Quarterly Review I (part 2): Solar radiation management – new field trials, research projects and funding – and growing opposition

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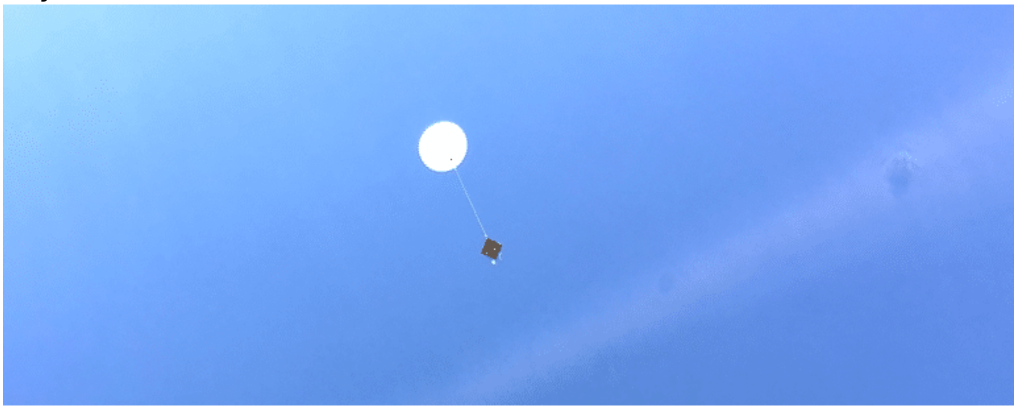

By Anja Chalmin

Part two of this first quarterly review 2022 looks at new plans and funding for solar radiation management (SRM) field trials and research activities – and there are even ideas that stretch into space. Currently, five SRM field trials are known and in planning. In addition, numerous research projects intend to further explore and develop SRM. And this despite the fact that the IPCC (Intergovernmental Panel on Climate Change) warned again strongly against the use of SRM approaches, e.g., because the proposals are associated with large uncertainties and knowledge gaps, could trigger devastating side effects and pose new risks to international cooperation and peace. It is therefore not surprising and vitally important that more and more parties are calling for a halt to SRM research and SRM field trials.

Weather modification (WM) is considered a precursor technology to SRM and believed to have only local or regional impacts. One of the common features of SRM and WM is that particles are to be introduced into the atmosphere. 70 years of experience with WM technology show that – compared to SRM – even small-scale atmospheric intrusions are unmanageable and may result in conflicts.

Whether solar radiation is to be controlled in the Earth's atmosphere or in space, neither SRM approaches nor space-based geoengineering have an answer to the causes of global warming, the increasing concentration of greenhouse gases in the Earth's atmosphere.

Solar radiation management – opposition to and concerns about the

use of these risky and unproven geoengineering proposals continue to grow

Solar radiation management (SRM) describes a series of theoretical proposals that attempt to reflect solar or thermal radiation back into space to suppress a temperature rise in the Earth's atmosphere. SRM proposals include Stratospheric Aerosol Injections (SAI), Marine cloud brightening (MCB) and cirrus cloud thinning (CCT). SAI aim to control the amount of incoming solar radiation. MCB and CCT attempt to influence the Earth's radiation balance through changes in cloud cover.

A precursor technology to SRM, weather modification (WM) is believed to have only local or regional impacts. One of the common features of SRM and WM is that particles are supposed to be introduced into the atmosphere. After 70 years of field trials and deployment of WM technology, its use has already led to regional conflicts and bilateral disputes, many interactions with the abiotic environment remain unclear, and there are no statistically validated results demonstrating significant effectiveness. Although SRM approaches, compared to WM, usually involve much larger-scale and longer-term measures, SRM proponents envision and plan SRM field trials and further research on SRM. But if WM is already unmanageable at the regional level and leads to conflict, where will SRM lead?

In addition, a look at the agendas of research institutions that deal with topics related to meteorology and climate reveals how many questions about weather and climate processes are still unanswered. Some of these questions include physical processes, research questions about cloud formation and processes in clouds, questions about the influence of clouds on weather and climate or the aerosol composition in the troposphere and stratosphere.

