Stratospheric sulfate aerosols (geoengineering)

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Main articles: Geoengineering and Stratospheric sulfur aerosols

Military jets or tanker aircraft have been suggested to deliver aerosol precursors to the stratosphere, to reduce the amount of sunlight reaching the Earth's surface.[1]

The ability of **stratospheric sulfate aerosols** to create a global dimming effect has made them a possible candidate for use in geoengineering projects[2] to limit the effect and impact of climate change due to rising levels of greenhouse gases.[3] Delivery of precursor sulfide gases such as hydrogen sulfide (H_2S) by artillery, aircraft[1] and balloons has been proposed.[4]

Tom Wigley calculated the impact of injecting sulfate particles, or aerosols, every one to four years into the stratosphere in amounts equal to those lofted by the volcanic eruption of Mount Pinatubo in 1991,[5] but did not address the many technical and political challenges involved in potential geoengineering efforts.[6] If found to be economically, environmentally and technologically viable, such injections could provide a "grace period" of up to 20 years before major cutbacks in greenhouse gas emissions would be required, he concludes.

Direct delivery of precursors is proposed by Paul Crutzen.[1] This would typically be achieved using sulfide gases such as dimethyl sulfide, sulfur dioxide (SO_2), carbonyl sulfide, or hydrogen sulfide (H_2S).[4] These compounds would be delivered using artillery, aircraft (such as the high-flying F15C)[1] or balloons, and result in the formation of compounds with the sulfate anion SO_4^{2-}.[4]

According to estimates by the Council on Foreign Relations, "one kilogram of well placed sulfur in the stratosphere would roughly offset the warming effect of several hundred thousand kilograms of carbon dioxide."[7]

Contents

Aerosol formation

Primary aerosol formation, also known as homogeneous aerosol formation results when gaseous SO_2 combines with water to form aqueous sulfuric acid (H_2SO_4). This acidic liquid solution is in the form of a vapor and condenses onto particles of solid matter, either meteoritic in origin or from dust carried from the surface to the stratosphere. Secondary or heterogeneous aerosol formation occurs when H_2SO_4 vapor condenses onto existing aerosol particles. Existing aerosol particles or droplets also run into each other, creating larger particles or droplets in a process known as coagulation. The larger the particles or droplets, the shorter their residence time in the stratosphere and the less effective they are at scattering visible sunlight.

Arguments for the technique

The arguments in favour of this approach are:

- **Natural process**[8] — Stratospheric sulfur aerosols are created by existing atmospheric processes (especially volcanoes), the behaviour of which has been studied observationally.[9] Other, more speculative geoengineering schemes, do not have natural analogs (e.g. space sunshade).
- **Speed of action**[10] — Solar radiation management works quickly, in contrast to carbon sequestration projects such as carbon dioxide air capture which would take longer to have an effect, as the latter relies on removing large amounts of carbon dioxide before they become effective;[5] however, gaps in understanding of these

processes exist (e.g. the effect on stratospheric climate and on rainfall patterns)[11] and further research is needed.[12]

- **Technological feasibility** — In contrast to other geoengineering schemes, such as space sunshade, the technology required is pre-existing: chemical manufacturing, artillery shells, fighter aircraft, weather balloons, etc.[4]
- **Cost** — The low-tech nature of this approach has led commentators to suggest it will cost less than many other interventions. Costs cannot be derived in a wholly objective fashion, as pricing can only be roughly estimated at an early stage. However, an assessment reported in Newscientist suggests a relatively low cost.[13]. According to Paul Crutzen annual cost of enough stratospheric sulfur injections to counteract effects of doubling CO_2 concentrations would be $25–50 billion a year.[3]
- **Efficacy** — Most geoengineering schemes can only provide a limited intervention in the climate - one cannot reduce the temperature by more than a certain amount with each technique. New research by Lenton and Vaughan suggests that this technique may have a high radiative 'forcing potential'.[14]
- **Tipping points** — Application of this technique may prevent climate tipping elements, such as the loss of the Greenland ice sheet[15]

Efficacy problems

All geoengineering schemes have potential efficacy problems, due to the difficulty of modelling their impact and the inherently complex nature of the global climate system. Nevertheless, certain efficacy issues are specific to the use of this particular technique.

- **Lifespan of aerosols** — Tropospheric sulfur aerosols are short lived.[16] Delivery of particles into the lower stratosphere will typically ensure that they remain aloft only for a few weeks or months.[17] To ensure endurance, high-level delivery is needed, ensuring a typical endurance of several years. Further, sizing of particles is crucial to their endurance.[18]

- **Aerosol delivery** — Even discounting the challenges of lifting, there are still significant challenges in designing a delivery system that is capable of delivering the precursor gases in the right manner to encourage effective aerosol formation. For example, it is unclear whether aerial shells should be designed to leak slowly or burst suddenly. The size of aerosol particles is also crucial, and efforts must be made to ensure optimal delivery.[18]

- **Distribution** — It is logistically difficult to deliver aerosols evenly around the globe.

