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Geoengineering radiation management: not so fast

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- The Earth's radiation balance has increased in line with the rise in temperature
- Geoengineering radiation management may offer a solution to this
- Technologies can be grouped into two categories: solar radiation management and the earth's radiation management
- In both cases they involve technologies that try to improve this Earth's radiation budget in order to reduce the heat trapped in the Earth's atmosphere
- But these forms of geoengineering are deeply contested topics and scientists are divided over whether they should be explored at all as a potential solution...
- ...and these technologies don't solve the root of the problem, namely the concentration of greenhouse gases in the atmosphere.
- The focus should remain on technologies that limit the rise of concentrations of greenhouse gases in the atmosphere or technologies that remove these greenhouse gases from the atmosphere

Introduction

The goal of policymakers is to reduce emissions to net zero by 2050 and at a sufficient pace to stay within the carbon budget corresponding to a pathway to stay below 2°C and pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels. There are several ways to achieve this goal. First, limiting and mitigating CO2 and other greenhouse gas emissions. Second, capture emissions from combustion. Third, capture CO2 and other emissions from the atmosphere. Fourth, other ways to manage radiation and to influence temperature rise. Removing CO2 from the atmosphere and radiation management fall into the category of geoengineering. To reach our climate goals, a combination of these ways is necessary. In our previous report (see more here), we explained what geoengineering is and we focussed on carbon sequestration technologies. This report focuses on the radiation management technologies and what they can do to help fighting temperature rise. We end with a conclusion.

What is geoengineering

Geoengineering refers to a set of emerging technologies that could manipulate the environment and partially offset some of the impacts of climate change. Geoengineering is a term that covers a lot of technologies which generally fall under three categories: carbon geoengineering, solar radiation management and earth radiation management. In this report we focus on radiation management including solar radiation management technologies and earth radiation technologies. These technologies try to break the link from emissions to concentrations (see more here). The tabel below provides an overview of the geoengineering radiation management technologies per category.

Radiation management technologies
Solar radiation management
Stratospheric aerosol injection
Surface albedo modification
Marine cloud brightening
Micro bubbles
Space-based technologies
Earth radiation management
Cirrus cloud thinning

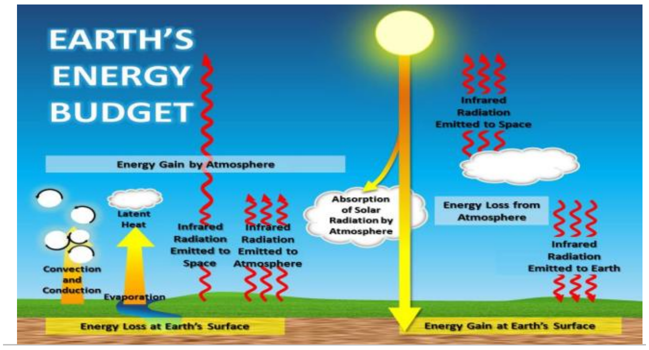
Source: Geoengineering Monitor (see more here)

Earth radiation budget

Before we do a deep dive into the technologies, we first delve into the concept of the earth radiation budget. A natural balance exists in the Earth system between incoming solar radiation and outgoing radiation that is emitted back to space as either light (direct reflection of sunlight) or heat (infrared emission from surfaces). This balance, referred to as Earth's radiation budget (ERB), determines the climate of the Earth and makes our planet hospitable for life (see more here). The graph below on the left illustrates this process.

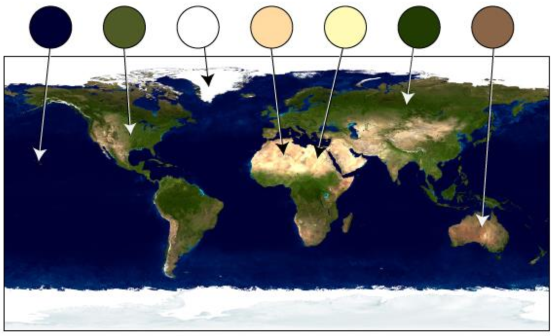
Increases in greenhouse gases (CO2 and methane) have changed the composition of the atmosphere and disrupted the planet's energy budget by trapping heat that would have previously escaped back into space. In short incoming solar minus reflected solar equals absorbed solar and absorbed solar minus outgoing longwave, which equals net radiation. The Earth's radiation balance has increased. This means that more heat is trapped. This has resulted in an increase in temperature.

