Discussion paper:

Geo-Engineering the Climate: Lessons from Purposeful Weather and Climate Modification

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Abstract

- Social acceptance of purposeful weather modification is used here as analog to judge social acceptance of geo-engineering
- Cloud seeding is a conscious effort to alter the weather and climate to provide benefits and reduce hazards
- Some geo-engineering approaches emulate cloud seeding
- Demand for weather modification may increase in a warming world
- Cloud seeding is in widespread use; some places have been seeded for decades thus, if effective, altering their climate
- Concerns about unintended consequences and liability have been inconsequential
- But experiments on hurricanes crossed some threshold of acceptability, and were curbed
- The hurricane experience appears relevant and suggests significant hurdles for geo-engineering field trials or application

Introduction

We are embarked on an important, though *ad hoc*, "technology assessment"[2] of geo-engineering fixes to the global warming problem, one of the most important technology assessments in history.

The challenge in many TAs is that the technology under review is often novel and unique, a break from the past and, thus, uncharted techno-social territory. This mostly holds true for climate geo-engineering. But it is also true that humans have attempted to change the weather and the climate for most of human history. Thus one way to cast some light on geo-engineering to mitigate global warming is to look back at purposeful efforts to modify at least

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[1] Disclosure: I have participated in cloud seeding experiments, conducted fieldwork to assess the effects of cloud seeding in South Florida, including gathering seeded rainwater for chemical analysis to assess whether silver was acting as a pollutant, and, as a panelist on the 1992 National Academy of Sciences study, *Policy Implications of Greenhouse Warming*, I took part in discussions of geo-engineering (all under my previous name, William E. Riebsame). My attitude is openness to such options, in case they can be shown to be effective, but my work stresses human adaptation to the environment, especially to climate change, see: http://spot.colorado.edu/~wtravis/

[2] What will be involved in such a technology assessment? One early step should be to look back at previous assessments, a wide range of which were conducted, for example, by the U.S. Office of Technology Assessment during its 23 years of operation up to 1995 (some 750 separate assessments!) available at: http://www.princeton.edu/~ota/ns20/pubs_f.html. Other major assessments were conducted for the super-sonic transport, nuclear power, and anti-missile technology. Typical TAs include a look at: feasibility, cost/benefit, risks, social and environmental impacts (positive and negative), institutional frameworks, ethical dimensions, and alternatives. Less typically, TAs take up the more nuanced issues of opportunity costs and interactions with other options, and factors that tend to narrow the range of choice.

local and regional weather and climate. The analog is useful on three counts: (1) past weather and climate modification efforts raised concerns similar to those about geo-engineering, so it injects evidence into the current discussion, which is heavy on speculation; (2) some of the emerging geo-engineering schemes aimed at global warming (e.g., enhancing oceanic clouds) are versions of more conventional weather modification techniques; and (3) we are likely increasingly to employ orthodox weather and climate modification in response to global warming, so a look back serves even if geo-engineering does not materialize.

This paper focuses on lessons from the social dimensions of weather modification.

Past Efforts at Weather and Climate Modification

As early as 1966, Sewell and Kates framed weather modification as "big science" and argued that: "For 'big science", external criteria are required and the suggested ones are based on considerations of technological merit, scientific merit, and social merit, and are designed to answer the question, why pursue this particular science?" (Sewell and Kates, 1966, p. 351). They were suggesting, in essence, a weather modification technology assessment, which never got done. Now we are asking this question of climate geo-engineering schemes.

Serious efforts have been made in the past century to change the climate of whole regions (the shelter-belt program on the U.S. Great Plain; snow-pack augmentation in the Southwest), and to routinely alter the meteorology of snow, rain, fog and hail at least locally; we even attempted to modify hurricanes. Weather and climate modification is currently practiced at local to regional scales around the world (Garstang et al., 2005), and will surely be ramped up if global warming is perceived as worsening weather- and climate-related problems (e.g., concerns about water supplies in the American Southwest have already evoked increased cloud seeding).

