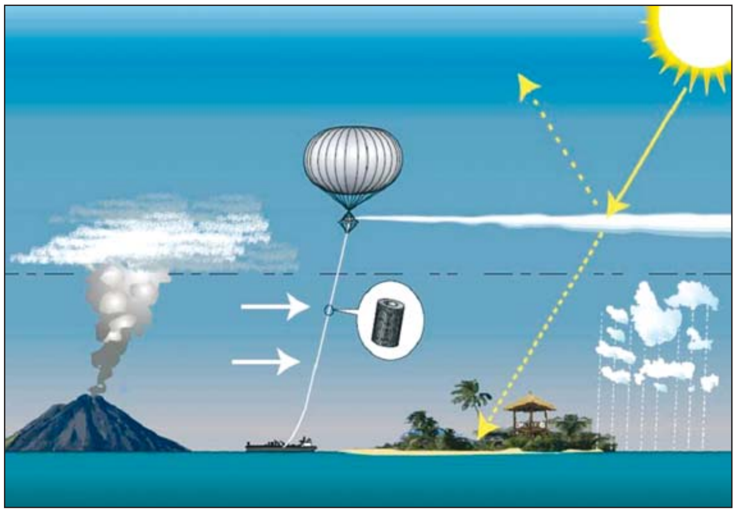
Solar Radiation Management

Geoengineering and Climate Change: Implications for Latin America

In brief



Natural and proposed artificial stratospheric aerosol injection to reflect more sunlight back into space. (CC) Wikimedia Commons

This briefing explores the potential consequences of using Solar Radiation Management (SRM) – a form of geoengineering being considered by some governments to address climate change. SRM is a set of technologies designed to reduce sunlight and lower temperatures. These technologies are currently only theoretical, but by using models, scientists have been able to look at potential impacts. They have found that while some countries in temperate zones would most likely benefit from SRM, other regions would be adversely affected.

This briefing considers the climate impacts for Latin America, where the models suggest major changes in precipitation patterns would exacerbate dry conditions and increase the possibility of droughts in large regions.

Little is known about the impacts of geoengineering on biodiversity and ecosystems, but the impacts of rapidly ending SRM experiments were found to pose a potentially acute threat to species. The resulting rapid changes in temperature could increase the probability of local extinctions in some of the most biodiverse regions on Earth.

Given the important social, agricultural and economic consequences suggested by the models, and the likely risks to biodiversity, we argue that governments should strengthen their precautionary approach and consider a ban on SRM.

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Policy background

The UN Convention on Biological Diversity (CBD) adopted a de facto moratorium on geoengineering activities in 2010 (decision X/33 (w)), based on the precautionary approach. The decision requests that governments do not allow geoengineering activities to take place because of the potential impacts on biodiversity and associated livelihoods.

In 2015, the Paris Agreement (PA) set a goal to keep global average temperature rise well below 2°C by the end of the century. The Agreement did not establish binding regulations to ensure the reduction of greenhouse gas (GHG) emissions. So, to avoid mitigation at the scale needed to comply with the PA goal, some governments in high emitting countries are considering geoengineering as a technological fix to lower temperatures or remove greenhouse gases from the atmosphere.

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Box 1

Terminology:

Geoengineering is the deliberate large-scale technological manipulation of Earth systems (in the stratosphere, in the ocean, or in the ground) to try to affect the climate.

This can include **Solar Radiation Management (SRM)** – where interventions are made that seek to partially block or reflect sunlight back to space to lower the Earth's temperature – and **Greenhouse Gas Removal (GGR)** interventions, including **Carbon Dioxide Removal (CDR)** technologies.

Stratospheric Aerosol Injection (SAI) is considered the most economic and technically practical form of SRM by its proponents. This involves spreading mineral "dust" 15-20 km up in the stratosphere to reduce sunlight and lower temperatures. "Dust" can be blown by pipes (like an artificial volcano) or by balloons or be distributed by a specially-outfitted aircraft. The most commonly considered proposal is to inject sulphate aerosol into the stratosphere. This entails a range of impacts and risks, including worsening ozone layer loss, changing precipitation patterns and a potential "termination shock" effect, resulting from the sudden change in temperature (see below).

Net Primary Productivity (NPP) is an indicator used to show the ability of the terrestrial biosphere to take up carbon dioxide. It may provide estimates of the impacts of geoengineering on agriculture (Kravitz et al., 2013).

Findings

Since 2014, the scientific community has developed computational models (Earth System Models, or ESMs) that can assess the impact that geoengineering has at both regional and global levels. Ten different models have been used to examine how SRM could reduce radiative forcing from the sun (see for example Yu, et al., 2015).

These studies agree that SRM could lead to a decrease in the mean temperature of the planet. However, the models point to different impacts in different parts of the world. They also suggest that while Artic sea ice loss would be slower, it would not stop, and the risks associated with higher sea level would continue (Berdhal et al., 2014).

