Geoengineering the Earth's Surface: Developments in making our planet more reflective

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This update on surface albedo modification summarises the latest developments on the Geoengineering Monitor Map, highlighting new trends for civil society and climate justice movements to follow in their efforts to oppose geoengineering globally.

*This update is Part Three of a four-part series on solar geoengineering, where we cover Solar Radiation Management projects at all distances between the Earth and the Sun: from the Earth's surface, through the clouds, into the stratosphere, and into outer space. It was researched and written by **Anja Chalmin**, and published with the support of the Geoengineering Monitor team.*

Critical developments covered in this update:

- Research and development into enhancing the Earth's surface reflectivity is centred around preserving and thickening glacial ice and snowcover, modeling the climate impacts of boreal forests, shading coral reefs to prevent bleaching and increasing the reflectivity of surfaces such as roofs.
- The Bright Ice Initiative is spreading large quantities of tiny glass spheres onto glaciers in the Indian Himalayas despite studies showing that this practice poses environmental risks.
- Huge and costly plastic fleeces that pollute the high mountains and the water cycle with microplastics are being used by the ski industry in numerous locations to cover glaciers and ski slopes to prevent melting, some of which are so large that they have to be transported by helicopter.
- Research into the climate impacts of deforesting or replanting boreal forests has recently been revived, with a new study showing that their climate interactions are actually much more complex than simply considering their albedo.
- A new project has recently been launched to develop various technologies capable of creating a layer of microbubles on the ocean surface to shade coral reefs, despite previous efforts failing to overcome serious technical challenges to this approach.
- The proposed sale of cooling credits to finance the installation of high-albedo surfaces such as white roofs is another example of the dangers posed by solar geoengineering offsetting schemes, especially when the environmental and energy costs are being ignored.

Surface albedo modification is a theoretical solar geoengineering technique that aims to reflect more sunlight back into space by increasing the reflectivity of surfaces that receive direct sunlight. Proposals span a wide range and include covering large areas of ice with reflective materials, clearing boreal forests in snow-covered areas, and adding reflective layers to the ocean surface — all with the common goal of increasing the Earth's albedo.

Creating large surfaces with a higher albedo could theoretically reduce surface temperatures. However, this would not reduce the concentration of greenhouse gases in the atmosphere, and even small-scale projects have negative impacts on ecosystems, which then affect the human communities that depend on them.

Geoengineering the Arctic and glaciers

The two most significant projects involving increasing the albedo of Arctic ice and glaciers are based on the same principle and approach, largely because they have the same founder. Whilst one recently closed down, the other, a spin-off from the first, is still conducting outdoor experiments aiming to increase the albedo of ice by covering it with a reflective material.

Arctic ice. Wikimedia Commons

Arctic Ice Project shuts down due to food chain impacts and lack of funding, USA and Canada

The Arctic Ice Project (AIP), founded by Leslie Field in 2007, proposed covering Arctic ice or land ice with a layer of floating, reflective material to slow the melting of the ice and/or restore it. The proposed cover material was a reflective silica glass, such as borosilicate glass, in the form of tiny hollow glass microspheres (HGMs). Since 2010, AIP had been testing HGMs at various outdoor test sites in the US and Canada. AIP's largest test site was North Meadow Lake near Utqiagvik (Barrow) in Alaska, which was highly controversial given that local community members were not consulted and never gave their consent to the experiments

Leslie Field proposed deploying the HGMs over an area of 100,000 square kilometers over the Beaufort Gyre, a major current with large amounts of sea ice in the Arctic Ocean. She estimated that this would require almost six million tonnes of HGMs for a single application, costing US$ 750 million (excluding labour), and that the material would need to be replenished annually.

In 2021, AIP announced a research collaboration with the Norwegian research institute SINTEF, which conducted laboratory tests to evaluate the performance of the HGMs in a simulated Arctic Ocean environment. These tests included ecotoxicological studies with key Arctic species and modelled how the material might disperse in the Arctic ecosystem. The assessments indicated that AIP's reflective material was "*likely to encounter and adversely impact key Arctic species*". Following the publication of this research, AIP announced in January 2025 that it was ceasing operations, which was widely welcomed by civil society groups. AIP cited increasing difficulties in securing funding as the reason behind the decision, but also stated that "*These financial barriers are compounded by broad skepticism toward geoengineering and resistance to introducing new materials into the Arctic Ocean*." In the lead-up to its closure, AIP had faced growing opposition from Indigenous communities and environmental groups concerned about likely harmful impacts on Arctic fauna, people and the environment.