Dietmar Dommenget, an associate professor at the School of Earth Atmosphere and Environment at Monash University works on the topic of climate change and warns: "*climate is quite chaotic – there is chaos in the system that cannot be predicted. […] The only thing it is safe to say is we should be careful, we should be assuming the worst – we don't know if it will happen, but we should assume the worst.*"

Voices pointing out the uncontrollable risks associated with SRM and speaking out against the use and further development of SRM approaches are becoming increasingly numerous and increasingly loud.

A recent IPCC report (Working Group II contribution to the Sixth Assessment Report of the IPCC), published in February 2022, warned again strongly against the use of SRM approaches because

- a change in solar radiation would not stop the rise of CO_2 concentration in the atmosphere, because it does not address the root cause of climate change. SRM would only "*mask*" the temperature rise, while, for example, the oceans would continue to acidify;
- SRM technologies lead to new threats to people and ecosystems that are not well understood – the technologies are associated with large uncertainties and knowledge gaps;
- SRM could trigger devastating side effects, e.g., altered rainfall patterns, increased flood and drought risk, ozone layer depletion, threats to biodiversity, ecosystems and human health;
- SRM may pose new risks to international cooperation and peace, e.g., due to conflicting temperature preferences;

- of the termination effect: This effect occurs when SRM is used while the CO_2 concentration in the atmosphere continues to rise. If the use is suddenly and permanently interrupted, rapid warming with significant negative impacts is predicted.

In January 2022, a group of more than 60 concerned senior climate scientists from around the world called for an international solar-geoengineering non-use agreement, as SRM poses unacceptable risks if ever implemented. This global call has since been endorsed by more than 320 scientists from the Global South and the Global North. The non-use agreement calls for banning SRM funding, prohibiting SRM outdoor experiments and restricting research on SRM technologies, including supporting technologies. Frank Biermann, et al., have detailed the arguments for a non-use agreement, against a normalisation of SRM and the core elements of the proposed international non-use agreement on SRM in a scientific paper. In January 2022, Frank Biermann explains why even well-intentioned research should also be banned: "*They [solar geoengineering researchers] engage in a highly risky project that they will not be able to control and master. Eventually, other powerful actors will take over. At present, the genie is still in the bottle. Don't let it out*."

In March 2022, more than 340 organisations sent a global call for climate action to governments, and the IPCC, calling for a rapid phase-out of fossil fuel production and use in order to avoid dangerous temperature overshoot. They also called for recognition of the fact that the deployment of SRM, as well as other large-scale geoengineering proposals, will cause irreversible damage to people and nature.

In addition to international pressure, there is also opposition to SRM on the ground, e.g., at sites selected for SRM field trials: in 2021, a planned series of trials to test SAI technology over indigenous territory in Kiruna, Sweden, was cancelled after protests by the Saami Council and environmental groups.

Solar radiation management – currently known and planned field trials

While warnings against the use and further development of solar radiation management (SRM) grow stronger, there are still efforts to further develop SRM approaches and to conduct field trials. Below is an overview of the (known) research groups and companies currently attempting to conduct SRM field trials. Thereafter, there are further details on the individual trials.

Figure 1: Locations of known planned SRM field trials (if available)

No.	Planned outdoor trial	Type of SRM	Organizer	Location & time (if available)	Scale (if available)
1	SCoPEx (Stratospheric Controlled Perturbation Experiment)	SAI	Harvard University	not yet decided, but "the group *hopes to launch the balloon in mid-2022*"	probably similar to the last attempt
2	Great Barrier Reef MCB trial(s)	MCB	Research team led by Southern Cross University	2022 (details not available to the public)	not available to the public
3	MCBP (Marine Cloud Brightening Project)	MCB	Washington University & further research partners	not available	"small-scale, controlled field experiments"
4	MCB with sea water	MCB	Stephen Salter (Edinburgh University) & CCRC	not available	plans to construct a prototype vessel
5	Iron Salt Aerosol Method	MCB	gM-Engineering	location: Bass Strait, time: not available	30-day field trial

