Response to Reviewers

We thank both reviewers for their helpful comments and suggestions, which we address in detail below. As a general remark upfront, we updated three figures in the revised version of the manuscript: Figure 2, panels a and b, and Figures 3 and 4. In Figure 2, we plotted the global burden in $TgSO_2$, but the title and figure caption showed TgS. Therefore, we correct the figure and now actually plot the burden in TgS. These changes do not affect the results or conclusions in the text. For Figures 3 and 4, we corrected a mistake in our plotting script for the modal aerosol model size distribution. The MAM4 size distribution, especially for H2SO4 injections (Figure 4), aligns better with the CARMA model. However, the same shortcomings in the nucleation mode for SO_2 injections and in the coarse mode in MAM4 persist. Finally, we changed the caption in Figure A5 from "Surface Temperature" to "Temperature" and added a zonal mean comparison of water vapor to Appendix A8, following the comment by Reviewer 1.

Reviewer 1:

Summary

This study systematically compares stratospheric aerosol intervention (SAI) simulations using two aerosol microphysical schemes – MAM4 (modal) and CARMA (sectional) – implemented within the same CESM2-WACCM6 framework, with all other model components identical. The experiments vary in injection material (SO2 vs. accumulation-mode H2SO4 aerosol), injection pattern (regional vs. point), and injection amount (5 vs. 25 TgS/yr). They show that the choice of microphysics alone can cause up to a twofold difference in simulated aerosol burden, and can even reverse the relative effectiveness of injection strategies (e.g., for SO_2, regional > point in MAM4 but the opposite in CARMA). These discrepancies arise because CARMA resolves a broader size distribution, leading to more nucleation of small particles and greater growth into coarse sizes, which enhances sedimentation and reduces total burden. They further show that these differences propagate to radiative forcing efficiency, stratospheric heating, and ozone responses, and that model divergence increases at higher injection rates.

Overall, this work provides a rigorous and timely evaluation of how aerosol microphysics shape SAI outcomes. As current SAI simulations (e.g., ARISE, GLENS) often rely on MAM schemes, this paper clearly points out that a better aerosol scheme might be needed when designing future community simulations. I recommend publication after minor revisions, as outlined below.

Comments

The SAI-induced stratosphere heating could also influence water vapor transport across the tropopause, which in turn changes radiative forcing as H2O is a GHG. I wonder if MAM4 and CARMA show different signals in stratospheric water vapor, and whether that could contribute to the difference in RF per injection (besides effects from aerosol burden and effective radius).

We thank the reviewer for this comment and added a new Figure in the appendix (Figure A8), which shows differences in water vapor. Clearly, the differences in stratospheric water vapor align with the amount of temperature increase in the lower tropical stratosphere for the different experiments. These changes are likely to cause a small positive radiative forcing that will counter some of the negative radiative forcing

from the aerosols, which is strongest for the regional injections and for MAM4 compared to CARMA. However, MAM4 radiative forcing for regional injections is still much stronger than for point injections, and also stronger compared to CARMA, suggesting a small effect from the water vapor changes.

To address this, we add the following test to the manuscript after discussion changes in lower tropical stratospheric heating: "**Differences in lower-stratospheric heating across the experiments also affect stratospheric water vapor, leading to a more substantial increase in water vapor with more heating for both CARMA and MAM4 (Figure A8). The increase in water vapor can partially offset the radiative forcing achieved by the sulfur injections.** "

Since community datasets like GLENS and ARISE use MAM, this work has direct implications for how we interpret those results. From Fig. 5b, the injection amount needed to reach a given forcing appears underestimated by roughly a factor of two in MAM4. Do the authors have any recommendations or comments on how ARISE or similar datasets should be used or interpreted moving forward?

As stated in the conclusion, there could be significant uncertainty in the SAI response to surface climate when using different aerosol models. One has to keep in mind that model results are always based on a specific model version and the experimental design, and one has to be cautious about a potential over- or underestimation of impacts. Indeed, required injection amounts in CARMA are much larger to reach the same RF and surface temperature response. This results in differences in different quantities. Here, we assessed two main quantities: stratospheric temperature change, which is important for changes in regional rainfall patterns, and effects on ozone. In general, we show that increases in stratospheric temperature between MAM4 and CARMA can differ by around 25%, with a bigger difference for larger injections. We also show that, dependent on the injection strategy (regional vs point injections), stratospheric temperatures can change. To address this comment, we modify this sentence in the conclusions to: "**The difference in the results highlights a significant uncertainty in the SAI response to surface climate, not only across different injection strategies but also across different aerosol models. To investigate the full effects of these differences on climate, future studies using an Earth System model with a fully coupled ocean are required.**"

Regarding ozone changes, we do show in part larger differences between MAM4 and CARMA, with the largest differences for SO2 injections, with 7% and 4-5% column ozone change per W/m2 in the SH polar regions for CARMA and MAM4, respectively. Analyzing process-based changes is more meaningful than quantifying climate impacts.

The study is based on single runs. I think this is fine since the focus is on comparing MAM4 and CARMA, but ozone and transport results (Section 6) could be somewhat sensitive to internal variability. A brief comment on this limitation would be helpful.

For this study, we performed 20 years for each injection experiment and used the last 10 model years for analysis. Since sea-surface temperatures are fixed, we don't think that the internal variability from the atmosphere alone will require additional years of simulation.

This paper involves multiple dimensions of comparison (SO2 vs. AM-H2SO4, regional vs. point, 5 vs. 25 TgS/yr), and at times these contrasts are discussed simultaneously, including some "difference in difference" discussions. Though the paper is generally very well written and I can infer meaning from context, many spots were confusing on the first read. I recommend adding clearer transitions when switching between

comparison dimensions and explicitly stating “compared to what” (though it may add some redundancy, it’s helpful to improve clarity).

We agree with the reviewer and slightly revised the text here and at some places, and hope it is easier to follow in the revised manuscript.

Two examples below, but this recommendation applies to the manuscript as a whole:

Lines 132-133: “CARMA results in a larger … for point injections …”. Is it “larger” than regional injection, or MAM4? Can also add reference to fig 2b here. To clarify, we added “than regional injections”.

Line 190-199: These two paragraphs are particularly confusing on first read, because all comparisons are mixed and it’s hard to track the logic. Maybe the authors could clearly state the structure, and use first paragraph to summarize results consistent across MAM4 vs. CARMA, and the second to highlight contrasting conclusions?

This paragraph introduces the similarities and differences between MAM4 and CARMA, which are discussed afterwards. We hope our modifications improve the sentence.

Technical corrections:

Line 280-281: explicitly introduce “SAD” in line 280 before using it in line 281.
Line 369: “TCO ozone” is repetitive
Line 373-374: parenthesis not closed

Thanks for the comments. We have corrected them.