Bright Ice Initiative's three-year field trial in the Himalayas, India

The Bright Ice Initiative (BII) was founded by Leslie Field after leaving the Arctic Ice Project (AIP) in 2022. It follows the same approach as the AIP by aiming to use a reflective material to slow the rate at which glaciers are melting and/or to restore them.

However, BII is ignoring the results of SINTEF's AIP risk assessment, as it continues to describe its approach as "*safe*" and the HGMs as "*eco-friendly*". Leslie Field appears to be employing the same communications strategy as she did during her time at AIP, by downplaying the risks of HGMs despite evidence to the contrary.

If deployed on a large scale in glacial areas, large quantities of HGMs would be washed away by rain or blown into glacial rivers and terrestrial ecosystems. Although the effects of this on water bodies and living organisms has not yet been researched, the vast quantity of HGMs involved mean that, adverse consequences are highly likely. In addition to ecotoxicological problems, the BII has also ignored a study that concluded that the glass microspheres may actually accelerate melting.

In September 2024, BII began a three-year field trial testing a reflective cover material on the Chhota Shigri Glacier in the Indian Himalayas with the permission of the Indian Ministry of Environment, which it had sought since 2022. The trial is being conducted in cooperation with the Department of Civil Engineering at the Indian Institute of Technology Indore and the Healthy Climate Initiative. BII previously conducted a two-month field trial on the Langjokull Glacier in Iceland in 2023.

Artificial snow management in glacial areas

Many projects are underway that aim to preserve glacial snow cover, either by covering them with plastic fleece or creating snow artificially. These are often small-scale operations carried out by the ski industry to protect its slopes, although some projects are being carried out on a larger-scale. These projects offer an insight into the likely effects of large-scale snow management schemes for albedo enhancement, and could be the precursor to geoengineering projects.

Snow management projects can have a significant environmental and landscape impact, even when deployed on a small-scale. For example, in Venezuela, scientists criticised government plans to cover the remnants of a glacier with polypropylene sheeting, due to concerns about microplastics and potential environmental impacts.

Furthermore, previous efforts have shown that these measures can only slow glacial retreat, but are unable to stop it. For example, a ski lift company that covered up to 6,000 square meters of the Zugspitze Glacier in southern Germany with fleece and truck tarpaulins abandoned the project because the area had become too small, despite the intervention. Such projects are also associated with high cost. For example, covering all of Switzerland's glaciers has been estimated to cost over one billion Swiss francs (1.1 billion Euros) each year.

Helicopters are used to transport huge plastic sheets in the Swiss Alps

The Gurschen Glacier in Andermatt was the first in Switzerland to be covered by plastic fleece blankets. Since 2005, the covered area has grown from 2,500 to 17,000 square meters. The plastic fleece sheets are now 70 meters long and five meters wide, and sandbags and water hoses are used to hold the fleece in place. The covering maintains a snow depth of around two metres, and in spring wet fleeces are flown down to the valley by helicopter for drying and storage given that each one can weigh up to 800 kilograms when wet. Ski lift companies in the Swiss Alps are also covering the Titlis Glacier with UV-resistant reflective white plastic fleece to shield it from the summer sun. According to the operators, this prevents around two meters of snow from melting. The fleece sheets cover an area of 90,000 square meters, are 50 meters long, six meters wide, and weigh 150 kilograms when dry. Once laid out, the sheets of fleece are sewn together on site using a sewing machine, and two 50-metre-long hoses are filled with water and placed at the edges to ensure that the fleece stays in place in windy conditions. Deploying and clearing away the cover requires approximately ten employees and takes several days.

Snow management in the Austrian Alps is material-intensive and generates a lot of waste

In 2003, Austrian mountain ski lift companies started wrapping numerous glaciers in commercially important areas of the Tyrolean Alps with fleece to slow the melting of ski slopes. Storing snow in snow depots has also become common practice in the region, for example, on the Stubai and Kitzbühel glaciers. Remaining snow is gathered and taken to a depot, where snow piles are shaped into trapezoids and compacted by snow groomers. The piles are then insulated with rigid foam boards and covered with a layer of silo film, which protects the snow from penetrating water. Finally, a non-recyclable reflective fleece is applied, which costs two Euros per square meter, and needs to be replaced approximately every two years, after which it is incinerated.

