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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Changes in stratospheric aerosol extinction coefficient after the 2018 Ambae eruption as seen by OMPS-LP and ECHAM5-HAM" *by* Elizaveta Malinina et al.

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We are very grateful to the reviewers, Daniele Visioni and Anonymous Referee #2, as well as for Pasquale Sellitto for providing their insightful and constructive comments on the manuscript. We appreciate input and think that the paper benefited from the suggested changes.

Below, the answers to the reviewers' questions and comments are provided. In order to make the text more distinguishable, we highlighted the reviewers' and Dr. Sellitto's comments in **bold** and authors' answers in blue font.

This paper combines measurements and model simulations to assess the outcomes of the 2018 Ambae eruption. It is an excellent study, and more of this kind are needed to understand the shortcomings of climate models in simulating volcanic plumes evolution and the radiative effects of the increase stratospheric sulfate. I think this paper is great for ACP, it is scientifically robust and novel. I have multiple suggestions to improve the text in places (especially the readability in English) and I have listed them below, but I don't think this is generally an obstacle for the publication of a relevant advance in our scientific knowledge, so after these suggestions are considered, the manuscript can be published promptly.

Abstract

Line 2: "These effects are more noticeable after..."

Corrected.

Line 4: no comma after studies

Corrected.

Line 4: "Besides" is not the right word here. I'd actually rephrase the entire concept using: "There have been several studies, where a volcanic eruption plume and the associated radiative forcing were analyzed using *either* climate models *or* data from satellite measurements: however, studies combining both models and measurements are rare."

During the manuscript revision, it was decided that this phrase in the abstract was inaccurate. We revised it to: "There have been several studies, where a volcanic eruption plume and the associated radiative forcing were analyzed using climate models and/or data from satellite measurements. However, few have compared vertically and temporally resolved volcanic plumes using both measured and modelled data."

Line 11: remove "the", leaving "for most latitude bins"

Corrected.

Line 12: remove ":"

Corrected.

Line 17: "to the" instead of "through"

Corrected.

Introduction
Line 24: "is" now well established.

Corrected.

Line 41: this is a nice overview. However, it does not mention quiescent degassing and non-explosive eruptions that are also an important source of sulfate for the UTLS, see for instance Pitari et al. (2016)

Thank you, we agree that those sources are important in the formation of the stratospheric aerosol layer. It is worth mentioning though, that talking about "moderate" (VEI 2-3) volcanic eruptions we also include non-explosive (VEI$<$4) eruptions. However, we agree that it is important to add quiescent degassing as a source. Therefore, we changed the sentence to "Although these sources along with quiescent volcanic degassing are undoubtedly important, the large scale changes to the stratospheric aerosol layer are primarily driven by moderate and large volcanic eruptions which emit sulfur dioxide (SO_2) directly into the upper troposphere lower stratosphere (UTLS) region (e.g. Kremser et al., 2016; Pitari et al., 2016, and references therein)."

Line 44-45: just to be precise, but it's not the models themselves, it's the underlying simulations without proper sulfate emissions. For instance, in Schmidt et al. (2018), they compare simulations with and without volcanic emissions in the same model.

We agree, it was not precise wording. We changed the sentence to "According to

Solomon et al. (2011); Haywood et al. (2014); Schmidt et al. (2018, and references therein), it has been shown that climate models' simulations that neglect forcing from volcanic eruptions since the year 2000 tend to project a faster rate of global warming for the first 15 years of the 21st century than the simulations including this volcanic forcing."

Line 57: comma after volcanoes.

Corrected.

Line 58: "in" instead of "of"

Corrected.

Line 62: "...the last decade, although it did..." (just fixed the punctuation)

Corrected.

Section 2
Line 127: remove comma after "highlight"

Removed.

Section 3:
I'm a bit confused by the structure of the sections: wouldn't it be better to have a Section 2 with a description of both the measurements (OMPS, SAGE III) and possibly the ECHAM simulations, and then move to the results? it would be a bit clearer to the reader.

