Engineering 9 (2022) 6–9

Contents lists available at ScienceDirect

Engineering

journal homepage: www.elsevier.com/locate/eng

News & Highlights

Solar Geoengineering to Reduce Global Warming—The Outlook Remains Cloudy

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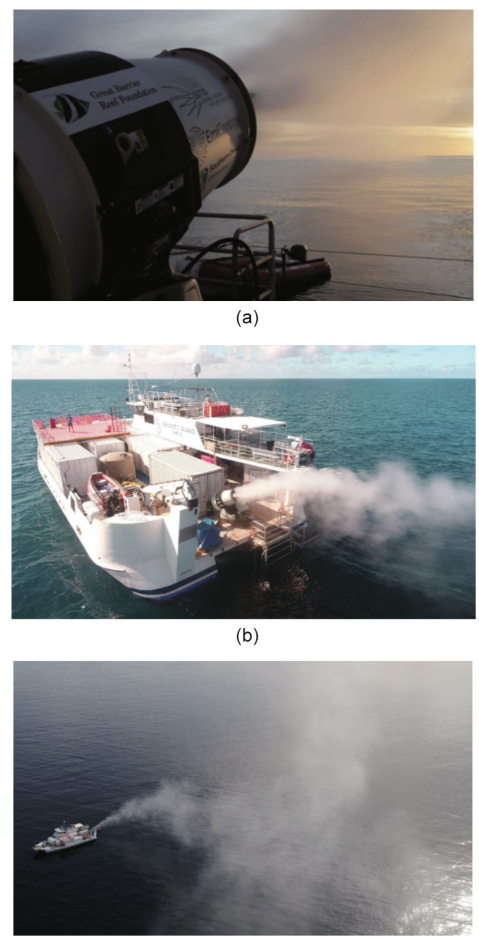
In March 2021, Australia's Great Barrier Reef played host to a rare field test of marine cloud brightening (MCB) technology. Blasting a seawater mist into the air from the aft of a research vessel using a turbine outfitted with novel spray nozzles, researchers watched the resulting white plume rise into the sky (Fig. 1) [1].

Over the last five years, the Reef has suffered multiple mass bleaching events because of ocean warming caused by climate change [2]. The MCB project, led by senior lecturer Daniel Harrison of Southern Cross University, Coffs Harbour, Australia, is part of the Reef Restoration and Adaptation Program [3], a government-backed research and development initiative that aims to "develop, test and risk-assess novel interventions to help keep the Reef resilient."

Harrison and team used drones and a variety of aerosol sensing equipment on a second vessel to study the behavior of the seawater mist they created. The amount sprayed was not sufficient to measurably perturb the clouds. But should the technology be further developed and scaled up, it could potentially bolster clouds above the Reef, making them more reflective to the Sun's rays and thereby providing a local cooling respite for the Reef's delicate ecosystem.

The researchers have yet to formally publish their results but were satisfied that as most of the sprayed seawater evaporated, significant amounts of the tiny salt particles left behind rose in the air to join the low clouds above. "In making these plumes over the Reef, one of our big concerns was that the cooling caused by evaporation might make the plume sink and flow along the ocean. That would be disastrous for the feasibility of the whole idea," said Harrison. "But we found that the plume rose in about 80% of our experiments, which was encouraging."

The work brought the nascent field of solar radiation modification (SRM)—or solar geoengineering—back into the headlines. Such work is rare, because field research with technologies designed to intentionally alter climate are politically and environmentally fraught and do not tend to attract funding. But as the outlook for climate change becomes increasingly concerning [4], there are small signs of a reappraisal of the potential of SRM to help mitigate the effects of climate change while policies to slash greenhouse gas emissions are gradually implemented.



(a) (b) (c)

Fig. 1. In a March 2021 field test of MCB on Australia's Great Barrier Reef, the research team used (a) a turbine with customised nozzle technology to (b) fire seawater mist into the air from the aft of their research vessel; (c) a photograph taken with a drone shows how the white plume rose into the sky. Credits: (a) Alejandro Tagliafico; (b, c) Brendan Kelaher, Southern Cross University, with permission.

https://doi.org/10.1016/j.eng.2021.12.005

SRM covers a handful of subcategories, with MCB and stratospheric aerosol injection (SAI) the most prominent examples. All operate on the principle that reflecting more sunlight back into space can create a cooling effect on the Earth below. With MCB, the wind carries fine particles sprayed over the ocean up into low, stratocumulus clouds, where they function as additional cloud condensation nuclei (CNN)—particles that moisture in the air requires to condense into clouds. Amplifying the number of CCN available for water to condense onto increases the reflective surface area, and therefore the brightness, of those clouds.