While SRM could theoretically restore global average temperatures to pre-industrial levels, this would alter global hydrology cycles. The precipitation changes are significant, with major potential impacts on agriculture, water supply, biodiversity and energy production. The highest reductions in rainfall and the greatest increased possibility of droughts are found to be concentrated in tropical and subtropical areas. There is a strong consensus that average global rainfall would be reduced by 4.5 percent. Reductions are predicted to be greater in monsoonal land regions such as North America (7 percent) and South America (6 percent) in most studies (Tilmes, et al, 2013; Robock et al., 2008; Bala and Nag, 2012; Trenberth and Dai, 2007).

While SRM could theoretically restore global average temperatures to pre-industrial levels, this would alter global hydrology cycles. The precipitation changes are significant, with major potential impacts on agriculture, water supply, biodiversity and energy production.

Within these regions, heavily populated and highly cultivated areas, including Mesoamérica, Central América, the Amazon Basin and northern South America are expected to have less tropical rainfall, which would have significant socioeconomic impacts, particularly on agriculture, water supply and energy production. This makes these areas particularly susceptible to drastic changes in climate (Marengo et al., 2012).

Blasting sulphates into the stratosphere, enhancing albedo over oceans or land, and other SRM techniques will not reduce carbon dioxide concentrations. SRM would merely postpone the impacts for as long as the technology continued to be deployed. If the technology was halted, it could result in abrupt and more extreme climate change (Jones A. et al., 2013).

Box 2

The IPCC's Representative Concentration Pathways (RCPs) and geoengineering

The Intergovernmental Panel on Climate Change (IPCC) uses four different greenhouse gas concentration trajectories in its fifth Assessment Report (AR5), known as Representative Concentration Pathways (RCPs). These are identified as RCP2.6, RCP4.5, RCP6, and RCP8.5, with each one named after a possible range of radiative forcing values in the year 2100, relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m[2], respectively).

These pathways are used in climate modeling to describe four possible climate futures, all of which are considered possible depending on the amount of greenhouse gases emitted in the coming years. Most scenarios reaching long-term concentrations of about 450 ppm of carbon dioxide equivalent (CO_2 eq) in 2100 are considered likely to keep global average temperature change below 2°C over the course of the century relative to pre-industrial levels. Note that only RCP2.6 and RCP4.5 would supposedly reach this goal (Figure B2.1).

The scenarios which keep global average temperature change below 2°C assume the use of large-scale CDR geoengineering, mainly through afforestation and the use of bioenergy with carbon capture and storage (BECCS), but they do not assume the use of SRM. Relying on existing CDR technologies would require vast, large-scale land use changes, and would cause local and regional environmental and socio-economic impacts, as well as transboundary risks for land and ocean ecosystems (i.e., extending beyond national boundaries).

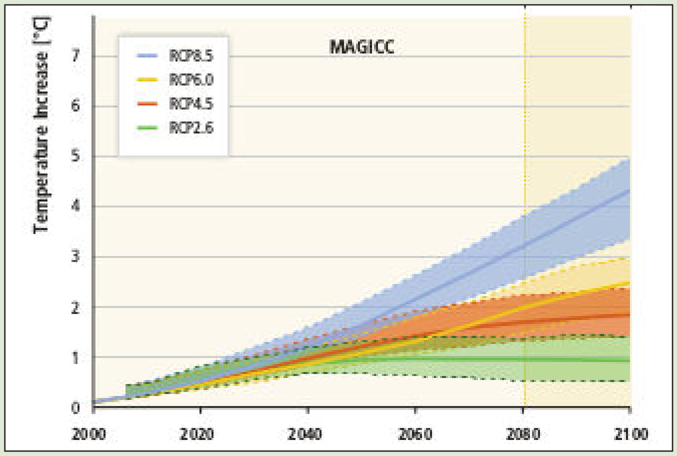

Figure B2.1. Temperature increase (relative to the 1986 – 2005 average) for the RCP scenarios. (IPCC, 2014b)

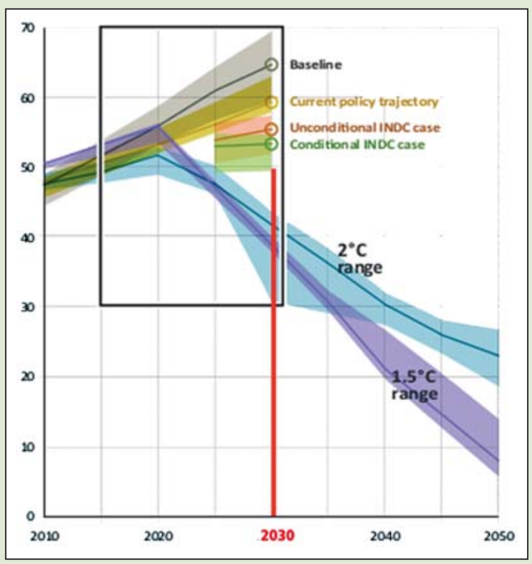

Figure B2.2 Annual Global Total Greenhouse Gas Emissions (GtCO2e) under different scenarios and the emissions gap in 2030 (UNEP, 2016).

These findings suggest that using CDR would pose additional challenges for cooperation between countries. These limitations, and the lack of technical, economic and environmental evidence as to the feasibility and viability of CDR proposals, mean that they likely cannot be deployed fast enough to meet the temperature reduction levels required.

