Solar geoengineering to cool the planet: Is it worth the risks?

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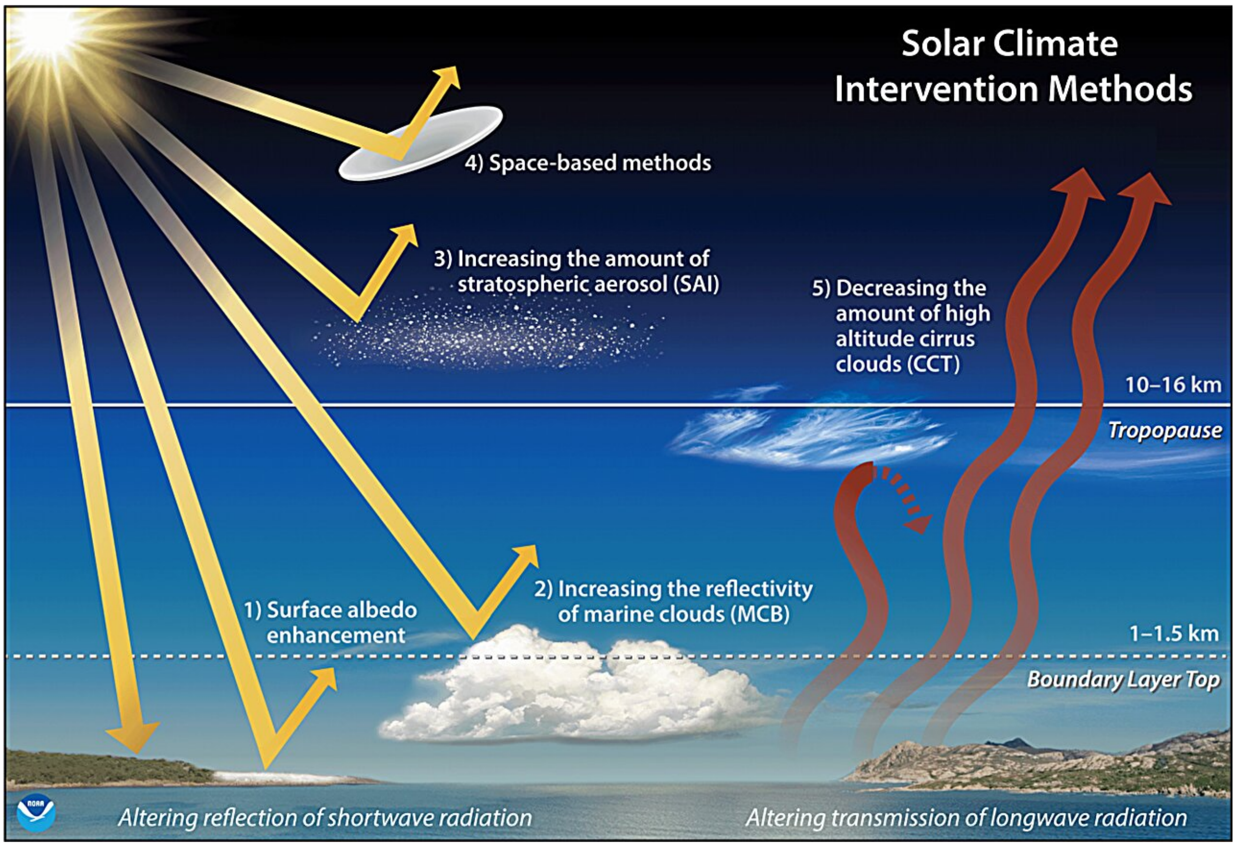

Credit: Chelsea Thompson, NOAA/CIRES

When I first wrote about geoengineering in 2012 , it was considered far-fetched at best, and crazy by most. But 12 years later, while there is still controversy and considerable resistance to deploying it, respectable scientists and institutions are pushing for more research into geoengineering—the deliberate and large-scale intervention in our climate system to moderate global warming.

Most of the current attention is focused on solar geoengineering, a strategy that involves reflecting sunlight away from Earth to cool the Earth. How much do we know about it and its risks? And where should we take it from here?

Why the growing support for solar geoengineering research?

For many years, all geoengineering research was discouraged by many scientists and experts for fear it would provide an excuse not to cut emissions. Some right-wing politicians such as Newt Gingrich promoted it as a way to reduce global warming without having to cut emissions. Geoengineering research is also controversial because there were and still are many uncertainties about its potential effects on the climate system and ecosystems.

Nevertheless, James Hansen, director of the Program on Climate Science, Awareness and Solutions at Columbia's Climate School, who first warned Congress about climate change risks in 1988, and a group of more than 60 scientists are calling for more research into solar geoengineering.