While much practical research has been performed over the decades into cloud seeding techniques to increase rain and snowfall [5]—essentially seeking the opposite effect of MCB—the potential of MCB is supported only by simulations because no intentional experiments have emitted sufficient particles to affect, or perturb, clouds for the explicit purposes of SRM. "Ship tracks," whereby low marine clouds brighten in streaks around the particulate pollution trails emitted by ships (Fig. 2), provide an example of inadvertent MCB—and, indeed, were the inspiration for the idea.

SAI, on the other hand, would require delivering aerosols—liquid or solid particles—into the stratosphere, where they would be distributed around the globe, forming a reflective layer high up in the atmosphere. What has happened in the wake of large volcanic eruptions well demonstrates the potential for SAI to cause planetary cooling. For example, the 1991 eruption of Mt Pinatubo in the Philippines spewed enormous amounts of hydrogen sulfide and sulfur dioxide into the stratosphere. The reflective sulfate particles which then formed lowered global temperatures by about 0.5 °C for at least a year [6].

Solar geoengineering is controversial, particularly because of the potential variety of unexpected or regionally problematic side effects from any large-scale implementation. "As a small-scale science experiment, cloud brightening is super interesting—not only in the context of geoengineering, but also to better understand the interaction of aerosols and clouds," said Professor Philip Stier, head of atmospheric, oceanic, and planetary physics at the University of Oxford, Oxford, UK. However, large-scale deployment is another issue altogether, he said. "You could deploy SRM and then realize you have changed the regional atmospheric circulation and the country next door suddenly suffers droughts. What is the governance of this? Who is responsible for the damage?"

Though the difference between small-scale, local testing of MCB and potential future large-scale deployment is vast, the research itself generates controversy [7,8]. "The ideological viewpoint of some is to oppose anything that intentionally tinkers with the climate system," said Sarah Doherty, senior research scientist at the University of Washington in Seattle, USA, and program manager for the Marine Cloud Brightening Project (MCBP), a national collaboration of atmospheric scientists and engineers that aims to advance the understanding of cloud responses to aerosol particles. "But then there is the more pragmatic viewpoint that climate change is happening, and significant warming is coming in the decades ahead. So, what is the portfolio of responses we might apply to reduce the risks?"

In their Great Barrier Reef field test, Harrison's team used MCBP-designed nozzles that eject seawater particles of a particular size range into the atmosphere at a very high rate (Fig. 3). The goal was to have the water evaporate quickly, leaving tiny salt particles in the air to act as CCN. The nozzle technology is the work of a group of retired engineers, led by prolific inventor Armand Neukermans, a pioneer of early inkjet technology, at the Palo Alto Research Center in California, USA. "We affectionately refer to them as the 'Old Salts,'" said Doherty. "These are engineers who are really concerned about the climate problem and, you know, their grandkids."

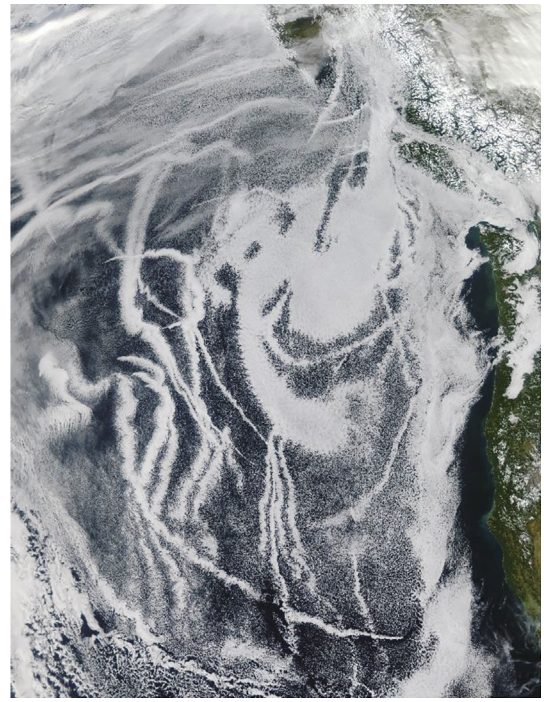


Fig. 2. The brighter streaks amid low marine clouds off the west coast of the United States are "ship tracks," created by the addition into the atmosphere of particles from ship-engine emissions. Credit: Jeff Schmaltz, Moderate Resolution Imaging Spectrometer Rapid Response Team, National Aeronautics and Space Administration/Goddard Space Flight Center (public domain).

