Projektaccount: **550** and **695**, Period: **1.1.2021 - 31.8.2021**

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

Authors: **Ulrike Niemeier (PI, 550, 695)**
(Max Planck Institute for Meteorology, Bundesstr.53, 20146 Hamburg, Germany, ulrike.niemeier@mpimet.mpg.de)

1 General remarks

The analysis of simulations on the impact of climate engineering (CE) techniques on the climate started in the EU Project IMPLICC and is currently being continued in the framework of GeoMIP, an endorsed CMIP6 project. The described simulations are contributions to the GeoMIP experiments G6sulfur and G6solar. The simulations for this project have been performed under project account bm0550, while data processing and storage was mostly done within the data project bm0695. Therefore, this report combines both projects.

The overall goal of the project is to significantly increase the level of knowledge about the feasibility and implications of CE options. One of the assumed techniques, the injection of sulfur into the stratosphere, which is also known as stratospheric aerosol intervention (SAI), requires detailed knowledge about the microphysical evolution of sulfur and the transport and distribution of the sulfate particles (Niemeier and Tilmes, 2017). Therefore, CE simulations on SAI were performed with a middle atmosphere version of the General Circulation Model (GCM) ECHAM5 (T63L95) that is interactively coupled to a modified version of the aerosol microphysical model HAM. The GeoMIP simulations have been performed with MPI-ESM.

2 Injection of sulfate into the stratosphere – Impact on surface temperature in different models

Different ESMs calculated surface cooling and radiative forcing within the GeoMIP Phase 6 experiment G6sulfur (Kravitz et al, 2015). One of the, MPI-ESM, was performed on DKRZ computers. G6sulfur aimed at lowering global mean surface temperatures from a high emission scenario (SSP5-8.5) to a medium emission scenario (SSP2-4.5) by increasing the simulated stratospheric AOD. In models with an interactive sulfur cycle and stratospheric aerosol microphysics this is done by simulating the injection of SO2 between 10/degree N and 10/degree S between 18 and 20 km, whereas in MPI-ESM this is done by imposing a sulfate distribution calculated offline (Visioni et al, 2021 for more details). MPI-ESM prescribes the AOD of sulfate aerosols, which were calculated with an aerosol micro-physical model, MAECHAM5-HAM (Niemeier et al, 2020)

Results of the SAI simulations differ clearly between the models. The different ESMs require very different amounts of sulfur injections of the course of the simulation (Fig. 1, bottom). The sulfur amount depends on the climate sensitivity of the model, the simulated temperature difference between the two scenarios, but also on details of the aerosol microphysics. The models simulate different spatial distribution and also different size distribution of the aerosols. Both results in different scattering of solar radiation and different absorption of terrestrial radiation and, consequently, on different surface cooling for a certain amount of injected sulfur. Fig 1 (top) shows the differences in surface cooling per injected sulfur (left) and the amount of sulfur required to cool the global surface temperature by 1K between the different models. The variations of the surface cooling are especially large for small injection amounts and tend

