Scientists alarmed by rapidly shrinking Arctic ice cap

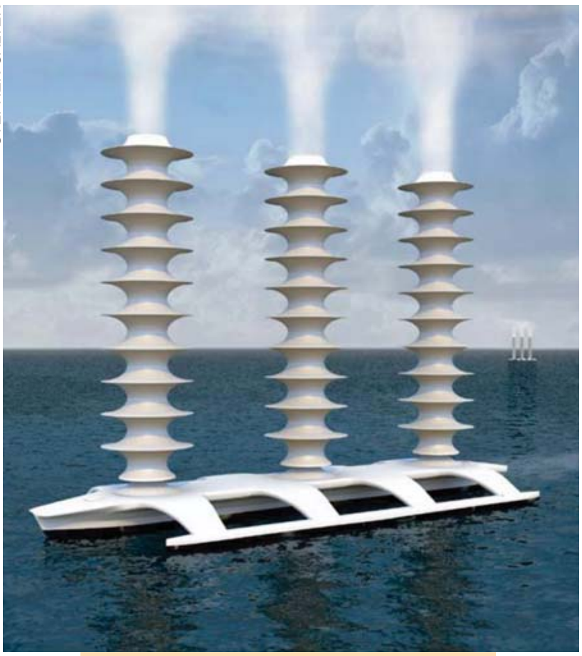
With summertime disappearance of polar sea ice expected as early as this decade, various geoengineering schemes have been proposed for mitigation. But each carries baggage.

In September 2012 Arctic sea-ice extent fell to its lowest level since the first satellite records in 1979. At 3.4 million km^2, the area was roughly half the median minimum coverage that occurred from 1979 to 2000. A 2011 MIT model showed the sea ice is thinning at four times the rate the United Nations Intergovernmental Panel on Climate Change estimated in 2007. The Pan-Arctic Ice Ocean Modeling and Assimilation System model developed at the University of Washington's Applied Physics Laboratory showed last year's minimum volume at 3263 km^3, roughly half the volume it had in 2007, the year of the previous record low. Some climate scientists are now warning that an ice-free summer Arctic Ocean could appear within a few years—more than a decade sooner than existing climate models have predicted.

With less ice and more open water, the top of the world absorbs more heat and reflects less. At the maximum angle of incidence, a calm ocean soaks up about 93% of the sunlight striking it—an albedo comparable to that of an asphalt parking lot. Snow-covered ice, by contrast, reflects more than 90% of solar energy. "The Arctic acts as a thermostat for the world. It's a heat sink," said Martin Jeffries, program officer and Arctic adviser at the Office of Naval Research, speaking at the American Geophysical Union's fall meeting on 5 December. "And by changing that reflectivity, we are changing the thermostat and the Arctic's contribution to the total Earth climate system." Even if warming could be limited to 2 °C globally—the generally accepted threshold for avoiding the more catastrophic impacts of climate change—the Arctic will warm by three to four times that amount, said Julienne Stroeve, senior scientist with the National Snow and Ice Data Center, at a 10 December roundtable discussion in Washington, DC.

In addition to producing largely uncertain impacts on ocean circulation and the meanderings of the jet stream, the lack of ice cover is allowing the waters of the shallow Arctic Ocean to warm, which in turn melts the permafrost on the continental shelf and releases millennia-old methane deposits. When measured over 20 years, methane has 75 times the global warming potential of carbon dioxide, says Michael MacCracken, chief scientist for climate change programs at the nonprofit Climate Institute. That new regional source of greenhouse gas could further amplify the Arctic warming, said Jeffries. But so far, he noted, there hasn't been evidence of that occurring.

STEPHEN SALTER



An artist's conception of ships that would be built for pumping seawater spray into marine clouds. Proponent Stephen Salter of Edinburgh University now advocates land-based spray stations instead, saying that the problem of sea-ice loss is too urgent to provide the necessary development time for ships.

One ice expert, Peter Wadhams of the University of Cambridge, has forecast the collapse of the summer sea ice within a few years. "The changes are happening a lot faster than we expected," admitted Stroeve at the December roundtable. Still, most estimates are that the summer ice won't completely disappear until sometime in the 2030s, said Donald Perovich, adjunct professor of engineering at Dartmouth College, speaking at the AGU meeting.

Dimming the Sun

The accelerating change in the Arctic has brought new attention to geoengineering, in particular to solar radiation management (SRM) methods that reflect sunlight back into space (see PHYSICS TODAY, August 2008, page 26). Advocates of SRM acknowledge that geoengineering is a last resort to be used only if the world fails to limit greenhouse gases. The failure so far to reach a global agreement to achieve meaningful emissions reductions invites the question of how an international consensus on geoengineering might be developed. Proponents of SRM techniques that modify the atmosphere acknowledge that adverse effects on local climates are likely, including changes in rainfall patterns. And no form of SRM would address the ocean-water acidification being caused by increased CO_2 emissions.

