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Polar geoengineering: not so simple

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A Viewpoint on the Frontiers in Science Lead Article

Safeguarding the polar regions from dangerous geoengineering: a critical assessment of proposed concepts and future prospects

Key points

- One of the original appeals of geoengineering was that it might "simplify" the complex challenge of global climate management, but the latest literature on polar geoengineering interventions reveals the uncertainty, complexity, and sheer impracticality of these proposals.
- The impacts of *polar* geoengineering, which aims at regional rather than global effects, are likely to be difficult to confine and may be undermined by interactions with changes to the global climate system.
- Climate management services could be delivered either through a collaborative international framework or a market-based approach, where specialized providers offer solutions to vulnerable beneficiaries—such as nations and cities threatened by rising sea levels. However, the complexities and obstacles associated with these models are increasingly apparent in today's global political climate.

As Thomas Schelling, the influential American economist and Nobel laureate, explained in 1996, the great promise of geoengineering is that it might "…immensely simplify greenhouse policy, transforming it from an exceedingly complex regulatory regime to a problem in international cost sharing, a problem that we are familiar with" (1). At that time, little technical detail existed about plausible ways to change the radiation balance at the planetary scale or to dramatically alter and accelerate the speed of global carbon sinks. His point was that in 50 years, much more would be known and judgment would be easier to make.

In the nearly 30 years since, two things have happened: substantial technical progress has been made on carbon dioxide removal (CDR) and solar radiation management (SRM), as well as on our understanding of Earth system processes affected by climate change; and much more thinking has been done about how to govern the development and potential implementation of these technologies. Many creative minds have proposed a wide range of alternatives (certainly a good thing), and we are in a much better position today to assess their likely effectiveness.

We are also in a better position to judge whether geoengineering really does simplify climate policy. The new assessment of polar geoengineering options by Siegert et al. (2) is a significant contribution to this burgeoning literature. What it confirms is that things are not looking promising. The novelty of their Frontiers in Science lead article lies in its focus on the regions worst affected by global warming: the poles. The Arctic and Antarctic have heated up about four times faster than the rest of the planet (3), making them appear to be promising candidates for early applications of geoengineering. If a regional effect limited to the poles could be demonstrated, it might offer a way to *tune* interventions to specific parts of the Earth system, thereby dampening warming and its impacts. One of the persistent challenges of geoengineering is that most proposals have planetary effects, yet fully understanding their short- and long-term consequences, and allocating costs and benefits, have proven anything but simple.

When a good idea meets real-world challenges

What is striking about each of the polar climate interventions assessed by Siegert et al. (2) are the logistics, the costs, and the likely limits of their effectiveness. Even the best understood method—stratospheric aerosol injection (SAI)—appears to suffer from obvious constraints. For example, it would not work during the polar winter since there is no solar radiation to reflect, and during the polar summer, its effectiveness would be reduced by lower insolation and the higher albedo of ice and snow. SAI would require a fleet of large aircraft flying continuously and indefinitely to avoid *termination shock*. It would need to be internationally coordinated and jointly financed. The environmental impacts are unclear (e.g., ocean acidification), and likely spillover effects on adjoining regions could spark international disputes. Where Schelling envisioned simplification, we are likely to be confronted with complexity and new sources of political tension. Geoengineering may even become an instrument of transactional power (4). Nowadays, it is all too easy to imagine a strongman threatening, *pay more, or I'll switch the SAI off*.

Some ideas, such as slowing polar ice sheet flow by removing basal waters, seem at the limits of the imaginable, requiring megawatt-scale power generation in Antarctica, boreholes of unprecedented depths and diameters, and complex infrastructure to handle the vast quantities of extracted water (perhaps using giant snow machines in frozen wastes). The scale of the infrastructure required in such extreme and remote environments, and the need to maintain operations year-round, may be comparable to maintaining a permanent presence on the Moon. Another question is how to achieve any of it through international cooperation when the benefits of reduced climate risk are so unevenly distributed. Could a single power, for example, the European Union, take on *ice sheet management* under a new Global Climate Protection Treaty? Who would pay, and how much? Would small island states feature on the board, arguing for greater investment to stem sea level rise? What would be the political risks for the EU and for participating nations? As we can see, it is not so simple.

One of the problems with Schelling's simplification argument is that the means and the effects of geoengineering interventions are typically exotic, uncertain, diffuse, and widespread. There would be "providers" of climate protection services seeking compensation and liability protection, and "service users" with divergent views on the value and consequences of these interventions, including, perhaps, nature and future generations. The more one thinks it through, as Siegert et al. do so carefully and methodically, the more complex and implausible it seems—much like a ball of wool unraveling.

Understanding the continued fascination with geoengineering

Despite these challenges, geoengineering has passed into mainstream policy and public discourse, and interest in testing and advancing these technologies continues to grow globally.

There seem to be three main reasons that help explain this persistence. First, international climate policy is failing to achieve its central goal: limiting global warming to 1.5°C–2.0°C above pre-industrial temperatures (5). Even without the widespread backsliding on net-zero carbon emissions commitments, achieving this goal by mid-century now feels out of reach. We may be in the middle of an accelerating energy transition, but it is still not happening at the pace that is needed and not yet at a global level. We are yet to reach *peak carbon*, and the move away from fossil fuels will likely take longer than models assume. An increasingly urgent search for alternatives is therefore understandable.

Second, the impacts of climate change are becoming more apparent, especially the growing frequency of heatwaves (6) and associated dangerous wildfires (7), changing patterns of rain- and snowfall (8), and clear ecological changes caused by shifting seasons (9). While adaptation has become a commonly accepted response in many parts of the world, it also induces anxiety. Adaptation can feel like passively accepting the changes all around us, pushing us out of our comfort zones. For many, adaptation also seems inherently unsustainable. Therefore, finding ways to actively intervene in unsettling changes seems a sensible course of action.

Third, we live in an age of utopian ideas about the transformative power of technology, whether through artificial intelligence or the dream of escaping from the frictions and complexities of life on Earth through colonizing Mars as a political project. Geoengineering plays into these grand and liberating notions, following a pattern rooted in science and technology fantasy. According to Sandbu (10), there are several explanations for the resonance of high technology with political ideals, but the appeal of heroic activism in the face of serious and systemic threats is evident wherever one stands on the political spectrum.

These are all powerful motivators for continued interest in geoengineering, and they explain why the patient assessment and debunking represented by Siegert et al. remain essential. Their

analysis suggests that large-scale field experiments of these technologies are also premature, given the risks and the uncertain benefits. But as Schelling argued, it is better to be informed, and we should be encouraging research into geoengineering options that do not impose risks for vulnerable communities and ecosystems.

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