MCB – Marine Cloud Brightening;
SAI – Stratospheric Aerosol Injection,
SRM – Solar Radiation Management
CCRC – Centre of Climate Repair

No. 1: SCoPEx (Stratospheric Controlled Perturbation Experiment)

The SCoPEx project is conducted by Harvard University and part of Harvard's Solar Geoengineering Research Program (SGRP). SCoPEx involves research, modelling and plans to conduct field trials for testing Stratospheric Aerosol Injections (SAI). The trials aim to scatter particles from a balloon at a height of 20 kilometres above the Earth. In implementing the field tests, three attempts have failed so far – at two sites in the USA, New Mexico and Arizona and at a test site in Sweden. Late last year, SCoPEx' principal investigator, Frank Keusch, expressed confidence that a new balloon partner and launch site would be found and stated that the SCoPEx research group hopes to start the planned field trials in mid-2022.

No. 2: Great Barrier Reef MCB trials

This series of experiments to test marine cloud brightening (MCB) in the open ocean began in March 2020 and is conducted by a research team led by Daniel Harrison, Southern Cross University. Data on the implementation is scarcely available to the public – the 2020 trial and details of its implementation were only published a month after its completion. After this first trial in the open ocean, the research team announced that further open ocean trials would follow in subsequent years with a trial area of up to ~400 km². In August 2021, Nature reported that the research group conducted another MCB field trial some 100 kilometres offshore in March 2021. To date, no information about the exact location, size of the test area or duration of the trial is publicly available. The same article reports that the Harrison team estimated that MCB can reduce incoming solar radiation over the Great Barrier Reef by about 6.5 % – but this would require 800 to 1,000 machines for MCB, each with about 3,000 nozzles to generate particles for cloud brightening. Last August, yet another MCB trial was announced for 2022. Since the two preceding trials were both conducted in March, at the end of the Australian summer, it is entirely possible that this year's trial has already taken place – again out of public view. In parallel to the field trials in the open ocean, the research team conducts research on MCB. For example, in March 2022, the University of Sydney announced PhD positions to study nozzle technology for MCB and to simulate MCB. Funding for MCB trials and research was secured in January 2022 for the period from 2022 to 2030, as the Australian government has provided one billion Australian dollars of funding to the Great Barrier Reef. Of this amount, 92.8 million will go to the Reef Restoration and Adaptation Program (RRAP) – MCB is one of the approaches being investigated under the RRAP. The Australian MCB project receives technical support from the U.S. Marine Cloud Brightening Project.

No. 3: MCBP (Marine Cloud Brightening Project)

The Marine Cloud Brightening Project (MCBP) was founded as 'Silver Lining Inc.' and renamed twice – to 'Silver Lining Project' and MCBP. The MCBP is a collaboration between the University of Washington, the Pacific Northwest National Laboratory (PNNL), a team of engineers from Silicon Valley, the Palo Alto Research Centre and other research partners. Kelly Wanser has been the project's executive director for most of the time; Robert Wood took over this position in ~2020. Since then, Kelly Wanser has continued to be a member of the MCBP leadership team, while also leading the organisation Silver Lining, which provides financial and advocacy support to the MCBP as well as MCB and SRM in general. A decade ago, after the most recent name change, the project announced multi-month and large-scale trials off the Californian coast and in the Northeast Pacific. These were not implemented due to lack of funds and public opposition. In September 2021, the MCBP has once again made a proposal to conduct field trials and proposed to conduct "*small, controlled field trials*". Details on the implementation have not yet become public.

No. 4: MCB with sea water

Stephen Salter of the University of Edinburgh has been conducting research on Marine Cloud Brightening (MCB) for many years. Salter's MCB proposal envisages wind-powered ships shooting jets of water into the sky, creating a mist of water droplets. He hopes to push the technology further and test it in the open ocean. So far, this has failed due to lack of funding. In 2021, the Centre of Climate Repair in Cambridge (CCRC) has agreed to support the design and construction of a prototype and one can probably assume that it will be tested then as well. Details on the implementation of the collaboration are not yet publicly available.

