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Stratospheric changes caused by geoengineering applications: potential repercussions and uncertainties

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Anthropogenic greenhouse gas emissions tend to warm the global climate, calling for significant rapid emission reductions. As potential support measures various ideas for geoengineering are currently being discussed. The assessment of the possible manifold and as yet substantially unexplored repercussions of implementing geoengineering ideas to ameliorate climate change poses enormous challenges not least in the realm of aerosol-cloud-climate interactions. Sulphur aerosols cool the Earth's surface by reflecting short wave radiation. By increasing the amount of sulphur aerosols in the stratosphere, for example by sulphur dioxide injections, part of the anthropogenic climate warming might be compensated due to enhanced albedo. However, we are only at the beginning of understanding possible side effects. One such effect that such aerosol might have is the warming of the tropical tropopause and consequently the increase of the amount of stratospheric water vapour. Using the 2D AER Aerosol Model we calculated the aerosol distributions for yearly injections of 1, 2, 5 and 10 Mt sulphur into the lower tropical stratosphere.

The results serve as input for the 3D chemistry-climate model SOCOL, which allows calculating the aerosol effect on stratospheric temperatures and chemistry. In the injection region the continuously formed sulphuric acid condensates rapidly on sulphate aerosol, which eventually grow to such extent that they sediment down to the tropical tropopause region. The growth of the aerosol particles depends on non-linear processes: the more sulphur is emitted the faster the particles grow. As a consequence for the scenario with continuous sulphur injection of totally 10 Mt per year, only 6 Mt sulphur are in the stratosphere if equilibrium is reached. According to our model calculations this amount of sulphate aerosols leads to a net surface forcing of -3.4 W/m2, which is less then expected radiative forcing by doubling of carbon dioxide concentration. Hence, larger injections might be required than previously assumed. Rasch et al. (2008) showed that smaller particles would be advantageous in terms of cooling the surface. However, with a continuous injection of sulphur dioxide into to lower tropical stratosphere aerosol size distributions with mode radii larger than 0.5 microns are likely to form.

An additional complication is that the sedimenting particles tend to heat the tropical tropopause region and as a consequence the entry mixing ratio of water vapour increases. For the extreme scenario of 10 Mt/year injection SOCOL predicts an enhancement of the water vapour entry mixing ratio by more than 1 ppmv. This is predicted to have a significant impact on the radiative forcing and the total ozone, because of enhanced heterogeneous reactions and because the increased water vapour intensifies the hydrogen and chlorine catalysed ozone destruction cycles. The intense warming of the lower stratosphere further intensifies the catalytic ozone destruction cycles. Furthermore, the stratospheric circulation is predicted to change due to the strong heating of the lower stratosphere. As a consequence of the intensified meridional temperature gradient the polar vortices are strengthened with enhanced formation of polar stratospheric clouds and ozone depletion. The ozone loss due to changed stratospheric dynamic is four times larger than the ozone loss caused by the increase of aerosol surface for heterogeneous reactions, which would postpone the recovery of the ozone hole even more as already pointed out by Tilmes et al. [2008].

At the same time the uncertainties involved in the different modelling steps are tremendous. Model validation, by comparing model runs of the 1991 Mt. Pinatubo eruption with observations, reveals that the temperature increase in the lower stratosphere and the tropopause region is probably overestimated by SOCOL. Other CCMs show similar behaviour. This lets us conclude that with the present modelling tools we are not capable to reliably predict the changes in stratospheric climate following geoengineering applications.

Rasch, P. J. et al. (2008), Exploring the geoengineering of climate using stratospheric sulfate aerosols: The role of particle size, Geophysical Research Letters, 35 (2), L02,809.

Tilmes, S. et al. (2008), The sensitivity of polar ozone depletion to proposed geoengineering schemes, Science, 320 (5880), 1201–1204.