The WILSON QUARTERLY
SURVEYING THE WORLD OF IDEAS

The Climate Engineers

by James R. Fleming

Beyond the security checkpoint at the National Aeronautics and Space Administration's Ames Research Center at the southern end of San Francisco Bay, a small group gathered in November for a conference on the innocuous topic of "managing solar radiation." The real subject was much bigger: how to save the planet from the effects of global warming. There was little talk among the two dozen scientists and other specialists about carbon taxes, alternative energy sources, or the other usual remedies. Many of the scientists were impatient with such schemes. Some were simply contemptuous of calls for international cooperation and the policies and lifestyle changes needed to curb greenhouse-gas emissions; others had concluded that the world's politicians and bureaucrats are not up to the job of agreeing on such reforms or that global warming will come more rapidly, and with more catastrophic consequences, than many models predict. Now, they believe, it is time to consider radical measures: a technological quick fix for global warming.

"Mitigation is not happening and is not going to happen," physicist Lowell Wood declared at the NASA conference. Wood, the star of the gathering, spent four decades at the University of California's Lawrence Livermore National Laboratory, where he served as one of the Pentagon's chief weapon designers and threat analysts. (He reportedly enjoys the "Dr. Evil" nickname bestowed by his critics.) The time has come, he said, for "an intelligent elimination of undesired heat from the biosphere by technical ways and means," which, he asserted, could be achieved for a tiny fraction of the cost of "the bureaucratic suppression of CO_2." His engineering approach, he boasted, would provide "instant climatic gratification."

Wood advanced several ideas to "fix" the earth's climate, including building up Arctic sea ice to make it function like a planetary air conditioner to "suck heat in from the midlatitude heat bath." A "surprisingly practical" way of achieving this, he said, would be to use large artillery pieces to shoot as much as a million tons of highly reflective sulfate aerosols or specially engineered nanoparticles

into the Arctic stratosphere to deflect the sun's rays. Delivering up to a million tons of material via artillery would require a constant bombardment—basically declaring war on the stratosphere. Alternatively, a fleet of B-747 "crop dusters" could deliver the particles by flying continuously around the Arctic Circle. Or a 25-kilometer-long sky hose could be tethered to a military superblimp high above the planet's surface to pump reflective particles into the atmosphere.

Far-fetched as Wood's ideas may sound, his weren't the only Rube Goldberg proposals aired at the meeting. Even as they joked about a NASA staffer's apology for her inability to control the temperature in the meeting room, others detailed their own schemes for manipulating earth's climate. Astronomer J. Roger Angel suggested placing a huge fleet of mirrors in orbit to divert incoming solar radiation, at a cost of "only" several trillion dollars. Atmospheric scientist John Latham and engineer Stephen Salter hawked their idea of making marine clouds thicker and more reflective by whipping ocean water into a froth with giant pumps and eggbeaters. Most frightening was the science-fiction writer and astrophysicist Gregory Benford's announcement that he wanted to "cut through red tape and demonstrate what could be done" by finding private sponsors for his plan to inject diatomaceous earth—the chalklike substance used in filtration systems and cat litter—into the Arctic stratosphere. He, like his fellow geoengineers, was largely silent on the possible unintended consequences of his plan.

The inherent unknowability of what would happen if we tried to tinker with the immensely complex planetary climate system is one reason why climate engineering has until recently been spoken of only sotto voce in the scientific community. Many researchers recognize that even the most brilliant scientists have a history of blindness to the wider ramifications of their work. Imagine, for example, that Wood's scheme to thicken the Arctic icecap did somehow become possible. While most of the world may want to maintain or increase polar sea ice, Russia and some other nations have historically desired an ice-free Arctic ocean, which would liberate shipping and open potentially vast oil and mineral deposits for exploitation. And an engineered Arctic ice sheet would likely produce shorter growing seasons and harsher winters in Alaska, Siberia, Greenland, and elsewhere, and could generate super winter storms in the midlatitudes. Yet Wood calls his brainstorm a plan for "global climate stabilization," and hopes to create a sort of "planetary thermostat" to regulate the global climate.