In addition, the US National Academy of Sciences, the Environmental Defense Fund, the Natural Resources Defense Council, and the Union of Concerned Scientists all support solar geoengineering research. A 2022 White House report also expressed strong support for the research.

Experts say support for research is growing because humanity is not doing enough fast enough to reduce carbon emissions to forestall severe and worsening climate impacts. Due to air quality regulations, a decrease in the sulfur dioxide aerosol emissions from coal plants and shipping that helped shield Earth from solar radiation has resulted in the world warming faster than was previously projected, according to a new study by Hansen and colleagues. They project that warming will surpass 1.5°C by the end of this decade and 2°C by 2050, which could result in disastrous climate impacts.

The potentially catastrophic climate impacts and the possibility of passing climate tipping points, such as thawing of the Arctic permafrost or the dieback of the Amazon rainforest, could necessitate the use of what were once unthinkable strategies.

In an open letter, the 60 scientists said that because of these serious risks, and the possibility of some desperate country one day resorting to solar geoengineering, it needs to be rigorously studied as soon as possible, with both benefits and drawbacks clearly assessed.

Most research into solar geoengineering strategies is currently focused on stratospheric aerosol injection (SAI, also called solar radiation management or SRM) and marine cloud brightening; other strategies include cirrus cloud thinning and the use of mirrors or sunshades.

Solar aerosol injection

After Mount Pinatubo in the Philippines erupted in 1991, sending 20 million tons of sulfur dioxide into the stratosphere, the Earth cooled by 0.5°C. When sulfur dioxide enters the atmosphere, it reacts with water vapor to form droplets—aerosols that reflect sunlight away from Earth. SAI would recreate Pinatubo's effect by shooting sulfur dioxide into the stratosphere to temporarily block sunlight.

Harvard's Solar Geoengineering Research Program claims SAI could lower sea surface temperatures, which would decrease the risks of coral bleaching, slow the movement of species towards cooler areas, and reduce sea ice loss and glacier melt. Results would be quick and buy humans more time to cut carbon emissions and transition to renewable energy.

But unlike CO_2 removal, a multifaceted geoengineering strategy that has more acceptance, solar geoengineering does not reduce CO_2 in the atmosphere. It would do nothing to address ocean acidification, which harms marine ecosystems, because the ocean absorbs 25% of the CO_2 humans emit, altering its chemistry.

Moreover, an abrupt use of SAI may not be effective enough to fully remedy changes caused by a warming deep ocean, such as the slowing of the Atlantic meridional overturning, according to a recent study. Other problems caused by a warming deep ocean, including altered weather patterns, sea level rise, and weakened currents, would also persist.

The uncertain impacts of SAI

Because there is no international governance for solar geoengineering, there is strong opposition to large-scale deployment of SAI. Almost all solar geoengineering research has been done with computer modeling, so no one knows exactly what might happen if it were deployed on a planetary scale.

Those against advancing SAI research are worried about its potential and uncertain impacts on the climate and ecosystems that modeling has revealed. Studies show that SAI could weaken the stratospheric ozone layer, alter precipitation patterns, and affect agriculture, ecosystem services, marine life, and air quality.

Moreover, the impacts and risks would vary by how and where it is deployed, the climate, ecosystems, and the population. Apart from deployment variations, small changes in other variables, such as the size of the aerosol droplets, their chemical reactivity, and the speed of their reactions with ozone can also produce different results.

For example, NOAA, Cornell, and Indiana University studied a number of deployment strategies by using a model that varied the amount of sulfur dioxide injected into the stratosphere and also where it was injected. The results showed decreased surface temperatures but also a reduction of ozone over Antarctica and impacts on large-scale circulation patterns and regional weather.

Twelve other models projected that if enough SAI were deployed to offset the warming of quadrupled CO_2, parts of the tropics could have 5% to 7% less rainfall each year compared to preindustrial times, which could damage crops and rainforests.

One model indicated that SAI deployed over the Indian Ocean to increase precipitation over the drought-stricken Sahel in North Africa would end up pushing the drought to countries in East Africa. And a 2022 study found that SAI could shift malaria from highland areas in East Africa to lowland areas in South Asia and sub-Saharan Africa as they became cooler.

According to Gernot Wagner, co-founder of Harvard's Solar Geoengineering Research Program and currently a climate economist at the Columbia Climate School, the most important and determinative modeling variables are how high up in the stratosphere and where specifically SAI is deployed. Wagner said that if only one hemisphere is cooled, you get "crazy results" such as turning off the Indian monsoon.

