The Discovery of Global Warming February 2018

Climate Modification Schemes

If human activities could change climate, why not change it on purpose, to suit us better? From 1945 into the 1970s, much effort went into studies of weather modification. American entrepreneurs tried cloud-seeding to enhance local rainfall, Russian scientists offered fabulous schemes of planetary engineering, and military agencies secretly explored "climatological warfare." The hopes and fears promoted basic research on climate change by raising large sums of government money and a few provocative ideas. In the mid 1970s the visionary projects were mostly abandoned. Research turned instead to controversial "geoengineering" schemes for interventions that might restrain global warming if it started to become unbearable.

"Intervention in atmospheric and climatic matters . . . will unfold on a scale difficult to imagine at present. . . . this will merge each nation's affairs with those of every other, more thoroughly than the threat of a nuclear or any other war would have done." — *J. von Neumann*(1)

At the close of the Second World War, a few American scientists brought up a troublesome idea. If it were true, as some claimed, that humans were inadvertently changing their local weather by cutting down forests and emitting pollution, why not try to modify the weather on purpose? For generations there had been proposals for rainmaking, based on folklore like the story that cannonades from big battles brought rain. Now top experts began to take the question seriously. Perhaps they were inspired by the almost unimaginable technical powers demonstrated in the war's gigantic bomber fleets and the advent of nuclear weapons. Whatever the impulse, at the end of 1945 a brilliant mathematician, John von Neumann, called other leading scientists to a meeting in Princeton, where they agreed that modifying weather deliberately might be possible. They expected that could make a great difference in the next war. Soviet harvests, for example, might be ruined by creating a drought. Some scientists suspected that alongside the race with the Soviet Union for ever more terrible nuclear weapons, they were entering an equally fateful race to control the weather.

As the Cold War got underway, U.S. military agencies devoted significant funds to research on what came to be called "climatological warfare."(2) Much of this lay behind a curtain of secrecy, although enough hints were published for attentive members of the public to see that human manipulation of climate could become a serious issue. For scientists like von Neumann, the main research thrust was plain: the nation needed computer modeling of weather systems. For the chief difficulty in figuring out how to change climate lay in predicting just how the atmosphere might

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respond to a given type of intervention. The only hope for answering that (aside from trying it out) was with computer models.

Meanwhile, far more visibly, the famous scientist Irving Langmuir and his associates at the General Electric company were exploring a new proposal for rainmaking. Their idea was to "seed" clouds with a smoke of particles, such as silver iodide crystals, that could act as nuclei for the formation of raindrops. Langmuir quickly won support from military agencies, and claimed success in field experiments. A small but energetic industry of commercial "cloud seeders" sprang up with even more optimistic claims. Controversy followed, polarizing scientists, exciting the public and catching the attention of politicians. As soon as some community attempted to bring rain on themselves, people downwind would hire lawyers to argue that they had been robbed of their own precipitation. Concern climbed to high levels of government, and in 1953 a President's Advisory Committee on Weather Control was established to pursue the idea. In 1958, the U.S. Congress acted directly to fund expanded rainmaking research. Large-scale experimentation was also underway, less openly, in the Soviet Union.(3)

Military agencies in the U.S. (and presumably in the Soviet Union) supported research not only on cloud seeding but on other ways that injecting materials into the atmosphere might alter weather. Although much of this was buried in secrecy, the public learned that climatological warfare might become possible. In a 1955 *Fortune* magazine article, von Neumann himself explained that "Microscopic layers of colored matter spread on an icy surface, or in the atmosphere above one, could inhibit the reflection-radiation process, melt the ice, and change the local climate." The effects could be far-reaching, even world-wide. "What power over our environment, over all nature, is implied!" he exclaimed. Von Neumann foresaw "forms of climatic warfare as yet unimagined," perhaps more dangerous than nuclear war itself. He hoped it would force humanity to take a new, global approach to its political problems.(4)

=>Government
<=>Aerosols

=>Public opinion

Through the 1960s, plans for cloud seeding and other interventions remained active and controversial. A review by the National Academy of Sciences tentatively supported some claims of success. Government agencies launched competing programs and conducted several large-scale field trials. The costly research programs were perpetually on the brink of proving something, but never got truly convincing results. Many academic meteorologists came to disdain the whole subject, infested as it was with unfulfilled promises and commercial hucksters.(5) Despite these misgivings, the U.S. government spent more than twenty million dollars a year on weather modification research in the early 1970s.

