General comments:

The paper is devoted to reducing the bias in climate simulations by improving the representation of volcanic aerosols in CMIP6 models. This objective failed, as no notable improvement was obtained. However, the research has a promise. The authors implemented a sulfur cycle and the formation of volcanic aerosols. This is advantageous compared to the prescription of monthly aerosol fields, as in most CMIP6 simulations. This approach is not new and has been widely implemented in different studies in the last 20 years. The second mechanism employed to reduce the bias is the indirect effect of volcanic aerosols on tropospheric clouds. This is good but not a new idea. Ulrike Lohman worked on detecting this effect after major volcanic eruptions. In addition, this effect is poorly described by the models, so the first thing the authors have to show is that their model can reproduce this effect. It, by itself, is a complex task. The authors claimed that volcanic aerosols affected low-level clouds and said nothing about the impact on upper-level clouds. This is hardly believable. Volcanic aerosols will first affect cirruses and upper-tropospheric clouds. I doubt any volcanic aerosols could reach the lower troposphere, and, in any case, their contribution will be negligible in comparison with tropospheric (natural and anthropogenic) aerosols. The figures are reasonably well prepared, although showing the globally averaged tropopause height is useless. The authors should more clearly define the statistical significance of the results and make ensemble calculations to reach statistical significance. The text is poorly written, with repetitions, incorrect terminology, and poor English.

All our responses are in blue color

We sincerely appreciate the reviewer's thoughtful and detailed feedback, which has helped us improve the clarity and scientific focus of our study. We acknowledge the concerns regarding the model's improvements and methodological choices, and we have carefully revised the manuscript to better communicate the study's objectives and findings. Below, we provide a point-by-point response to the reviewer's comments.

**Model Improvement & Scientific Contribution**

We recognize that our implementation did not fully resolve the mid-20th-century surface temperature cold bias. In response to this concern, we have substantially revised the manuscript to better clarify the purpose of this study. The primary goal of our work is to assess the impact of an improved volcanic sulfate aerosol representation on climate simulations, particularly in its influence on aerosol-cloud interactions. We have updated the title to **"Assessing the Climate Impact of an Improved Volcanic Sulfate Aerosol Representation in E3SM"** to better reflect this objective.

We also acknowledge that our initial presentation may have overemphasized the extent of improvement achieved. To address this, we have refined the most parts of the manuscript to provide a more clear and reliable assessment of our results. Rather than focusing solely on reducing the cold bias, we now highlight the more realistic volcanic sulfate aerosol representation and evaluate the implementation's impact on historical cloud forcing changes. We also discuss the possible next steps to further improve E3SM's bias. The abstract has been revised accordingly to reflect these clarifications.

"Accurately simulating historical surface temperature variations is essential for evaluating climate models, yet many struggle to reproduce the mid-20th-century temperature trends associated with significant volcanic eruptions. This study examines the impact of volcanic sulfate aerosol representation on these biases using the Energy Exascale Earth System Model (E3SM). The standard CMIP6 protocol prescribes volcanic forcing through radiative perturbations, omitting volcanic aerosol-cloud interactions (VACIs). Here, we implement an emission-based approach with an updated volcanic eruption inventory that directly incorporates volcanic sulfur dioxide ($SO_2$) emissions, enabling a more process-based representation of volcanic forcing. This approach leads to improved surface temperature variability and a modest reduction in cold biases between 1940 and 1980 compared to the CMIP6 setup. Additionally, we assess cloud property responses to a more realistic volcanic sulfate aerosol representation, which weakens cloud-induced cooling during periods of lower volcanic activity. However, despite these refinements, a significant temperature cold bias remains, indicating that further improvements in aerosol microphysics, cloud processes, and model parameterizations are needed to fully resolve this issue in E3SM."

we hope these revisions address reviewer's concerns.