Challenges therefore exist in creating a network of delivery points sufficient to allow viable geoengineering from a limited number of launching sites.

Possible side effects

Geoengineering in general is a controversial technique, and carries problems and risks, such as weaponisation. However, certain problems are specific to, or more pronounced with this particular technique.[19]

- **Drought**, particularly monsoon failure in Asia and Africa is a major risk.[20]
- **Ozone depletion** is a potential side effect of sulfur aerosols;[21][22] and these concerns have been supported by modelling.[23]
- **Tarnishing of the sky**: Aerosols will noticeably affect the appearance of the sky, resulting in a potential "whitening" effect, and altered sunsets.[24]
- **Tropopause warming** and the humidification of the stratosphere.[22]
- **Effect on clouds**: Cloud formation may be affected, notably cirrus clouds and polar stratospheric clouds.
- **Effect on ecosystems**: The diffusion of sunlight may affect plant growth.[25][26][27]
- **Effect on solar energy**: Incident sunlight will be lower,[28] which may affect solar power systems both directly and disproportionately, especially in the case that such systems rely on direct radiation.[29]
- **Deposition effects**: Although predicted to be insignificant,[30] there is nevertheless a risk of direct environmental damage from falling particles.
- **Uneven effects**: Aerosols are reflective, making them more effective during the day. Greenhouse gases block outbound radiation at all times of day.[31]

Further, the delivery methods may cause significant problems, notably climate change[32] and possible ozone depletion[33] in the case of aircraft, and litter in the case of untethered balloons.

Delivery methods

Various techniques have been proposed for delivering the aerosol precursor gases (H_2S and SO_2).[3] The required altitude to enter the stratosphere is the height of the tropopause, which varies from 11 km (6.8 miles/36,000 feet) at the poles to 17 km (11 miles/58,000 feet) at the equator.

- **Aircraft** such as the F15-C variant of the F-15 Eagle have the necessary flight ceiling, but limited payload. Military tanker aircraft such as the KC-135 Stratotanker and KC-10 Extender also have the necessary ceiling and have greater payload.[1]
- Modified **Artillery** might have the necessary capability,[34] but requires a polluting and expensive gunpowder charge to loft the payload.
- **High-altitude balloons** can be used to lift precursor gases, in tanks, bladders or in the balloons' envelope. Balloons can also be used to lift pipes and hoses, but no moored balloon has ever been deployed to the necessary altitude.[*citation needed*]

See also

- Weather Modification Operations and Research Board

Further reading

- Crutzen, P. J. (2006). "Albedo Enhancement by Stratospheric Sulfur Injections: A Contribution to Resolve a Policy Dilemma?" (http://www.springerlink.com/content/t1vn75m458373h63/fulltext.pdf) . *Climatic Change* **77**: 211–220. doi:10.1007/s10584-006-9101-y (http://dx.doi.org/10.1007%2Fs10584-006-9101-y) . http://www.springerlink.com/content/t1vn75m458373h63/fulltext.pdf.

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External links

- Tropospheric Aerosol Program (http://www.tap.bnl.gov/) , United States Department of Energy Atmospheric Science Program (ASP)
- What can we do about climate change? (http://www.tos.org/oceanography/issues/issue_archive/issue_pdfs/5_2/5.2_revelle.pdf) , Oceanography magazine
- Global Warming and Ice Ages: Prospects for Physics-Based Modulation of Global Change (http://www.osti.gov/accomplishments/documents/fullText/ACC0229.pdf) , Lawrence Livermore National Laboratory
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- Geo-Engineering Climate Change with Sulfate Aerosols (http://www.ucar.edu/governance/meetings/oct08/followup/head_and_chairs/phil_rasch.pdf)

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- Geo-Engineering Research (http://www.parliament.uk/documents/upload/postpn327.pdf) , Parliamentary Office of Science and Technology
- Geo-engineering Options for Mitigating Climate Change (http://www.defra.gov.uk/environment/climatechange/research/pdf/geo-engineering-0409.pdf) , Department of Energy and Climate Change
- Unilateral Geoengineering (http://www.cfr.org/content/thinktank/GeoEng_Jan2709.pdf) , Council on Foreign Relations
- An overview of geoengineering of climate using stratospheric sulphate aerosols (http://rsta.royalsocietypublishing.org/content/366/1882/4007.abstract) , The Royal Society

Related Patents

- US patent 5003186 "Stratospheric Welsbach seeding for reduction of global warming"

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