Review of ‘’In-plume and out-of-plume analysis of aerosol-cloud interactions derived from the 2014-15 Holuhraun volcanic eruption’’ by Peace et al., submitted to Atmospheric Chemistry and Physics (ACP)

Manuscript number: “acp-2024-360”

Decision: “Major revision”

The study focuses on the uncertainty surrounding aerosol effective radiative forcing (ERF) and aerosol-cloud interactions, which are crucial for understanding climate sensitivity and predicting future climate change. Using the 2014-15 Holuhraun volcanic eruption as a natural experiment, the researchers evaluate the impact of volcanic aerosols on cloud properties during the first month of the eruption, comparing observations with simulations from the UK Earth System Model (UKESM1-A). During the initial two weeks of the eruption, both observations and simulations show a shift to smaller and more numerous cloud droplets within the volcanic plume, along with changes in liquid water path (LWP) values. However, in the third week, this shift is neither observed nor accurately modeled, and discrepancies exist between observations and simulations in the fourth week. The study underscores the influence of air mass history and background meteorological factors on aerosol-cloud interactions across different weeks. Most parts of the manuscript are well written, but there are several issues to be addressed. Based on the descriptions outlined above, my decision is “major revision,” and I encourage the authors to revise the manuscript.

**Major comments:**

Definition of Volcanic Plume:

Using $SO_2$ as a proxy for the volcanic plume in the 3rd and 4th weeks following an eruption may not be entirely accurate, as the $SO_4$ formed from it can dissipate from the source and the location of the $SO_2$ plume and $SO_4$ plume could be different. Therefore, it is possible that in the bounding boxes outside the plume area, some fingerprints of $SO_4$ could still be present. Have you thought about comparing the $SO_4$ plume with the $SO_2$ plume in your volcano simulations? I recommend providing a figure similar to Figure 2 for UKESM1-A, but with plots for $SO_4$. Or alternatively provide a comparison in distribution of one of the variables such as cloud droplet effective radius for outside of plume in simulations with the volcano eruption and without the volcano eruption.

UKESM1-A simulations:

I believe that additional details regarding your simulations are necessary. Could you please provide information about the cloud microphysics, cloud cover, and convection scheme utilized in your simulations?

- Additionally, since you use the satellite simulator from the COSP package, were subcolumns employed, and if so, how many subcolumns were utilized given the coarse resolution which is used?

- I'd like to inquire whether the information of size distribution of hydrometeors used as an input for the MODIS simulator, which is essential for simulating MODIS signals, was taken into account in your simulations?
- Regarding the resolution of your simulations, which is mentioned as 1.875 x 1.25° at the equator. What does this resolution correspond to in the North Atlantic, where your analysis takes place? Additionally, it's noted that OMPS and MODIS data are gridded at 0.5 x 0.5-degree resolution. Could you please explain how this resolution compares to your simulation's resolution?

The LWP response:

- In your paper, there is significant discussion regarding the LWP response. I believe it is essential to include analyses of LWP for different weeks of the study in the main manuscript. Therefore, I suggest providing a figure similar to Figure 5 for LWP.
- Does your analysis of precipitation in Figure 8 for the first two weeks of the eruption indicate any suppression in precipitation?

Discussion about cloud fraction:

- Could you elaborate on why analyses in Table 1 for cloud fraction are not included for simulations?
- It would improve the discussion on cloud fraction to compare the results obtained from MODIS with those presented in the study by Chen et al. (2022), which suggests enhancing cloud fraction appears to be the leading cause of climate forcing.

**Minor comments:**

- In Table 1, can you please explain why the mean value for $N_d$ for outside plume in control and Hol simulations for week 3 and 4 is very different? I believe this also can be related to my first comment on the definition of volcano plume.
- Do the simulations conducted with UKESM1-A cover the entire globe? It would be beneficial to briefly discuss the advantages and disadvantages of employing global simulations compared to regional cloud-resolving simulations.
- Please provide some short information in the manuscript regarding the time at which you analyzed simulations. Is it the daily mean or at the time of MODIS-AQUA overpass?
- In Figure 5, regarding the average enhancement observed for $r_{eff}$ and $N_d$, I'm curious about why the decrease in mean enhancement for $r_{eff}$ is more pronounced in weeks 4 and 2 compared to week 1, while the increase in mean enhancement in $N_d$ is less pronounced in weeks 2 and 4 compared to week 1. Regarding the fact that in the relationship used to calculate $N_d$, it seems that $r_{eff}$ has a stronger impact compared to cloud optical depth.
- I propose moving Figure 3 to the supplementary materials or combining the information in the legend with Figure 5.
- In line 191, did you mean event by vent?
- In Figure 4 for $r_{eff}$, it is demonstrated in< out the plume while in figure 5, for $r_{eff}$, the in> out plume is demonstrated. I recommend maintaining consistency between these two figures.

- In the abstract, can you discuss briefly how LWP has changed in the first 2 weeks? In the current version, it is just mentioned that it is changed.
- In Figure 5 caption, Nd should be $N_d$.