<=>Aerosols

The Soviet Union was determined not to be left behind in any grandiose technology. Little is known of what studies the Soviets undertook on climatological warfare, but some novel ideas did become public. One starting-point was a Russian

legacy of hydraulic engineering fantasies, notably an old scheme to divert Siberian rivers. Why not take the water flowing uselessly into the Arctic Ocean, and send it south to turn the parched soils of central Asia into farmlands? The plans were reported in the early 1950s, catching the attention of the public and scientists in the West, although a decade would pass before Soviet scientists examined the details in open publications. These scientists pointed out that the diversion of fresh water would make the surface layers of the Arctic Ocean more salty. Therefore much of the icepack might not form in winter. Wouldn't that mean increased warmth, a boon to Siberians? A few Russian meteorologists questioned the scheme, even though Communist authorities frowned upon anyone who cast doubt over potential engineering triumphs. O.A. Drozdov, in particular, used weather records to empirically check what could happen around the Arctic in years of less ice, and reported there had been serious changes in precipitation.

=>Simple models

An even more gargantuan proposal aimed directly at climate. Around 1956, Soviet engineers began to speculate that they might be able to throw a dam across the Bering Strait and pump water from the Arctic Ocean into the Pacific. This would draw warm water up from the Atlantic. Their aim was to eliminate the ice pack, make the Arctic Ocean navigable, and warm up Siberia. The idea attracted some notice in the United States — presidential candidate John F. Kennedy remarked that the idea was worth exploring as a joint project with the Soviets, and the discussion continued into the 1970s. Such giant engineering projects were in line with traditional American technological optimism, and still more with the Communist dogma that "man can really be the master of this planet." As the title of an enthusiastic Russian publication put it, the issue was "Man versus Climate." However, it was hard to tell whether giant projects such as a Bering Dam made sense. Mikhail I. Budyko, the most prominent Russian climate expert, pointed out that the effects of such interventions would be unpredictable, and he advised against them.(6)

A more feasible scheme would be to spread particles in the atmosphere, or perhaps directly on the ground. Beginning around 1961, Budyko and other scientists speculated about how humanity might alter the global climate by strewing dark dust or soot across the Arctic snow and ice. The soot would lower the albedo (reflection of sunlight), and the air would get warmer.(7) Spreading so much dust year after year would be prohibitively expensive. But according to a well-known theory, warmer air should melt some snow and sea-ice and thus expose the dark underlying soil and ocean water, which would absorb sunlight and bring on more warming. So once dust destroyed the reflective cover, it might not re-form.

<=>Simple models

Russian scientists were not sure whether this would be wise, and scientists elsewhere were still more dubious. In 1971 a group of American experts said that "deliberate measures to induce arctic sea ice melting might prove successful and

might prove difficult to reverse should they have undesirable side effects."(8*) As the respected British climate expert Hubert Lamb suggested, before taking any action it seemed like "an essential precaution to wait until a scientific system for forecasting the behavior of the natural climate... has been devised and operated successfully for, perhaps, a hundred years."(9)

By this time, the early 1970s, feelings about human relations with the natural environment had undergone a historic shift. Many technologies now seemed less a triumph of civilized progress than wicked transgressions. If it were true, as some scientists claimed, that human emissions were inadvertently changing the entire global climate, the chief result seemed to be droughts and other calamities. As for deliberate rain-making attempts, if they were successful (which remained far from proven) they might only be "stealing" the rain from farmers downwind who would have gotten it instead. Such projects might even harm the very people who got the rain. For example, a 1972 U.S. government rain-making operation in South Dakota was followed by a disastrous flood, and came under attack in a class-action lawsuit. One cloud-seeding airplane was even shot at. An increasing number of people objected in principle to any such meddling with natural processes. The idea of changing the weather had shifted from a benign dream of progress to a nightmare of apocalyptic risk. Between 1972 and 1975 the U.S. government dramatically cut its budget for weather modification.(10) (Attempts persisted here and there; for example, the Chinese government pursued rainmaking extensively in the early 21st century.)