The structure of the sections has been changed in accordance with your remark and recommendations from referee #2.

Line 153: "Ångström" is missing an s(but it has all the correct accent marks, which usually nobody bothers with!)

Corrected.

Line 159: no comma after "Both"

Corrected.

Line 164: no "the" before the dates

Removed.

Line 168: this is my ignorance, being a modeler, but how can there be negative Extinction values? Is it an error in the retrieval algorithm (and if that's the case, why not remove them?). Or something else? If it can be briefly explained, it should be.

We agree that intuitively the negative aerosol extinction coefficient seems to be erroneous. However, it is not exactly an error, rather a feature of the retrieval algorithm, and negative extinctions are statistically possible. Damadeo et al. (2013) discuss this problem for SAGE II instrument. In their paper, the authors mention, that negative extinctions can occur in the situations when the extinction value is low and signal-to-noise ratio is small. They also state that removing them would introduce a positive bias to the extinctions. We haven't found a literature reference for SAGE III, however, Robert Damadeo (pers. com. 2019) recommended us not to filter negative values for SAGE III exactly for the same reason, which was stated in the lines 168-169 of the original manuscript. We revised them by adding " We did not filter negative Ext_{869} because this would bias the comparison (see Damadeo et al. (2013) for details)."

Line 178: "observed" instead of "seen"

Corrected.

Line 187: I see what the authors mean, but "put" is not the right word. If the original observations where spatially non uniform, and the authors obtained a uniform grid out of them, then it's technically a 2D interpolation.

We see, our expression was confusing. What we actually mean is the binning rather

than interpolating. The paper text has been corrected.

Section 4
Line 202: remove "the" before height

Removed.

Line 206: a periodicity, or periodic signal

Changed to periodic signal.

Section 5
Line 216: remove "the" before altitudes

Removed.

Line 217: "However" instead of Although

Changed.

Line 229: northward and southward

Corrected.

Section 6:
Again, it's a bit weird to have Fig. 3 with the ECHAM results before a description of the simulations. I'd have most of this section much earlier in the text.

We changed the structure of the paper to account for your comments and those of the reviewer #2

Line 247: for two reasons.

Corrected.

Line 261: the phrase "Furthermore, the radiative cloud fractions less than 0.2 and a solar zenith angle less than 70° were required" doesn't make sense to me.

This is a very relevant objection because the radiative cloud fraction is not needed to filter the OMI data when the retrieval algorithm assumes an SO_2 profile with a center of mass in the lower stratosphere. Therefore we recalculated the SO_2 burden without a constraint for this variable. We still excluded all SO_2 data that were measured at solar zenith angles above 70° as it is recommended by the OMI manual: "Volcanic SO_2 data from all rows of the OMI, with the exception of rows affected by the row anomaly, can be used. As with the PBL SO_2 data, it is best to use retrievals from scenes with SZA$<$70° " [citation from the manual:"OMSO2 README File v1.3.0 Released Feb 26, 2008 Updated: June 16, 2016" https://so2.gsfc.nasa.gov/Documentation/OMSO2Readme_V130_20160616.pdf] We rephrased the sentences to: "Only the measurements obtained at solar zenith angles less than 70° were used."

Section 6.2: this section is explained in an excellent way, but I have a doubt that I can't seem to find in the text: what's the horizontal extent of the SO_2 in these measurements? I.e. when the authors say "Finally, the SO_2 mass of the entire grid per batch are summed up to obtain the total SO_2 burden.", what's the horizontal span of the grid that contains, say, 99% (or 95%) of the SO_2 used in the estimates you present for the volcanic eruption? This is potentially an interesting point to include.

We are very grateful to the reviewer for this comment. However, it was very challenging to give an estimate on the position of the longitudes that contain 95% of the SO_2 mass inside the plume, and sadly we are not sure if there is a definite answer.

