Response to reviewer comments: Effect of volcanic emissions on clouds during the 2008 and 2018 Kilauea degassing events

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Review Reports

The authors thank the reviewers for the thorough comments. Responses are given below.

Reviewer 1 comments and authors' responses

Major Points

Comment: *I am a little confused about the current description on changes in cloud properties during the 2008 event, and the "similarity" between the two events. If we look at the summary of MODIS observations in Table 2 and 4, 2 liquid cloud parameters (COD and Reff) show a p-value less than 0.3, whereas all the observed parameters have a p<0.3 during the 2018 event. Simulated changes are also less significant than the simulation for the 2018 events. Interestingly, the authors themselves have conducted the 2008_5x simulation to illustrate that stronger and statistically significant anomalies (similar to the 2018 events) could be derived by enhancing the 2008 emissions, and states that "This and the similarities in spatial patterns for cloud anomalies in JJA 2008 (Figure 6) and MJJ 2018 (Figure 7) suggested a threshold response to overcome meteorological effects"*

Therefore, my understanding is that the 2008 event is DIFFERENT from the 2018 event. The observed anomalies are not as strong to overcome possible anomalies from meteorology in liquid cloud properties other than COD and Reff, and the plume cannot reach as high up to modify ice cloud properties. I do agree that this difference is possibly due to the weaker volcanic emissions, which makes the 2018 analysis unique and important. I suggest the authors to modify the description of "similarity" between the two events in the paper (I will also mention several places later), and emphasize their difference and the uniqueness of the 2018 event in the revision.

Response: We aimed to establish whether the difference between the effect of the two volcanic plumes on clouds is solely due to the enhanced amount of material ejected in 2018, or due to differences in the evolution of the plumes. We agree with the reviewer that this point needs clarification. We have added text to describe what is meant by a "similarity in spatial patterns."

In both events the anomalies approximate a Gaussian-like appearance, where the source and maximum zonal mean of the anomaly lies at Kilauea and decreases in strength to the west and north/south, respectively.

We have also added the description for spatial similarity as "anomalies largely constrained by and maximized within the plume domain" to the text. We now explicitly state, with respect to the 2008_5× experiment, that "an increase in aerosol loading of similar magnitude to that observed during MJJ 2018 would have been sufficient to overcome meteorological effects which dampened the 2008 JJA anomalies with respect to long-term behavior."

Minor Points

1. **Comment:** *Page1, Line 8-9: Since the two events are not similar in all aspects, please specify the parameters that are"similarly changed". For example, "Significant changes (p<0.3) in cloud effective radius and cloud optical depth in both events suggested that…"*

   Response: We have added the suggested text to the abstract.

2. **Comment:** *The presentation flow in the introduction (before Section 1.1) is a little confusing. Paragraph 3 (Page 2, Line 10-20) is detailed description of the AIE, which follows Paragraph 1 more closely. At the same time, Paragraph 2 (Page 2 Line 1-9) introduces AGCM and the difficulty to disentangle meteorology effects when interpreting observations, and I think Paragraph 4 (about the unique conditions Kilauea provides) follows closely from that point. Therefore, I suggest Paragraph 2 and 3 to be swapped.*

   Response: Excellent point - we have reorganized the introduction by switching paragraphs 2 and 3, as suggested.

3. **Comment:** *Page 6, Line 13: In the other simulations where the emission height is changed (2008_PH2km and 2018_PH4km), how are the emissions distributed vertically?*

   Response: In the default configuration of GEOS, the volcanic plume is injected as a point source at about 1.2 km, resulting from the assumption that that volcanic emissions height is constrained by the planetary boundary layer ($<$ 2 km). For the 2008_PH2km and 2018_PH4km runs the base of the plume is assumed still to to be around 1.2 km but it extends vertically up to 2 km and 4 km, respectively. In practice, this means that the volcanic emissions represent a point source at a height about $1/3$ of the top of the plume. The above clarification has been added to the text.

4. **Comment:** *Page 8, Line 10: Add "2008_PH2km" in the sensitivity simulations.*

   Response: Done.

5. **Comment:** *Page 8, Line 10-11: Add "and interpret their differences GEOS simulations."*

   Response: Done.

6. **Comment:** *Page 12, Line 1: This statement only applies to the 2018 event.*

Response: The statement has been modified to " Student's *t*-test statistics indicated that the anomalies were statistically significant, typically to a 70%-80% level ($p < 0.3$, except for AOD and CF in 2008 which are significant only to 60%) for R_{eff} and CDNC more so than for other variables".

7. **Comment:** *Page 12, Line 5: Delete"The plume domain"*

   Response: Done.

8. **Comment:** *Page 12, Line 6: Add "and agrees in magnitudes with the 2018_1x."*

   Response: Done, and added the following sentence: "The similarity in the magnitude of simulated anomalies for 2008_5× and 2018_1× suggested that increased aerosol loadings would have been sufficient to overcome meteorological effects which dampened the 2008 JJA anomalies with respect to long-term behavior."

9. **Comment:** *Page 17, Line 21: "25.8" disagrees with the number in Table 4 (20.59). Please double check consistency of numbers cited in the text and in the tables.*

   Response: Thank you for catching that error. We have checked through the text, and also have made sure that all numbers cited in the text use two decimal places for consistency with the tables.

10. **Comment:** *Page 17, Line 22-23: I am confused. Should this indicate microphysical control is weaker than meteorology for IWP?*

    Response: While the $GEOS_{CLIM}$ mimicked the strength of the MODIS anomaly, the zonal mean profile of the GEOS IWP 2018_1×−2018_0× difference had higher correlation with MODIS. We have reworked the text to clarify this.

11. **Comment:** *Section 5.1, Figures 10-11: Does it make sense to also include the discussion of climatological profiles?*

    Response: Yes it does. We have included the climatological (excluding 2008 and 2018) profiles in Figures 10 and 11. In general, the climatologies tended to show smaller values of liquid and ice properties than the 0X experiments, with the notable exception of ice mixing ratio and number concentration in 2008. The latter indicating a strong control of the meteorology on the ice phase. This discussion has been added to the text.

12. **Comment:** *Figure 11: typo in the legend, should be "2018_PH4km"*

    Response: Corrected.

13. **Comment:** *Page 28, Line 18: suggested to be revised to "the simulated ACI signatures…"*

    Response: Done.

14. **Comment:** *Page 29, Line 10: add "and their discrepancies are largely attributable to different magnitudes of volcanic activities and aerosol loadings."*

    Response: Done.