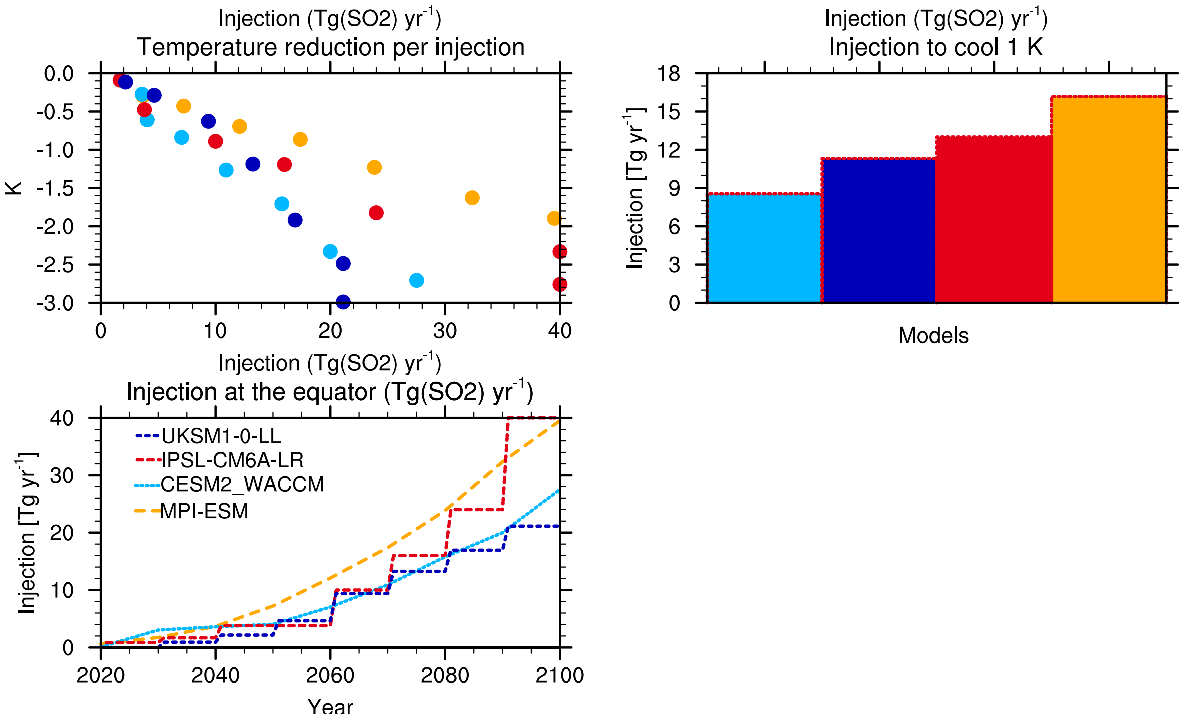

Figure 1: Different EMSs calculated surface cooling within the GeoMIP Phase 6 experiment G6sulfur (Kravitz et al, 2015). G6sulfur aimed at lowering global mean surface temperatures from a high emission scenario (SSP5-8.5) to a medium emission scenario (SSP2-4.5) by increasing the simulated stratospheric AOD.
A) Temperature reduction in relation to injection rate of SO2 into the stratosphere.
B) Amount of SO2 that needs to be injected to cool the global average earth surface temperature by 1 K.
C) Amount of SO2 injected per year (after Visioni et al, 2021).

to diverge for larger injection amounts (Visioni et al, 2020). The relationship of temperature reduction to sulfur injection is almost linear for injection larger than 20 Tg (SO2). However, the results differ strongly between the models, which in turn, says the amount of sulfur needed to cool the global surface mean temperature by 1 K is still quite uncertain (Fig. 1, left).

References

Niemeier, U., Richter, J. H., and Tilmes, S. (2020): Differing responses of the QBO to SO2 injections in two global models, Atmos. Chem. Phys., 20, 8975-8987, https://doi.org/10.5194/acp-20-8975-2020

Niemeier, U. and Tilmes, S.: Sulfur injections for a cooler planet, Science, Vol. 357, Issue 6348, pp. pp 246-248, DOI: 10.1126/science.aan3317, 2017.

Niemeier, U. and Timmreck, C.: What is the limit of climate engineering by stratospheric injection of SO_2?, Atmos. Chem. Phys., 15(16), 9129-9141, doi:10.5194/acp-15-9129-2015, 2015.

Vattioni, S., Weisenstein, D., Keith, D., Feinberg, A., Peter, T., and Stenke, A.: Exploring accumulation-mode H2SO4 versus SO2 stratospheric sulfate geoengineering in a sectional aerosol-chemistry-climate model, Atmos. Chem. Phys., 19, 4877-4897, https://doi.org/10.5194/acp-19-4877-2019, 2019.

Visioni, D., MacMartin, D. G., Kravitz, B., Boucher, O., Jones, A., Lurton, T., Martine, M., Mills, M. J., Nabat, P., Niemeier, U., Séférian, R., and Tilmes, S.: Identifying the sources of uncertainty in climate model simulations of solar radiation modification with the G6sulfur and G6solar Geoengineering Model Intercomparison Project (GeoMIP) simulations, Atmos. Chem. Phys., 21, 10039–10063, https://doi.org/10.5194/acp-21-10039-2021, 2021.