Review of "Volcanic aerosol effects on warm and cold cloud microphysics: ICON-ART simulations of Holuhraun and La Soufrière eruptions" by Zarei et al. [MS No., egusphere-2025-6082]

This study examines the response of cloud microphysical processes to volcanic aerosols by simulating two volcanic eruptions: the 2014–2015 Holuhraun eruption, in which warm-phase and mixed-phase clouds dominate, and the 2021 La Soufrière eruption, where ice clouds are more prevalent. By conducting sensitivity experiments with and without volcanic aerosols, the authors quantify how the number concentrations of cloud droplets and ice crystals, along with associated precipitation processes, respond to enhanced volcanic aerosol loading. Their results show that in warm clouds, cloud droplet numbers increase while rain formation processes are suppressed. In contrast, for cold-phase clouds, the total number of ice crystals decreases due to the activation of ash particles, which deplete water vapor and suppress homogeneous ice nucleation. The study also explores the potential role of mixed-mode aerosols acting as CCN.

Overall, the paper is well written and organized, and easy to follow. The study provides valuable insights into the process-level understanding of aerosol effects on both warm- and cold-phase clouds through simulations of natural volcanic events. However, some clarification is needed regarding the model configuration and the potential co-influence of meteorological factors when interpreting aerosol effects. If these concerns, along with the issues outlined below, are addressed, I believe the paper would be suitable for publication in ACP.

Major comments:

1. A major concern is the very large initial bias in cloud droplet number concentration in the Holuhraun simulation. The authors state that the original simulation produced a relative enhancement (RE) of 6167%, compared with 42% from MODIS observations, and that tuning reduced the modeled RE to 1219%. Although this represents an improvement, the remaining discrepancy is still substantial. This suggests that the aerosol perturbation associated with the volcanic eruption may still be overly strong in the simulation.

This raises the question of whether the simulated reduction in warm-rain processes (or the increase in cloud water shown in Figure 3d) could partly be an artifact of an excessively strong activation response. In particular, previous observational studies reported no detectable or only minor changes in liquid water path during the Holuhraun eruption (Malavelle et al., 2017; Haghighatnasab et al., 2022). Please discuss how the remaining bias in droplet number concentration may influence the interpretation of the results and the robustness of the conclusions.

In addition, was a similar tuning applied to the simulations for the La Soufrière case? Moreover, for the background aerosol setup, are the assumed aerosol concentrations based on observational constraints? If not, it is possible that the large bias in RE partly originates from the background aerosol configuration. This aspect should also be discussed.

2. Since this study aims to understand aerosol effects, it is important to clarify how the influence of meteorology is controlled across the simulations. Did the authors apply any nudging strategy (e.g., toward reanalysis data) to constrain the large-scale wind fields and ensure comparable

meteorological conditions among the simulations? If not, please compare the wind fields across the simulations, particularly the vertical velocity within the plume region, as differences in dynamical forcing could strongly influence cloud development and precipitation processes.

Also, in the Holuhraun simulations the authors seem to attribute the differences in the behavior of cloud and rain inside and outside the plume primarily to volcanic aerosol effects, while ignoring the regional variations in meteorological factors. To more convincingly isolate aerosol impacts, it would be helpful to examine whether key meteorological factors (e.g., free-tropospheric moisture, lower-tropospheric stability, large-scale subsidence) differ between the plume and non-plume regions.

3. The authors conducted the VOLCANO-MIXED simulation for the La Soufrière case to examine the activation of mixed-mode aerosols as CCN. However, the results indicate that ice clouds dominate in this case, with relatively limited involvement of warm-phase cloud processes. Since CCN activation mainly affects warm-cloud microphysics, it may be more appropriate to conduct the VOLCANO-MIXED experiment for the Holuhraun case, where warm-phase clouds are more prevalent. The authors should discuss whether testing it in the Holuhraun simulations would be more meaningful.

4. Please provide more details on how the Mann-Whitney U test was applied to compare the two simulations. For example, the authors should clarify the statistical basis of the test, the temporal and spatial scales of the analyzed data, and the effective sample size used in the analysis. It would be helpful to include a brief description of these aspects in the Method section.

Technical suggestions:

- Figures 6 and 13: To make these figures more informative, I suggest adding the magnitude of the changes, or at least the sign of the changes, for each bin so that readers can more easily interpret the relevant processes.
- Some case descriptions and modeling setup details could be slightly tightened to reduce repetition between the Case Studies, Results, and Conclusions sections.
- The manuscript may benefit from a summary figure for each case that illustrates the proposed causal chain. For example, for Holuhraun, a schematic linking sulfate, increased cloud droplets, suppressed warm-rain processes, and reduced graupel would be helpful. But whether to include this figure is up to the authors.
- The correspondence line seems to contain a typo: “kit.deu”.

Minor comments:

L245: Change “(d, f)” to “(e, f)”

L229: Just curious how sensitive the conclusions are to the choices of the threshold. If it does not require substantial effort, it would be helpful to test the robustness of the results to such choices.

L339: But it is not close for snow. Please soft the tone.

L411: The larger number concentration of ice crystals between 10 and 12 km in the VOLCANO run compared to other runs seems not significant.

L415: Please elaborate how water mass conservation is applied to Figure 10f.

L428: How is Figure 11a different from Figure 10f?