No. 5: Iron Salt Aerosol Method

The German company "gM-Engineering" proposes the use of iron-salt aerosols (ISA), aiming to combine marine cloud brightening (MCB), methane removal and ocean fertilisation. ISA is intended to enter the atmosphere, for example, by being added to exhaust gases. The introduction of ISA into the troposphere (lower atmosphere) is then initially intended to promote cloud formation by providing condensation nuclei (MCB). In the air, ISA is also supposed to initiate oxidation processes that break down the greenhouse gas methane. Later, the iron-containing ISA is eventually washed out of the atmosphere into the ocean, aiming to promote the growth of marine algae through iron fertilisation. gM-Engineering is led by Franz Oeste, a chemical engineer. In 2019, gM-Engineering announced a thirty-day field trial with ISA in Bass Strait, north of Tasmania. However, this trial has not yet been conducted. The company has been seeking funding for the field trial since ~2017, continues to seek funding and is apparently "*in early discussions with the Australian local Government to plan an initial trial off the Bass Strait between the south coast of Australia and Tasmania*".

What most of the trials have in common is that they will be (or have been) carried out as far as possible without revealing information to the public. This non-transparent behaviour highlights the need for the recently proposed international solar-geoengineering non-use agreement. Most of the projects have already made several attempts to perform field trials and so far only the Australian project has carried out the planned MCB trials. In the past, there have been repeated renaming's of projects after planned trials have failed – to acquire new funding and promote field trials under a new name – the MCBP represents one of these projects.

Solar radiation management – recent developments in research and funding

The UK-based The Degrees Initiative (former Solar Radiation Management Governance Initiative (SRMGI))launched the DECIMALS Fund (Developing Country Impacts Modelling Analysis for SRM) in 2018. DECIMALS provides funding to enable researchers in the Global South to model SRM approaches and analyse the potential impacts of SRM on their regions. In 2018, eight research teams shared US$ 0.43 million in funding. In 2022, the annual budget increased to US$ 1 million and the number of research teams increased to eleven – based in Argentina, Bangladesh (two teams), Benin, Indonesia, Iran, Ivory Coast, Jamaica, Kenya, Philippines, and South Africa.

Table 2: Research supported by the DECIMALS Fund -research topics addressed

Country	Research activity	Research topic
Argentina	Modelling SRM	Hydrological impacts of solar radiation management in the La Plata Basin in South America (since 2018, a publication is not yet available)
Bangladesh	Modelling SRM Modelling SRM	Modelling possible impacts of SRM on temperatures, rainfall and the transmission of diseases as malaria (since 2018, a publication is not yet available); Assessing the impacts of SRM on hydrology in Bangladesh (since 2022)

Benin	Modelling SAI, using GLENS data	Da-Allada, et al. (2020): Changes in West African Summer Monsoon Precipitation Under Stratospheric Aerosol Geoengineering, in Earth’s Future, https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2020EF001595
Indonesia	Modelling SAI, using GeoMIP data	Kuswanto, et al. (2021): Impact of solar geoengineering on temperatures over the Indonesian Maritime Continent, in International Journal of Climatology, https://rmets.onlinelibrary.wiley.com/doi/10.1002/joc.7391
Iran	Modelling SAI, using GLENS data	Karami, et al. (2020): Storm Track Changes in the Middle East and North Africa Under Stratospheric Aerosol Geoengineering, in Geophysical Research Letters, https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2020GL086954
Ivory Coast	Modelling SAI, using GeoMIP data	GeoMIP-Africa: impact of SAI on temperature and precipitation extremes over West and Central Africa and implications for water resources (since 2018, a publication is not yet available)
Jamaica	Modelling two SAI scenarios, GeoMIP data	Clarke, et al. (2021): The Caribbean and 1.5 °C: Is SRM an Option?, in Atmosphere, https://www.mdpi.com/2073-4433/12/3/367
Kenya	Modelling SRM	Impacts of SRM on extreme rainfall and urban floods in East Africa (since 2022)
Philippines	Modelling SRM	Impacts of SRM on agriculture: the Southeast Asian case (since 2022)
South Africa	Modelling SAI, using GLENS data	Odoulami, et al. (2020): Stratospheric Aerosol Geoengineering could lower future risk of ‘Day Zero’ level droughts in Cape Town, in Environmental Research Letters, https://iopscience.iop.org/article/10.1088/1748-9326/abbf13
	Modelling SAI, using GLENS data	Pinto, et al. (2020): Africa’s Climate Response to Solar Radiation Management With Stratospheric Aerosol, in Geophysical Research Letters, https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2019GL086047