"The science has more or less coalesced around the idea that you want to be [deployed] somewhere between plus and minus 15 degrees from the equator. And wherever you are around the equator, you want to do the same north as you do south," he said. "It doesn't matter which longitude because it will spread globally.

"By and large, the hundreds of climate models agree that [if SAI is deployed this way] you have more or less a uniform global effect. That means that most of the stuff that we can measure—temperatures, water availability, extreme temperature, extreme precipitation—gets closer to pre-industrial levels with solar geoengineering than without."

Wagner cited a Harvard paper that modeled a version of solar geoengineering with a slow ramp-up to halve warming. "When modeled in admittedly this idealized fashion, solar geoengineering seems to have these frankly surprising net benefits. The benefits dwarfed the costs by so much," he said. "It is encouraging in a way that leads me to believe it is worth it to continue doing research."

What would SAI deployment take?

In 2011, David Keith, Harvard's Solar Geoengineering Research Program co-founder who is now at the University of Chicago, and atmospheric scientist Ken Caldeira estimated that to reverse 10% of the warming caused by a doubling of CO_2 levels compared to the pre-industrial era, several hundred thousand tons of sulfur dioxide would have to be injected annually over a decade. To significantly slow warming or reverse it, SAI would require millions of tons of sulfuric dioxide each year.

Currently only a few research planes can operate at the necessary altitude because the atmosphere is so thin, and in addition, they are not capable of carrying that many tons of sulfur dioxide. This means that a new fleet of high-altitude planes designed specifically for the purpose would have to be built; creating this fleet could take a decade or more. Once the planes are built, SAI could cost $18 billion per degree of cooling each year.

While that sounds like a lot of money, Wagner said the cost is miniscule compared to the potential social benefits. But because the benefits exceed the costs by so much, which would normally lead us to conclude we should go headlong into SAI, a cost-benefit analysis is not the right criterion for making decisions about SAI. Rather, he said, "It's about weighing the risks of unmitigated climate change—the world we are heading towards—against the risks of a world that also considers solar geoengineering.

"But even if the risks are large, even if the climate uncertainties are so large as to dwarf everything else, since it seems to be true that solar geoengineering gets us closer to pre-industrial levels of global average temperatures, it should also help us mitigate and understand those risks and uncertainties," said Wagner.

Once begun, SAI would have to continue for a few decades if we manage to cut our emissions, or perhaps centuries or millennia if we don't. But if SAI were stopped suddenly, the planet could experience termination shock—when temperatures rebound to the levels they would have reached without SAI. Because SAI would not reduce greenhouse gas emissions but only mask their warming effect, emissions would continue to build up in the atmosphere.

Right now, the planet is warming gradually. Sudden warming would be catastrophic because ecosystems and humans would have less time to adapt. And the faster the climate is changed, the greater the risk of unforeseen impacts. Natural disasters, terrorist attacks, or political aggression could all potentially precipitate termination shock.

Small SAI experiments

Small field SAI experiments that enable researchers to better understand aerosol behavior, chemical reactions, monitoring capabilities, and how ozone is affected, are increasing.

In 2021, Harvard planned a small field trial which would have been the first experiment done in the stratosphere. The Stratospheric Controlled Perturbation Experiment (SCoPEx) would have launched a self-propelled balloon into the sky, releasing half a kilogram of sulfate—which is found naturally in nature—and then monitoring how the particles dispersed and how much sunlight was reflected off them.

The test launch in Sweden was cancelled because of objections from the local Saami indigenous people and environmental groups who feared that SAI "entails risks of catastrophic consequences."

UK researchers launched several balloons in 2021 and 2022. The 2022 launch of a high-altitude weather balloon released a few hundred grams of sulfur dioxide into the stratosphere, with the goal of testing the balloon system.

Meanwhile Make Sunsets, a startup company, says it has launched 52 balloons, and "neutralized 16,141 ton-years of warming." It sells "cooling credits" for $10, each of which, it claims, will offset the warming effect of one ton of CO_2 for a year. In 2023, Make Sunsets conducted two unauthorized launches that released sulfur dioxide in Mexico, which resulted in the Mexican government banning solar geoengineering.

Marine cloud brightening

Marine cloud brightening (MCB) would spread sea salt aerosols into the atmosphere to create stratocumulus clouds that reflect the sunlight. Sea salt aerosols are highly reflective, attract water molecules, and keep clouds in the sky longer than normal. While salt aerosols occur naturally as winds whip them up from the ocean, MCB would generate them from a floating barge and send them into the atmosphere. By its very nature, MCB would be localized. Some scientists claim using MCB over just 5% of world's oceans could offset the impacts of global warming.

