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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, the injection of sulfur into the stratosphere, which is also known as stratospheric aerosol intervention (SAI), requires detailed knowledge on the microphysical evolution of sulfur and the transport and distribution of the sulfate particles (Niemeier and Tilmes, 2017). Many simulations for the aerosol microphysical evolution of sulfur are still done with ECHAM5-HAM, a relatively old, but well functioning model. For dynamical issues we invest time into the development of ICON-XPP, a NWP version of ICON, which will be used for the next CMIP simulations. We tuned the model in R2B4 resolution with the focus on stratospheric transport. This lead to a very successfully comparison to observations on the transport of water vapor after the Hunga Tonga eruption in 2022 (Niemeier et al, 2023).

2 ICON-XPP: Simulations for stratospheric dynamics on CPU and GPU

The current goal of our work is to determine the role of model resolution for the transport of species. The transport of the initial gas and aerosols in the stratosphere changes their concentrations and influences the resulting particle size evolution. The particle size determines the radiative heating of the aerosols which impacts the transport of the aerosols. This feedback is important for understanding the rather large differences between model results. To disentangle the microphysical particle size evolution of aerosols from the impact of transport, we started simulations with a passive tracer emitted in the model (SF6).

To achieve our goal we need a model tuned in different resolutions. So we started to tune ICON-XPP in R2B6 resolution as well. This took most of our time this year. We wanted to run this resolution on GPUs, which had not been done on Levante before. With the help of MPI-M, DWD and ETH we ran a version that was also used at CSCS in Switzerland. However, the performance of the model was not good and we had to switch back to the CPU version. Just recently we got some updates of the model code. We hope that the new version will then perform better on GPUs.

The tuning of the troposphere and the stratosphere resulted in a reasonable performance of the stratospheric dynamics. The model simulates the QBO in R2B4 resolution not perfectly, but quite well (Fig 1, left). In R2B6 the westerly winds are very weak and descend down below an altitude of 30 hPa. Instead, strong easterly winds develop between 100 and 70 hPa (Fig 1. right). Unfortunately this has an impact on the tracer transport, since the meridional transport out of the tropics depends on the QBO phase. A detailed analysis and further simulations of the transport processes are still in progress.

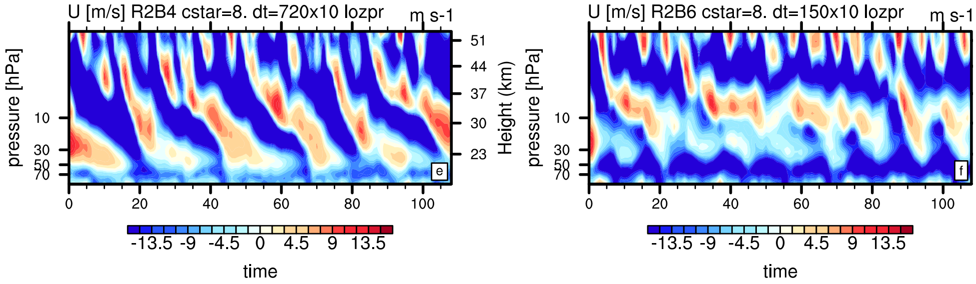

Figure 1: Zonal and monthly averaged zonal winds in the inner tropics of the quasi-biennial oscillation over 110 months simulated with ICON-XPP. Left: Results from R2B4 (180 km) resolution. Right: Results from R2B6 (40 km) horizontal grid resolution. Both simulations use a vertical grid with 130 levels and max 500m up to 35 km altitude.

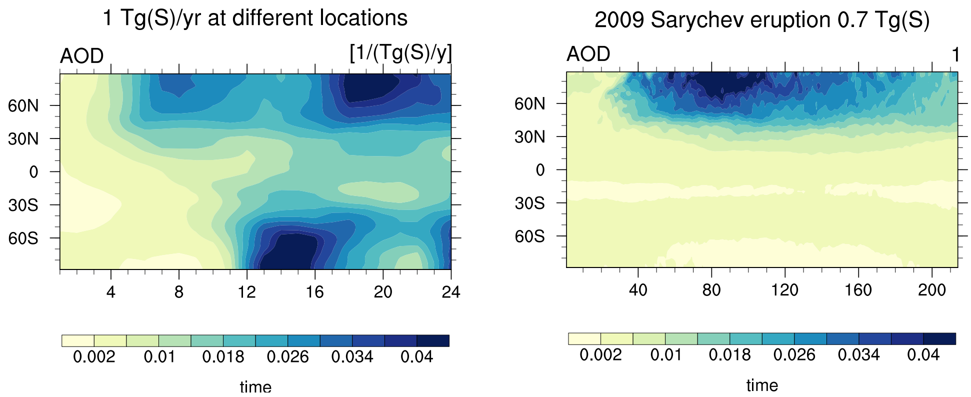

Figure 2: Aerosol optical depths (AOD) of sulfate simulated with ECHAM-HAM. Left: 1 Tg/yr sulfur was injected at different locations during the year. Right 0.4 Tg (S) was injected within 12 hours in a simulation of the 2009 Sarychen eruption. The simlation of the Sarychev eruption can be compared to satellite observations.

3 ECHAM-HAM: Aerosol microphysics and climate engineering

We used ECHAM-HAM to simulate small stratospheric sulfate injections. The question behind this is the detectability of small amounts of sulfur by satellite. Therefore, we performed simulations with sulfur injections of one and two Tg(S)/yr. The results are used within the satellite retieval to test the detectability of the sulfur. The lowest values were detected after an injection of 0.1 Tg(S). This work continues with a simulation of injections at different locations during the year (Fig 2, left).

We also compare the ECHAM-HAM results with satellite observations after small eruptions (Fig 2, right). The sulfur load in the stratosphere after these small eruptions is much closer to the situation in climate engineering simulations. This helps us to get a better understand the particle size evolution and the setup of the aerosol module for realistic particle size simulations.

References

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