

Geoengineering: What, how, and for whom?

I have been thinking about geoengineering for climate modification since I worked on the committee that produced the 1992 National Academies report, *Policy Implications of Greenhouse Warming*. Over the years, and increasingly now, I have been puzzled by the scientific community's attitudes toward the issue; those puzzles were raised again by Barbara Goss Levi's story (PHYSICS TODAY, August 2008, page 26).

It has been customary to discuss geoengineering without offering an explicit definition. I propose the following one: Geoengineering is purposeful action intended to manipulate the environment on a very large—especially global—scale. Geoengineering is, presumably, undertaken to reverse or reduce impacts of human actions.

Decreasing human emissions of carbon dioxide and other greenhouse gases is a good idea for many reasons, including climate modification; yet it is not clear to me why manipulating the CO₂ content of the atmosphere is not considered geoengineering. If, using the above definition but narrowing it to the case under consideration, geoengineering includes purposeful manipulation of physical, chemical, and biological variables on the global scale for the purpose of changing global climate, then manipulation of carbon dioxide concentrations fits the definition as well as do, for example, manipulating atmospheric aerosol content to control albedo or manipulating the ocean's iron content to increase the long-term oceanic storage of carbon.

Exclusion of carbon dioxide manipulation from geoengineering has led to

a double standard in considering possible negative consequences. There is legitimate concern about side effects of particulate manipulation and the like, but I have not heard much worrying about manipulating carbon dioxide.

In a highly nonlinear feedback-controlled system like global climate, we would expect complex hysteresis effects: Decreasing a control variable such as greenhouse gas will not necessarily lead the climate back along some path like the one it followed when the control variable was increased. The end state of control-variable manipulation may not at all resemble the original state before the control variable was increased, nor will it necessarily be a state we want to be in. I have heard of no concern about those possibilities, which might be rate dependent, involve transient behavior not to our liking, or lead us through bifurcations into unexpected states.

It seems to me we need to be concerned about possible not-so-benign effects of decreasing carbon dioxide and other greenhouse gases before we grab the control knob and turn it down. I hope someone is at least exercising suitable climate models, if relevant ones exist, to examine possible end states, paths to them, and transient effects of carbon dioxide geoengineering.

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The Issues and Events report on the viability of geoengineering to counter global warming did not address the ethical issue. I use the following fable to illustrate the point.

Once upon a time in an idyllic country, near a small town and a farming community, a rope hung out of the sky. One pull on the rope changed the weather from fine and sunny to cloudy and rainy, and the next pull changed it back. For many years the people cooperated; the farmers used the rains to help grow crops, and the townspeople enjoyed the sunny periods. But there came a time when the townspeople protested the rain and wanted more sunshine. The farmers were concerned about their crops. And so arguments broke out, with a person from the town pulling on the

rope, followed quickly by a farmer pulling it again, and they pulled and pulled and . . . broke the rope.

Given that the climate is changing because of inadvertent consequences of human activities, the question arises as to whether efforts should be made to deliberately change climate to counteract the warming. Aside from the wisdom and ability to do such a thing economically, the more basic question is the ethical one of who controls the rope. Who makes the decision on behalf of all humanity and other residents of planet Earth to change the climate deliberately?

Climate change is not necessarily bad. The climate has always varied to some degree, and changes have occurred over decades and millennia. Humans and other creatures have adapted to the changes or perished; it is a part of evolution. Changes projected with increased greenhouse gases in the atmosphere may have some aspects that could be regarded as bad; increased heat waves and wildfires in summer, increased and more intense droughts, heavier rains and risk of flooding, stronger storms, decreases in air quality, and increases in bugs and disease are all likely threats. But in some areas, climates improve, high-latitude continents become more equable, growing seasons are longer, and so on. There are winners and losers. And it is possible to adapt to such changes—at least if the changes occur slowly enough. In other words, key issues are the rate and duration of change, perhaps more so than the nature of the new climate. In that sense, it is the disruptive part of climate change that might be argued as being bad.

Given that climate change is not universally condemned, how can anyone justify deliberately acting to change the climate to benefit any particular group, perhaps even a majority? The ethical questions associated with climate manipulation loom so large that some forms of geoengineering are simply unacceptable. The forms that are acceptable include those that reduce emissions and mitigate the rates of change or reduce the amount of carbon dioxide in the atmosphere. Forms that propose to block sunlight in some fashion, per-

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