The Great Barrier Reef Foundation has been researching MCB as the reef experiences its fifth mass bleaching in eight years. The reef is at the greatest risk of bleaching when the weather is hot and there are few clouds. Researchers employed a sea salt sprayer on a barge that sucked up seawater, atomized it, and shot microscopic sea salt crystals into the sky. The modeling research found that the sprayers would need to operate for weeks to months, cooling the waters gradually.

Recently, a group of atmospheric scientists proposed an MCB research program including modeling, lab studies, and field experiments. University of Washington researchers, who are also running an MCB project, estimate it will be a decade before they know enough to try MCB at large enough scale to cool the planet.

Uncertainties about MCB

Large-scale MCB that could offset serious climate impacts, however, might also alter climate and weather patterns. A researcher from UC Santa Barbara found that while MCB could quickly lower temperatures, it would also suppress ENSO, the El Niño-Southern Oscillation which affects global weather patterns. MCB could cause the La Niña phase of ENSO to persist, which would make the southern US hotter and drier and increase Atlantic hurricane activity. The research suggested that MCB could also increase warming in Indonesia and Northern Australia.

Because of uncertainty about MCB's effects, 101 countries as Parties to the London Convention and Protocol—international treaties that regulate the dumping of wastes at sea—signed a statement saying that marine geoengineering activities other than scientific research should be deferred.

Other solar geoengineering strategies

Cirrus cloud thinning

High-altitude cirrus clouds are composed of ice crystals and thus reflect sunlight, but also result in warming because they trap the heat that radiates from Earth's surface. Cirrus-cloud thinning involves spraying particles of silver iodide into the clouds at altitudes of 4,500 to 9,000 meters. This serves to enlarge the ice crystals in the cirrus clouds so that they fall out of the atmosphere.

The fewer and thinner cirrus clouds that remain would trap less radiation from Earth. The risks of cirrus cloud thinning are not yet fully understood, and some researchers are concerned that it could affect regional and seasonal precipitation.

Sunshades

Some scientists are researching the possibility of sending a giant sunshade to a point between Earth and the sun to block solar radiation. An MIT group is exploring creating a shade of "space bubbles," while University of Hawaii researchers are considering tying an enormous solar shield to an asteroid.

Israeli researchers are designing a small prototype of a group of sunshades that would not completely block the sun but diffuse it. Others have proposed similar strategies in the past. But French scientist Susanne Baur who studies solar radiation modification says that the sunshade strategy would be too expensive, too easily damaged by space rocks, and take too long to implement.

The need for geoengineering governance

There is no international, national, or state framework that currently governs geoengineering. As a result, one worrisome future scenario is that climate impacts in a particularly vulnerable country will be so severe that it resorts to deploying SAI on its own before the world is ready for it. This could cause political instability or provoke retribution from other countries that suffer its effects.

Another possible scenario is that an individual or a startup decides to experiment with geoengineering on their own. Today in the U.S., anyone who wants to shoot aerosols into the sky simply needs to fill out a one-page form for the Commerce Department and NOAA ten days beforehand.

It is critical for the world community to establish an international governance structure for solar geoengineering. But because this is such a daunting and complex undertaking, many countries, organizationss and scientists object to even allowing the research to progress.

In 2010, a global de facto moratorium on large-scale geoengineering, including solar geoengineering, was put in place. Recently a motion to convene a research group to study the potential applications, risks, and ethical considerations of solar geoengineering was voted down by delegates at the U.N. Environment Assembly. The panel would have comprised experts from the UNEP and international scientific organizations.

Because the motion might have undermined the existing moratorium, however, the African, Pacific, and Latin American countries, which are more vulnerable to climate impacts, blocked it. In 2022, 500 scientists from around the world signed a call for an International Non-Use Agreement on Solar Geoengineering, stipulating no public funding, no outdoor experiments, no patents, no deployment, and no support in international organizations.

Wagner believes that a moratorium on solar geoengineering deployment is necessary, but that research should continue. "Basically, you say no deployment above a certain size, and you give permission for research to proceed up to that point," he said. To ensure these guidelines are followed, high-level formal, legal, regulatory governance agreements to guide solar geoengineering research would be needed.

Wagner would also like to see a solar geoengineering organization with a massively funded research program that tries to answer the important questions in a rational way, and that makes the research transparent to inform policy choices that should ultimately be made by democratically elected leaders.

"Looking at climate radiative forcing impacts in a semi-rational fashion ought to lead you to conclude that a modicum of solar geoengineering should be part of the climate policy portfolio, because it does help take the edge off unmitigated climate change," Wagner said. The portfolio should "include cutting CO_2 emissions in the first place, as well as adaptation." But, he added, "SAI technology is not going to be the sole savior here. That is absolutely clear."

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