<=Public opinion

<=Public opinion

=>Government

Meanwhile the U.S. government had secretly been spending many millions of dollars on a grand experiment in actual climatological warfare. The Department of Defense directed extensive cloud-seeding over the Ho Chi Minh Trail, hoping to increase rainfall and bog down the North Vietnamese Army's supply line in mud. Hints about the program were leaked in 1971, but the public did not learn the full extent of the effort until 1974, two years after it wound down in failure. Many people were dismayed when they learned of the experiment. There followed a series of resolutions, in bodies from the U.S. Senate to the General Assembly of the United Nations, outlawing climatological warfare. The movement culminated in a 1976 international convention that foreswore hostile use of "environmental modification techniques."(11)

=>Public opinion

=>Government

Of course we were already modifying the world's atmosphere with quantities of polluting aerosols and greenhouse gases vastly beyond anything the most aggressive warrior had imagined. If that raised a risk of damage to climate, some thought we were obliged to prepare a remedy. Now when scientists discussed steps to melt arctic snows or the like, it was not to craft utopian weather, but with the aims implied in the title that Lamb gave a 1971 review article: "Climate-engineering schemes to meet a climatic emergency."(12)

Already back in 1965, a Presidential advisory panel had suggested that if greenhouse effect warming by carbon dioxide gas ever became a problem, the government might take countervailing steps. The panel did not consider curbing the use of fossil fuels. They had in mind what later came to be called "geoengineering" schemes — spreading something across the ocean waters to reflect more sunlight, perhaps, or sowing particles high in the atmosphere to encourage the formation of reflective clouds. Some back-of-the-envelope arithmetic suggested such steps were feasible, and indeed could cost less than many government programs.(13) In 1974, Budyko calculated that if global warming ever became a serious threat, we could counter it with just a few airplane flights a day in the stratosphere, burning sulfur to make aerosols that would reflect sunlight away.

=>Government

<=Aerosols

For a few years in the early 1970s, new evidence and arguments led many scientists to suspect that the greatest climate risk was not warming, but cooling. A new ice age seemed to be approaching as part of the natural glacial cycle, perhaps hastened by human pollution that blocked sunlight. Technological optimists suggested ways to counter this threat too. We might spread soot from cargo aircraft to darken the Arctic snows, or even shatter the Arctic ice pack with "clean" thermonuclear explosions.

<=Climate cycles

<=Public opinion

Whether we used technological ingenuity against global cooling or against global warming, Budyko pointed out that any action would change climate in different ways for different nations. Attempts at modification, he insisted, "should be allowed only after the projects have been considered and approved by responsible international organizations and have received the consent of all interested countries." The bitter fighting among communities over cloud-seeding would be as nothing compared with conflicts over attempts to engineer global climate. Moreover, as Budyko and Western scientists alike warned, scientists could not predict the consequences of such engineering efforts. We might forestall global warming only to find we had triggered a new ice age.(14)

=>Public opinion

Such worries revived the U.S. military's interest in artificial climate change on a global scale. A group at the RAND corporation, a defense think tank near Los Angeles, had been working with a computer climate model that originated at the University of California, Los Angeles. This was normal scientific research, funded by the civilian National Science Foundation. Around 1970, however, with opponents of the Vietnam war attacking anything that smelled of militarism, the NSF backed out of funding work with overt military connections. The RAND group had to scramble to find support elsewhere. They turned to the Advanced Research Projects Agency of the Department of Defense. ARPA was meanwhile on the lookout for computing projects that could justify the funds it had lavished on its ILLIAC supercomputer. The menace of Soviet climate engineering schemes gave a plausible rationale. ARPA awarded the project millions of dollars, a secret classification, and a code name, NILE BLUE.