Synthetic geotextiles are being used to extend the ski season in Italy

The Presena Glacier in northern Italy has lost two-thirds of its volume since the 1960s. Since 2008, companies that are economically dependent on the glacier have been covering ski slopes with large reflective geotextiles to limit summer melt, allowing the ski season to start earlier and last longer. The geotextiles are petroleum-derived and can only be used for about two years. They are stitched together to prevent warm air from entering under them and are covered with sandbags to hold them in place. In 2025, 120,000 square meters of glacier surface was covered, at an annual cost of 200,000 Euros, requiring eleven workers and taking one and a half months to install and remove.

Fleece blankets pollute mountains and aquatic ecosystems with microplastics in Switzerland

Since 2008, mountain ski lift companies have been covering sections of the Diavolezza Glacier in Switzerland with fleece blankets, made of white plastic, to shield it from the summer sun. On average, this preserves 50 to 60 percent of the underlying snow. Covering usually begins in May and the fleece is removed in September, requiring heavy machinery (snow groomers) and a large number of employees, and is repeated year after year.

Operators have been criticised for causing microplastic pollution in the high mountains due to the polypropylene material that is used, which is often left frozen to the snow when the cover is removed. This results in polypropylene fibers being torn off and, as the ice melts, the fibers enter the water cycle. In 2022, the Academia Engiadina research centre tested and compared alternative materials such as wood wool, hemp fiber fleece and polylactide with a reference area covered with polypropylene and investigated whether glaciers can be covered manually, without machinery. However, the new approaches do not seem to have prevailed so far.

Significant concentrations of microplastics have also been found in glacial lakes in Austria. They originate from hiking and skiing equipment, as well as materials used to cover glaciers. These particles threaten aquatic ecosystems and can contaminate drinking water, since wastewater treatment plants can currently only partially filter out particularly small nanoplastic particles.

Modelling study predicts high water consumption and energy costs for snowmaking on a glacier in China

Researchers from the Chinese Academy of Sciences used field data and modelling to assess the impact of artificial snowmaking on the Dagu Glacier, a site of significant tourism value located on the easternmost edge of the Tibetan Plateau. The study involved covering 30,000 square meters of the glacier in 2024, and claimed that the glacier’s survival could be extended by decades if certain snowmaking cycles were implemented. However, the cost of snowmaking is high, with one cubic meter of artificial snow requiring around 600 liters of water. Assuming an annual snowmaking period of 60 days and a daily snow production rate of 0.15 meters per square meter over the entire study area, the total annual water requirement would be around 160,000 cubic meters, and consume around 54,000 kWh of electricity. In addition, it costs up to 700,000 Chinese Yuan (83,000 Euros) to maintain snowmaking operations and up to 1.5 million (180,000 Euros) to procure snowmaking equipment.

MortAlive concept: Artificial snowmaking with meltwater in Switzerland

The MortAlive concept was developed by Swiss researchers and has been tested on a small scale on the Diavolezza

Glacier in the Swiss Engadin Valley, with the aim of implementing it on the nearby Morteratsch Glacier to slow its melting. MortAlive researchers believe that their approach is practically feasible and continue to seek funding to further develop it. MortAlive's artificial snowmaking technique requires the construction of a freshwater reservoir, snow cables (similar to those used in mountain gondola systems), and special nozzles (NESSY ZeroE) installed across a glacier to produce artificial snow. In order to cover the entire 0.8 square kilometer Morteratsch Glacier with 10 to 12 meters of artificial snow all year round, 2.5 million cubic meters of water would be needed. The estimated cost of installing the system, excluding operation, is around CHF 150 million (160 million Euros). However, the project would only prevent a third to a quarter of summer melt, and it would involve significant interference in a pristine natural environment. Water reservoirs have been built at other ski resorts to produce artificial snow, but there is often insufficient water, meaning that additional water has to be pumped up from the valleys below.

