Model results of cirrus cloud modifications in a climate engineering framework.

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Keywords: cirrus, heterogenous freezing, climate engineering.

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Cirrus clouds are an important element of the climate system and they can have a large impact on the Earth's radiation budget. Recent observations of mid-latitude cirrus clouds forming at temperatures below -40°C suggest that they are primarily formed by homogeneous freezing (Mitchell et al., 2011). These clouds hence tend to mainly consist of numerous small ice crystals. However, if efficient ice nuclei are present, heterogeneous freezing will be favoured, due to the suppression of the required supersaturation with respect to ice (Kärcher and Lohmann, 2003).

Mitchell and Finnegan (2009) proposed a climate engineering technique exploiting this competition between homogeneous and heterogeneous freezing, in order to cool the global climate. The term climate engineering, or geoengineering, can be defined as intentionally interfering with the climate system in order to temporarily offset or reduce the increase in surface temperatures by global warming.

The idea is to inject ice nuclei into cirrus forming regions, then a small number of ice crystals would form heterogeneously and grow rapidly by vapour diffusion. The large ice crystals would gain large fall speeds. Sanderson et al. (2008) found that the ice fall speed from cirrus clouds strongly affect climate sensitivity. The cirrus cloud coverage, life cycle, optical depth and upper tropospheric water vapour amounts are dependent on the ice fall speed. Seeding the cirrus with an effective ice nuclei could outcompete any pre-existing natural ice nuclei for the water vapour. Larger ice crystals could form, leading to a fall out of the cloud and hence cloud removal. This facilitates for more outgoing longwave radiation (OLR) being able to escape the climate system. Targeting the highest and coldest cirrus would be the most effective at increasing the OLR.

As the upper tropospheric water vapour is exported to the lower troposphere, the water vapour greenhouse effect is reduced. The combination of water vapour and cirrus cloud reduction should combine to give a cooling to counteract the surface warming due to high CO_2 concentrations.

The suggested seeding material is bismuth tri-iodide (BiI_3) (Mitchell and Finnegan, 2009). It is non-toxic, relatively cheap and can be produced in aerosol form by combustion of BiI_3 alcohol solution. It has an atmospheric residence time of 1-2 weeks.

The idea of climate engineering of cirrus clouds is a new one and until now not tested in GCMs. We present results of model experiments investigating the potential of the proposed climate engineering method using the CAM5 global climate model and WRF-CHEM cloud resolving model. This is done in the framework of the Barahona and Nenes (2009) ice nucleation scheme. The cirrus cloud parametrisation takes both homogeneous and heterogeneous freezing into account, including their interaction, when calculating ice crystal number and size distribution.

Compared to other suggested climate engineering methods, the one explored here has the advantage of addressing the longwave radiation directly, which is the part of the spectrum that is being perturbed by anthropogenic greenhouse gases. This avoids some of the caveats of other proposed climate engineering methods, e.g. stratospheric sulphur injections or seeding of marine stratus clouds. I.e. solar radiation management techniques where the reflected solar radiation to space is increased. It should however be noted, that none of these methods tackle the ocean acidification issue.

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