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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Effect of volcanic emissions on clouds during the 2008 and 2018 Kilauea degassing events" *by* Katherine H. Breen et al.

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This is an important contribution on the interaction of Kilauea volcanic gas and aerosol emissions with meteorological clouds. In reading through the manuscript, I was left with some questions regarding the SO2 emissions data used in this study. The 2008 and 2018 degassing episodes discussed here differed in two ways that I believe may be important for this discussion. For one, SO2 degassing in 2008 occurred mostly at the summit of the volcano while the majority of degassing in 2018 occurred at lower elevations in the lower East Rift Zone. Also, and perhaps more importantly, the SO2 emission rate during May-July 2018 was approximately an order of magnitude greater

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Discussion paper

than during 2008. In both cases, I believe the authors have not yet considered the state-of-the-art in our understanding of SO2 degassing to the atmosphere during these eruptive episodes. Below, I've listed a few more details in this regard which I hope might help the authors to further improve their study.

The manuscript (e.g. Figure 1 caption) mentions peak sulfate emissions of 50 kt/d. This is confusing in several ways – for one, we (the USGS) did not measure sulfate, but rather SO2 emissions. High temperature volcanic vents like those at Kilauea emit sulfur mostly in the form of SO2. The SO2 is then converted to sulfate over the course of hours to days. Throughout the manuscript, it is therefore probably best to refer to SO2 emissions rather than sulfate emissions. The 50 kt/d value refers to SO2 and was an estimated minimum value reported by Neal et al. 2019. These emissions occurred mostly from the lower East Rift Zone, not the summit crater shown in the image which is also confusing. Since the publication by Neal et al. in 2019, we have made significant further progress in quantifying the gas emissions related to the 2018 eruption of Kilauea. As Allan Lerner points out in his comment, please refer to Kern et al. 2020 for this information. For example, we now know that peak SO2 emissions of more than 100 kt/d appear to have been sustained throughout the month of June and into early July 2018 (Figure 10 in Kern et al. 2020). We also broadly discuss the topics of aerosol formation and pyrocumulus cloud formation over the lower East Rift Zone, as well as the coincident gas emissions from the volcano's summit and middle East Rift Zone, all of which the authors may find useful in refining thier work.

Regarding the 2008 emissions, please note that Kilauea Volcano was in a state of eruption at its summit Halema'uma'u Crater during the entire 2008-2018 timeframe, not just in 2008. However, the authors are correct in that the highest SO2 emissions (likely > 10 kt/d) occurred during 2008 (see comment below). I would like to encourage the authors to clarify this somewhat, stating that they are focusing on the first year of the 2008-2018 summit eruption during which the highest SO2 emissions occurred, rather than just referring to a 2008 event. I think this would be important given the fact that emissions averaged about 5 kt/d long after 2008 and continued to have a significant impact on environment and air quality in downwind regions during this entire time. See the following two references on this topic:

Businger S, Huff R, Pattantyus A, Horton KA, Sutton AJ, Elias T, Cherubini T (2015) Observing and Forecasting Vog Dispersion from Kilauea Volcano, Hawaii. Bull Amer Meteor Soc 96:1667–1686. https://doi.org/10.1175/BAMS-D-14-00150.1

Pattantyus AK, Businger S, Howell SG (2018) Review of sulfur dioxide to sulfate aerosol chemistry at Kilauea Volcano, Hawai'i. Atmos Environ 185:262–271. https://doi.org/10.1016/j.atmosenv.2018.04.055

For our best estimates of SO2 emissions during the 2008-2013 period, please refer to our recent data release available here:

Elias, T., Kern, C., Sutton, A.J., and Horton, K., 2020, Sulfur dioxide emission rates from Kilauea Volcano, Hawaii, 2008-2013: U.S. Geological Survey data release, https://doi.org/10.5066/P9K0EZII.

Figure 1A in the above reference provides an overview of SO2 emission rates reported by different authors and using various methods. The estimates vary in magnitude but note that, regardless of the utilized methodology, emissions vastly exceeded the 1,000 t/d level mentioned on page 4, line 17 of the manuscript.

As for the SO2 emissions in 20108, the authors state on page 6, line 10 that they used daily varying SO2 emission rates for their analyses. However, the reference cited is from 2017, so it's unclear where the data corresponding to the 2018 eruption come from. Assuming they come from an analysis of OMI operational SO2 products, it would be quite important to discuss the uncertainty of these data. As described in Kern et al (2020), we had to go to significant effort to account for complex radiative transfer in and around the gas plumes emitted from Kilauea's lower East Rift Zone when analyzing our ground-based DOAS measurements. Similar corrections are likely needed when analyzing satellite remote sensing observations of these dense gas clouds. As we discuss in the 'Future Work' section of Kern et al 2020, operational satellite products are likely to underestimate the true magnitude of emissions without such corrections. It may therefore be better to use the SO2 emission rates reported in Kern et al 2020 for these analyses (the values are included as a supplement to the paper, along with some measurements of plume height).

Finally, it is also not clear whether it is valid to initialization of the model with the same plume heights for the 2008 and 2018 events, given that the 2008 emissions occurred from the summit of the volcano and the 2018 emissions mostly occurred from the lower East Rift Zone. I would encourage the authors to clarify the assumptions made in their study in this regard, and as one of the reviewers also states, discuss the uncertainties associated with these assumptions in more detail.

Thank you for the opportunity to provide feedback on this effort. I look forward to reading the final version of this important manuscript.

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