcanic eruptions by a prescribed forcing from the GloSSAC reanalysis dataset (Thomason et al., 2018), E3SMv2-SPA instead replaces this treatment with a stratospheric prognostic aerosol (SPA) capability, using the SO_2 emissions database from VolcanEESMv3.11 (a modified version of the initial release by Neely and Schmidt (2016), described in Mills et al. (2016)). Rather than prescribing stratospheric light extinction directly, SO2 is emitted as a tracer into the stratosphere, which ~~forms a sulfate aerosol as governed by the tuned,~~causes the formation of sulfate aerosol according to the prognostic equations of the four-mode Modal Aerosol Module (MAM4~~; Liu et al. (2016)~~) introduced by Liu et al. (2016) and modified for E3SMv2 by Wang et al. (2020). In E3SMv2-SPA, further modifications were made to MAM4 in order to improve the representation of stratospheric sulfate aerosols following the eruption of Mt. Pinatubo, as MAM4 was designed firstly for the fidelity of tropospheric aerosol calculations (see Brown et al. (2024), Section 2 for details). Compared to SO2 emission in standard E3SMv2, this modified configuration results in a more accurate lifetime of stratospheric sulfate aerosols following the 1991 eruption of Mt. Pinatubo, ...

Comment 6

EC: ***L151: Is there a justification for starting the model simulations two weeks prior to the volcanic eruption to capture the true dynamical response in the stratosphere? Please clarify it in section 2.***

AR: Yes, and we attempted to clarify this in the text when we said "this is enough time to allow for synoptic-scale differences between members to manifest, while the large-scale circulation remains qualitatively consistent. It is in this sense that the intra-ensemble variability is "limited"..." In other words, we manually tuned this 2-week timescale to achieve a "limited" intra-ensemble variability, as described. A shorter timescale would lead to less variability, and a longer timescale would see large-scale differences between the members. Specifically, we observed that longer timescales could result in very different transport of the initial SO2 plume. We do not describe this tuning method, since it was simply a manual "guess-and-check", which was sufficient for our purposes. We have added a few more words to make all of this a bit more clear:

> ...Because the ensemble begins on June 1, 1991, the individual members have only two weeks to diverge before the eruption occurs on June 15, 1991. Through a manual tuning process on this timescale, we found that two weeks was ~~This is~~enough time to allow for synoptic-scale differences between members to manifest, ~~while~~ and also ensured that the large-scale circulation remains qualitatively consistent (we found that much longer timescales resulted in qualitatively different transport of the initial plume, as would be expected for independent initial conditions). It is in this sense that the intra-ensemble variability is "limited", and thus the ensemble average should capture the robust climatic response to the Mt. Pinatubo event, conditioned on the real-world initial atmospheric state. ...

Comment 8

EC: ***L485: It's unclear about the "several factors" mentioned here. The first factor is explicitly discussed. Where are the second, third, etc.?***

AR: This language was not meant to imply that we have knowledge of all of the factors at play here. Rather, we said this to suggest that the one factor that is explicitly discussed may or may not be the whole story. There may be (and likely are) other differences between our model and that of Bittner et al. (20216) that we have not identified, but are playing a role. We have tweaked the language slightly to avoid the implication that we might be aware of other factors that were left undiscussed:

> The fact that we are able to robustly identify the wave-deflection for a 10 Tg eruption may be due to ~~several~~various factors. ~~First~~For example, the model employed by Bittner et al. (2016) was described as showing excessive interannual variability compared to observations...