The UNEP 2016 Emissions Gap Report concluded that while proposed national emission reductions plans, i.e., countries' Intended Nationally Determined Contributions (INDCs), would reduce emissions compared to global "business as usual" emission levels (black line in figure B2.2), the contributions are far from what is required for an emission pathway consistent with staying below 2°C (blue line). The report estimated that full implementation of both unconditional and conditional INDCs would imply an emissions gap of 12 gigatonnes of carbon dioxide equivalent (GtCO2e) in 2030. This is equivalent to China's current carbon dioxide emissions from fossil fuel use and industry. This gap reflects the difference between the INDCs and the least-cost emission level for a pathway to stay below 2°C and translates into a global average increase of temperature of 2.9 to 3.4°C.

This gap has been used by geoengineering proponents and some governments to argue that both SRM and CDR techniques will be needed to achieve the goals set out in the Paris Agreement.

Computer Model Scenario Results for Stratospheric Aerosol Injection experiments

Models indicate that under all the proposed SRM experiments analysed by a geoengineering comparison project (GeoMIP) (see Box 3), the mean temperature of the planet could be reduced to pre-industrial levels, or to the mean temperature between 2010 and 2029 (RCP4.5; experiments G3 and G4). This temperature reduction would differ between regions because temperatures at the north and south poles would continue to increase. According to one study, SAI (G3 and G4 experiments) would not stop Arctic sea ice loss (which is currently declining at approximately 12 percent per decade) (Berdahl et al., 2014).

In two of the five models, the total September ice loss (when Artic sea ice is at its minimum) would occur before 2060 despite SRM interventions.

All geoengineering interventions (see Box 3) decreased the average precipitation worldwide, but regional effects vary (Figure 1). Precipitation is harder to model than temperature and because of this the maps in Figure 1 show variation between the models for large areas of the planet (indicated with black dots).

Box 3

Geoengineering simulations and baselines

The Geoengineering Model Intercomparison Project (GeoMIP) was created to record and compare the expected climate effects of geoengineering simulations. The first two GeoMIP experiments (G1 and G2) simulated geoengineering to reduce the amount of sun entering the atmosphere, i.e., solar dimming (by blocking the sun from outer space). Subsequent experiments, G3 and G4, simulated stratospheric aerosol injection (SAI) using sulphate aerosols, in either a time-varying way or at the constant rate of five Tg of sulphur dioxide (SO2) year for the period 2020-2070 (for comparison, the Mount Pinatubo eruption in 1991 caused a one-off release of 17 Tg SO_2). Much higher injection rates (up to 45 Tg SO_2 per year) would be needed to maintain 2020 temperatures if 'business as usual' emission rates were to continue (Niemeier and Timmreck, 2015).

Many studies agree that space-based solar dimming (G1 and G2 experiments) and SAI (G3 and G4 experiments) would have unequal consequences for temperature and precipitation at the regional scale.

The impacts of the changes in precipitation patterns in particular can be very severe (Yu X. et al, 2015; Kalidindi S. et al, 2014). This briefing focuses on the results of experiments related to the potential impacts of SAI deployment.

To assess the results of computer simulations, a baseline must be established to serve as the reference period from which the modelled future change in climate is calculated. Most impact assessments seek to determine the effect of climate change with respect to the present, and therefore recent baseline periods are usually favoured (IPCC, 2001). More recently, the Coupled Model Intercomparison Project Phase 5 (CMIP5) used as baseline the projected future climate state (averaged over 2006-2300) resulted from RCP4.5 greenhouse gas concentration pathway for comparison purposes (Taylor et al., 2012).

Whichever baseline period is adopted, it is important to acknowledge that the choice will affect the result (IPCC, 2001). For example, projected changes in precipitation and temperature due to a geoengineering simulation are expected to be larger if the baseline is a pre-industrial climate rather than the 20th century climate. This means that the accumulated environmental and social impacts would be greater than estimated in this paper.

Findings for Latin America

For Latin America, at least one of the GeoMIP experiments predicts (i.e., more than 70 percent of the models used agree) that precipitation will be reduced by 0–100 mm/year (yellow colours in Figure 1) in Mexico, Guatemala, Belize, El Salvador, Honduras, Cuba, The Antilles, Colombia, Brazil, Venezuela, Guyana, Suriname, French Guyana, Ecuador, Peru, Bolivia, Chile, Argentina and Uruguay with regional variations within countries. Small increases in rainfall levels (blue colors in Figure 1), ranging from 0–50 mm/year could be expected in Central America, Argentina, Paraguay and Uruguay (only considering experiments G3 and G4, using uniform SAI). Reductions in the Amazon basin are very significant, although there is greater variability between the models for this region compared to the rest of the world.

A 2013 study showed changes in precipitation and Net Primary Productivity (NPP) for northern and north eastern (NE) Brazil, before sulphate injections were applied. Sulphate injections in the Northern Hemisphere were likely to increase precipitation patterns and NPP in NE Brazil, with increased rainfall of up to 100 mm/month.[2] Northern Brazil, however, could see a decrease of up to 80 mm/month (Figure 2a). Similar results were found regarding NPP (not shown). When sulphate injections were modelled in the Southern Hemisphere, NE Brazil saw a decrease in both variables with a rainfall reduction of up to 80 mm/month, while Northern Brazil saw an equivalent increase (Figure 2b) (Haywood et al., 2013).

