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)"**

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 of the impact of climate engineering (CE) techniques on the climate started in the EU project IMPLICC and is currently continued 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 (ART, ZDF, Stern, MPG publications MAX). The simulations for this project were carried out under project account bm0550, while most of the data processing and storage was done under data project bm0695. Therefore, this report combines both projects.

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). During the last year we intensified the use of ICON-NWP in the so-called seamless version and contributed to the tuning efforts of the German Weather Service (DWD), in particular with the successfully tuning of the stratosphere. The focus of this project is on the stratospheric aerosol and its 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 attempts to test the stratospheric dynamics performance of ICON-Seamless were rather disappointing. Even though the vertical resolution of the model within the stratosphere was strongly increased, from 1000 to 1500 m down to 500 m, including an increase of the number of vertical levels from 90 to 130 levels, no quasi-biennial oscillation (QBO) was generated in the model (Fig 1, left). Also the polar vortexes were not in the correct position. Both dynamical features are important for the simulation of a good tracer transport in the stratosphere.

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

The tuning attempts of the troposphere and the stratosphere, resulted in much better results of the stratospheric dynamics. The model simulates the QBO quite well, with a good phase,

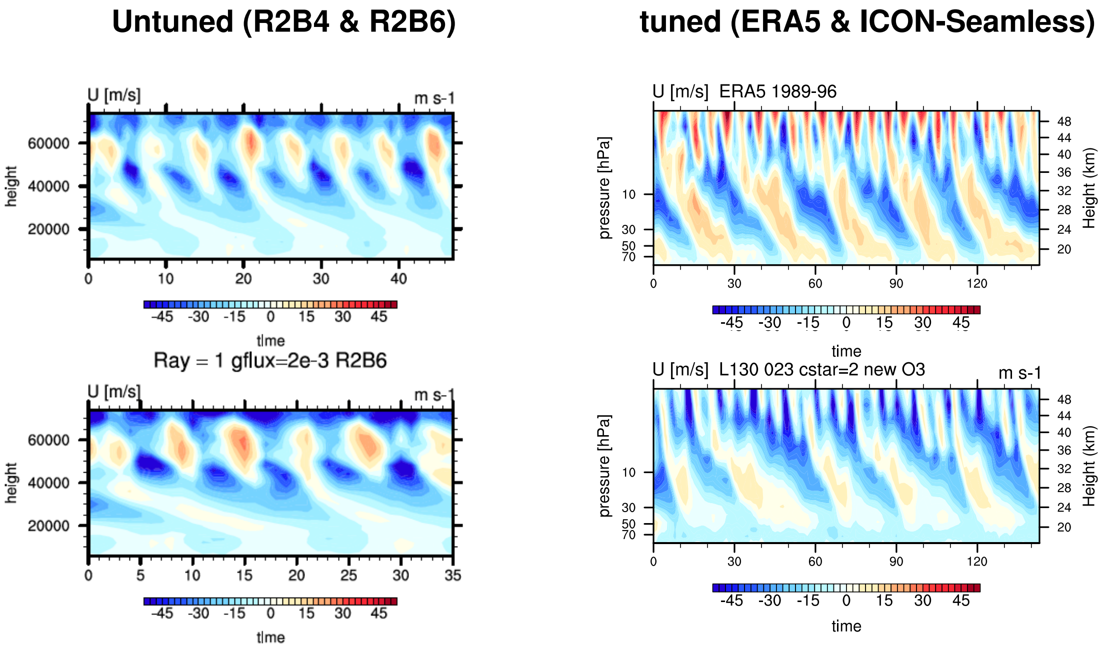

Figure 1: Zonally and monthly averaged zonal winds in the inner tropics of the quasi-biennial oscillation. Left: Zonal winds of the non-tuned version of ICON-Seamless for R2B4 (top) and R2B6 (bottom) resolution. Right: QBO of ERA5 data (top) and QBO in ICON-Seamless after the tuning of the stratospheric and tropospheric parameterizations. The x-axis shows months.

but slightly weak zonal velocities (Fig 1, right, bottom) compared to ERA5 (Fig.1 right, top) and the untuned version (Fig 1, left). The polar vortex biases are in the range of $\pm$ 16 m/s at an altitude of 50 hPa in both hemispheres. This is half the bias of ICON-ESM as published in Jungclaus et al. (2021).

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

References

Jungclaus, Johann H., et al. "The ICON earth system model version 1.0." Journal of Advances in Modeling Earth Systems 14.4 (2022): e2021MS002813.

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 et al, 2023. How the Hunga Tonga - Hunga Ha'apai water vapor plume impacts its transport through the stratosphere: Dynamical and radiative effects, GRL, submitted