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Project title: **"Implications and Risks of Engineering Solar Radiation to Limit Climate Change (IMPLICC)"**

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1 General remarks

We analyse simulations of the impact of climate engineering (CE) techniques on the climate in the context of GeoMIP, a CMIP6-endorsed project. Our simulations contribute to several GeoMIP experiments and were used in Chapter 6 of the World Meteorological Organization (WMO) Ozone Assessment 2022 and 2026 (Haywood and Tilmes, 2022). CE is a controversial topic. Nevertheless, the knowledge gained from the simulations in this project has attracted significant media interest (ARTE, ZDF, Stern, MPG podcast).

The project's main objective is to significantly increase knowledge of the feasibility and implications of CE options. One of the techniques discussed is the injection of sulphur into the stratosphere, also known as stratospheric aerosol intervention (SAI). This technique requires an in-depth understanding of the microphysical evolution of sulphur and the transport and distribution of sulphate particles. Simulations of sulphur's microphysical evolution are performed using MAECHAM5-HAM. Our work with this model has led to a model intercomparison which is currently ongoing as part of the ESA STATISTICS project. The aim is to improve our understanding of particle formation after tropical volcanic eruptions, with a particular focus on smaller eruptions. This is important for SAI studies because volcanic eruptions are the only natural analogue for evaluating the model, and small eruptions are a better analogue than large ones, such as the eruption of Mt. Pinatubo in 1991. Recently, we investigated the question of a lower limit for detecting sulphur from satellites (Lange et al., 2025). A small amount of sulphur was injected at various locations over the course of a year in ECHAM5-HAM. The output was then used to determine whether satellites could detect these small amounts, with the aim of establishing a lower detection limit (Lange et al., 2026).

2 Formation of small sulphate particles after a tropical eruption

A study by Wrana et al. (2023) revealed complex changes in particle size following the 2019 volcanic eruptions of Raikoke and Ulawun. They observed a reduction in particle size following the Ulawun eruption, which occurred at an altitude of 18 km and lasted several months. The model also simulated this reduction in particle size (second row of the figure), but this only lasted for two months. The reason for this discrepancy is unclear. Therefore, a model intercomparison was initiated within the STATISTICS project. One outcome was the identification of the crucial role of nucleation parameterisation in the formation of small particles.

Figure 1 shows the results of simulations performed using ECHAM-HAM with two different parameterisations. Vehkamäki et al. (2002) developed the parameterisation that is used in many aerosol microphysical models. Määttänen et al. (2018) updated this parameterisation to cover a wider range of parameters (including very low temperatures) and incorporated particle collision (i.e. kinetic or barrierless nucleation) as a distinct nucleation process in the event of high sulphur loads. These processes are important when simulating the evolution of a volcanic cloud after an eruption, since the lower stratosphere is very cold. The Määttänen et al. (2018) parameterisation produces smaller particles in the tropical lower stratosphere in August and less particle growth in September.

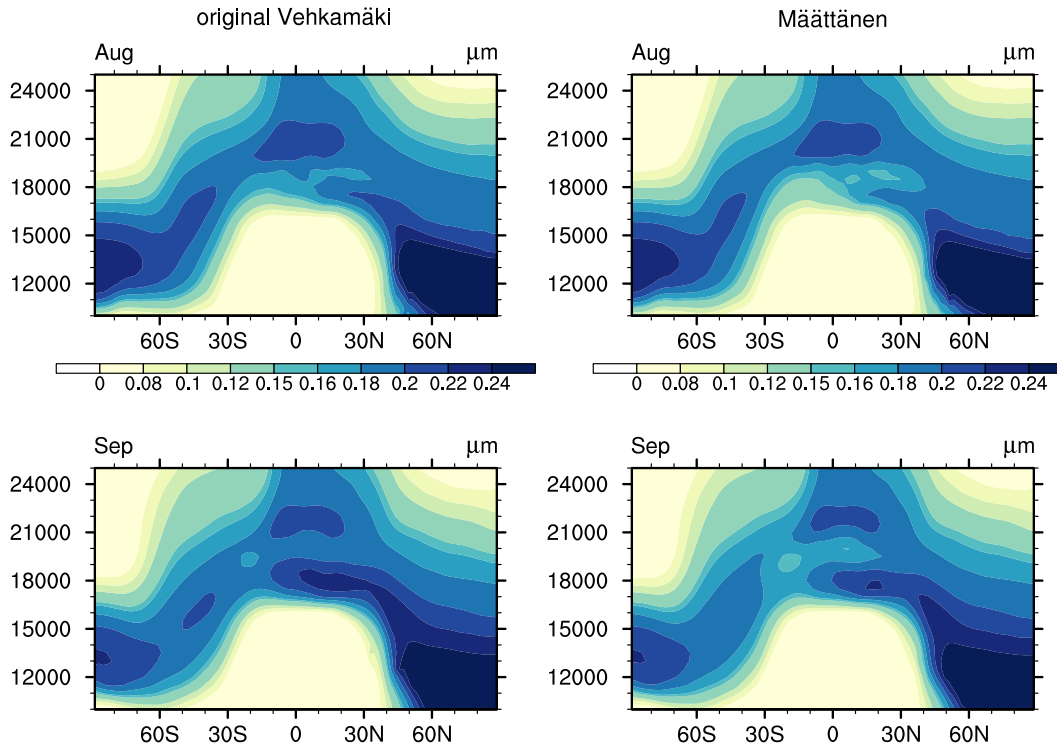


Figure 1: Zonal means of the vertical structure [m] of monthly averaged effective radius (μm) simulated with two different nucleation parameterizations within ECHAM-HAM. Left: Nucleation parameterization after Vehkamäki et al. (2002). Right: after Määttänen et al. (2018).

3 Prescribe optical properties of sulphur aerosols in ICON

Similar to the way in which the sulphate aerosols of a volcanic eruption are prescribed in MPI-ESM, we have also incorporated this into ICON. ICON requires more detailed information, including not only the aerosol optical depth and effective radius, but also the single scattering albedo and asymmetry. The number of bands for radiation also had to be increased. Therefore, preparing the output from ECHAM5-HAM is more demanding and requires more computation time, as the required output must be prepared in several simulations.

References

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