Modelling the climate impact of boreal forests

Some years ago, studies in the US led by Dartmouth College and Yale University theorized that deforesting the planet's remaining boreal forests, which are primarily found north of the 45th parallel in Russia and Canada, would have a cooling effect on the climate. They reasoned that deforested areas have more snow cover which reflects solar radiation, whereas forested areas have less snow cover and absorb more of it. This overly simplistic theory led to boreal deforestation being considered as a potential climate mitigation strategy. The publication of several new studies has revived the debate, highlighting the complexities of ecosystem interactions with the climate and the likelihood of approaches to geoengineering having unintended consequences.

- In a recent article in Nature Geoscience, Kristensen et al. (2024) suggest that planting trees in boreal forest areas leads to a net warming due to albedo change, and that potential carbon storage does not counteract this effect. The authors warn against policies with a narrow focus on biomass carbon storage that incentivize tree planting in high-latitude regions.
- Another study (Quaas & Han, 2024), in Nature Communications, emphasizes that considering surface albedo alone is too simplistic an approach to assessing the climate impact of forests. The study presents research results indicating that deforestation leads to a decrease in cloud cover and, consequently, cloud albedo, which would have a net warming effect.

Boreal pine and spruce forest, South-East Norway. Peter Prokosch, GRID-Arendal resources library.

Dsouza et al. (2024) also highlight the fact that clouds are more likely to form over forests than areas without tree cover, particularly in the summer, which has a cooling effect. Using field data and modelling, the authors demonstrate that the average winter soil temperature in forested areas across much of the boreal zone, including boreal permafrost sites, is significantly lower than in open terrain. In spring, forests can slow the rate of snowmelt by reducing soil warming, while snow melts faster in open areas. Forests also increase evapotranspiration, thereby reducing soil moisture and, consequently, soil thermal conductivity. Further still, the mosses typical of boreal forests form '*thick insulating mats*' that protect the soil from higher surface temperatures.

Shading coral reefs to protect them from bleaching

The following projects aim to cover the ocean surface with either a layer of microbubbles or a surface film in order to shade coral reefs and protect them from the effects of climate change. Generating microbubbles has proven practically challenging, and research and development around creating a surface film over coral reefs has now ceased.

Shading coral reefs with microbubbles

The newly-launched research project Undercurrent is studying technologies capable of creating microbubbles on the ocean surface. The project is being conducted with seed funding from the Renaissance Philanthropy Fund, which is also funding geoengineering research into mixed-phase cloud seeding in the Arctic. Two of the Funds research fellows are also co-founders of Charm, a biochar and bio-oil production company, showing the extent to which the Fund is involved in a range of geoengineering-related research. The aim of the project is to produce a layer of microbubbles that will increase the albedo of the ocean surface in order to reduce the amount of heat absorbed by seawater, protecting coral reefs from extreme temperatures. According to the project description, the microbubbles will be created without the use of chemical additives.

Previous attempts at this approach have encountered problems with bubble durability and high energy consumption that could not be easily resolved. Research at University College London has shown that the longer a microbubble layer is required to last, the greater the amount of energy is required to produce it. The project also revealed that "*the more local the deployment, the less uniform may be the effect on temperature and precipitation*". Experiments at Harvard and Rutgers universities have also shown that the bubbles likely do not persist long enough to be effective in large marine areas.

Using a surface film to protect the Great Barrier Reef

The Reef Sun Shield project formed part of the Australian Reef Restoration and Adaptation Program (RRAP), a long-term government-funded scheme aimed at developing, testing and assessing interventions to protect the Great Barrier Reef (GBR) from the impacts of climate change, including geoengineering approaches such as Marine Cloud Brightening. Conducted by the University of Melbourne, the Australian Institute of Marine Science and the Great Barrier Reef Foundation, the project aimed to reduce the amount of light entering a body of water by twenty percent to protect coral reefs from the sun and mitigate the severity of coral bleaching on a local scale. The researchers developed a surface film made of reflective calcium carbonate particles designed to sit on the water surface, and considered the possibility of releasing the film via drones, aircraft, vessels or buoys. This so-called 'sun shield' was tested in a laboratory on seven coral species at the Australian Institute of Marine Science's National Sea Simulator, in smaller and larger outdoor tanks filled with seawater, as well as in the open ocean, where two outdoor trials in 2018 covered 25 square meters with the film. Information about the results of these trials was finally published in late 2024, but RRAP is no longer pursuing research into the surface film approach.