We provide an estimate using the following technique, first, we averaged the SO_2 mass (the threshold was applied beforehand) over all batches, see the left panel of Figure 1 of this document. To get the horizontal extent of the plume, we subsequently averaged over all latitudes (right panel in the Figure 1). Finally, we moved the the boundaries of the outer longitudes towards the center until the sum of the SO_2 mass between the boundaries reached 95% of the total SO_2 mass. Using this approach, we may say that 95% of the SO_2 mass was detected between 152.9°E and 142.8°W.

P.S.: Sorry, the full caption for Fig 1 didn't fit in the system: Left: average of the SO_2 mass over all batches. Right: the time averaged SO_2 mass was averaged over each latitude to estimate the expansion of the plume. The red dotted lines mark an area that contains 95% of the total SO_2 mass.

Line 326: "vertical" instead of "altitudinal"

Corrected.

Line 335: most aerosols are

Corrected.

Line 339: "blob" is not a very technical word... Maybe just "area"? (also in line 376)

The text has been changed to "A disagreement is seen, however, around the 19.5 km altitude in November, where OMPS-LP data show an increased extinction not present in ECHAM simulations." to account for a comment of reviewer #2. We changed the word "blob" in line 376 of the original manuscript to "area".

Section 7
Line 360-361: just a comment, but I'm also quite amazed at how well the plume is reproduced in ECHAM! This is a great result.

Thank you! We are also very satisfied with it.

Line 368: "with" observations

Corrected.

Line 374: observed instead of "seen"

Corrected.

Line 382: is the SO_2 amount big enough to produce a noticeable w* increase produced by the heating? Can the authors give some information on the strato-

spheric temperature perturbation? (the nudging ensures that this doesn't translate in additional w*, of course, but can we actually see an effect on stratospheric temperatures with 0.4 Tg-SO_2?)

In the ECHAM model only atmospheric waves with large wave numbers are nudged. The residual vertical velocity should change. However, as the reviewer speculates, the eruption was too small to show a clear signal on the residual vertical velocity. We compared our simulation to a control simulation without a clear result.

The Figure 2 shows the anomaly of the residual vertical velocity as a difference to the control run, a nudged simulation without volcanic eruption.

Line 384: "The" Ambae eruption

Corrected.

Figure 6: there might be some problem with the legend: the (869) part is missing.

Thank you for drawing our attention to it. This might have happened during the manuscript uploading, now the plots are in png-format, so the problem is resolved.

Line 422: "the" reader's attention

Corrected.

Line 433-434: how do you estimate the 0.13 W/m2 value? Doesn't look like it's the value from the green line only. Is it an average between all curves? Some? An explanation is warranted.

This is a value from the blue solid line, calculated using the "original" Hansen formula. We change the sentence to "For the particular Ambae eruption studied in this paper, using Hansen's formula, we estimate the tropical radiative forcing caused by an increase in stratospheric aerosols to be about -0.13 W/m^2."

Conclusions

Line 446: "observed" instead of "seen"

Corrected.

Line 447: "the" tropics

Corrected.

Line 449: "global aerosol model" is not really precise? I'd suggest using "GCM with a coupled aerosol microphysical model"

We change the text to "from a GCM with coupled aerosol microphysics".

Line 453-456: This phrase is a bit confusing. I've tried to reword it below a bit "For the first eruption ECHAM underestimated the strength of the plume as well as the time by which it reaches 20.5 km of altitude, whereas for the second eruption the modeled plume reaches higher altitudes about two to three weeks earlier, and the plume lives longer while being slightly weaker overall at those altitudes"

Following the comments from anonymous reviewer #2, it was decided to revise the discussion without the phrase about first eruption, as it is too small to be traced uniquely.

Line 459: "the" aerosol radiative forcing

Corrected.

Line 461: the time "evolution" is a better term

Corrected.

Line 466: "the model" with no "s". Can't assume the same for other models...

Changed to "the model gives".