Modern weather and climate modification arose in the last half century based on growing understanding of atmospheric processes; yet it has a checkered scientific history (Committee on the Status and Future Directions in U.S Weather Modification Research and Operations, 2003). Precipitation enhancement has long been the focus, but atmospheric engineering schemes have gone well beyond rainmaking. The Soviet Union in particular advanced large-scale efforts to reduce hail, tornadoes, and drought (Cotton and Pielke, Sr., 1995); a scheme emerged to divert Arctic Slope freshwater runoff, thus increasing the salinity and decreasing the ice cover of the Arctic Ocean (Kellogg and Schneider, 1974), a plan eerily similar to mechanisms that some scientists now fear could affect the thermohaline circulation. The United States embarked on an effort to reduce hurricane intensity (Dorst, 2007), and several large-scale modification projects (most still in practice) sought to regularly increase snow-pack in the Rocky Mountains and Sierra Nevada, and rainfall in, for example, Texas, Florida and Dakotas (Garstang, et al. 2005). Some of these efforts, by virtue of their long-term implementation, have ostensibly changed the climate of those places---some stream basins in the Sierra Nevada have been seeded almost every winter for 50 years!

Contemporary weather modification programs rest on a mixture of slender, but encouraging, scientific substantiation and skeptical analysis (Committee on the Status and Future Directions in U.S Weather Modification Research and Operations, 2003) as well as sincere, but also wishful, thinking. The goal here is not to evaluate cloud seeding technology *per se*, but to assess the social response, decision-making, and other implications for geo-engineering.

Social Response to Weather and Climate Modification

A small but useful body of analysis exists on social response to conventional weather and climate modification schemes, coming especially from sociologists, policy scientists, and geographers (e.g., Steinberg, 2000; Farhar, 1977; Farhar and Mewes, 1975; Sewell, 1966).

Fleming's (2007) dismissive *Wilson Quarterly* piece casts past weather and climate modifiers as arrogant "Titans" with no regard for social or environmental consequences. Discussing a 1965 proposal to increase the Earth's albedo with bright particles spread across the tropical oceans (among the first serious global warming geo-engineering schemes), Fleming claims that "No one thought to consider the side effects of particles washing up on tropical beaches or choking marine life, or the negative consequences of redirecting hurricanes, much less other effects beyond our imagination. And no one thought to ask if the local inhabitants would be in favor of such schemes." (p. 58). This is simply not true of many weather and climate modification programs (including hurricane modification, which, I will argue below, was suspended largely due to social concerns), and my sense is that the recent writing about geo-engineering, even by proponents, is actually weighted to concerns about unintended social and ecological consequences.

I first ran into a sociologist asking people what they thought of cloud seeding in 1971 while I was a student employee on NOAA's Florida Area Cumulus Experiment (FACE; see: Woodley et al., 1977). Admittedly the project meteorologists did not think much of his efforts, believing that simply asking people about the project would bias them against it, but the results (also for Colorado and South Dakota projects) showed strong support for cloud seeding (Haas, 1973). Ironically, when he (and I) asked sugarcane farmers in the seeding target area what they thought, some said that they, themselves, already partly controlled the rain by flooding their fields; they were little bothered by the fed's cloud seeding.

So, there is indeed a history of asking whether "the local inhabitants would be in favor of such schemes," despite Fleming's argument, and the answer, to my reading of the thin literature, is "Yes." The most well-developed assessment was conducted in the 1970s for hail suppression (Changnon et al., 1978). Extensive surveys and other social analyses found that a majority of the public, especially farmers, believed that the technology could work and that its benefits would outweigh the costs. But the hail studies also asked urbanites what they thought, and explored how cities might deal with extra rainfall (more car accidents). Fears about "unintended consequences" and "over-correction" seem to have been relatively mild, though they were expressed. Because the High Plains of the Dakotas and Black Hills had been a favorite testing ground, the 1972 Rapid City flash flood, which occurred amidst a Bureau of Reclamation seeding program, certainly tested social acceptance. Steinberg's (2000) study of the flood's connection (real or imagined) to seeding, based on hearings and reviews by the Bureau of Reclamation, found that if a flood happens to occur in an area undergoing cloud seeding to increase rainfall (even if the events are not on the same day or in the seeded area), then alarms will be raised by at least some proportion of the affected population, especially those at risk and those who feel that humans should not try to change nature or interfere in "God's will" (Steinberg, 2000). But Farhar[3] (1976), based on surveys of residents, found that the perceived link between cloud seeding and the flash flood had only a small effect on support for cloud seeding in the area, which was strong before and after the flood. Indeed, the dominant concern that developed in the hail project area, based partly in the science and partly on perceptions, was that regular hail suppression would decrease rainfall (i.e., create permanent drought), a sensible worry based in the causal-chain that cloud seeders themselves presented (Farhar, 1975; 1977).