Earth's energy budget



Source: Climate Science Investigations NASA

Earth's albedo



Source: UCAR SciEd with NASA image

The Earth's radiation balance has increased in line with the rise in temperature. Both solar radiation management and earth radiation management include technologies that try to improve the Earth's radiation budget in order to reduce the heat trapped in the Earth's atmosphere.

Earth's albedo

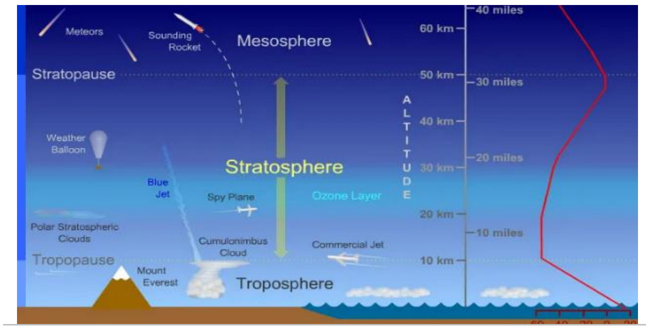
Albedo is the fraction of light that a surface reflects. If it is all reflected, the albedo is equal to 1. So this is the maximum. The albedo of Earth's surface (atmosphere, ocean, land surfaces) determines how much of the incoming solar energy, or light, is immediately reflected to space. This is critical for the earth's energy and radiation balance (see more here). When sunlight hits pale coloured surfaces, much of it is reflected, bouncing back out to space. For example bright light clouds, snow and ice caps reflect most of the sunlight and have a high albedo. When sunlight hits dark coloured spaces, very little of it is reflected (see more here). Most of it is absorbed for example oceans have a low albedo effect. The graph above on the right shows a sampling of the Earth's colours. The light colours have a higher albedo than the dark colours. When warming causes snow and ice to melt, darker coloured surfaces are exposed and albedo decreases and the planet warms even more.

Solar radiation management

Solar radiation management refers to technologies that seek to reflect a fraction of the sunlight back into space to cool the planet. In other words, this would improve the earth's albedo so that less heat is absorbed. Solar engineering does not aim to solve the root of the problem, but instead, aims to break the link from concentrations to temperatures, thereby reducing some climate damages (see more here). There are several solar radiation technologies, namely: stratospheric aerosol injection, surface albedo modification, marine cloud brightening, micro bubbles and space-based technologies. Below we will explain these technologies. Solar geoengineering is a deeply contested topic and scientists are divided over whether it should be explored at all as a potential solution. The UN's top environmental agency chief has warned that a rush into experimental techniques to cool the atmosphere by partially blocking the sun risked harming wildlife, oceans, the ozone layer and crops, after a failure by governments to agree on how to control geoengineering.

Stratospheric aerosol injection
Before we explain this technology, we first explain the stratosphere. The stratosphere is the second layer of the atmosphere as you go upwards. About 10% of the atmospheric mass is in the stratosphere. But the air in this layer is still so thin that you'd freeze in an instant. The stratosphere is very dry air, containing little water vapor. Because of this, few clouds are found in this layer. Due to the lack of vertical convection in the stratosphere, materials that get into the stratosphere can stay there for long times. Large volcanic eruptions and major meteorite impacts can fling aerosol particles up into the stratosphere where they may linger for months or years, sometimes altering Earth's global climate (see more here). The stratosphere is filled with ozone (O3) and this absorbs harmful ultraviolet radiation from the sun. The absorbed ultraviolet radiation from ozone causes the temperature in the stratosphere to rise.

Earth's stratosphere



Source: UCAR/Randy Russell

Stratospheric aerosol injection (or SAI) is a relatively new concept. It aims to mimic the planet cooling effect of volcanic eruptions by injecting sulfur dioxide (SO2) directly into stratosphere. This sulfur dioxide turns into aerosols, which reflect part of the sun's heat.

Although the overall goal of SAI is straightforward (reflect more sunlight), when it comes to considering how such an intervention could or would be implemented, a complex patchwork of side effects and trade-offs emerges. Researchers found a complicated picture: a diverse range of outcomes beyond just decreased surface temperatures, that included impacts on the stratospheric ozone layer, large-scale circulation patterns, and regional weather and precipitation, that vary both spatially and seasonally (see more here). Sulfur containing compounds called aerosols into the atmosphere which can produce sulphuric acid, which can also deplete the ozone layer.