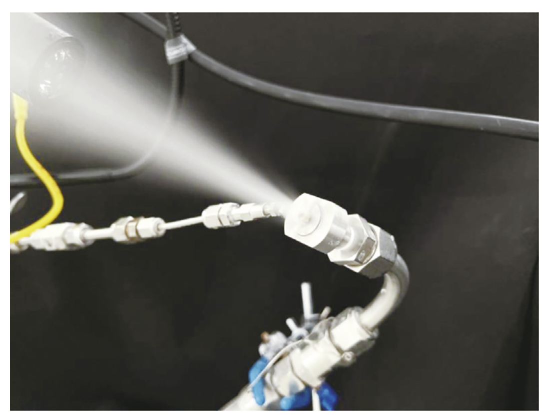


Fig. 3. The customized spray nozzle used in the MCB field test produces a high output of very small (~50 nm dry diameter) sea salt particles by creating a high-pressure two-phase flow mixture inside a small cavity and then ejecting the air and liquid droplets in a way that avoids the immediate collision and growth of particles to larger sizes. Credit: Palo Alto Research Center, with permission.

The size of the ejected particles is crucial for MCB. A cloud that consists of large numbers of smaller water droplets (created by smaller CNNs) reflects more than an otherwise similar cloud made up of larger droplets—a phenomenon known as the Twomey effect [9]. The MCBP team has determined that the spray system must create seawater droplets that will dry to salt crystals ranging from 30 to 100 nm in diameter [10]. Particles smaller than that will not act as CNN, and ones slightly larger would still work but less efficiently. "Anything significantly larger and you can actually induce precipitation in the clouds, resulting in cloud dimming as you lose water," Doherty said.

With field tests of the actual impact of the latest MCBP nozzle technology on clouds likely years away, the team's primary focus remains on high-resolution modelling of the aerosol/cloud interactions to better understand its potential effects (Fig. 4). Like with MCB, most work on SAI technology has been limited to simulations. Expensive and hard to fund, proposed experiments to release particles into the stratosphere also typically encounter stiff public opposition. In March 2021, for example, the public outcry halted a long-anticipated field experiment led by a Harvard University (Cambridge, MA, USA) team. The researchers had planned to float the Stratospheric Controlled Perturbation Experiment (SCoPEx) above Sweden's Esrange Space Center, within the Arctic Circle, with a high-altitude balloon. This first flight would not have injected anything into the air; its objective was to gain experience with the equipment. Nevertheless, researchers cancelled the test in response to concerns raised by stakeholders including environmentalists, scientists, and Sweden's Saami indigenous community [11].

The SCoPEx Advisory Committee recommended that "societal engagement should occur in Sweden" before proceeding with further work [12]. "While some people will always remain opposed, others may potentially come on board with the proposed research," said Sikina Jinnah, an associate professor of environmental studies at the University of California, Santa Cruz, CA, USA, who joined the SCoPEx Advisory Committee in May 2021. "It is important to put the time and effort into engaging with the public about the research and its social implications."

One of the problems for scientists working in this area, said Doherty, is that safe and small-scale basic research is frequently equated with actual deployment of SRM. "Before making any decisions about deploying these technologies, we will certainly need rigorous consultation. But that is wholly separate from doing the fundamental research needed to understand if this could actually work. In a lot of conversations, these distinctions are not being recognized."

Stier agreed and voiced what is known as the "moral hazard" argument against performing research on SRM and other geoengineering strategies: "If people thought politicians would interpret this sort of research cautiously, and that it would not detract from the deep emissions cuts that are really needed to curb climate change, then I think there would be much broader support for it. The worry is that this research will be misinterpreted as 'we do not need to do anything about emissions.'"

In March 2019, concerned nations introduced to the United Nations Environment Assembly a resolution aimed at gathering information and suggesting a preliminary governance framework for both SRM and direct carbon capture (DCC) technologies (see Ref. [13] for a report on recent DCC developments), but no agreement was reached [14]. "Governance is basically non-existent. And it is tricky because there currently is actually very little to govern," said Jinnah.

The political and cultural inertia around SRM might be starting to shift, though. For example, in early 2021, around the same time the SCoPEx flight in Sweden was shelved, the US National Academies of Sciences, Engineering, and Medicine released a report on solar geoengineering that called for 100 million–200 million USD in funding over five years to explore the feasibility of such interventions [15]. This budget, the report stated: "should be able to accommodate major field campaigns," though only if very strict criteria are met, including "that they can provide critical observations not already available and not likely to become available through laboratory studies, modeling, and experiments of opportunity (e.g., observing volcanic eruptions, rocket plumes, or ship tracks)."