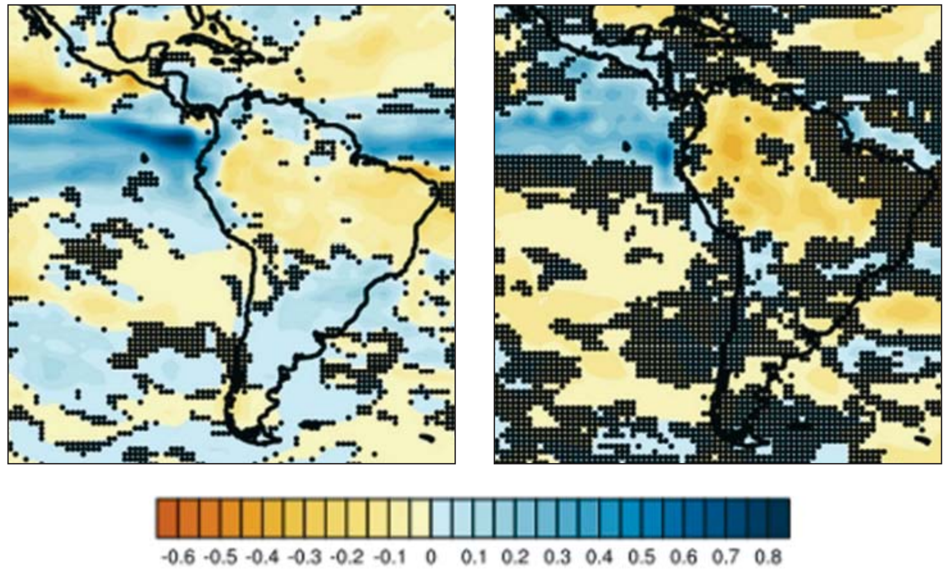

Figure 1. Ensemble[1] mean precipitation anomalies between GeoMIP experiments and RCP4.5 average climate over the period 2010–2029 for G3 (left panel) and G4 (right panel) experiments. Stippling indicates where fewer than 70 percent of models agreed on whether precipitation would increase or decrease (Yu X. et al., 2015).

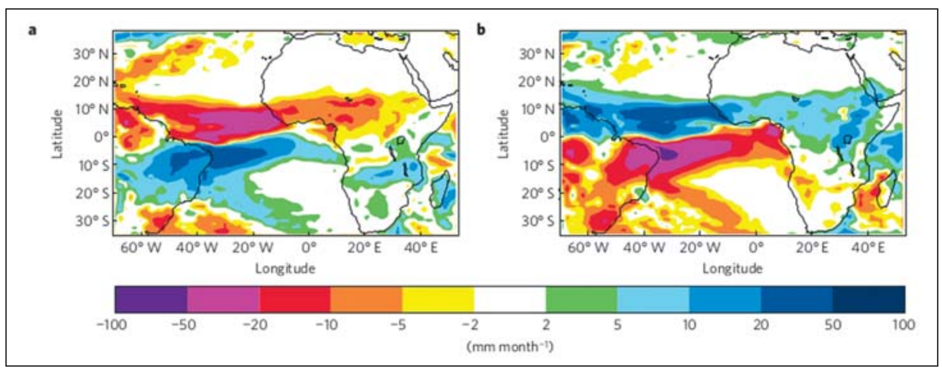

Figure 2. Model precipitation response to geoengineering simulations. The change in annual mean precipitation averaged over the period 2020–2070 for sulfate injections released in the Northern Hemisphere (a) and Southern Hemisphere (b) (Haywood et al., 2013).

1 Ensemble is the result of the process of running two or more related but different computational models and then synthesizing the outcomes into a single score or spread in order to improve the accuracy of predictive analytics.

2 The authors used the HadGEM2-ES climate model to perform two experiments that were variants of the Geoengineering Model Intercomparison Project (GeoMIP) G4 experiment. The level of sulfate aerosol injections in the experiments was 5 Tg SO_2 /year.

Ferraro et al. (2014) developed a risk-based framework for classifying impacts according to whether geoengineering increases or decreases the risk of substantial climate change. This study considered a quadrupling of carbon dioxide concentrations (relative to pre-industrial levels)[3] and used uniform SAI to restore future global temperatures to 20th century levels. The authors found that previous considerations would result in substantial precipitation changes across almost half of the Earth's surface area (42 percent). The affected areas are home to 36 percent of the global population and generate 60 percent of the world's gross domestic product (see Figure 3).

