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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

The analysis of simulations of the impact of climate engineering (CE) techniques on the climate are performed in the context of GeoMIP, an endorsed CMIP6 project. Our simulations are contributions to several GeoMIP experiments and have been used for Chapter 6 of the WMO Ozone Assessment 2022 (Haywood, Tilmes, 2022). CE is a controversial topic. However, the knowledge gained from the simulations in this project is attracting wide interest in the media (ARTE, ZDF, Stern, MPG podcast).

The overall objective of the project is to significantly increase the level of knowledge on the feasibility and implications of CE options. One of the discussed techniques is the injection of sulfur into the stratosphere, also known as stratospheric aerosol intervention (SAI). This technique requires detailed knowledge of the microphysical evolution of sulfur and the transport and distribution of sulfate particles. Simulations of the aerosol microphysical evolution of sulfur are still performed using MAECHAM5-HAM. Work with this model within this account 550 has led to a model intercomparison currently ongoing under the ESA project STATISTICS. We are trying to better understand particle formation after tropical volcanic eruptions. This is important for SAI studies because volcanic eruptions are the only natural analogue for evaluating the model. Recently, we investigated the question of a lower limit for detecting sulfur from satellites (Lange et al., 2025).

2 Detecting SAI from satellite

Studies of SAI and its climate impact are only performed computationally.Therefore, a satellite retrieval study used aerosol optical properties from MAECHAM5-HAM simulations instead of real satellite data. SAI could probably be observed, for example, with satellite solar occultation instruments like SAGE III/ISS. The aim of the study is to analyze, using MAECHAM5-HAM simulations as well as transmission calculations and stratospheric aerosol extinction profile retrievals with the radiative transfer program SCIATRAN, whether it is possible to detect the formed stratospheric aerosols from continuous emissions of 1 and 2 Tg S/y (sulfur per year) with the currently active satellite solar occultation instruments, taking into account an error estimate that is as realistic as possible. Assuming these smaller amounts of sulfur are detectable, it is reasonable to conclude that larger amounts would also be detectable.

The basic idea is that the artificial aerosol enhancement is observable in a certain altitude range, if the background profile (i.e. MAECHAM5-HAM simulation results for the background (0 Tg S/y)) is outside the error range of the retrieved aerosol extinction profiles of 1 and 2 Tg S/y. The results of the study show that the stratospheric aerosols formed from continuous emissions of 1 and 2 Tg S/y can be detected in the quasi-steady-state phase. To examine whether the signal can be distinguished from natural variability under nearly background conditions, SAGE II data from 2002 to 2004 were analyzed. The geoengineering signal is considered detectable if the corresponding SAOD is outside the 2 σ range of the natural variability.

For the quasi-steady-state phase with 1 and 2 Tg S/y, the SAOD values lie outside the 2 σ limit. This means that the emissions, i.e. the stratospheric aerosols formed, can also be detected taking into account an realistic measure of the natural variability. In contrast, the SAOD values in the first month of the initial phase with 1 Tg S/y are within the range of natural variability, so at this point it is probably

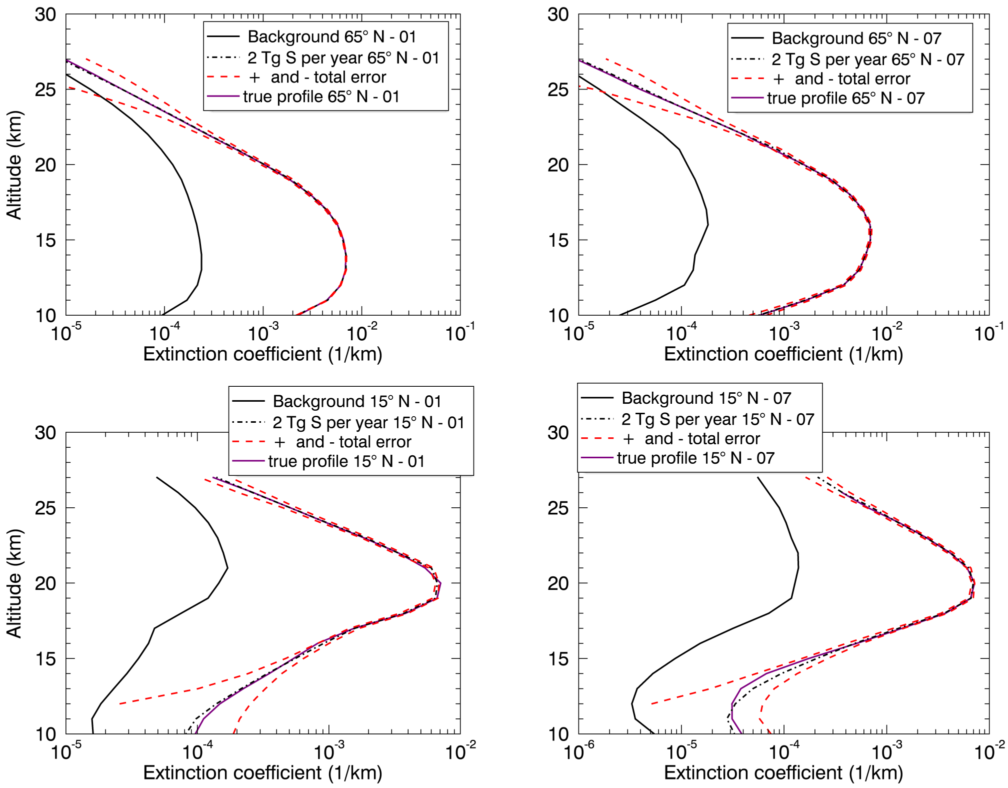

Figure 1: Retrieved aerosol extinction profiles at 520 nm for 2 Tg S/y, January (left column) and July (right column) for the quasi steady-state phase including total errors, background profiles (520 nm) and true profiles (520 nm) (ECHAM simulation results). Latitudes: 65 ° N (upper panels) and 15 ° N (middle panels) (From Lange et al., 2025).

not possible to distinguish the geoengineering signal from the natural variability.

It can be concluded that considering the measurement errors, the natural variability, and the assumptions in the simulations with MAECHAM5-HAM and SCIATRAN, it is very likely that the formed stratospheric aerosols, from the emissions of 1 and 2 Tg S/y, can be observed in the quasi steady-state phase over all latitudes and months considered here. In the first month of the initial phase, the signal of the emission of 1 Tg S/y cannot be distinguished from the natural variability, which is why the detection of the formed stratospheric aerosols as geoengineering signal is probably not possible. Accordingly, it can be assumed that smaller emission rates cannot be detected as geoengineering signals during the first month of the geoengineering experiment.

References

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