

SPECIAL SECTION ON THE ETHICS OF GEOENGINEERING

Will Geoengineering With Solar Radiation Management Ever Be Used?

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Summary: I don't think geoengineering will ever be implemented

As a meteorologist, I understand the limits of prediction of physical systems, let alone human ones, but here I will attempt to predict whether geoengineering will ever be used. While the term 'geoengineering' has come to encompass several different responses to global warming, here I will use the term to refer to solar radiation management, ideas about reducing incoming sunlight to cool the planet (Lenton & Vaughan, 2009; Shepherd *et al.*, 2009).

The geoengineering ideas that have gotten the most attention are the creation of a stratospheric aerosol cloud, to mimic the effects of episodic volcanic eruptions, and the brightening of low clouds over the ocean, to mimic ship tracks. No cloud has ever been produced on purpose in the stratosphere, and no low cloud has ever been brightened on purpose, and there are serious issues with the practicality of either of these ideas, but for now I will assume that at some time in the future they will become technically possible and affordable. Still I do not think either will ever be implemented on a global basis, because of the inherent risks and uncertainties.

Geoengineering could reduce or reverse global warming (Robock, Oman, & Stenchikov, 2008). The impacts of rising temperature on agriculture in general are negative. Pongratz, Lobell, Cao and Caldeira (2012) showed that if the temperature did not rise in a geoengineered world, enhanced CO₂ would increase agricultural productivity in general. Still, regional precipitation changes (droughts and floods), as well as the continuing ocean acidification, argue against a world with rising CO₂ and the need to continue strengthening geoengineering, with no end in sight. In addition, if society lost the will or means to continue the geoengineering, the rapid warming that would follow would be more dangerous than the gradual warming we are now experiencing.

One of the most serious possible side effects of a stratospheric cloud is reduction of summer monsoon precipitation over India and China (Robock *et al.*, 2008).

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Similarly, marine cloud brightening might devastate the Amazon (Jones, Haywood, & Boucher, 2009). But this precipitation reduction would be on a background of large random interannual variations. For example, the summer monsoon in India was below average in 2009 with drought, but was above average in 2010 with significant flooding.

Due to this natural climate variability, it is impossible to test whether stratospheric geoengineering would work by using small stratospheric clouds, as the response to them would be impossible to detect. In situ testing would essentially be full-scale implementation (Robock, Bunzl, Kravitz, & Stenchikov, 2010). MacMynowski, Keith, Caldeira and Shin (2011) propose periodic forcing of the climate system to conduct in situ testing at less than the full scale of implementation, but their proposal calls for large-scale manipulation of the climate system for multiple decades, which I think would also be found unacceptable. Long climate model simulations can investigate the change in multi-decadal mean precipitation, but those statistics will include large interannual variations. Imagine that soon after implementation of stratospheric geoengineering, India or China received two or three years of anomalous summer precipitation. It would be impossible to attribute those to the geoengineering, but certainly there would be accusations that these actions were causing it and demands for the geoengineering to stop.

What if computer modeling determines that geoengineering overall would help the planet by reducing the worst impacts of global warming, but that there would be regions that would suffer at the same time? How would it be possible to determine which adverse situations were caused by the geoengineering, and which were just bad weather luck? Even if it were possible, how could those suffering be compensated? There is not a good record of this happening, even in cases where the cause is obvious. For example, are people moved out of river valleys because of dam construction in general happy with their new situations?

How would the planetary governance decision be made as to whether to implement geoengineering, and if so how much? Whose hand would be on the planetary thermostat? Would the decision process be the same successful model used to implement mitigation of greenhouse gases emissions? I am participating in the Solar Radiation Management Governance Initiative, sponsored by the Royal Society, and so far we have not even been able to agree on rules for in situ testing of cloud brightening or stratospheric aerosols. For example, some advocate a 'small-scale' test, one that would produce important scientific information and pose no danger to the environment. But how do you define 'small-scale'? What amount of material, over what area, and for how long would emissions be acceptable? Is it acceptable if emissions are less than other ongoing emissions, such as current emissions from cargo ships? Or do two wrongs not make a right? Is it acceptable if the impacts cannot be detected for some period after the tests end, even if detection technology is imperfect, or the effects might not appear until sometime later? There are no rules, and agreement does not seem near.

Certainly, extensive computer modeling of the processes being investigated and of the potential consequences of both small-scale tests and geoengineering implementation is needed. In my opinion, testing of geoengineering should be indoors for the foreseeable future, either in computer models or laboratories, with no potential to affect the environment. Only once we feel that we have developed a good

understanding of a potential system and have devised an outdoor test that is crucial, should it go ahead, and then only if it can be shown to be safe. I am not sure we will ever get to that point.

To help the progress of research on stratospheric geoengineering, we have initiated the Geoengineering Model Intercomparison Project (GeoMIP) (Kravitz *et al.*, 2011; Robock, Kravitz, & Boucher, 2011). Climate modeling groups from around the world are conducting standardized experiments of greenhouse gases and solar reduction scenarios to examine the robustness of previous results of the response of the hydrologic cycle to geoengineering, and will examine all other climate responses. This will help us to better understand the potential benefits and risks of such a strategy. The first results (for example Schmidt *et al.*, 2012) are now being published.

In addition to the above issues, there are more that would affect the implementation of planetary geoengineering. The principle of informed consent governs medical interventions. How could we get the informed consent of the entire planet? What if a big multinational corporation was in charge? Would you trust the fate of the planet to the BP Geoengineering Corporation? The US military is the best at flying material up into the atmosphere. Would the rest of the world trust them, or any military, to have their best interests at heart? Certainly the developed world is most capable of doing any geoengineering implementation. The history of colonialism will make the rest of the world wary of climate manipulations that are presumably for their benefit.

Global agreement is not necessary for regional- or global-scale geoengineering to be implemented. What if one country determined that intervention would benefit them, say by relieving drought caused by global warming, and their research showed that the negative aspects elsewhere would be minimal? In this rather unlikely event, and if the research proved correct, there may be no retribution. Yet the creation of a stratospheric cloud in one location will allow the cloud to spread globally if in the Tropics and covering half a hemisphere in high latitudes, so it is bound to have large-scale effects. Similarly, cloud brightening on a scale large enough to change regional climate will also have effects in other nations. And it is highly unlikely that the effects outside the target area will be only positive, or that it will be possible to determine them amidst the weather noise.

So here is my prediction. Global warming will continue with only meager mitigation actions for the next decade or two. Rich nations will work to adapt to the continuing climate changes. Poor nations will continue to suffer out of proportion. Weather catastrophes, such as strong hurricanes hitting Guangzhou, China, or Washington, DC, USA, will get the world's attention for a while, but there will still be arguments that individual events cannot be tied to global warming. Ongoing geoengineering research using computer models will identify clear risks of both cloud brightening and stratospheric aerosol production, including ozone depletion and reduction of water supplies to large natural areas, such as the Amazon, and large regions that depend on water supplies for food production. Even suggestions of temporary geoengineering to relieve the most dangerous aspects of global warming will be met with so many of the above issues that there will never be world agreement to implement. I can imagine worse scenarios, including global nuclear war started in response to unilateral geoengineering implementation. I can imagine better scenarios,

with technological breakthroughs of carbon-free energy sources or charismatic world leaders taking us to a future using existing technology with little additional dangerous climate change. I can only hope that this latter scenario will play out.

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