<=Models (GCMs)

=>Models (GCMs)

=>Government

The money supported a variety of large-scale computer studies and even some work on ancient climates. Nothing of obvious military significance turned up, but the program's results proved useful for other climate scientists. After a few years the program was demilitarized. The NSF took over funding as work with the RAND model migrated to the University of Oregon, where it contributed to studies of global warming.(15)

As environmental concerns grew more widespread and sophisticated, experts and the public alike demanded a cautious approach to any intervention. A 1977 Academy report looked at a variety of grand schemes we might use to reduce global warming, should it ever become dangerous—for example, massive planting of forests to soak up carbon dioxide gas from the atmosphere. The experts could not muster much optimism for any of these schemes. The panel thought that a turn to renewable energy resources seemed a more practical solution.(16)

People nevertheless continued to come up with projects we might pursue if greenhouse warming made us desperate enough. To cite another of the many ideas, we could collect carbon dioxide from the furnaces where coal was burned, compress it into a liquid, and inject it into the depths of the Earth or the oceans. That sounded like an engineer's fantasy, but studies indicated it might in fact be done at reasonable cost.(17) Another fantastic yet perhaps feasible proposal was to fertilize barren tracts of the oceans with trace minerals. In the 1990s, calculations and field trials suggested that an occasional tanker load of iron compounds could induce massive blooms of plankton. The creatures would absorb carbon and take it to the ocean bottom when they died. However, scientists could not be sure whether in the end that really would lower the total of greenhouse gases in the atmosphere.(18)

<=Biosphere

Dozens of other schemes for mitigating the greenhouse effect were published, ranging from modest practical improvements in energy systems (for example, energy-efficient light bulbs) to futuristic visions (vast mirrors in space to reflect sunlight!?). When a National Academy of Sciences panel convened in 1991 to catalog the options, the members got into a long and serious debate over whether to include the grand "geoengineering" ideas. Might hopes of a future fix just encourage people to avoid the work of restricting greenhouse gas emissions? The panel reluctantly voted to include every idea, so that preparations could start in case the climate deteriorated so badly that radical steps would be the lesser evil. Their fundamental problem was the one that had bedeviled climate science from the start — if you pushed on this intricate system, nobody could say for sure what the final consequences might be.(19)

<=>Government

"Weather modification," a participant had written ruefully back in 1974, "is based on sound physical principles that cannot be applied precisely in the open atmosphere because several processes are interacting together in a manner

difficult to predict." Moreover, attempts to change the weather "are superimposed upon natural processes acting, perhaps indistinguishably, to the same or opposite effect.... Therefore it should not be surprising that the history of weather modification is one of painfully slow progress."(20) Much the same could be said of research on climate modification.

As the levels of global temperature and greenhouse gases continued to climb in tandem, the debate dragged on, largely below the level of public awareness. In 1997 the famous nuclear-bomb expert Edward Teller caught some attention with an essay in the *Wall Street Journal*, claiming that it would cost only a billion dollars a year to put a sun-screen in the stratosphere. He argued that "if the politics of global warming require that 'something must be done'," America should devote its technical prowess to preparing such a response. Most people who followed the debate distrusted that kind of high-technology vision (which Teller represented only too well, as chief proponent of a multi-billion-dollar "Star Wars" project that had ignominiously failed to invent lasers that could shoot down ballistic missiles).(21) Others continued to insist that the world should prepare to take emergency action, just in case. But few were willing to plunge into studies, and still fewer wanted to fund them.

As the world began to visibly suffer from global warming, scientists revisited the issue. In 2004 a group gathered at a symposium in Cambridge, England to review the possibilities for climate "Macro-Engineering". Wider attention converged on the issue in 2006 after Paul Crutzen, widely respected for his Nobel Prize-winning work on ozone, sent the leading journal *Climatic Change* an article that called for more research on climate engineering. "Given the grossly disappointing international political response" to calls to restrict greenhouse emissions, Crutzen argued that such research should no longer be "tabooed." His submission roused passionate opposition from some senior colleagues, who insisted it would be irresponsible to publish the article. Eventually they accepted a compromise that gave them space for counter-arguments.