Some 15-20 seeding projects have been operated in and around the Colorado River Basin for over 20 years, and plans are underway for a coordinated project to run for the next quarter

[3] Farhar, as far as I can tell, has more experience studying public acceptance of purposeful weather and climate modification than any other social scientist, and almost all this work was conducted before c.1980. She has retired to Boulder, CO, and has made her extensive weather modification files available for further research.

century (Peterson, 2007). One project, winter seeding in the San Juan Mountains of SW Colorado (an effort under BuRec's Project Skywater) elicited a series of impact studies and hearings at its beginning in 1971, where some concerns were raised about flooding and avalanche; seeding in the area has run with little overt opposition since, with a hodgepodge of local, federal and private funding. Cloud seeding in Texas is so popular that local tax districts pay for it. Overall, cloud seeding seems to evoke little negative response, and everyone from farmers, to skiers, to water managers evince at least the hope that it can help. No implacable opposition to precipitation enhancement has emerged.

But maybe rain and snow augmentation is too tame; perhaps modifying hurricanes is a better analog for climate geo-engineering. Beginning in the 1960s the U.S. experimented with hurricane seeding to reduce storm intensity (Simpson and Simpson, 1966). The social response to Project Stormfury (Dorst, 2007) is poorly recorded (and deserves more digging), but both lay and professional fears were raised, and I believe it fair to conclude that this potentially useful technology was indeed stymied, even in the experimental stage, by social and political concerns. Worries included: that hurricanes might intensify and/or change course; that more rainfall would cause worse flooding (a fear founded in the Stormfury's physical logic); and even that tempering hurricanes would affect hemispheric climate by interfering with the poleward transfer of tropical energy. The scientists involved tip-toed around such concerns and preferred to keep a low profile (this was mostly before NEPA, EIS's, and public input), but I heard personally from some of the principals that public concerns, media hype, and bureaucratic fears kept the project from achieving its experimental goals. Some of this frustration peeks through in the Dorst, 2007, history of Stormfury, and in biographies of those involved, see, for example: http://earthobservatory.nasa.gov/Features/Simpson/simpson.php (I worked as a student employee for Joanne Simpson in 1971-73 when, frustrated by lack of access to hurricanes, she had turned to seeding individual clouds over Florida.)

In "The Decision to Seed Hurricanes", a classic early quantitative risk analysis still used in risk assessment classes today, Howard et al. (1972) raised concerns about "responsibility costs," the notion that once the government seeds a hurricane, it then "owns" the damage done by that storm, at least the damage above some nominal level that would have occurred naturally, a level notoriously difficult to assess. They even suggested that given the large value of hurricane losses (even then, before we had multi-billion dollar storms), that the responsibility costs might be so large as to preclude ever seeding a storm. They concluded that perhaps only emergency seeding in the face of catastrophic storms would over-ride this threshold. [The current draft AMS policy statement on geo-engineering picks up on this theme: "Geoengineering could conceivably offer targeted and fast-acting options to reduce acute climate impacts and provide strategies of last resort if abrupt, catastrophic, or otherwise unacceptable climate change impacts become unavoidable by other means."]

