Review on:

High-resolution stratospheric volcanic SO2 injections in WACCM

Emma Axebrink et al.

egusphere-2024-1448

June 7, 2024

The paper by Axebrink et al. highlights an important aspect for simulations of the sulfate aerosol evolution in the stratosphere after a volcanic eruption. They performed simulations with three different SO2 emission profiles and show that the results depend strongly on the profile used.

Emission rate, altitude, profile and timing are important for a realistic simulation. The evolution of the sulfate aerosol formation is very non-linear and depends on SO2 and background concentrations. The emission altitude determines the direction in which the volcanic cloud is transported in the model. Many of these aspects are nicely highlighted in the paper.

The paper is well written and reads well. I recommend publication after a few minor corrections.

General:

The article misses the aspect of microphysical processes and the consequent differences in particle size between the different simulations. Scattering of sulfate aerosols depends on the particle size (e.g. Laakso et al 2022). This could be another reason for the differences in the simulated forcing. My recommendation is to take a look at the particle size, e.g. calculate the effective radii, and include a short discussion.

The description of your experiments is a bit misleading. The table implies that your vertical grid of the S21s simulations has a vertical grid spacing of 200 m. This is not the case. Instead, you must interpolate the input data onto the model grid. Right? So it is not the resolution of the injection input data that is important. What is more important is the injection profile in the model. What does it look like and what does the model grid look like? Figure 6 shows quite similar profiles for June. So I assume that the height resolution of the input data disappears in the model. You can show and explain more details and show an initial phase profile.

A clear reason for the differences in the forcing calculations is the simulated altitude of the volcanic cloud (Fig 6). Surprising is the different behaviour between S21-1D and S21-3D. A better explanation should be added.

Have a look for other papers of volcanic eruptions, especially using WACCM, and add some citations.

Specific comments:

Line 38: What means significant here?

Line 43: A residence time of several years is quite unrealistic.

Line 49: No, the climate impact is estimated from the simulations. Satellites provide estimates on eruption rate and altitude.

Line 62: ....climate impact. Do you have a reference?

Line 63: Maybe, but due to the non-linear nature of the aerosol formation your simulations miss the early phase of the eruption. The may lead to different particle sizes and aerosol concentration.

Line 72-73: Add a reference for the dataset.

2.2 Model description: Information on the vertical grid are important here.

Table 1: Very misleading. Starting with 'Simulation name' and 'Vertical resolution' this could also be the vertical resolution of the model. What means single column? Should be in the model 0.95 x 1.25 as well.

Fig 1: b) shows the vertical integral, the burden, of SO2?

Line 165: SO2 does not disappear.

Line 184 and line 187-188: This argument is valid if your volcanic cloud stays at the same altitude (in meters). But from Fig 6 you can see a different behavior of the cloud. So the sulfur evolution cannot be deduced from Fig 1S alone. Microphysical processes are also important. You may have different particle size, different sedimentation, and different altitude, all of which affect the lifetime.

Line 189: The wording is difficult here. In principle, a model simulates one out of many possible weather/climate conditions. So, a model has its own reality. As you nudge the model, the results should be close to reality. On the other hand, a strongly nudged model cannot feedback and change the transport of the volcanic cloud caused by the heating inside the cloud due the absorption.

Figure 3: The difference between the solid and the dashed line is difficult to understand for the quick reader. My first impression was that the dashed line shows the total SO2 (volcanic plus background) and the solid the volcanic SO2 only.

Figure 3: Do you show an average over a specific region or the max values or another mean?

Line 194-195: I don't agree with this statement. As said before, in S21-3D the model misses the initial phase of the sulfur evolution and you get different results. A nudged model should simulate the transport well in case your timing and altitude of the injection is correct.

Line 197: Better first weeks.

Figure 4: Units? Do you show Tg (SO2) and Tg (SO4)? The same unit should be used, which is Tg (S).

Line 219: I don't understand the averaging of the 5th column. Do you show a global average? A zonal mean is an average over longitudes, so where is the difference to the other figures? Ahh, OK, the caption says NH average. Please, change the sentence and say NH average in the text as well.

Figure 5: Do you show the vertical integral, the burden here? Why do you subtract SO2 when you show SO4?

Line 230: This differs between the months. In July M16 seems to be the best.

Line 239: OK, but the altitude is substantial. I would say in the S21 simulations, especially S21-3D, the aerosol is at a too high altitude.

Line 249: Please, explain this with a few more words.

Line 257: Agree, but your aerosol in not at the right altitude. Timing of the eruption is important as well.

Figure 6: Please add the average area, e.g. zonal mean.

Fig 6e, are the colours correct? S21-3d show the smallest values and highest altitude.

Fig 7: global mean?

Line 270: All three simulation reproduce the observations. M16 has a larger bias, an error of roughly 25%. This is a bit, but it could be much worse.

Line 271 to 282: This last paragraph is right and important. However, your results are a bit more complex. I cannot agree that the S21 simulations are in general better than M16. S21-1D is better, but S21-3D simulates the volcanic cloud in a too high altitude. This impacts all results, especially lifetime and forcing.

Line 275: The limits are more complex. You do not mention microphysical processes. They are extremely important and highly non-linear. The sulfur evolution depends on your emission profile, emission rate, and on the timing of the eruption. It depends also on the microphysical scheme (Tilmes et al, 2023; Laakso et al 2022). You have to broaden your discussion and you should also discuss your results more critically.

Specific comments:

Laakso, Anton, Ulrike Niemeier, Daniele Visioni, Simone Tilmes and Harry Kokkola, Dependency of the impacts of geoengineering on the stratospheric sulfur injection strategy part 1: Intercomparison of modal and sectional aerosol module, Atmos. Chem. Phys., 22, 93–118, https://doi.org/10.5194/acp-22-93-2022, 2022

Tilmes, S., Mills, M. J., Zhu, Y., Bardeen, C. G., Vitt, F., Yu, P., Fillmore, D., Liu, X., Toon, B., and Deshler, T.: Description and performance of a sectional aerosol microphysical model in the Community Earth System Model (CESM2), Geosci. Model Dev., 16, 6087–6125, https://doi.org/10.5194/gmd-16-6087-2023, 2023.