Suppose the climate turned so bad that some nation insisted on launching a geoengineering project? Crutzen and his supporters argued that it would be best to have research on hand in advance to point out the true possibilities and pitfalls. Another respected senior climate scientist followed up with calculations reaffirming that it was economically feasible to spread sulfate particles in the stratosphere to hold back warming. Yet Crutzen himself admitted there was a risk that hopes for a cheap technical fix would be used "to justify inadequate climate policies." (22*)

Over the next few years the hope that geoengineering would solve the problem of global warming was indeed taken up by people who opposed government regulation of greenhouse gases. The debate grew intense.(23) Two companies were founded that proposed to fertilize the oceans and get paid

for offsetting carbon emissions elsewhere. Sea trials failed to prove that the results would be beneficial, and legal battles erupted, exposing the lack of any framework of international law to deal with such initiatives. Not only a single nation, but even a private group, could engage in climate engineering. In 2008 an international agreement declared a moratorium on large-scale ocean fertilization experiments, but pressure for studies of every option persisted.

Ocean fertilization was only one approach to what was coming to be called "Carbon capture and storage (CCS)." Capturing carbon dioxide (CO_2) as it was emitted from power plants was probably feasible at a cost of perhaps a fifth of the plant's energy production. The gas could be stored underground or deep in the oceans, although it would be hard to guarantee it would stay there. CCS could only affect a fraction of CO_2 emissions and did not touch the other greenhouse gases.

It was also technically possible to extract CO_2 from the atmosphere itself by combining it with calcium or through some other chemical process, or to sequester it biologically through management of forests, agricultural soils, and the like. Indeed the commitment that nations made in the 2015 Paris Agreement to keep global temperature rise below 2°C could not be met without such "negative emissions." That would mean constructing industrial and agricultural systems on the scale of, say, the entire global coal industry, at vast expense and using technologies not yet developed. Only the most sanguine imagined that would actually happen. Research was pursued in hopes of a miraculous breakthrough, but the obviously most efficient option would be simply to produce less emissions in the first place.

<=>International

Any climate engineering effort was bound to produce winners and losers, as in the old fights over rainmakers "stealing" precipitation from folks downwind. Preliminary computer studies suggested, for example, that spreading sulfates in the atmosphere might shut down the Asian monsoon. Would India and China stand idly by while droughts starved their populations? Still more worrisome were calculations showing that once a sulfates program began it would have to continue for centuries, regardless of economic disruption or wars. For if the program paused, global temperatures would snap to a higher level with catastrophic speed. As one team explained, "Coming generations would have to live with the danger of this 'Sword of Damocles' scenario, the abruptness of which has no precedent in the geologic history of climate." Most ominous of all was the likelihood that there would be consequences nobody had even guessed at. Many of the scientists who advocated research on climate engineering did so in the belief that the results would serve mainly to persuade people it was too risky to attempt, except as a last-ditch attempt in the midst of global cataclysm. It would be far safer and easier to negotiate restrictions on greenhouse gas emissions.(24)

The problem was not only means, but ends: whose goals

would climate engineering serve? Even the nightmare of climatological warfare could stalk back into history, strengthened by scientific advances. As a historian remarked, "Who would have the wisdom to dispense drought, severe winters, or the effects of storms... If, as history shows, fantasies of weather and climate control have chiefly served commercial and military interests, why should we expect the future to be different?"(25) The technical, political and ethical problems raised by deliberately influencing the global climate remained at least as great as the problems raised by our ongoing unintended influence.

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NOTES

1. von Neumann (1955), p. 41 of reprint. BACK

2. For this and all the following see Fleming (2006); Fleming (2010); Hamblin (2013). Kwa (2001); Kwa (1994); Keith (2000), p. 252; Fleming (2007a), pp. 54-57; A. Spilhaus, interview by R. Doel, Nov. 1989, AIP. BACK