Depending upon the scenario analysed, aggregate costs for SAI through the remainder of the century can range from roughly $250 billion to nearly $2.5 trillion, with an annual budget in the year 2100 of $7 to $72 billion (all in 2020 USD). What remains remarkably constant however, is the annual cost to suppress 1 °C of warming. This is about USD 18 billion per year per degree Celsius of warming avoided (see more here).

Surface albedo modification

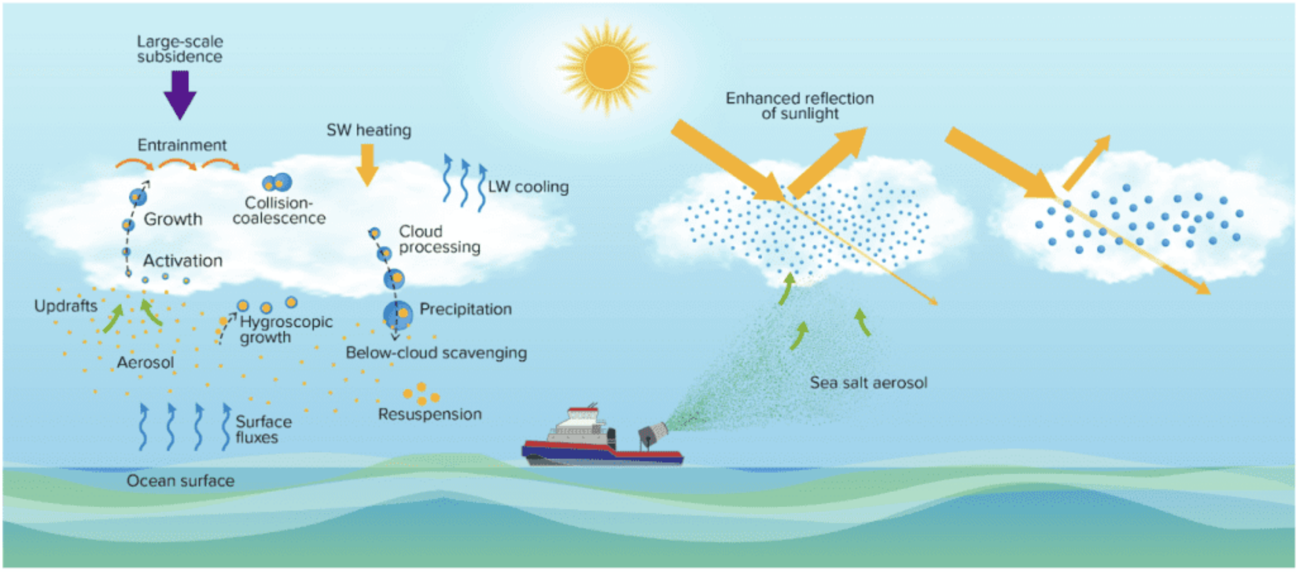
Surface albedo modification is a technology that aims to increase the albedo effect so that more sunlight is reflected back to space. This is a theoretical technique. There are proposals that span a wide range. From example we can grow crops that reflect more light. Another example is to apply a layer of reflective material to the Artic ice and glaciers. This will function as a reflective band aid to insulate rapidly melting snowpack. Furthermore mountain tops and roofs could be whitened with white paint (see more here).

Marine cloud brightening

Marine cloud brightening refers to a technique that aims to increase the reflectivity of certain clouds in order to reflect more sunlight back into space. The most common proposal for achieving such a goal is to inject naturally occurring sea salt into shallow marine clouds to brighten them, increasing their reflection of sunlight and reducing the amount of heat absorbed by the water below (see more here).

The graph below shows the key aerosol, cloud, dynamics, and radiation processes in the marine boundary layer (left) and the marine cloud brightening approach using ship-based generators to produce fine sea-salt aerosol droplets (right). Current proposals rely on saltwater spray, which would mimic plumes of sulfur-rich emissions from ship stacks or volcanoes, to increase the aerosol concentration in the lower marine atmosphere. Ideally, droplets in the saltwater spray evaporate to produce fine particles that are carried up to the cloud layer by turbulent and convective air motions (see more here).

Marine cloud brightening



Source: NOAA research, Credit: After Sorooshian et al. 2019.