Several SRM management techniques might be tailored to mitigate Arctic sea-ice loss. The lofting of sulfate aerosols into the stratosphere has long been considered a sure and relatively inexpensive method of SRM. One group of scientists recently showed in models that stratospheric aerosols could also be made to counteract polar ice melt while minimizing undesired effects elsewhere. A paper published in the November 2012 issue of *Nature Climate Change* argued that reversing polar ice melt would require only a fraction of the solar shading that would be needed for planet-wide cooling. Smaller amounts of sulfates would mean fewer changes in rainfall patterns and less damage to the ozone layer. "If the problem is too little Arctic sea ice—and that is an important problem over the next half-century—then I would say that aerosols are the cheapest and most effective way [to address the problem]," says David Keith, a professor of applied physics at Harvard University who coauthored the paper. "There's hardly anything else we can do, because cutting emissions [of greenhouse gases] isn't going to do much over the next half-century—though in the long run we must cut emissions to near zero to limit climate risk." Keith has also suggested that aerosols composed of engineered nanoparticles could be concentrated in polar latitudes through photophoresis—a phenomenon in which sunlight will cause the migration of particles suspended in a gas.

As for the price tag, Keith points to a paper he and colleagues published in *Environmental Research Letters* in August 2012. They concluded that several methods, including airplanes and blimps, could possibly deliver the million metric tons of aerosols required for solar shading for less than $8 billion per year. The paper compares that with the range of $200 billion to $2 trillion per year for the estimated cost of damage resulting from climate change or the cost of mitigating greenhouse gas emissions.

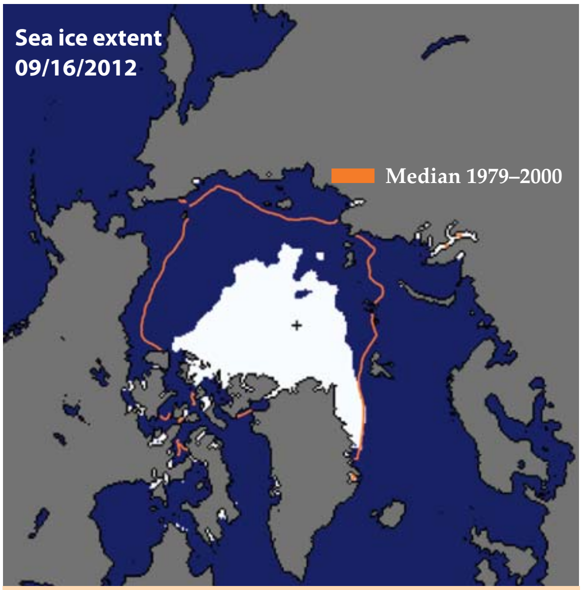
Whiter clouds

John Latham of the National Center for Atmospheric Research has advanced a different SRM approach to save Arctic sea ice: brightening marine stratus clouds. The process involves the use of hundreds of towers on land or on ships to spray a fine mist of seawater into clouds. The seawater will create cloud droplets that are much finer and more highly reflective than those of ordinary clouds. Stephen Salter, emeritus professor of engineering design at Edinburgh University who has produced designs for the nozzles required, says the first test tower could be built in 18 months once funding becomes available. "Once you know what you want to make, then you can make them all over the world very quickly," he says. A network of 200–300 spray sources on purpose-built ships should reduce irradiation by around a watt per square meter, he figures.

One benefit of cloud albedo enhancement is that it could be halted quickly if some harmful impact were to result; effects would disappear within four days of stopping spraying, Salter says. Sulfate aerosols, in contrast, don't settle out of the stratosphere for about two years.

But cloud enhancement has its drawbacks, too. "Depending on where you do the spraying, we know it can either increase or reduce precipitation," Salter says. "We're now working out where we could do this to benefit everybody." For example, models show that spraying clouds in Namibia will reduce rainfall in the Amazon basin and that spraying in the Aleutian Islands makes the Amazon wetter. Spraying anywhere in the Northern Hemisphere will cool the Arctic, but the effect would be more immediate if it was done over water flowing toward the pole, such as between Iceland and Norway or through the Bering Strait.

Spraying from remote locations such as the Aleutian and Faroe Islands also would minimize negative impacts on population centers. "People are worried about spraying salt around, even though there's an awful lot more salt being pushed up by breaking waves," Salter explains.



Arctic sea ice in September 2012 reached a record minimum since satellite records began in 1979. The orange line indicates the median minimum summer ice extent from 1979 to 2000.

Since marine cloud formation varies seasonally, a fleet of ships would best be suited to perform the spraying. He estimates that a development program would cost about $30 million, with an annual cost of about $300 million to build and operate the ships. Recently, Salter has advocated building spray stations on land instead; he says the urgency of the sea-ice crisis won't allow time to develop the ships.

Reflections on the water

Methods for raising the albedo of the ocean also have been proposed. One plan would be to brighten the ocean itself by generating a subsurface fog of micron-diameter bubbles. The microbubbles can exhibit surprising stability; just as water drops in clouds are too small to fall through the air, microbubbles are too small to rise through water. In a 2011 paper in the journal *Climatic Change*, Harvard physics fellow Russell Seitz, chief scientist for Microbubbles LLC, suggests creating microbubbles by supersaturating seawater with compressed air that vessels pump into their wakes. The brightening of a kilometer-wide band of water at the edge of the retreating ice sheet would slow the melting, he says.