3. Lambright and Changnon (1989); Byers (1974); Soviet: Keith (2000), p. 250-51. BACK

4. von Neumann (1955), pp. 108, 151. BACK

5. National Academy of Sciences (1966); Lambright and Changnon (1989); Byers (1974). BACK

6. Lamb (1971); Lamb (1977), pp. 660-61; for Soviet and other conquest of nature ideology see Josephson (2002). I have not seen Lamb's Russian-language references, which include: for diversion, Adabashev (1966); Drozdov (1966); for dam, Borisov (1962) ; Budyko (1962); inadvisable: Budyko (1977), pp. 237-38; for U.S. reaction, see e.g., National Academy of Sciences (1966), vol. 2, p. 61; for the whole story, Ponte (1976), pp. 220-29; Keith (2000), p. 251, quoting "master of this planet" from Rusin and Flit (1960). BACK

7. For discussion and references, see Lamb (1977), pp. 46, 660-61, 676, 797; I have not checked his Russian references, which include Budyko (1961); Budyko (1962); Rakipova (1966); 1966 Rakipova reports in English translation are cited by Sellers (1969). See Fleming (2010) p. 236-37. BACK

8. Donn and Shaw (1966) (without reference to Budyko); Fletcher (1966); Sellers (1969) however calculated a temperature rise of only 7°C if the ice pack were destroyed, probably insufficient to keep ice from re-forming; Wilson and Matthews (1971), quote p. 182. BACK

9. Lamb (1971), quote p. 95. BACK

10. Ponte (1976), pp. 156-58; Kwa (2001); on all the foregoing, Fleming (2006). BACK

11. For the public acknowledgment, see *New York Times*, May 19, 1974, p. 1, also Shapley (1974). Indications were already published in 1971 in a Jack Anderson column in the Washington Post, 18 March 1971, and in the "Pentagon Papers," see Seymour Hersh, "Weather as a weapon of war," *New York Times*, July 9, 1972, p. IV:3; for background and response, see Ponte (1976), ch. 11; Fleming (2006), pp. 13-14. Convention on the Prohibition of Military or any Other Hostile Use of Environmental Modification Techniques, UN Treaty Ser. 1108:151.See Harper (2017) for the US government and weather control 1950-1980 in general. BACK

12. Lamb (1971). BACK

13. President's Science Advisory Committee (1965), estimated cost $500 million per year, p. 127; see National Academy of Sciences (1966), vol. 2, pp. 60-62. The term "geoengineering" may have first appeared in Marchetti (1977) but only became common in the 1990s. BACK

14. Budyko (1977), p. 240; Budyko and Korol (1975), p. 469; see Fleming (2010), pp. 241ff.; Landsberg (1970), p. 1268. He cites 1968-69 RAND Corp. reports by J.O. Fletcher; for spreading smog from supersonic transports, see Wilson and Matthews (1971), p. 9; a summary with warnings is Kellogg and Schneider (1974), pp. 169-70. BACK

15. Hecht and Tirpak (1995), p. 375; personal communication from John Perry, 2001, and Rapp (1970) . BACK

16. National Academy of Sciences (1977); for discussion of Academy reports, see Keith (2000). BACK

17. Notably Marchetti (1977). BACK

18. Coate et al. (1996); Chisholm (2000). BACK

19. Schneider (2001), p. 418; National Academy of Sciences (1992). BACK

20. Byers (1974), p. 3. BACK

21. Teller, “The Planet Needs a Sunscreen,” Oct. 17, 1997. Teller’s 2002 technical paper on the subject is here. BACK

22. Crutzen (2006); see the entire *Climatic Change* special issue on geoengineering, with commentaries by Cicerone, M.G. Lawrence and others (vol. **77** nos. 3-4, Aug. 2006). On Crutzen see the essay on other greenhouse gases. Sulfate calculations: Wigley (2006). Press reports include Kerr (2006) and William J. Broad, *New York Times*, June 27, 2006. For the history see also Morton (2007). BACK

23. For example the best-selling Levitt and Dubner (2009) and a report issued by Lomborg's center, Bickel and Lane (2009). Good discussions include Inman (2010), Blackstock and Long (2010), Keith et al. (2010), all three published in the same month. BACK

24. A good summary: Strong (2009). One computer model: Jones et al. (2010). Damocles: Brovkin et al. (2009), p. 255. For post-1965 history in general see Caldeira and Bala (2017). One broad overview of contemporary ideas on geoengineering is Boettcher and Schäfer (2017). BACK

25. Fleming (2007), p. 60. BACK