Cautionary rules developed for when hurricanes could be seeded (derived from precisely the kind of concern for unintended consequences that Fleming claims has been ignored) so constrained the experimental area that opportunities to seed storms failed to materialize. Efforts to shift the program to the more active Pacific were thwarted by logistics and the expressed concerns of Pacific Rim countries, a foreshadowing perhaps of the geo-politics of geo-engineering. Ultimately, Stormfury seeded only four storms in 21 years, a run that sapped its enthusiasm, and, finally, its funding in 1983 (Dorst, 2007). There's little doubt that concerns about the unintended consequences of hurricane seeding were one factor in the project's failure. But Stormfury offers another cautionary tale for geo-engineering. The research associated with it, including much better hurricane monitoring, revealed the episodic intensity changes (especially eye-wall replacement cycles) that to this day still dog hurricane forecasting. The more they learned, the more that Stromfury researchers realized how hard it would be to demonstrate an effect (Willoughby et al., 1985). By the same token they realized that they could not constrain their potential responsibility in a seeded hurricane disaster.

So the history of weather modification offers a mixed message. Routine cloud seeding for more rain and snow is permissible, even desired, and practiced with little regard to liabilities or demonstrated effectiveness year after year in the U.S. and around the world. Yet the arguably more vital, but spookier, effort to modify hurricanes is impermissible, and ran aground on fears of unintended consequences, political sensitivities, and the *a priori* indeterminacy of its effectiveness.

Yet in many ways the literature suggests that public perception of routine weather and climate modification leans toward the positive and credulous, perhaps even toward an outsized sense of control over nature, a willingness to accept poorly-supported claims of effectiveness, and a belief that we can change atmospheric systems quite dramatically, for better or worse. And almost without exception a very positive benefit/cost ratio adheres to, and furthers, cloud seeding: application is relatively cheap compared to the benefits even of an effect (signal) that resides within, or just barely rises above, the noise of weather variability. This applies to everything from snow pack augmentation to hurricane seeding (Sorkin, 1982, p. 95); even a small reduction in wind speed in a hurricane destined to cause billions of dollars of damage would pay off handsomely. Current estimates of additional water in the Colorado River yield benefit/cost ratios of 4-1 to 60-1. Finally, cloud seeding is palliative. Cotton (2008), a cloud seeding veteran, finds that weather modification appeals to politicians wishing to "do something" when local economies are threatened by weather problems, and the field's history is full of applied efforts called for by political and business leaders, despite lack of evidence for effectiveness. Recent hurricanes disasters have re-kindled interest in hurricane modification (Department of Homeland Security, 2008).

Implications for Geo-Engineering

Purposeful weather modification is an imperfect analog to geo-engineering, but does offer some lessons. Certainly the appeal is similar: geo-engineering offers an alternative if others fail and/or if climate change is worse than we think. Like weather modification, geo-engineering offers rather large assumed benefits compared to costs. Cost-effectiveness calculations made by Panel on the Policy Implications of Greenhouse Warming (1992, p. 486), though rough, seem in line with recent estimates.

Geo-engineering as Weather Modification

Realized global warming is likely to elicit more conventional local and regional weather modification, including especially precipitation enhancement and, maybe, hurricane modification, so a geo-engineering technology assessment must at least address traditional weather modification writ larger. It also works out that, despite much attention to novel schemes like stratospheric aerosol injection, many anti-global warming schemes are based on more conventional weather modification techniques, including seeding to change the albedo of naturally-extensive cloud systems like oceanic strato-cumulus or high level cirrus (ships already enhance oceanic clouds from their stack effluent and jets make cirrus clouds via contrails) (Cotton, 2008; Latham et al., 2008). Since cloud seeding is currently conducted on a routine basis in many places in the U.S. and around the world, without discernible negative effects or significant social opposition (Cotton and Pielke, 1995; Garstang et al., 2005), it would seem that geo-engineering schemes that emulate past weather modification seem more likely to advance to field trials than others. But the Project Stormfury experience does suggest bigger hurdles for bigger projects, and my hunch is that large-scale geo-engineering will run afoul of the same frustration: field tests are so constrained that they become infeasible.

