Projektaccount: **550** and **695**, Period: **1.1.2023 - 31.12.2023**

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 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. Our simulations are contributions to different GeoMIP experiments and have been used for Chapter 6 of the WMO Ozone Assessment 2022 (Haywood, Tilmes, 2022). The topic is controversial discussed. However, the knowledge gained by our simulations gains wide interest in the media (ART, ZDF, Stern, MPG-Publications MAX). 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). Within the last year we intensified the use of ICON-NWP in the so called seamless version and contributed to the tuning efforts of DWD, especially with successfully tuning the stratosphere. In this project the focus is on stratospheric aerosol and their relation to stratospheric dynamical processes. Therefore, our focus has been on the performance of the stratospheric dynamics and transport transport processes.

# 2 Stratospheric dynamics within ICON-Seamless

The first attempt to test the performance of stratospheric dynamics of ICON-Seamless were quite disappointing. Even the vertical resolution of the model was strongly increased within the stratosphere, from 1000 to 1500 m down to 500 m, including an increase of the number of vertical levels from 90 to 120, there was no quasi-biennial oscillation (QBO) generated (Fig 1, left). Also the polar vertices were not on the right position. Both dynamical features are important for the simulation of a good transport of tracers in the stratosphere.

The efforts to tune the AMIP version of ICON-Seamless were done at DWD for the troposphere. Within this project we tuned the gravy wave drag. This parameterization follows Scinocca et al (2003) within ICON-Seamless. The two tuning variables 'gflux_$laun$' and 'C$^\star$ impact the Elisassen-Palm flux divergence and the dissipation of wave energy, thus, when and where the energy of waves is dumped within the model. Changing the wave dissipation, increasing C$^\star$, results in a colder mesosphere in winter because of the dissipation of wave energy.

Both tuning attempts, for the troposphere and the stratosphere, resulted in much better results of stratospheric dynamics. The model simulates the QBO quite well, with a good phase, but slightly weak zonal velocities (Fig 1, right). The biases of the polar vortexes are in a range of $\pm$

Figure 1: Zonally averaged zonal winds within the inner tropics of the quasi-biennial oscillation. Left: Zonal winds of the non-tuned version of ICON-Seamless. Right: QBO after tuning of stratosphere and troposphere.

16 m/s at an altitude of 50 hPa. This halves the bias if ICON-ESM, as published in Jungclaus et al (2021).

We further simulated the transport of water vapor after the Hunga Tonga Hunga Ha'apai eruption in January 2022 and compared it to MLS satellite observations. This work was done in strong cooperation with project 1093 (VolImpact). The results are currently in review (Niemeier et al, GRL, submitted, 2023)

## References

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.