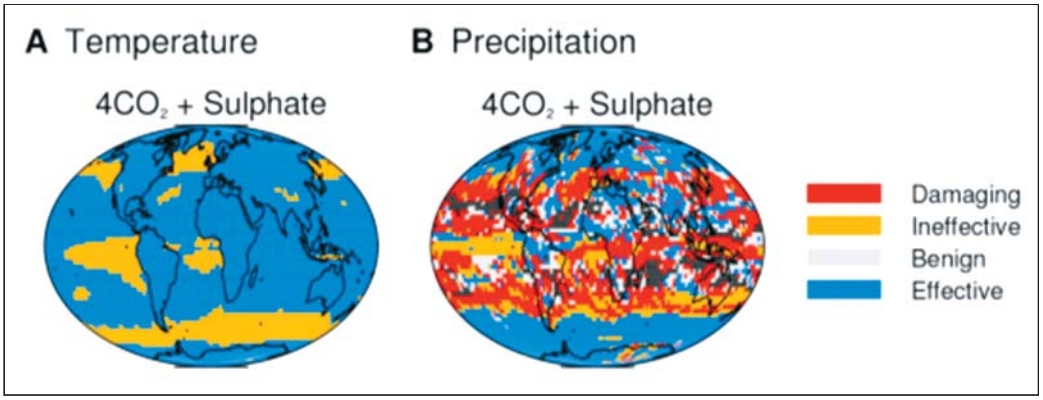

Figure 3. Maps of outcomes of geoengineering (SRM) with SAI. The risk-based framework is used to classify outcomes for (A) annual-mean climatological surface temperature and (B) annual-mean climatological precipitation. "$4CO_2$" simulation refers to an atmospheric CO_2 concentration of 4x355= 1420 ppmv (Ferraro et al., 2014).

These results show that sulphate aerosol geoengineering is likely to be ineffective[4] because it enhances temperature changes in areas already at risk, particularly over oceans such as the Southern Ocean and the north and south Atlantic and north and south Pacific. In equatorial and subtropical regions, the results show damaging increases in climate risk from precipitation changes in areas presently not at risk from climate change.[5]

3 Using 355 ppvm, the CO_2 concentration of preindustrial times.

4 Ineffective (yellow color in Figure 2) means that risk is increased in at-risk areas. In areas where a change was more likely than not under 4CO2, geoengineering increases the probability of a change.

5 Damaging (red color in Figure 2) means that risk is increased in areas not at risk. In areas where a change was less likely than not under $4CO_2$, geoengineering increases the probability of a change.

6 The authors used a configuration of HadGEM2 and GeoMIP G4 scenario. The control simulation was based on RCP4.5 with no RM geoengineering.

7 The authors used NCAR CAM3.1 model and a 70-year simulations are performed using the slab ocean configuration (analysed the last 40 years of simulation for studying equilibrium climate change.): (1) a control "$1xCO_2$" simulation with an atmospheric CO_2 concentration of 355 ppmv, (2) a "$2xCO_2$" with 710 ppm and (3) a "Geo" simulation in which the CO_2 concentration is doubled to 710 ppm and the cloud droplet size over continental regions is .0041 mm.

Other solar geoengineering experiments

A 2015 study looking at six different SRM schemes – crop albedo modification, desert albedo modification, ocean albedo modification, sea-spray geoengineering, cirrus cloud thinning, and stratospheric sulphur dioxide injections – showed that potentially damaging changes in regional precipitation were a common feature(Crook et al., 2015).[6]

An earlier study found that albedo enhancement over land[7] decreased global precipitation by 13 percent, decreased runoff over land by 22 percent, and resulted in reduced soil water (Bala and Nag, 2012). Most of the decreases in precipitation (around 500 mm/year) were in tropical land areas such as the Amazon and Central America. Important decreases were also seen across South America with reductions of around 100–300 mm/year (Figure 4).

More recently, an experiment[8] modelling the use of a non-dispersive foam (made of tiny, highly reflective microbubbles) over the ocean surface above the three subtropical ocean currents in the Southern Hemisphere found that precipitation levels would increase or be maintained in highly populated and heavily cultivated regions, particularly in regions dependent on monsoon precipitation (Gabriel et al. 2017). However, deployment of this technology at a large scale is presently infeasible. The impacts on fisheries and marine biodiversity were not assessed.