Who would control such a "thermostat," making life-altering decisions for the planet's billions? What is to prevent other nations from undertaking unilateral climate modification? The United States has no monopoly on such dreams. In November 2005, for example, Yuri Izrael, head of the Moscow-based Institute of Global Climate and Ecology Studies, wrote to Russian president Vladimir Putin to make the case for immediately burning massive amounts of sulfur in the stratosphere to lower the earth's temperature "a degree or two"—a correction greater than the total warming since pre-industrial times.

There is, moreover, a troubling motif of militarization in the history of weather and climate control. Military leaders in the United States and other countries have pondered the possibilities of weaponized weather manipulation for decades. Lowell Wood himself embodies the overlap of civilian and military interests. Now affiliated with the Hoover Institution, a think tank at Stanford University, Wood was a protégé of the late Edward Teller, the weapons scientist who was credited with developing the hydrogen bomb and was the architect of the Reagan-era Star Wars missile -

defense system (which Wood worked on, too). Like Wood, Teller was known for his advocacy of controversial military and technological solutions to complex problems, including the chimerical "peaceful uses of nuclear weapons." Teller's plan to excavate an artificial harbor in Alaska using thermonuclear explosives actually came close to receiving government approval. Before his death in 2003, Teller was advocating a climate control scheme similar to what Wood proposed.

Despite the large, unanswered questions about the implications of playing God with the elements, climate engineering is now being widely discussed in the scientific community and is taken seriously within the U.S. government. The Bush administration has recommended the addition of this "important strategy" to an upcoming report of the Intergovernmental Panel on Climate Change, the - UN-sponsored organization whose February study seemed to persuade even the Bush White House to take global warming more seriously. And climate engineering's advocates are not confined to the small group that met in California. Last year, for example, Paul J. Crutzen, an atmospheric chemist and Nobel laureate, proposed a scheme similar to Wood's, and there is a long paper trail of climate and weather modification studies by the Pentagon and other government agencies.

As the sole historian at the NASA conference, I may have been alone in my appreciation of the irony that we were meeting on the site of an old U.S. Navy airfield literally in the shadow of the huge hangar that once housed the ill-starred Navy dirigible U.S.S. *Macon*. The 785-foot-long *Macon*, a technological wonder of its time, capable of cruising at 87 miles per hour and launching five Navy biplanes, lies at the bottom of the Pacific Ocean, brought down in 1935 by strong winds. The Navy's entire rigid-airship program went down with it. Coming on the heels of the crash of its sister ship, the *Akron*, the *Macon*'s destruction showed that the design of these technological marvels was fundamentally flawed. The hangar, built by the Navy in 1932, is now both a historic site and a Superfund site, since it has been discovered that its "galbestos" siding is leaching PCBs into the drains. As I reflected on the fate of the Navy dirigible program, the geoengineers around the table were confidently and enthusiastically promoting techniques of climate intervention that were more than several steps beyond what might be called state of the art, with implications not simply for a handful of airship crewmen but for every one of the 6.5 billion inhabitants of the planet.

Ultimate control of the weather and climate excites some of our wildest fantasies and our greatest fears. It is the stuff of age-old myths. Throughout history, we mortals have tried to protect ourselves against harsh weather. But weather *control* was reserved for the ancient sky gods. Now the power has seemingly devolved to modern Titans. We are undoubtedly facing an uncertain future. With rising temperatures, increasing emissions of greenhouse gases, and a growing world population, we may be on the verge of a worldwide climate crisis. What shall we do? Doing nothing or too little is clearly wrong, but so is doing too much.

Largely unaware of the long and checkered history of weather and climate control and the political and ethical challenges it poses, or somehow considering themselves exempt, the new Titans see themselves as heroic pioneers, the first generation capable of alleviating or averting natural disasters. They are largely oblivious to the history of the charlatans and sincere but deluded scientists and engineers who preceded them. If we fail to heed the lessons of that history, and fail to bring its perspectives to bear in thinking about public policy, we risk repeating the mistakes of the past, in a game with much higher stakes.