Scientific studies indicate that aerosols in the atmosphere of the right size and concentration could significantly increase the reflectivity of specific types of clouds. Indeed more smaller drops have a higher reflectivity than fewer larger drops. The idea is to use particles of salt from sea water, a natural source of cloud-forming aerosol particles, to brighten clouds over parts of the ocean in order to reduce climate warming. In this approach, sea salt particles from the ocean would be sprayed from ships into areas of low-lying clouds. Once emitted, the particles would remain in the atmosphere for only a few days, within localized areas see more here).

But researchers need to develop sufficient confidence that appropriately sized particles can be generated and delivered to the clouds, and once there, act to form cloud droplets that efficiently scatter sunlight. They would need to show that clouds could be brightened consistently and over a large enough area to meaningfully cool the ocean below – and that trying to manipulate clouds would not cause clouds to thin, or droplets to rain out, which might allow for increased heating (see more here). But there are also disadvantages. This technique may diminish solar radiation reaching the Earth's surface, but it would not reduce the concentration of greenhouse gases in the atmosphere and could have impact on weather patterns with potentially less favourable impacts. Moreover, modelling results predict that this technique could reduce average global temperatures, they also show that it would have considerably varied and potentially detrimental impacts in different parts of the world. Global mean precipitation could decrease along with temperatures. The models show that once you start cooling the Earth with this technology you must do even more of this to keep achieving the same effect (see more here).

Micro bubbles

The basis of these techniques is the same as marine cloud modifications only it is not done to whiten the clouds but to whiten the surface of water bodies and/or ice. They aim to reflect more sunlight back to space. In order to do so ships should be equipped with technology to produce large quantities of microbubbles. Moreover the microbubbles will be stabilized by the addition of chemicals. Depending on the material used it can have chemical polluting effects on the sea and these microbubbles could have negative effects on ocean food chains and reduce oxygen levels (see more here).

Space-based technologies

These technologies try to alleviate the effects of climate change by reducing the amount of sunlight that hits the Earth see more here). The technologies are technically challenging and expensive in nature. Approaches include sunshades, reflectors, mirrors and clouds of sun blocking particles

Earth's radiation management

Above we discussed solar radiation management technologies. In this section, we focus on earth radiation management. Earth radiation management suggests that the negative effects of climate change can be offset by allowing heat to escape into space (see more here). Solar and earth radiation management look similar but they differ. The Sun emits solar radiation in the form of ultraviolet radiation or shortwave radiation. The Earth emits infrared or longwave radiation. As these are two different types of radiation they also need to be managed differently. But both forms of radiation are part of the Earth's radiation budget or ERB.

Cirrus cloud thinning

Cirrus clouds are high cold ice clouds that both reflect sunlight and absorb warming infrared radiation. Compared to clouds at lower altitudes, they are less effective at reflecting incoming sunlight and more effective at blocking outgoing longwave radiation emitted by the Earth. So they often absorb on average more infrared than they reflect sunlight, resulting in a net warming effect on the climate. Thinning these clouds would reduce their heat trapping capacity because more longwave radiation is able to escape the Earth system into space, cooling the planet. This technology has significant disadvantages. First this technology could have considerable impact on regional climates. The injection of "too many" ice-nucleating particles into cirrus clouds may produce the opposite effect – more and thicker clouds may be produced, so that even more heat is trapped, which could lead to increased global warming. The level at which over-seeding occurs is not known, adding considerable uncertainty to current models (see more here).

Conclusion

The Earth's radiation balance has increased in line with the rise in temperature. In the report we focused on radiation management technologies: solar radiation management and earth's radiation management. Both include technologies that try to improve this Earth's radiation budget in order to reduce the heat trapped in the Earth's atmosphere. Solar radiation management refer to technologies that seek to reflect a fraction of the sunlight back into space to cool the planet. But solar geoengineering is a deeply contested topic and scientists are divided over whether it should be explored at all as a potential solution. Earth's radiation management suggests that the negative effects of climate change can be mitigated by allowing heat to escape into space. But earth radiation management has also many disadvantages. Overall, these technologies are not ready to be implemented on a large scale and even if they are, the question is if this would be desirable. Moreover, these technologies don't solve the root of the problem, namely the concentration of greenhouse gases in the atmosphere. It would be better to focus on technologies that limit the rise of concentrations of greenhouse gases in the atmosphere or technologies that remove these greenhouse gases from the atmosphere.