References

Pitari, G., Visioni, D., Mancini, E., Cionni, I., Di Genova, G., & Gan-

dolfi, I. (2016). Sulfate aerosols from non-explosive volcanoes: Chemical-radiative effects in the troposphere and lower stratosphere. Atmosphere. https://doi.org/10.3390/atmos7070085

Damadeo, R. P., Zawodny, J. M., Thomason, L. W., and Iyer, N.: SAGE version 7.0 algorithm: application to SAGE II, Atmos. Meas. Tech., 6, 3539–3561, https://doi.org/10.5194/amt-6-3539-2013, 2013.

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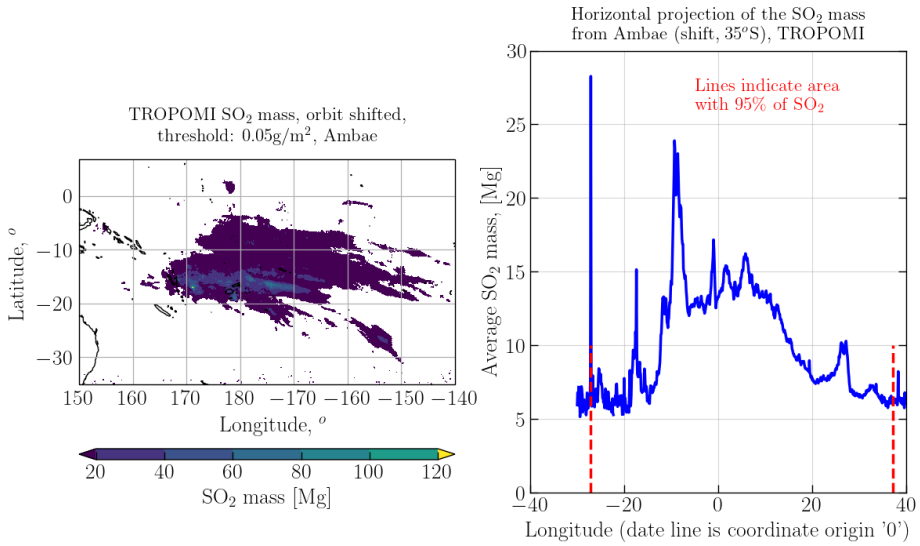

Fig. 1. Left: average of the SO2 mass over all batches. Right: the time averaged SO2 mass was averaged over each latitude to estimate the expansion of the plume. The red dotted lines mark an area that contain

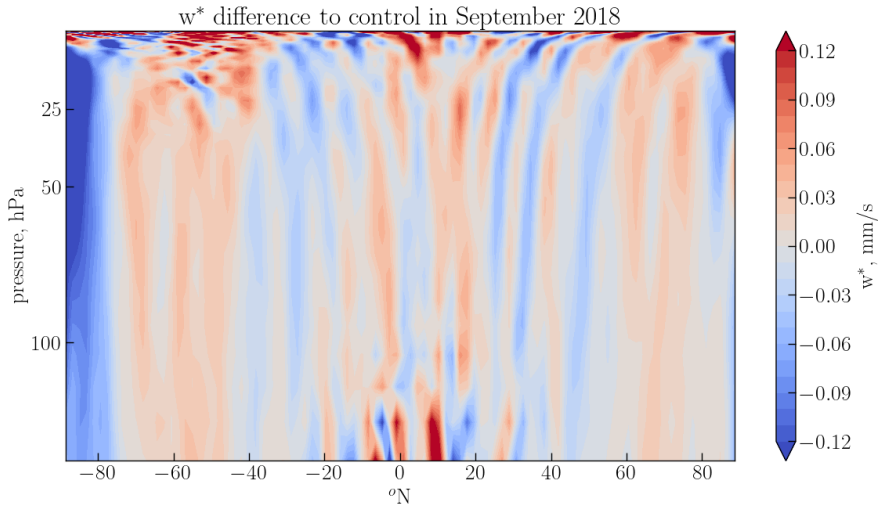

Fig. 2. Difference in vertical velocity (wˆstar) in September 2018. The difference was obtained by subtracting the control run (without the eruption) from the run with the eruption.