Three stories (there are many more) capture the recurring pathologies of weather and climate control schemes. The first involves 19th-century proposals by the U.S. government's first meteorologist and other "pluviculturalists" to make artificial rain and relieve drought conditions in the American West. The second begins in 1946 with promising discoveries in cloud seeding that rapidly devolved into exaggerated claims and attempts by cold warriors to weaponize the technique in the jungles of Vietnam. And then there is the tale of how computer modeling raised hopes for perfect forecasting and ultimate control of weather and climate—hopes that continue to inform and encourage present-day planetary engineers.

James Pollard Espy (1785–1860), the first meteorologist employed by the U.S. government, was a frontier schoolmaster and lawyer until he moved to Philadelphia in 1817. There he supported himself by teaching mathematics and classics part time while devoting himself to meteorological research. Working through the American Philosophical Society and the Franklin Institute, Espy gained the support of Pennsylvania's legislature to equip weather observers in each county in the state with barometers, thermometers, and other standard instruments to provide a larger, synoptic picture of the weather, especially the passage of storms.

Espy viewed the atmosphere as a giant heat engine. According to his thermal theory of storms, all atmospheric disturbances, including thunderstorms, hurricanes, and winter storms, are driven by "steam power." Heated by the sun, a column of air rises, allowing the surrounding air to rush in. As the heated air ascends, it cools and its moisture condenses, releasing its latent heat (this is the "steam") and producing rain, hail, or snow. The thermal theory is now an accepted part of meteorology, and for this discovery Espy is well regarded in the history of science.

His stature has been diminished, however, by his unbridled enthusiasm for rainmaking. Espy suggested cutting and burning vast tracts of forest to create huge columns of heated air, believing this would generate clouds and trigger precipitation. "Magnificent Humbug" was one contemporary assessment of this scheme. Espy came to be known derisively as the "Storm King," but he was not -deterred.

Seeking a larger stage for his storm studies and rainmaking proposals, Espy moved in 1842 to Washington, D.C., where he was funded by the Navy and employed as the "national meteorologist" by the Army Medical Department. This position afforded him access to the meteorological reports of surgeons at Army posts around the country. He also collaborated with Joseph Henry at the Smithsonian Institution to establish and maintain a national network of volunteer weather observers.

The year Espy moved to Washington, the popular magazine writer Eliza Leslie published a short story in *Godey's Lady's Book* called "The Rain King, or, A Glance at the Next Century," a fanciful account of rainmaking set in 1942 in Philadelphia, in which Espy's great-great-grand-nephew offers weather for the Delaware Valley on demand. Various factions vie for the weather they desire. Three hundred washerwomen petition the Rain King for fine weather forever, while cabmen and umbrella makers want perpetual rain. An equal number of applications come from both the fair- and foul--weather camps, until the balance is tipped by a late request from a winsome high-society matron desperately seeking a hard rain to prevent a visit by her country-bumpkin cousins that would spoil the lavish party she is planning.

Of course, when the artificial rains come, they satisfy no one and raise widespread suspicions. The Rain King, suddenly unpopular because he lacks the miraculous power to please everybody, takes a steamboat to China, where he studies magic in anticipation of returning someday. “Natural rains had never occasioned anything worse than submissive regret to those who suffered inconvenience from them, and were always received more in sorrow than in anger,” Leslie wrote. “But these artificial rains were taken more in anger than in sorrow, by all who did not want them.”