Liability

Liability and "robbing-Peter-to-pay-Paul" arguments are common in weather modification discourse, but actual cases simply have not materialized during decades of active cloud seeding. I believe the field has managed to stay in business partly because cloud seeders get to claim a beneficial effect that is small enough not to cause problems. Barely a dozen court cases since 1950 have yielded no findings of liability, nor tort precedence (Standler, 2002, 2006). Howard et al. (1972) raised the possibility of "responsibility costs" in hurricane seeding, and even suggested they may be so large as to shut down any seeding program. But right now there is only null experience in weather and climate modification liability. But, evidence that stratospheric aerosols might reduce the South Asian Monsoon raise the specter of potential harm. Schneider (2008) even suggested that the total climate change (cooling plus warming) across the globe might be *increased* by geo-engineering schemes that nevertheless achieve their goal of GMT cooling and stabilization, suggesting that losers might be legion even in an effective program.

Governance

Weather modification "governance" is almost non-existent. Professional best-practices and standards do exist, along with a professional society (the Weather Modification Association) and WMO and American Meteorological Society (AMS) policy statements on weather modification and guidelines for projects (http://www.wmo.int/pages/prog/arep/wmp/STATEMENTS/statwme.pdf) and http://www.ametsoc.org/policy/wxmod.html). But, only very weak regulation and government oversight has emerged in any of the cloud seeding projects around the world. Several U.S. states have weak weather modification laws; some have repealed them, or left them un-enforced (Standler, 2002, 2006). The UN general assembly passed in 1977 a resolution proscribing environmental modification as an act of aggression, weaponization, or purposeful harm to another national state. The AMS policy statement on weather modification addresses mostly scientific issues, and only lightly suggests attention to liability, compensation, and environmental effects.

The current draft AMS policy statement in geo-engineering calls for: "Development and analysis of policy options to promote transparency and international cooperation in exploring geo-engineering options along with restrictions on reckless efforts to manipulate the climate system." We are along way from this, even for conventional weather and climate modification.

Final Note:
A Slippery Slope?

Some discussions of geo-engineering suggest that even thinking about this particular cure might worsen the disease, that serious attention to geo-engineering solutions could exacerbate the problem by reducing our commitment to mitigation, and that even analyzing engineering solutions puts us on a slippery slope to relying on them instead of mitigation (e.g., Kiehl, 2006; Fleming, 2008; Robock, 2008). In this vein, the thinking goes, serious attention to climate-cooling schemes might invoke the "moral hazard" associated with insurance behavior, or even the paradox that natural hazards researchers call the "levee effect" (i.e., that dams and levees encourage flood zone development, thus exacerbating future losses when inevitable failures occur).

The moral hazard argument is difficult to sustain or refute, at least party because its proponents have not demonstrated its real-world effects in analog cases. I think we lack evidence-based argument here. Insurance programs seem more affected by adverse selection than by moral hazard, and the question of whether disaster relief encourages risky behavior has not been settled after years of debate among hazards researchers, suggesting to me that the effect is not very strong. Mileti (1999) concludes that expectations of relief do not necessarily encourage hazard zone occupance, but insurance might. The leading scholar of hazards insurance, Howard Kunreuther, who has argued that well-designed insurance systems lessen the potential for moral hazard, concluded after Hurricane Katrina that expectations of government aid do indeed reduce adoption of both pre-hazard mitigation and of insurance (Kunreuther, 2006). Of course, insurance companies have a hook to enforce mitigation (e.g., increased premiums for risky behavior, and discounts for risk reduction behavior) and relief rarely compensates for all losses, so the logical homeowner, for instance, does not use either as an excuse to ignore risks.

On the other hand, there is some evidence for the "levee effect" whereby levees and dams invite development that then incurs even greater losses when they fail (not just that they invite development, that's what they are designed to do, but that they in some cases increase net losses) (Kates et al., 2006). The levee effect is not quite analogous to a moral hazard, but it may inform our thinking about geo-engineering. For example, maybe the problem is not so much that the geo-engineering prospect squelches mitigation, but dampens adaptive efforts.

