Geoengineering Our Climate?

Ethics, Politics and Governance

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Use of Models, Analogs and Field-Tests for Geoengineering Research

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Introduction

Geoengineering[1] has been suggested as a theoretical response to anthropogenic global warming.[2] However, geoengineering has not been conducted, so there are no data or observations of it. How then can geoengineering be studied? One obvious technique is to use global climate models ("indoor" research) to simulate various proposed geoengineering schemes, such as adding aerosols to the stratosphere to reflect incoming sunlight or adding sea salt to marine stratus clouds to brighten them. Since these two techniques mimic volcanic eruptions and ship tracks, another suggestion is to study those phenomena as analogs to geoengineering. There have also been several suggestions for field experiments, as well as some small scale tests ("outdoor" research), to learn about geoengineering. In this article, we review these different research methods, commenting on their utility, safety, ethics, and governance. We also discuss natural analogs for geoengineering, such as the 1991 eruption of Mt. Pinatubo and the observation of ship tracks, highlighting both their utility in learning about the effects of geoengineering and their limits in providing knowledge. As we will demonstrate, geoengineering research is inseparable from climate research.

Climate Models

Climate models are an obvious tool for geoengineering research. In these models, it is possible to perturb the climate system with various patterns of stratospheric aerosol injection or marine cloud brightening and investigate the climate system response. The vast majority of geoengineering research so far has been with climate models, and these investigations have proven to reveal much about the effects of certain methods of geoengineering, as well as the fundamental underpinnings of climate system response to perturbations. The Geoengineering Model Intercomparison Project (GeoMIP)[3] has resulted in a special issue of the *Journal of Geophysical Research*, with a dozen or so papers examining the climate response to four different scenarios of stratospheric geoengineering. The large voluntary participation of climate modeling groups from around the world in this project, and the opportunity to compare their responses to standardized forcing, clearly demonstrate the utility of this type of research. New climate modeling experiments, including the design of three experiments for marine cloud brightening,[4] promise that much additional knowledge about geoengineering will be provided in the near future.

Natural and Anthropogenic Analogs

Volcanic eruptions are a clear natural analog for stratospheric sulfate aerosol geoengineering.[2,5,6] Robock et al. (2013) discuss this issue in great detail, and here we only summarize some of the points. The observation that large volcanic eruptions cool the planet was one of the original motivations for suggesting geoengineering.[2,7] For example, the eruption of Mount Pinatubo in 1991 cooled the planet by roughly 0.5°C[8] by injecting approximately 20 Mt SO_2 into the stratosphere. However, volcanic eruptions are an imperfect analog for stratospheric geoengineering, because of

[1] In this paper we only address solar radiation management and use the term "geoengineering" to specifically refer to those sets of technologies.
[2] Crutzen 2006
[3] Kravitz et al. 2011

[3] Kravitz et al. 2011
[4] Kravitz et al. 2013
[5] Wigley 2006
[6] Robock et al. 2013
[7] Budyko 1977
[8] Soden et al. 2002

confounding effects of volcanic ash, because volcanic eruptions are into a clean stratosphere, and because of differences between continuous and impulsive injection of material into the stratosphere. The difference in the longevity of the injected particles means that climate system responses with long time scales, such as oceanic responses, would be different between volcanic eruptions and long-term geoengineering, but rapid responses, such as seasonal responses of monsoon circulations and precipitation would be quite similar[9], and the volcanic analog would be appropriate. Geoengineering in particular seasons could increase the effectiveness of geoengineering,[10] decrease the amount of direct interference in the climate system through geoengineering, and make the analog of volcanic eruptions more applicable.

Nevertheless, volcanic eruption analogs already reveal many things about the potential effects of continuous stratospheric sulfate aerosol clouds. Some examples include cooling the surface, reducing ice melt and sea level rise, increasing the land carbon sink,[11] reduced summer monsoon precipitation,[12,13,14] destruction of stratospheric ozone that allows more harmful UV at the surface,[15] whitening of the sky[16], reduction of solar power[17], damage to airplanes flying in the stratosphere[18], and impacts on remote sensing.[19] Study of past and future large volcanic eruptions promises to help answer additional questions, including the growth and distribution of sulfate aerosols, impacts on ozone and on cirrus clouds, and the effects of increased water vapor (because of a warmer tropical tropopause) in the stratosphere.