Leslie had identified the fundamental political pitfalls of manufactured weather that dog it to this day. But the enthusiasm for pluviculture was just beginning. During the Civil War, some began to suspect that the smoke and concussion of artillery fire generated rain. After all, didn’t it tend to rain a day, or two, or three following most battles? Skeptics wondered whether generals simply preferred to fight under fair skies, with rainy days therefore tending naturally to follow, and some pointed out that Plutarch had noticed the correlation between battles and rainfall long before the invention of gunpowder. Nevertheless, in 1871 retired Civil War general Edward Powers argued in favor of cannonading in his book *War and the Weather, or, The Artificial Production of Rain.*

Two decades later, the publication of the second edition of Powers’s book coincided with a severe and prolonged western drought, prompting a congressional appropriation of $10,000 for a series of field experiments. Secretary of Agriculture Jeremiah Rusk, nominally in charge of both this project and the newly formed U.S. Weather Bureau, chose as the lead investigator Robert St. George Dyrenforth, a flamboyant patent lawyer from Washington, D.C., who possessed no scientific or military experience. Dyrenforth arrived in Texas in August during a severe drought, but also conveniently at the traditional (and commonly noted) onset of the Texas rainy season. He brought an arsenal of explosives, including bombs, cannon, and hydrogen balloons, to be detonated at various altitudes, and engaged in what one observer called “a beautiful imitation of a battle.”

After several months of assaults on the heavens, it did indeed rain. Dyrenforth claimed victory, concluding that his practical skills, combined with his use of special explosives “to keep the weather in an unsettled condition,” could cause or at least enhance precipitation—when conditions were favorable! He warned that bombarding the sky in dry weather, however, would be fruitless, since his technique could stimulate clouds and precipitation but not create them.

The Nation, which criticized the government for wasting tax dollars, observed that the effect of the explosion of a 10-foot hydrogen balloon on aerial currents would be less than “the effect of the jump of one vigorous flea upon a thousand-ton steamship running at a speed of twenty knots.” But if there is one lesson from the long history of efforts to modify the weather and climate, it is that neither - commonsense criticism nor flops deter geoengineers.

Just over 100 years after Espy arrived in Washington, another seminal episode in the history of weather and climate control commenced at the General Electric Research Laboratory in Schenectady, New York. On a warm, humid day in 1946, a laboratory technician named Vincent Schaefer dropped some dry ice into a home freezer unit he was using as a cloud chamber. To his surprise, he saw the moisture in his breath instantly transform into millions of tiny ice crystals. He had generated the ice cloud from “supercooled” water droplets. As Schaefer recalled, “It was a serendipitous event, and I was smart enough to figure out just what happened. . . . I knew I had something pretty important.” Soon after, another member of the GE team, Bernard Vonnegut of

MIT, discovered that silver iodide smoke also "caused explosive ice growth" in supercooled clouds.

On November 14, 1946, Schaefer rented an airplane and dropped six pounds of dry ice pellets into a cold cloud over Mount Greylock in the nearby Berkshires, creating ice crystals and streaks of snow along a three-mile path. According to Schaefer's laboratory notebook, "It seemed as though [the cloud] almost exploded, the effect was so widespread and rapid." Schaefer's boss was Nobel laureate Irving Langmuir, a chemist who had worked on generating military smoke screens and de-icing aircraft in World War II—and who did not lack for media savvy. Langmuir watched the experiment from the control tower of the airport, and he was on the phone to the press before Schaefer landed. According to an article in *The New York Times* the next day, "A single pellet of dry ice, about the size of a pea . . . might produce enough ice nuclei to develop several tons of snow," or perhaps eliminate clouds at airports that might cause dangerous icing conditions, thus, in the words of the story's headline, "Opening Vista of Moisture Control by Man." *The Boston Globe* headline read "Snowstorm Manufactured."

From this moment on, in the press and before the meteorological community, Langmuir expounded his sensational vision of large-scale weather control, including redirecting hurricanes and changing the arid Southwest into fertile farmland. His first paper on the subject used familiar military terminology to explain how a small amount of "nucleating" agent such as dry ice, silver iodide, or even water could cause a "chain reaction" in cumulus clouds that potentially could release as much energy as an atomic bomb, but without radioactive fallout. The Department of Defense took due note. It would take an intense interest in the military possibilities of weather modification in the years ahead.