8. The authors used CESM CAM4-Chem model and RCP6.0 as baseline.

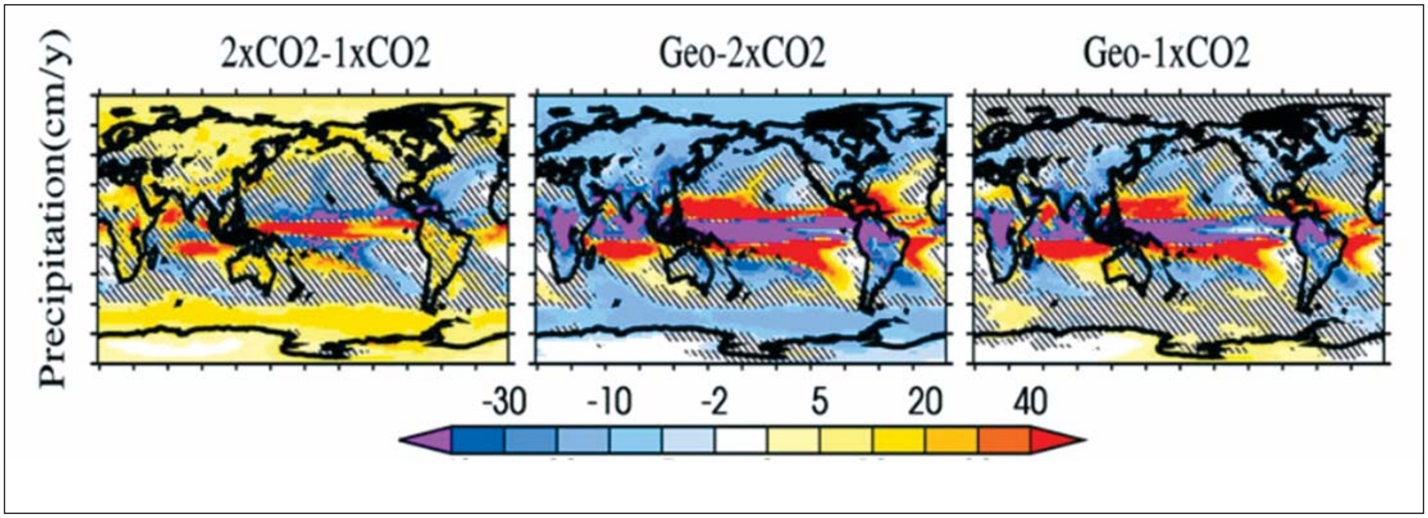

Figure 4. Changes in global and annual mean precipitation, due to doubled atmospheric CO_2 content (2x CO_2 - 1x CO_2), enhanced albedo (Geo - 2x CO_2) and geoengineered (Geo – 1x CO_2) cases. The grey-shaded areas indicate regions where the changes are not significant at 99 percent level of confidence. "1x CO_2" simulation refers to an atmospheric CO_2 concentration of 355 ppmv, and "2x CO_2" simulation to 710 ppmv. (Bala and Nag, 2012).

What happens when you stop SRM?

Several studies have pointed out that if SRM was suddenly halted, it would lead to a rapid temperature increase that could result in higher temperatures than before the intervention was deployed (referred to as "termination shock"). This would be more difficult for nature and society to adapt to than a gradual temperature increase.

One study used 11 different models to examine the changes in climate caused by a sudden halt after 50 years of reducing solar radiation to offset a one percent per annum increase in carbon dioxide concentrations (Jones et al., 2013). All the models agreed there would be a rapid increase in global mean temperature following the end of the intervention, accompanied by increases in global mean precipitation rates and decreases in sea ice cover. The models did not show a common impact on the rate of change of global mean plant NPP. But there was considerable agreement for the geographical distribution of temperature change, with faster warming at high latitudes and over land.

The best way to evade the shock from a sudden halt would be to avoid large amounts of SRM being needed to reduce climate risks (Parker and Irvine, 2018). Ideally, ambitious reductions in greenhouse gas emissions would eliminate the need for stratospheric injection.

How is biodiversity affected?

The indirect impacts of geoengineering are less studied. In particular, the biodiversity and ecosystem impacts of geoengineering are almost completely unexplored. One study compared biodiversity impacts looking at a moderate climate change scenario (RCP4.5), with rapid geoengineering interventions, followed by a rapid halt (Trisos, et al. 2018), using "climate velocities" as an indicator.

Climate velocities are the speeds and directions that species would need to move to try to survive changes in climate (see Figure 5). Compared to a moderate climate change scenario (RCP4.5), rapid geoengineering interventions would reduce temperature velocities towards zero (providing momentary relief to heat-stressed species such as corals) in terrestrial and marine biodiversity hotspots. In contrast, a sudden end to SRM would increase both ocean and land temperature velocities to unprecedented speeds that are more than double the temperature velocities for recent and future climate change. Temperature velocities at termination are most extreme in tropical oceans, the biodiversity-rich Amazon Basin, Africa, Eurasia and polar regions.

