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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 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 April 2018. 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.

2 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, requires detailed knowledge on the microphysical evolution of sulfur and the transport and distribution of the particle.

In a recent study, Niemeier and Timmreck (2015) raised the question 'What is the limit of climate engineering by stratospheric injection of SO_2?'. The study was motivated by the fact that the efficiency of SO_2 injections decreases with increasing injection rate. We added now another component to this study: the number of model levels was increased to 90, which allows the simulation of the QBO. Currently we determined the impact of the QBO on the transport of stratospheric sulfate.

2.1 Injection of sulfate into the stratosphere – impact on stratospheric dynamics

CE simulations 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.

The injection of sulfur into the stratosphere has a strong impact on the dynamics of the tropical stratosphere: the QBO frequency changes. The stratospheric sulfate not only scatters short wave radiation, which cools the earth surface, it also absorbs in the long wave. The consequent heating of the stratosphere induces an additional vertical motion in the stratosphere. If the warming gets strong enough, this vertical motions inhibits the QBO downward propagation. Additionally induces the thermal wind relation stronger westerly winds, which causes the strong westerly component in the lower stratosphere (Fig. 1).

Injecting 4 Mt(S)/y at 60 hPa shows a prolongation of the westerly phase in the lower stratosphere (70 to 25 hPa). Injecting 8 Mt(S)/y has the consequence of a complete shut down of the oscillation. In the lower stratosphere, between 50 hPa and 25 hPa a layer with constant westerly winds develop, accompanied by a layer of constant easterly winds above. This structure of the jets differs from a normal QBO also in the vertical extension of the jets. In an undisturbed QBO the westerly jet can extend throughout the stratosphere, similar for easterly jets. After the injection of sulfur the easterly shear is dominating.

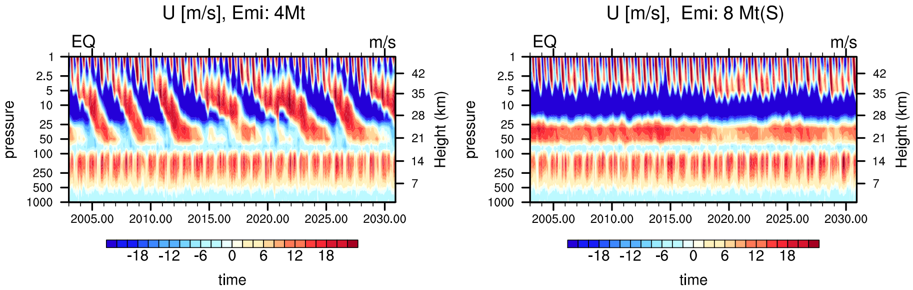

Figure 1: Zonal mean zonal wind velocity at the Equator for injection of 4 Mt(S)/yr and 8 Mt(S)/yr at a height of 60 hPa and 8 Mt(S)/yr at 30 hPa (bottom).

2.2 Injection of sulfate into the stratosphere – impact on transport

We try to understand the relation between dynamics and transport and how both is influenced by the changes in the QBO.

Figure 2 shows the normalized sulfate burden in a Hovmøller diagram (time against latitude). The data are normalized by dividing the injection rate. The blocking of the transport to the south pole is stronger when injecting 8 Mt/y than 4 Mt/y. With the stronger westerly jet in 8Mt60 compared to 4Mt60 the meridional transport decreases. This is indicated by slightly higher anomalies in the tropics and smaller ones around 30N.

Very obvious are the differences between the two injection heights: injecting at 30 hPa reduces meridional transport clearly compared to the 60 hPa cases. Injecting at higher levels causes a vertical expansion of the westerly wind zone and wind speed is highest between 25 hPa and 10 hPa (Fig. 1). The normalized concentrations in the tropics are high and meridional transport is reduced quite strongly. This reduces the cooling at the surface in the extra-tropics.

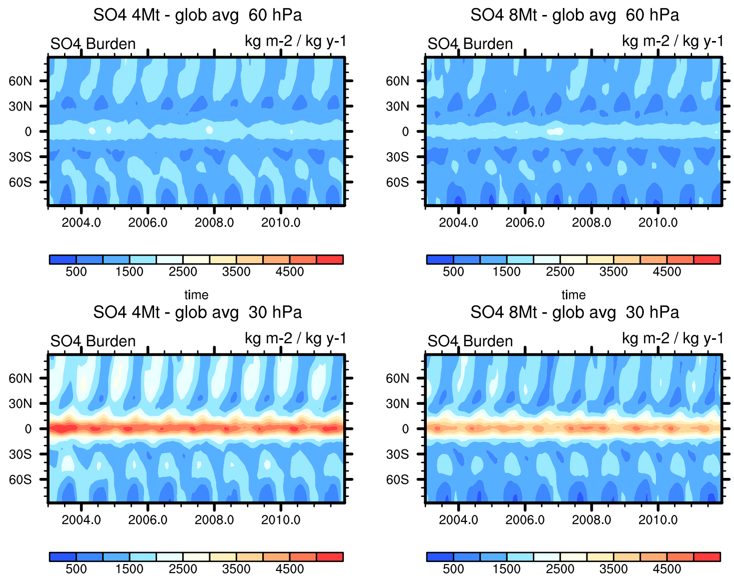

Figure 2: Hovmøller diagram of normalized zonally averaged monthly sulfate burden for injection rat of 4 Tg(S)/y (left) and 8 Tg(S)/y (right) and an injection height of 60 hPa (top) and 30 hPa (bottom). To normalize the data each field is divided by the injection rate.

References

Niemeier and Timmreck (2015): 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.