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Statement on Geo-engineering (solar radiation management by the injection of aerosols into the stratosphere) for the reduction of climate change

Rising concerns about increased greenhouse gases have led to suggestions that various geo-engineering concepts be investigated as possible temporary "solutions" for moderating climate change[1]. In particular, solar radiation management (SRM) by the injection of aerosols into the stratosphere has been proposed as a technique to increase the reflectivity of the Earth's atmosphere, and thereby reduce the amount of solar energy passing through the atmosphere to the Earth's surface. This reduction of incoming solar energy could counteract the increase in surface temperatures caused by increasing abundances of greenhouse gases.

Early research has suggested that the deliberate injection of aerosols into the stratosphere would directly alter not only climate (as intended), but also stratospheric ozone levels and the climate in the lower stratosphere (unintended consequences). Ozone changes are of particular concern because ozone screens the Earth's surface from harmful solar ultraviolet radiation. The discovery of the Antarctic ozone hole in 1985 and subsequent scientific research demonstrated that the ozone layer has been endangered by massive emission of chlorine and bromine compounds into the atmosphere (the so-called ozone depleting substances – ODS, e. g., chlorofluorocarbons and halons) by human activities. This research revealed the important role of heterogeneous chemistry occurring on stratospheric aerosol and polar stratospheric clouds for ozone depletion in Polar Regions and at global scale (heterogeneous chemistry also occurs on surfaces of volcanic aerosols). The 1987 Montreal Protocol regulated the production and consumption of ODS, and the ozone layer should recover during this century.

The effects of aerosols in the stratosphere are broadly understood because of many years of research on the evolution of injections of volcanic plumes into the stratosphere. The Mt. Pinatubo eruption, in particular, which occurred in 1991 in a

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[1] Crutzen, P. J., Albedo enhancement by stratospheric sulfur injections: A contribution to resolve a policy dilemma?, *Climatic Change, 77*, 211-219, doi: 10.1007/s10584-006-9101-y, 2006

period of high ODS levels in the stratosphere, injected a sulfur dioxide cloud into the stratosphere that spread across the planet and led to reduced levels of ozone.

The Mt. Pinatubo eruption demonstrated the efficacy with which future deliberate injections of stratospheric aerosols could cool the Earth's surface. However, in spite of numerous studies of this massive injection, our ability to fully simulate the eruption remains relatively crude and a number of open questions about the eruption's impact in the stratosphere are still unanswered. For example, it is clear that while stratospheric chemistry was significantly altered in both hemispheres, only the Northern Hemisphere exhibited large stratospheric ozone losses. Current models of the stratosphere have been unable to simulate this basic difference in ozone losses. Hence, most current models are also not adequate to simulate the full effects of deliberately injected aerosols.

Closing this gap in modeling the effects of stratospheric aerosols from natural or anthropogenic sources will require a focused effort within the atmospheric modeling community. The Geo-engineering Model Intercomparison Project (GeoMIP) is a first effort to assess model simulations of geoengineering concepts such as direct aerosol injection. Continued observations of vertically highly resolved stratospheric composition and dynamics in the upper troposphere and lower stratosphere will be required to support a focused modeling effort by providing essential modeling constraints.

The understanding of aerosol and ozone changes gained from the Mt. Pinatubo eruption was a direct result of careful observations by ground stations, aircraft, balloons, satellites, and modeling studies conducted both before and after the eruption. Observations prior to an eruption provide a baseline for evaluating the ozone and climate perturbations caused by the volcanic aerosols. Large volcanic eruptions reaching the stratosphere are episodic on a multi-decadal timescale. Hence, maintaining global observational resources for ozone, aerosol and related atmospheric parameters is essential if we are to achieve a comprehensive understanding of the effects of aerosol injection into the stratosphere.

Based on the expertise of its members, the IO_3C recommends that research institutions around the world continue to support observational and modeling research related to stratospheric aerosol science in order to fill the known gaps in our current understanding and modeling skills and to respond fully to interest from the policy community in how stratospheric ozone may respond in an atmosphere changed by unexpected volcanic emissions or deliberate anthropogenic sulfur emissions.

Thanks to the Montreal Protocol, the levels of ODS are now declining in our atmosphere and it is expected that ozone levels will rebound back towards their natural levels in the coming few decades. However, the ozone layer is meanwhile very vulnerable, and deliberate injections of aerosols into the Earth's atmosphere have the potential to cause significant ozone reductions.