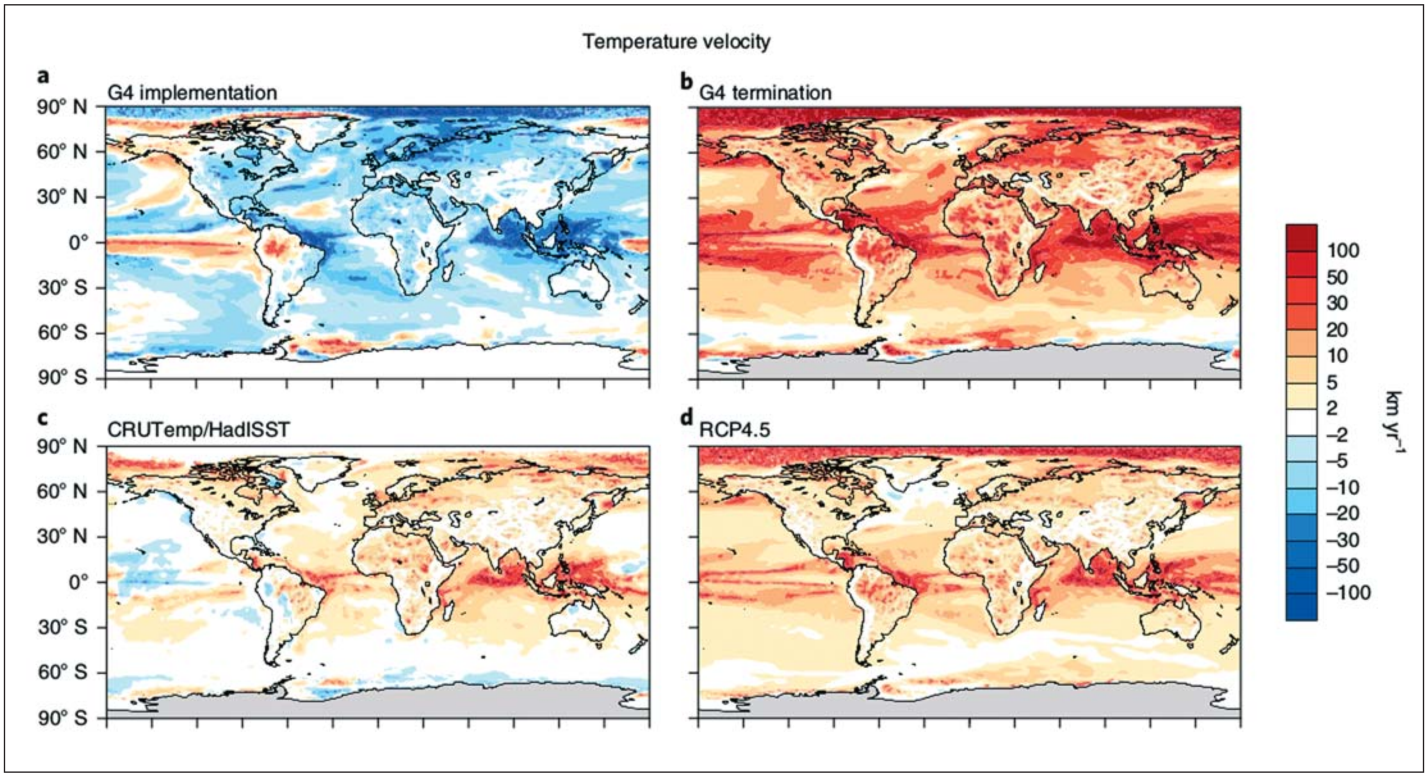

Figure 5. Temperature velocities for geoengineering implementation (a), termination (b), historical climate 1960-2014 (c) and RCP4.5 (d). (Trisos et al., 2018)

Compared to RCP4.5, an additional 32 percent of the Earth's surface was predicted to be exposed to high climate displacement (>10 km per year) from sudden SRM termination. Subtropical and northern temperate oceans, much of North America, Africa and Eurasia would be particularly affected. These regions were expected to face the most significant increases in local extinction risk from a sudden halt to SRM as species fail to adapt to faster moving climates (Trisos, et al. 2018).

In biomes where climate velocities more than doubled, rapid climate fragmentation occurred, with large differences for example between temperate grasslands and forests. Climate fragmentation means large and spatially divergent predicted changes in temperature and precipitation, resulting in species being unable to move in response to changes in climate.

Halting geoengineering interventions would significantly increase the threats to biodiversity from climate change. Temperate grasslands, temperate forests and Mediterranean-type biomes are most exposed to this increased speed of climate fragmentation because in these regions a more rapid divergence in temperature and precipitation conditions could increase local extinction probabilities as species' climate niches (i.e., the climate needed by a species to survive) fragment (Trisos et al., 2018), see Figure 6.