**Novelty of the Approach**
We appreciate the reviewer's point that an emission-based approach to volcanic sulfate aerosol representation is not entirely new, as prior studies, including those by Lohmann et al. (2002), have explored aerosol-cloud interactions from volcanic eruptions. However, our study specifically integrates this approach within E3SM and evaluates its long-term impact on mid-20th-century historical transient climate simulations. Given the significant temperature biases in CMIP6-era models, we believe this assessment provides valuable insights.

Additionally, we build upon the work of Schmidt et al. (2012), who emphasized that background volcanic degassing has long-term climate implications. Our study extends this discussion by assessing the role of explosive volcanic eruptions in shaping aerosol-cloud interactions. Since the standard CMIP6 protocol prescribes volcanic forcing primarily through radiative perturbations, neglecting aerosol-cloud interactions, our approach offers a novel contribution by explicitly quantifying these effects within a fully coupled Earth system model. We have revised the introduction to better situate our work in the context of prior research and clarify its contributions.

**Volcanic Aerosol Effects on Upper vs. Lower Troposphere Clouds**
We appreciate the reviewer's suggestion to consider the impact of volcanic aerosols on high clouds and have now included an additional analysis in **subsection 3.3 and Table 4**. While our study primarily focuses on interactions between volcanic sulfate aerosols and lower-tropospheric clouds, we agree that a comprehensive evaluation should also assess upper-level cloud impacts.

Lohmann et al. (2002) conducted foundational work on the influence of the Pinatubo eruption on homogeneous ice nucleation and cirrus clouds. However, observational studies such as Luo et al. (2002) found no significant climate feedback from aerosol–cirrus–radiative interactions when examining multiple satellite products. This discrepancy highlights the complexity of these processes and the challenges in representing them in models.

From a modeling perspective, the response of cirrus clouds to volcanic sulfate aerosols is strongly dependent on the choice of ice nucleation parameterization. The current E3SM MAM4 aerosol scheme (Liu et al., 2016) and the ice nucleation scheme based on Liu and Penner (2005) may not be well-suited for investigating these effects in detail. We acknowledge this limitation and have added a discussion of it in the revised manuscript.

Furthermore, Figure 3 now includes the vertical distribution of sulfate aerosols, which clearly shows that a substantial fraction of volcanic sulfate can descend into the middle and lower troposphere, where it influences cloud microphysical processes. We have also clarified this in the revised discussion.

**Statistical Significance & Ensemble Considerations**

We appreciate the reviewer's comments regarding the need for clearer statistical significance testing. To address this, we have revised our figures and tables as follows:

- **Figure 6**: Now includes uncertainty markers to indicate ensemble uncertainty range.
- **Figure 7 and Table 4**: Now include statistical significance indicators to clarify where differences between simulations are meaningful.

We believe these additions improve the robustness of our analysis.

**Language & Clarity**

We acknowledge the reviewer's concerns regarding clarity and readability. The manuscript has undergone extensive revisions to reduce redundancy, refine terminology, and improve overall readability.

Specific comments:

L105: macrophysics > microphysics

We thank reviewer's suggestion and correct it.

L148: processes > microphysics

We thank reviewer's suggestion and rewrite this part.

L262: Not only LW

We thank reviewer's suggestion and rewrite this part.

L279-285: Improve language

This part of manuscript has been rewrite.

L287-290: Volcanic aerosols penetrate into the troposphere mostly through tropopause folds and in high-latitudes

We thank reviewer's suggestion.

L362: optical properties of the atmosphere in the stratosphere

We thank reviewer's suggestion

L388: light extinction > aerosols extinction

We very appreciate this detailed correction.

Helka > Hekla in multiple places

We very appreciate this detailed correction

L393: response > extinctionon

We thank reviewer's suggestion

L408: mentioned > showed

We thank reviewer's suggestion

L412: Panel c > Figure 7c

We very appreciate this detailed correction

L417: panel d > Figure 7d

We very appreciate this detailed correction

L422-426: Clarify the text

This part has been rewrite.

L488: dimmer volcanic eruptions?

We changed the word choice here.

L491 anomalies are warmer > anomalies are greater

We changed the word choice here