A similar argument was raised against research on adaptation to climate change, which could also be seen as dampening efforts to reduce greenhouse gases.[4] Critics argued that the adaptation sub-panel of the Panel on Policy Implications of Greenhouse Warming (1992) was over-optimistic about the potential for social adaptation to global warming. Two panelists wrote dissenting statements to this effect (pp. 84-84, and p. 659).[5] I believe we have usefully gotten past the argument that research on adaptation is counter-productive (because both mitigating and adaptation appear necessary), but the debate over geo-engineering opens up lots of room to revisit such arguments.

References

Changnon, S.A., Jr., B.C. Farhar, and E.R. Swanson (1978) "Hail suppression and society: Assessment of future hail suppression technology reveals its development should be sizeable or ignored." *Science* 200: 387-394.

Cicerone, R. (2006) "Geoengineering: Encouraging research and overseeing implementation." *Climate Change* 77: 221-226.

Committee on the Status and Future Directions in U.S Weather Modification Research and Operations (2003) *Critical Issues in Weather Modification Research*. National Research Council, Washington, D.C.

Cotton, W.R. (2008) "Weather and climate engineering." Pre-prints of the Weather Modification Association/American Meteorological Society Conference on Planned and Inadvertent Weather Modification. Westminster, CO, April. See: http://ams.confex.com/ams/17WModWMA/techprogram/programexpanded_492.htm

Cotton, W.R. and Pielke, Sr., R.A. (1995) *Human Impacts on Weather and Climate*. Cambridge University Press.

Crutzen, P.J. (2006) "Albedo enhancement by stratospheric sulfur injections: A contribution to resolve a policy dilemma?" *Climate Change* 77:211-219.

Dorst, N. M. (2007) "The National Hurricane Research Project: 50 years of research, rough rides, and name changes." *Bulletin of the American Meteorological Society* 88: 1566-1588.

[4] This argument was made to me personally by prominent climatologists at the Toronto Conference on The Changing Atmosphere in 1988 and at the Second World Climate Conference in Geneva in 1992, where I presented a paper on adapting to global warming.

[5] I was a member of the panel, under my previous name, William E. Riebsame.

Farhar, B.C. and J. Mewes (1975) Social Acceptance of Weather Modification: The Emergent South Dakota Controversy. Monograph 23, Natural Hazards Research and Applications Information Center, University of Colorado, Boulder. 204 pp.

Farhar, B. C. (1976) "Impact of the Rapid City Flood on Public Opinion about Weather Modification." *Pacific Sociological Review* 19: 117-144.

Farhar, B. C., ed. (1977) *Hail Suppression: Society and Environment*. Monograph 24, Natural Hazards Research and Applications Information Center, University of Colorado, Boulder. 293 pp.

Farhar, B. C. and S.A. Changnon, Jr. (1977) *Hail Suppression: Impacts and Issues.* Final Report, Technology Assessment of the Suppression of Hail. Urbana: Illinois State Water Survey.

Flemming, J. (2007) "The climate engineers." *The Wilson Quarterly* 31 (2, Spring): 46-60.

Garstang, M., R. Bruintjes, R. Serafin, H. Orville, B. Boe, W. Cotton and J. Warburton (2005) "Weather Modification: Finding common ground." *Bulletin of the American Meteorological Society* 86:647-655.

Haas, J.E. (1973) "Social aspects of weather modification." *Bulletin of the American Meteorological Society* 54: 647-457.

Hale, B. and L. Dilling (in revision) "Carbon sequestration, ocean fertilization, and the problem of permissible pollution." Science and Technology Policy.

Howard, R.A., J. E. Matheson, D. W. North (1972) "The decision to seed hurricanes." *Science* 176: 1191-1202.

Jamieson, D. (1996) "Ethics and intentional climate change." *Climatic Change* 33: 323-336.

Kates, R.W., Colten, C.E., Laska,S., and Leatherman, S.P. (2006) "Reconstruction of New Orleans after Huricane Katrina: A research perspective." *Proceedings of the National Academy of Sciences* 103: 14653-14660.

Kellogg, W.W. and Schneider, S.H. (1974) "Climate stabilization: for better or worse?" *Science* 186, 1163–1172.