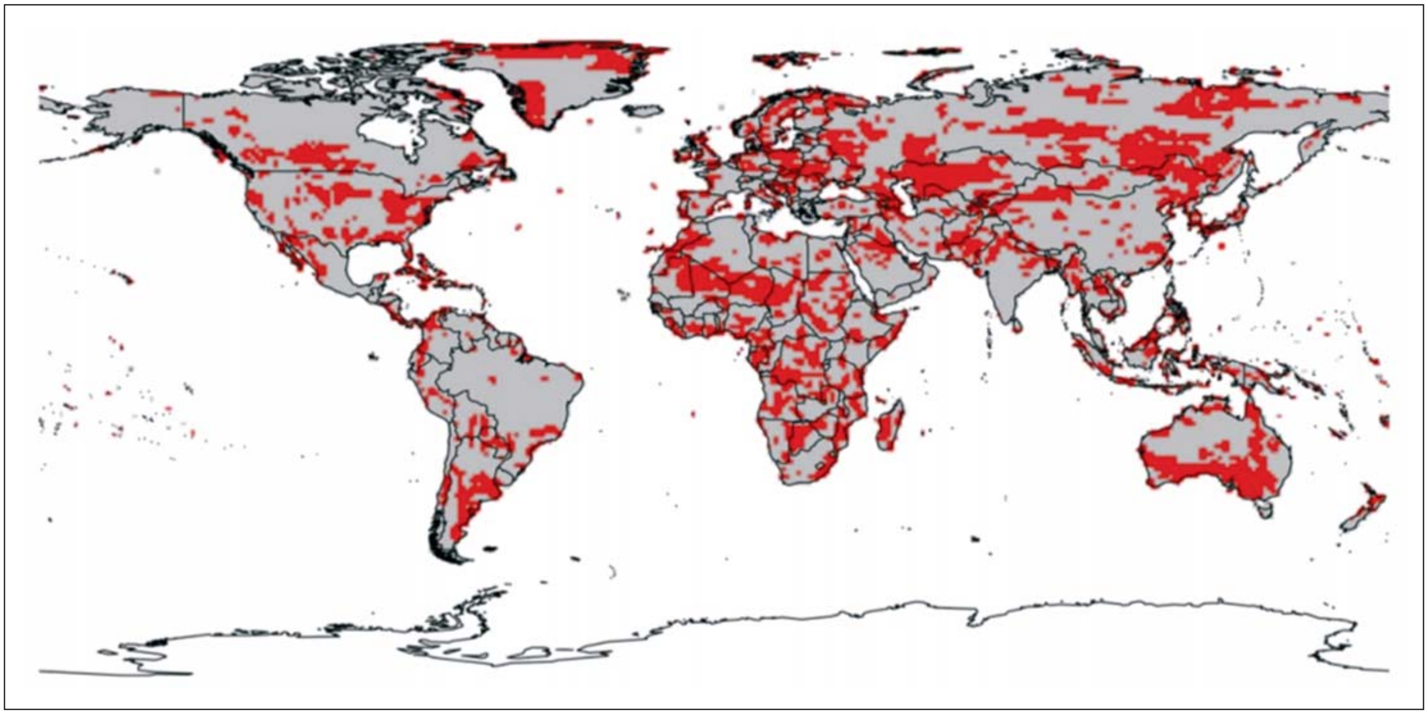

Figure 6. Relative increase in climate fragmentation risk with sudden termination of geoengineering. Red indicates regions that are both (1) where G4 termination velocity speeds for both temperature and precipitation are double or more than double RCP4.5, and (2) where G4 termination velocities for temperature and precipitation diverge in direction by >90° (Trisos et al., 2018).

Researchers found that as geoengineering continued, temperature velocities were not further reduced, even though temperature increases were offset. This means that a geoengineering intervention would only offer momentary relief (during the first decades of stratospheric injection), after which species would face similar temperature velocities. Across terrestrial and marine biodiversity hotspots, sudden termination results in extreme temperature velocities that are two to four times faster than those based on either historical data or future climate change.

Most of Earth's biodiversity resides in the tropics. For tropical species that are sensitive to temperature change, even relatively small amounts of warming threaten their survival (McCain et al., 2011). Tropical species are more sensitive to temperature than their temperate counterparts and often live near or above optimal temperatures, making climate tracking more important for their survival. A halt to geoengineering interventions would therefore represent a potentially acute threat to species survival in the most biodiverse regions on Earth (Trisos et al., 2018).

Conclusions

In the last few years, the scientific community has developed more and better computational models to evaluate the possible impacts of geoengineering at global and regional levels. Most of these models agree that at a global level, SRM could reduce temperatures, but that it would not prevent the melting of the ice caps at the North and South poles, or the resulting rise in sea levels.

The great majority of the models indicate that the average precipitation at planetary level and particularly in Latin America will decrease as a result of an SRM intervention compared to a climate change scenario. Any extended period of low precipitation in this region could have damaging impacts on agricultural and energy sectors, as well as on the livelihoods of billions of people.

The Amazon Basin (northeastern South America) is expected to see particularly dramatic effects on rainfall patterns from the deployment of SAI and other albedo enhancing schemes, with potentially catastrophic regional-scale ecological and socioeconomic consequences.

Recent peer-reviewed studies on SRM – briefly presented in this document – indicate strong consensus that there are vast regions of the planet in which SAI would be harmful and ineffective, with damaging impacts concentrated in the tropical and subtropical regions.

Model uncertainty is still a crucial issue to evaluate SRM proposals, particularly in aspects related to precipitation, Net Primary Production of ecosystems and ocean acidification. These shortcomings directly affect the confidence and credibility that can be given to the effectiveness of the proposed geoengineering approaches as well as the reliability of long-term projections about its effects.

Recent peer-reviewed studies on SRM – briefly presented in this document – indicate strong consensus that there are vast regions of the planet in which SAI would be harmful and ineffective, with damaging impacts concentrated in the tropical and subtropical regions.

Notwithstanding, most or even all models on proposed SRM schemes show significant and unequal impacts. Given the importance of rain and vegetation for human societies, living species, cultural and biological diversity, this lack of knowledge should lead to a strict application of the precautionary approach to avoid greater future risks.

Furthermore, the changes resulting from the sudden ending of geoengineering interventions would be highly damaging for biodiversity, as the scope for biological adaptation would be very much reduced. In addition, halting geoengineering interventions represents a potentially acute threat to species survival in the most biodiverse regions on Earth. The predicted climatic changes caused by "termination shock" are likely to increase the probability of local extinctions as species' climate niches are fragmented.

An SRM geoengineering intervention offers only momentary relief (during the first decades of stratospheric injection) for heat-stressed species, after which dispersal rates to keep pace with climate change are predicted to be similar to a moderate climate change scenario. So, in terms of biodiversity there are more warnings than benefits. The impacts on biodiversity and environmental consequences are poorly explored and a significant lack of knowledge remains.

Given the risks for Latin American countries described in this briefing, governments should strengthen the precautionary approach established in the CBD de facto moratoria and consider broadening the moratoria to a ban on Solar Radiation Management to prevent a group of powerful countries from continuing to develop and eventually deploying geoengineering with catastrophic consequences for the continent.

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