Degrees says of itself that it takes a neutral stance on SRM: “*Degrees is neutral on SRM and does not take a position on how any research should be governed or on whether SRM geoengineering should ever be used. Instead, we believe that broadening the international conversation, in particular by bringing in more voices from the Global South, will strengthen humanity’s ability to handle the issue prudently and equitably.*” However, the funded DECIMALS projects all work in the same thematic field – they all model the deployment of SRM. The basis for the modelling is provided by climate models created in the Global North GeoMIP (Geoengineering Model Intercomparison Project) and GLENS (Geoengineering Large Ensemble). Duncan McLaren comments on the DECIMALS research portfolio as follows: “*Unfortunately while the topics of investigation have been defined by Southern partners, the models, norms, and practices applied in DECIMALS remain primarily those of the dominant Northern research community*”. Laurence Delina adds that DECIMALS has also narrowed down the choice of research topics: “*very little to zero funding was made available to other experts, particularly in policy, social sciences, and the humanities, despite their interest in doing the work*”.

In late 2019, **the US government decided to provide funding** to the National Oceanic and Atmospheric Association (NOAA) for research on SRM. The budget was allocated for studying the stratosphere, “*including the impact of the introduction of material into the stratosphere from changes in natural systems, increased air and space traffic, proposals to inject material to affect climate, and the assessment of solar climate interventions*“. For the current year, NOAA has been allocated US$ 11 million (for comparison: US$ nine million in 2021, US$ four million in 2020).

The FICER fund (Fund for Innovative Climate and Energy Research) is financed by Bill Gates and is administered by David Keith (Harvard University) and Ken Caldeira (Carnegie Institution for Science). FICER was created to support projects addressing research questions related to geoengineering, e.g., modelling SRM. The fund supported geoengineering projects, such as the Marine Cloud Brightening Project (MCBP) and the Stratospheric

Controlled Perturbation Experiment (SCoPEx). The FICER fund has thus also supported projects that have been planning to conduct SRM field trials for some time. The website now states that projects funded by FICER should not carry out field tests: „*FICER has not supported and will not support any field tests of methods that introduce new kinds of interference into the climate system (e.g., solar radiation management, ocean fertilization)*". However, this does not rule out indirect funding, e.g., preparatory laboratory tests. For several years, the fund's website has reported the same total amount of funding – US$ 8.5 million. It remains unclear whether additional funds have not been provided in recent years or whether the figure has not been updated.

Researchers from the **Institute for Atmospheric and Climate Science at ETH Zurich** have completed a modelling study on Cirrus Cloud Thinning (CCT). The study concludes that CCT is not practical on a global scale, but encourages further research for selected target regions. CCT is a hypothetical SRM proposal which aims to eliminate or thin cirrus clouds to allow heat to escape into space. As with all solar geoengineering technologies, CCT could lead to unpredictable side-effects, including large regional and seasonal changes to precipitation. Even if the use is limited to the regional level, negative effects, for example on neighbouring regions, can still not be ruled out.

The Washington-based organisation Resources for the Future (RFF) initiated the RFF Solar Geoengineering Research Project in 2021. The project aims "to fund research on the risks, benefits, and uncertainties of solar geoengineering" and has selected eight research teams, most of which are conducting modelling studies on solar radiation management. The research team at the Indian Institute of Science is exploring strategies to promote solar geoengineering research in India. Researchers at the University Islamabad plan to conduct a survey to investigate attitudes towards solar geoengineering in developing countries. The teams are expected to submit research papers for publication in peer-reviewed journals by November 2022.