Satellite image of the Great Barrier Reef, Australia. NASA | Wikimedia

Increasing the reflectivity of terrestrial surfaces

Constructing large areas of reflective surfaces is being trialed as a climate mitigation approach, with the aim of reducing temperatures both regionally and globally. Project developers are also exploring cooling credits as a way of financing these projects.

Roof whitening is the most prominent of these approached, and aims to increase a roof's albedo so that it absorbs less heat during periods of high solar radiation, thereby reducing the interior temperature of the building and the need for air conditioning. This approach is usually proposed for use in urban heat islands, with some evidence of localized public health benefits, including during extreme heat events. However, to have a global impact and achieve climate-relevant effects, it is estimated that up to two percent of the Earth's surface would need to be covered in white paint – an area approximately the size of the USA.

Plans to sell cooling credits to finance high albedo surfaces neglect environmental impact, USA

The Los Angeles-based organisation Climate Resolve promotes the large-scale installation of high-albedo surfaces in urban heat islands, such as on roofs, walls and pavements, as an effective way to counteract global warming. In a recent video, Climate Resolve explains that "…*if we replaced 80% of roofs and pavements in U.S. cities with cool materials it would offset the global warming produced by up to 12 years of the country's greenhouse gas emissions.*" However, the practical problems associated with roof whitening remain, and the ecological footprint of this has not been considered by the company. Climate Resolve intends to finance its scheme through the sale of cooling credits or "*albedo-based offsets*" to big greenhouse gas emitters on the voluntary carbon markets. In 2024, the organisation received one million US dollars in funding from the ClimateWorks Foundation's Clean Cooling Collaborative and the Grantham Foundation.

Whitening roofs to reduce global temperatures has significant ecological and energy impacts, USA

Researchers at Purdue University in the USA have developed a paint with a solar reflectance of 98.1% containing barium sulphate nanoparticles. The researchers stated that the paint "*offers great promises to reduce space cooling cost, combat the urban island effect, and alleviate global warming*". However, the high barium sulphate content of the paint would require large amounts of the mineral barit to be mined. Calcium carbonate has also been proposed as a reflective pigment, which would also need to be mined.

The Cool Roof Rating Council has created an online directory that measures the albedo of roofing products before and after a three-year weathering process. However, there is currently no information on the environmental footprint of the reflective paints, and very little on their durability, or sensitivity to abrasion, or how often the coating would need to be renewed. It is also likely that the painted surfaces would require frequent cleaning.

Trials with reflectors on rooftops, lakes and on agricultural land aim to redirect solar radiation back into space, USA, Sierra Leone and India

The Mirrors for Earth's Energy Rebalancing (MEER) project is headquartered in California and originated from the Rowland Institute at Harvard University. It aims to reduce both local and global temperatures by redirecting solar radiation back into space using large reflectors. According to MEER, around ten million square kilometers of reflectors would be required to stabilise the climate at 2022 levels by the year 2100 (RCP4.5 scenario), at an estimated cost of US$ 200–500 billion per year. MEER estimates that the reflectors could reduce global temperatures by one to two degrees. The reflectors consist of an aluminum layer applied to recycled materials, such as polyethylene terephthalate (PET) packaging. They plan to install the reflectors over bodies of freshwater, such as reservoirs and rivers, as well as on agricultural land and in urban heat islands, while some of the reflected radiation may be used to generate energy. According to MEER, the reflectors have cooled the interior of buildings by six degrees, but there is no independent evidence to support this claim.

Field tests and research and development work are currently being carried out in the USA and Sierra Leone in collaboration with local businesses and Stanford University, with more planned in India. In the US, small-scale trials, covering 300 square meters, are being conducted in urban environments and on bodies of water outside San Francisco, California. The urban trials aim to explore the placement of reflectors and various other materials, for example variations in angles that they are placed at and how they are positioned on roofs.

The trials on water surfaces study the impact of altering albedo on water temperature and evaporation rates, however, there is no indication that the potential ecological impact of this on the aquatic environment is being investigated. In Sierra Leone, ongoing small-scale trials currently cover 1,025 square meters of rooftops in Freetown with the primary objective of reducing sunlight absorption. Various concepts have been tested, including white paint, zinc roofs and MEER’s reflectors, and plans are in place to increase the covered roof area to 10,000 square meters. In India, MEER plans to conduct a small-scale trial in Pune, covering 500 square meters of roofs.