Kunreuther, H. (2006) "Disaster mitigation and insurance: Learning from Katrina." *Annals of the American Academy of Political and Social Science* 604: 208-227.

Latham, J., P. Rasch, C.-C. Chen, L. Kettles, A. Gadian, A. Gettelman, H. Morrison, K. Bower, and T. Choularton (2008) "Global temperature stabilization via controlled albedo enhancement of low-level maritime clouds." *Phil. Trans. R. Soc. A.* 366: 3969–3987.

Lempert, R.J. and M.T. Collins (2007) "Managing the risk of uncertain threshold responses: comparison of robust, optimum, and precautionary approaches." *Risk Analysis 27: 1009-1026.*

MacCracken, M.C. (2006) "Geoengineering: Worthy of cautious evaluation?" *Climate Change* 77:235-243.

Mileti, D. (1999) *Disasters by Design: A Reassessment of Natural Hazards in the United States*. Joseph Henry Press, Washington, D.C.

Peterson, T. (2007) "Cloud seeding." *Aqueduct* (the magazine of the Metropolitan Water District of Southern California), 73 (1).

Department of Homeland Security (2008) *Hurricane Modification Workshop Report*. Science and Technology Directorate, Washington, DC (in cooperation with the NOAA Global Systems Division of the Earth Systems Research Laboratory, Boulder, CO). March.

Pielke, Jr., R.A., Prins, G., Rayner, S., and Sarewitz, D. (2007) "Lifting the taboo on adaptation." Nature, Vol. 445, pp. 597-598.

Pielke, Jr., R.A., T. Wigley, and C. Green (2008) "Dangerous assumptions: How big is the energy challenge of climate change?" *Nature* 452: 531-532.

Pileke, Jr., R.A. (2009) "Does geo-engineering meet criteria for a successful technological fix?" SeedMagazine.com, May. 19. http://seedmagazine.com/content/article/will_the_future_be_geo-engineered1/

Robock, A. (2008) "20 reasons why geoengineering may be a bad idea." *Bull. Atomic Scientists*, 64, No. 2, 14-18, 59, doi:10.2968/064002006.

Sarewitz, D. and R.X Nelson (2008) "Three rules for technological fixes." Nature 456: 871-872.

Sewell, W. R. D., ed. (1966) *Human Dimensions of Weather Modification.* Department of Geography Research Paper 105, University of Chicago.

Schneider, S.H. (2001) "Earth system engineering and management." *Nature* 409: 417.

Schneider, S.H. (2008) "Geo-engineering: Could we or should we make it work?" *Phil. Trans. R. Soc. A*. 366: 3843-3862.

Sewell, W.R.D. and R.W. Kates (1966) The Evaluation of Weather Modification Research. In Sewell, W. R. D., ed., *Human Dimensions of Weather Modification.* Department of Geography Research Paper 105, University of Chicago, pp. 347-362.

Simpson, R.H. and J. Simpson (1966) "Why experiment on tropical hurricanes?" *Transactions of the New York Academy of Sciences* 28: 1045-1062.

Sorkin, A.L. (1982) *Economic Aspects of Natural Hazards*. Lexington Books, Lexington, Mass.

Standler, R.B. (2002, 2006) "Weather modification law in the U.S.A." Available at: www.rbs2.weather.com/pdf.

Steinberg, T. (2000) *Acts of God: The Unnatural History of Natural Disaster in America*. Oxford University Press, New York.

Travis, W.R. (in revision) "Going to Extremes: Propositions on the Social Response to Severe Climate Change" *Climatic Change*.

Wigley, T.M.L. (2006) "A combined mitigation/geoengineering approach to climate stabilization." *Science* 314: 452–454.

Willoughby, H.E., D.P. Jorhense, R.A. Black, and S.L. Rosenthal (1985) "Project STORMFURY: A scientific chronicle 1962-1983." *Bulletin of the American Meteorological* Society 66:505-514.

Woodley, W.L., J. Simpson, R. Diondini, and J. Berkeley (1977) "Rainfall results, 1970-1975: Florida area cumulus experiment." *Science* 195: 735-742.