The Mirrors for Earths Energy Rebalancing (MEER:ReflEction) project was recently featured in various media. MEER is based at Harvard University, directed by Ye Tao and was launched in 2019. The project aims to explore methods to reflect solar radiation back to space and proposes the use of large mirrors to increase the Earth's albedo (reflectivity). The project is modelling the deployment of vast arrays of aluminum-coated glass mirrors on water and on land. Not all solar radiation should be reflected – a part of the radiation is to be concentrated and redirected to use solar energy for agriculture and renewable energy. A timetable for the application is also already in place: "*We find it feasible and necessary to deploy the mirror arrays within single-digit years to fully rebalance Earth's energy*".

Solar radiation management – space-based proposals

Space-based geoengineering aims to control the amount of incoming solar radiation. Thus, like other solar radiation management geoengineering projects, it also has no answer to the causes of global warming, the increasing concentration of greenhouse gases in the Earth's atmosphere. The approaches explored are all models of a hypothetical nature. What all space-based proposals also have in common is that the incoming solar radiation is to be reduced by erecting a structure between the sun and the earth. More than half of the known research projects on space-based geoengineering aim to establish the structure between the Earth and the Sun at the so-called Lagrange point L1. Lagrange point L1 is a point in space between the Earth and the sun where the gravitational forces of the planet and the sun virtually neutralise each other. The point is 1.5 million kilometres away from the Earth, which means that this branch of geoengineering is limited to modelling for the time being.

In 2021, **OHB System AG, a subsidiary of the German OHB SE**, established a consortium to research space-based geoengineering. The consortium includes eight research institutes from five countries: University of Bremen and Alfred Wegener Institute Bremerhaven (Germany), Cranfield University (UK), TU Delft, NHL Stenden and University of Utrecht (the Netherlands), University of Patras (Greece) and the University of Applied Sciences Wiener Neustadt (Austria). The consortium proposes to place spacecrafts between the sun and the Earth, where they will act as solar shields. Under the proposal, thousands of spacecrafts, e.g., 30,000, would have to reach the Lagrange point L1. Once at this point, each spacecraft unfurls a 100 km^2 sail. All the sails together are to form a huge umbrella that floats between the Earth and the sun.

The Oregon-based Planetary Sunshade Foundation, founded by Ross Centers in 2020, has also suggested installing a planetary sunshade at the Lagrange point L1. The sunshade, in the form of a giant solar sail, is supposed to reflect sunlight back into space and block some of the sun's energy. According to Planetary Sunshade, the sail needs to be one million square kilometres in size to cool our planet by one degree. Planetary Sunshade is modelling two design strategies: 1.) Building solar sails on Earth, e.g., using a thin layer of aluminium or silicon, and deploying the sails in space; 2) Using space resources, e.g., lunar and asteroidal material, to build the solar sails in space.

Since ~2002, **researchers at Glasgow University** have repeatedly explored concepts of space-based geoengineering. The approaches considered include placing a dust cloud captured near Earth's asteroids, or a large solar shield at the Lagrange point L1. The **Californian Lawrence Livermore National Laboratory (LLNL)** was among the first research institutions to explore space-based geoengineering. In 1989, James T. Early (LLNL) published the first study proposing a space-based solar shield at the Lagrange point L1. His study suggested the construction of a thin shield made from lunar materials – 2,000 km wide and 10 µm-thick. In 2006, Roger Angel, a scientist at the **University of Arizona**, proposed cooling the Earth with a cloud of ~16 trillion flying small spacecrafts, each 30 cm in radius. The cloud would be placed at the Lagrange point L1. Research on space-based geoengineering is also underway **in China** – Jie He, Xi'an Aeronautical University and Fei Zheng, Xidian University modelled and proposed placing a giant parasol in space to reduce the average global temperature by a third of a degree Celsius. In 1992, the **California-based National Academy of Sciences** published the proposal to place 55,000 mirrors in space, each with an area of 100 km^2. In 2002, the **company Star Technology and Research Inc.** researched *"the creation of an artificial planetary ring about the Earth to shade it and reduce global warming*". Theoretically the ring would consist of passive particles or controlled spaceships with parasols.