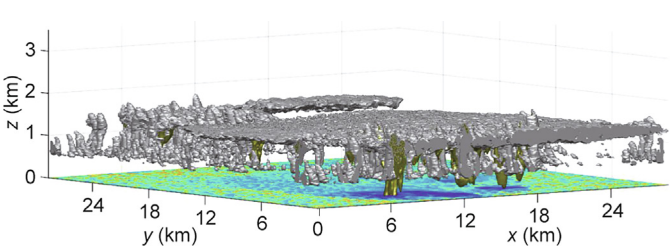


Fig. 4. A simulated cloud field generated from the high-resolution large eddy simulating model used by MCBP to study the effects on low marine clouds of spraying sea salt aerosol from below the clouds. The colors beneath the white/gray clouds represent sea-surface temperatures, with blue coolest and yellow warmest. The vertical yellow regions indicate precipitation. Credit: Peter Blossey, University of Washington, with permission.

Released in August 2021, the latest report of the Intergovernmental Panel on Climate Change called for urgent large-scale reductions in greenhouse gas emissions before limiting warming to close to 1.5 °C or even 2 °C is beyond reach. While the report recognized the potential of SRM to help achieve the goals of the Paris Agreement, it judged as "low" its confidence in the current research capacity to accurately inform policy considerations of the strategy [4].

This lack of confidence is not surprising, given the difficulties associated with securing funding and political backing for practical SRM research involving adding particles to the atmosphere. To date, that aspect of the research needed has effectively been barred, said Doherty, with federal funding agencies in the United States reluctant to support it.

For Harrison's work at the Great Barrier Reef, it took impending disaster to unlock the money, he said. "There is a clear and present danger. We know we are going to lose the Reef within the next couple of decades if we do not do something. Even the most optimistic projections on climate action will not be enough to preserve the Reef in its current form."

What will be required to unlock wider work in SRM science? "There is a disconnect between thinking about solar geoengineering in a problem-solving framework and recognizing at the same time that concerns about its potential dangers carry equal, if not more weight," said Jinnah. "Having those two things in opposition is very politically charged. Figuring out how to navigate these politics will be crucial if solar geoengineering is ever to have a practical future in the world."

References

[1] Tollefson J. Can artificially altered clouds save the Great Barrier Reef? Nature 2021;596(7873):476–8.

[2] Readfearn G. Great Barrier Reef's third mass bleaching in five years the most widespread yet [Internet]. London: The Guardian; 2020 Apr 6 [cited 2021 Oct 27]. Available from: https://www.theguardian.com/environment/2020/apr/07/great-barrier-reefs-third-mass-bleaching-in-five-years-the-most-widespread-ever.

[3] The Reef Restoration and Adaptation Program [Internet]. Brisbane: Reef Restoration and Adaptation Program; [cited 2021 Oct 27]. Available from: https://gbrrestoration.org/.

[4] AR6 climate change 2021: the physical science basis [Internet]. Geneva: Intergovernmental Panel on Climate Change; [cited 2021 Oct 27]. Available from: https://www.ipcc.ch/report/ar6/wg1/.

[5] Wang J, Yue Z, Rosenfeld D, Zhang L, Zhu Y, Dai J, et al. The evolution of an AgI cloud-seeding track in central China as seen by a combination of radar, satellite, and disdrometer observations. JGR Atmos 2021;126(11):2020JD033914.

[6] Parker DE, Wilson H, Jones PD, Christy JR, Folland CK. The impact of mount Pinatubo on world-wide temperatures. Int J Climatol 1996;16(5):487–97.

[7] Parson EA. Geoengineering: symmetric precaution. Science 2021;374(6569):795.

[8] Keith DW. Toward constructive disagreement about geoengineering. Science 2021;374(6569):812–5.

[9] Twomey S. Pollution and the planetary albedo. Atmos Environ 1974;8(12):1251–6.

[10] Murphy K, Cooper G, Doherty S, Wood R. Here's how we could brighten clouds to cool the earth [Internet]. New York City: IEEE Spectrum; 2021 Sep 7 [cited 2021 Oct 27]. Available from: https://spectrum.ieee.org/climate-change.

[11] Fountain H, Flavelle C. Test flight for sunlight-blocking research is canceled [Internet]. New York City: The New York Times; 2021 Apr 2 [cited 2021 Oct 27]. Available from: https://www.nytimes.com/2021/04/02/climate/solar-geoengineering-block-sunlight.html.

[12] SCoPEx Advisory Committee [Internet]. Cambridge: Harvard University; 2021 Mar 31 [cited 2021 Oct 27]. Available from: https://scopexac.com/march-31-2021/.

[13] O'Neill S. Direct air carbon capture takes baby steps—giant strides are needed. Engineering 2022;8:3–5.

[14] Jinnah S, Nicholson S. The hidden politics of climate engineering. Nat Geosci 2019;12(11):876–9.

[15] The National Academics of Sciences Engineering Medicine. Reflecting sunlight: recommendations for solar geoengineering research and research governance. Washington DC: The National Academies Press; 2021.