Projektaccount: **550** and **695**

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

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

Period: **1.1.2019 - 31.12.2019**

The analysis of simulations on the impact of climate engineering (CE) techniques on the climate started in the EU Project IMPLICC (ended Sept 2012) and is currently being continued within the project CELARIT of the SPP (1689) of the German Science Foundation that runs in the second phase until summer 2019. The CMIP6 endorsed project GeoMI is independent and will continue in the next years.

1 Scientific accomplishments

The overall goal of the project is to significantly increase the level of knowledge about the feasibility and implications of climate engineering (CE) options. Among these possibilities, a deliberate manipulation of the radiative budget of the Earth may allow a counterbalancing of the effects of continued greenhouse gas emissions on global temperature, but may also result in undesirable side effects. A complex climate model and a model which includes aerosol microphysics are used to quantify the effectiveness and side effects of such CE concepts. One of the assumed techniques, the injection of sulfur into the stratosphere (stratospheric aerosol manipulation, SAM), requires detailed knowledge about the microphysical evolution of sulfur and the transport and distribution of the particle (Niemeier and Tilmes, 2017). The studies were performed with a middle atmosphere version of the General Circulation Model (GCM) ECHAM5 that is interactively coupled to a modified version of the aerosol microphysical model HAM.

1.1 Injection of sulfate into the stratosphere – impact impact of injection strategy and model resolution of efficiency

The impact of SAM on climate and stratospheric dynamics is caused by aerosol radiation interactions, the scattering of solar radiation and absorption of infrared radiation. The resulting aerosol radiative forcing depends on sulfur evolution: the chemical transformation of sulfur dioxide into the aerosol phase, and the resulting particle size; but also on stratospheric dynamics and sink processes. Niemeier and Timmreck (2015) could show that the efficiency of the injection and, thus, the cooling at the surface, decreases exponentially per injected unit when increasing the injection rate (orange line in Figure 1, left). Increasing the injection rate increases the particle size and larger particles scatter less. Niemeier and Schmidt (2017) used the same model but with 90 levels instead of 47 levels. This allowed to generate a quasi biennial oscillation (QBO) in the tropical stratosphere. The heating of the stratospheric aerosol layer impacts the QBO. The phase of the oscillation slows down and shuts of for injections of 8 Tg(S)/yr or higher. This impact of the sulfate heating on the QBO decreased the efficiency given in Niemeier and Timmreck (2015). The TOA forcing gained per a certain amount of sulfur injection gets lower (Figure 1 left, blue line). We have also shown that the assumption, the efficiency of the injection increases with increasing injection altitude might not be valid for stronger injection rates (red curve, Figure 1 left). The velocity of the zonal wind, the jet in the tropical stratosphere, gets stronger with higher injection altitude and increased injection rate. This increases the confinement of the aerosols in the tropics and reduces the impact of the aerosol layer in the extratropics. The consequence is a lower TOA forcing than when injecting at lower altitude.

This findings can also be seen in the sulfate burden, the vertical integral of the sulfur concentration, of different simulation with an injection rate of 10 Tg (S)/yr in Figure 1 (right). The simulation with injection at 30 hPa (red line) show much stronger burden in the tropics. This results in larger particles which scatter less. This reduces the forcing in the extratropics compared to the lower injection altitude, even the burden is partly higher.

If changing the amount of vertical levels has such a clear impact, it may not wonder that other models show very different results. Several results of model inter-comparison projects (GeoMIP, VolMIP, ISA-MIP) show different sulfur evolution pathways and transport which result in a large inter-model spread in the simulated radiative forcing and thus the surface cooling effect. In order to better understand the different results, we compare in detail results of ECHAM5-HAM and WACCM (Richter et al, 2017) in a close collaboration with NCAR scientist Simone Tilmes and Yaga Richter.

One outcome of the study was a set of simulations with ECHAM5-HAM with increased horizontal resolution. ECHAM-HAM in T42 resolution needs four times higher injection rates to show a similar impact on the QBO than WACCM. The comparison was done with simulations of very different horizontal resolution. To get closer to the horizontal resolution of WACCM, we performed a series of simulations with T63 resolution instead of T42. The results is given in the dashed green line in both figures. T63 results in a higher efficiency of the forcing compared to all T42 simulations. The burden is higher at all latitudes, mostly because of a better representation of sedimentation processes in the T63 resolution.

This T63 simulations with different injection rates are the base for the GeoMIP G6_sulfur experiments where we prescribe the aerosol optical properties in MPI-ESM. The optical properties are calculated in the described single ECHAM-HAM simulations.

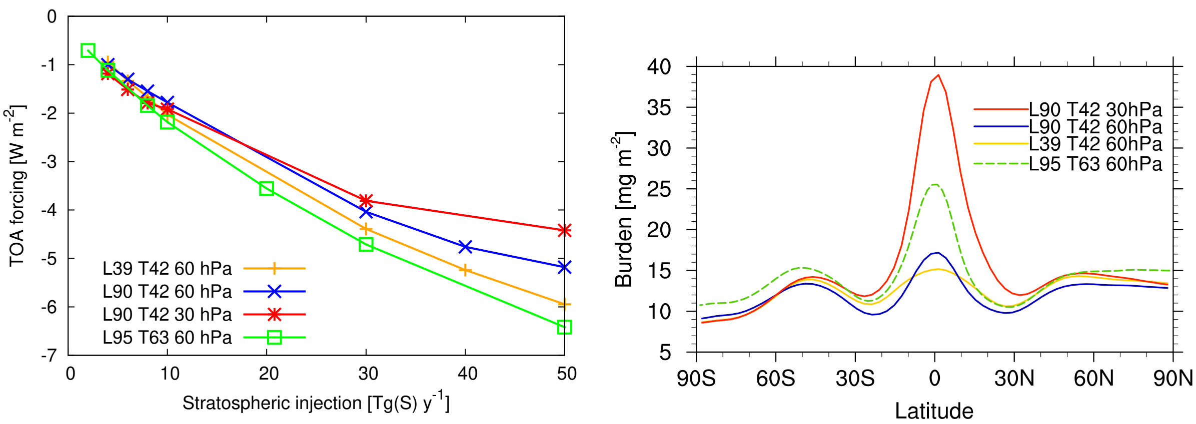

Figure 1: Left: Top of the atmosphere (TOA) forcing imbalance for different injection rates and different simulations: T42 L39 resolution (orange) without internally generated QBO, T42 L90 resolution with internally generated QBO with injection at 60 hPa (blue) and 30 hPa (red), and T63 L95 resolution (green). Right: Zonal mean of the vertically integrated sulfur concentration (burden) for the same set of simulations but all the an injection rate of 10 Tg(S)/yr.

References

Niemeier, Ulrike and Claudia Timmreck: What is the limit of climate engineering by stratospheric injection of SO_2?, ACP, 15(16), 9129-9141, doi:10.5194/acp-15-9129-2015, 2015.

Niemeier, Ulrike and Hauke Schmidt: Changing transport processes in the stratosphere by radiative heating of sulfate aerosols, Atmos. Chem. Phys., 17, 14871-14886, https://doi.org/10.5194/acp-17-14871-2017, 2017

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

Richter, J. H., S. Tilmes, M. Mills, J. Tribbia, B. Kravitz, D. MacMartin, F. Vitt, J. F. Lamarque, 2017: “Stratospheric dynamic response and ozone feedback in the presence of SO2 injections”, J. Geoph. Res., 122, 12,557–12,573. Doi: 10.1002/2017JD026912