Ship tracks, where there is a clear cloud signal resulting from the injection of aerosols from the ship exhaust,[20] can indicate the effectiveness of increasing the brightness of marine boundary layer clouds through the injection of aerosols such as sea salt.[21] Robust relationships among changes in precipitation, cloud albedo, and cloud coverage have not yet been established from observations, but both careful data analysis, and greater observational capability may help to better understand how cloud brightness, lifetime, and extent would respond to particle injections. Aerosols in clouds can produce many more subtle effects in addition to the visible ship tracks, and cloud albedo is not always enhanced by increasing the aerosol concentration.[22]

Field Tests (Outdoor Experiments)

It is almost certainly true that some questions about geoengineering can only be answered through outdoor field tests. However, the claim that there is a need for these field tests[23,24] would need to be substantiated. Without clear goals for such research, demonstration that the research is safe, and externally evaluated, monitored, and regulated governance, such outdoor research is unethical.[25] Some proposed research involves emission of pollutants, such as SO_2, into the atmosphere, and the emissions need to be regulated to prevent environmental damage.

[9] MacMynowski et al. 2011
[10] MacMartin et al. 2013
[11] Mercado et al. 2010
[12] Trenberth and Dai 2007
[13] Oman et al. 2006
[14] Robock et al. 2008
[15] Tilmes et al. 2008
[16] Kravitz et al. 2012
[17] Murphy 2009
[18] Bernard and Rose 1996
[19] Strong 1984
[20] Christensen and Stephens 2011
[21] Latham, 1990
[22] Christensen and Stephens 2012
[23] Lane et al. 2007
[24] Parson and Keith 2013
[25] Robock 2012

Some of the aspects of geoengineering proposals could be tested outdoors at a small scale that would provide useful information while not significantly increasing risk to the environment. For example, can an airplane be constructed that can take a tank of SO_2 gas (or other sulfate aerosol precursor) into the lower stratosphere, spray it out, and create a cloud of sulfuric acid droplets of a desired size distribution? If so, how much would it cost and how dangerous would it be to the operators of the system? Rough estimates made so far suggest that such an apparatus would not be expensive,[26] but field tests could calibrate these estimates. However, this experiment would not test whether such a cloud could be produced that would limit the growth of the aerosols.[27] Such an outdoor test would have to be done at a scale that would essentially be actual implementation of geoengineering.[28]

The distinction between small and large-scale tests can be somewhat blurry, but caution can still be used in determining whether a field test should be conducted. First, experiments should be designed to meet a clear goal and in such a way that minimizes risks to other parts of the environment. Secondly, the benefits of conducting the experiment should outweigh the risks. Field studies in many branches of science, such as with weather modification, pesticides, or genetic crop modification, proceed with the knowledge that the experiments may cause harm, but the knowledge gained is deemed to be more beneficial than the potential risks. Such determinations and weightings of benefit and risk are made by external regulatory agencies, and the experiments are monitored closely. These governance structures would also be necessary for geoengineering field studies to be conducted ethically.[24,25]

Outdoor experiments should not be conducted if there is another, less risky way of obtaining the same information. For example, volcanic eruptions, climate model simulations, and previous studies of the radiative effects of aerosols have shown that layers of aerosols can intercept solar radiation, so there is no need to conduct an additional field experiment[29] to do the same thing. And some risky experiments should never be done, such as in the Arctic,[23] even if they promise to provide information to test theoretical results. The prime example of such a societal decision is that nuclear weapons are no longer tested, even underground.

The Relationship between Geoengineering Research and Climate Science

All of the methods mentioned above for conducting geoengineering research were developed for general climate studies. The scientists conducting the research are climate scientists. Climate models continue to be developed in centers around the world as a representation of our best knowledge about how the climate system works. Field campaigns are routinely conducted to observe and measure the atmosphere and how it is changing. A network of satellites, air-based measurements, and ground-based measurements continually provides information about the current climate state. Any climate modeling studies of the effects of geoengineering will use climate models, and any measurement of the effects of field tests or deployment would use the current observation network.

[26] Robock et al. 2009
[27] Heckendorn et al. 2009
[28] Robock et al. 2010
[29] Izrael et al. 2009

Moreover, some of the fundamental questions about the effectiveness of geoengineering are intimately related to fundamental questions in climate science. How does the climate respond to changes in radiative flux? How do aerosols and clouds interact? What observation system is needed to determine the effects of the next large volcanic eruption? The study of the climate and the study of geoengineering are tightly linked. Conducting geoengineering research has proven to be very useful in understanding the fundamental processes that govern climate behavior, and in turn, a better understanding of the climate will promote a better understanding of the effects of geoengineering.

Summary

Transparent research on geoengineering is an essential part of the discussion wherein the benefits and risks of geoengineering can be determined. There is little reason to regulate curiosity-driven indoor research, provided it does not cause any dangerous environmental effects. However, outdoor experiments should be assessed to determine whether they are dangerous, and they should be regulated, even if these experiments are for scientific purposes. There is precedent for governing dangerous human inventions, such as ozone depleting substances and nuclear weapons. Such mechanisms are based on widely accepted norms of environmental protection and independent regulation. These structures are necessary to weigh the benefits of knowledge about geoengineering against the risk of not knowing.

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