The big question is how long microbubbles can be made to last. Seitz believes a 10-hour lifetime could allow a fleet of 100 ships to substantially slow the retreat of an ice sheet with a periphery of 10 000 km. Natural ocean microbubbles, sustained by ambient surfactants, occasionally last that long, but producing them in the Arctic likely would require adding tons per day of surfactants—either natural ones derived from kelp or biodegradable synthetic ones. While the task could require hundreds or thousands of tons of surfactants each season, Seitz notes that arctic plankton blooms generate larger amounts of natural surfactants. He adds that Stokes's law prevents suspended microbubbles from making suds.

Seitz says the surface chemistry and the energy and engineering scaling required to estimate cost have not yet been done. The chief downside to microbubbles is the reduction in sunlight available for photosynthesis in the sea. But, Seitz adds, the degree of shading caused by the bubbles is comparable to that of a cloudy day.

Probably the most controversial scheme for ocean brightening would be to blanket portions of the Arctic Ocean with trillions of tiny reflective glass spheres. Stanford University consulting professor Leslie Field, whose nonprofit Ice911 Research Corp has been testing prototypes of the glass, or "floating sand," on a small lake in the Sierra Nevada for four years, says the materials could also be deployed on glacial melt ponds to slow glacial melting. In lake tests, mesh bags are used to contain the reflective materials. Whether the glass deposited in the ocean should be similarly confined is still an open question, she says. Unrestrained, the material might become incorporated in regrown sea ice that, due to its higher albedo, should melt more slowly than normal newly formed ice, perhaps acting more like multiyear ice, Field says.

Field estimates it would take $500 million in materials to cover 50 000 km², an area roughly the size of the ice loss experienced in 2000, which was an order of magnitude smaller than this year's decline. The cost obviously grows if the materials need to be contained or retrieved. And shipping and deploying adds further costs, she says. Because Field insists that any geoengineering be readily reversible, she says it might be advisable for a strategic placement of soot to be readied to counteract the geoengineered albedo enhancement. Field acknowledges she has yet to have her research published in a refereed journal.

Apart from the uncertain environmental impacts of releasing so much material into the ecosystem, the potential fouling of the floating glass by marine organisms, which would reduce their reflectivity, could be another drawback of the Ice911 approach.

David Kramer

Dark-matter search gets started deep in Sanford Lab

If more experiments, in particular the Long-Baseline Neutrino Experiment, go forward, what scientists had hoped to get in one go will instead be realized incrementally.

The outlook for building a US underground laboratory nosedived in late 2010 when NSF pulled out of the project. But quietly and with little fanfare, such a lab is being realized in the defunct Homestake gold mine, thanks to unwavering support from the host state of South Dakota and philanthropist T. Denny Sanford and to the Department of Energy. In August 2011 DOE stepped up with operations money to keep alive two experiments in the mine: the Large Underground Xenon (LUX) search for dark matter and the Majorana Demonstrator for neutrinoless double beta decay (see PHYSICS TODAY, February 2011, page 21, and August 2011, page 23).

"DOE had thought of itself as putting experiments in the facility," says Los Alamos National Laboratory's Steven Elliott, spokesman for the Majorana Demonstrator. "Taking responsibility for the facility itself was different." Tensions were high for a while, he says. "But the longer we are there, and DOE supports us, the more confident we become. We hope we are not the turkey before Thanksgiving." DOE is so far ponying up $15 million a year; its activities at the lab are overseen by a team based at Lawrence Berkeley National Laboratory.

Now known as the Sanford Underground Research Facility, the site has been excavated, renovated, and outfitted using some of the $70 million from Sanford and $40 million from South Dakota, and the governor has requested another $2 million in state funding for the next fiscal year. The Sanford Lab celebrated its opening on 30 May 2012. The next day, experiments began moving in.

Both the Majorana Demonstrator and LUX were poised to begin collecting data as PHYSICS TODAY went to press. And on 10 December 2012, the DOE granted preliminary approval to the Long-Baseline Neutrino Experiment (LBNE), in which intense beams of neutrinos would be shot 1300 km from Fermilab to the Sanford Lab. "That is a very big deal," says LBNE cospokesman Bob Svoboda of the University of California, Davis. "Ongoing projects weather things like continuing resolutions better than new [projects]." Moreover, the prospect of the Sanford Lab hosting the LBNE, with its 20-year lifetime, could well attract to the site other experiments that require shielding from cosmic rays.

Getting started

The LUX detector is located 4850 feet deep in the Davis campus—named for Ray Davis Jr, whose pioneering solar neutrino experiment began running in the Homestake mine four decades ago. The dark-matter detector consists of 350 kg of xenon in a cryostat suspended in a 70 000-gallon tank of purified water. Experimenters are looking for a recoil signal—of both light and charge—when weakly interacting massive particles pass through. The WIMPs