Ironically, in 1953, at the very same time Langmuir was involved in making exaggerated and highly dubious claims for the efficacy of weather and climate modification, he presented a seminar at GE titled "Pathological Science," or "the science of things that aren't so." Yet there is hardly any scientific foundation for most claims about weather modification. Cloud seeding apparently can augment "orographic" precipitation (which falls on the windward side of mountains) by up to 10 percent. It is also possible to clear cold fogs and suppress frost with heaters in very small areas. That is the extent of what has been proved. Nevertheless, millions are still spent on cloud seeding today, largely by local water and power companies.

About the time Langmuir was giving his seminar, the great futurist and science-
fiction writer H. G. Wells toured the GE labs, and the young publicist who escorted him tried to interest the writer in its weather control research. Wells gave a lukewarm response. The young man was Bernard Vonnegut's brother, Kurt, and he took up the subject himself in the novel *Cat's Cradle* (1963), in which a quirky and amoral scientist named Felix Hoenikker, loosely modeled on both Irving Langmuir and Edward Teller, invents a substance called "ice-nine" that instantly freezes water and remains solid at room temperature. Hoenikker's intent is to create a material that would be useful to armies bogged down in muddy battlefields, but the result is an unprecedented ecological disaster. Vonnegut got the idea of ice-nine from Langmuir, who suggested it to Wells as a story line.

Weather modification technology seemed of such great potential, especially to military aviation, that Vannevar Bush, a friend of Langmuir's who had served as head of the Office of Scientific Research and Development during World War II, brought the issue to the attention of Secretary of Defense

George C. Marshall and General Omar Bradley, chairman of the Joint Chiefs of Staff. The Pentagon immediately convened a committee to study the development of a Cold War weather weapon. It was hoped that cloud seeding could be used surreptitiously to release the violence of the atmosphere against an enemy, tame the winds in the service of an all-weather air force, or, on a larger scale, perhaps disrupt (or improve) the agricultural economy of nations and alter the global climate for strategic purposes. Military planners generated strategic scenarios such as hindering the enemy's military campaigns by causing heavy rains or snows to fall along lines of troop movement and on vital airfields, or using controlled precipitation as a delivery system for biological and radiological agents. Tactical possibilities included dissipating cloud decks to enable visual bombing attacks on targets, opening airfields closed by low clouds or fog, and relieving aircraft icing.

Some in the military had already recognized the potential uses of weather modification, and the subject has remained on military minds ever since. In the 1940s, General George C. Kenney, commander of the Strategic Air Command, declared, "The nation which first learns to plot the paths of air masses accurately and learns to control the time and place of precipitation will dominate the globe." His opinion was echoed in 1961 by the distinguished aviator-engineer Rear Admiral Luis de Florez: "With control of the weather the operations and economy of an enemy could be disrupted. . . . [Such control] in a cold war would provide a powerful and subtle weapon to injure agricultural production, hinder commerce, and slow down industry." He urged the government to "start now to make control of weather equal in scope to the Manhattan . . . Project which produced the first A--bomb."

Howard T. Orville, President Dwight D. Eisenhower's weather adviser, published an influential 1954 article in *Collier's* that included a variety of scenarios for using weather as a weapon of warfare. Planes would drop hundreds of balloons containing seeding crystals into the jet stream. Downstream, when the fuses on the balloons exploded, the crystals would fall into the clouds, initiating rain and miring enemy operations. The Army Ordnance Corps was investigating another technique: loading silver iodide and carbon dioxide into 50-caliber tracer bullets that pilots could fire into clouds. A more insidious technique would strike at an adversary's food supply by seeding clouds to rob them of moisture before they reached enemy agricultural areas. Speculative and wildly optimistic ideas such as these from official sources, together with threats that the Soviets were aggressively pursuing weather control, triggered what *Newsweek* called "a weather race with the Russians," and helped fuel the rapid expansion of meteorological research in all areas, including the creation of the National Center for Atmospheric Research, which was established in 1960.

Weather warfare took a macro-pathological turn between 1967 and '72 in the jungles over North and South Vietnam, Laos, and Cambodia. Using technology developed at the naval weapons testing center at China Lake, California, to seed clouds by means of silver iodide flares, the military conducted secret operations intended, among other goals, to "reduce trafficability" along portions of the Ho Chi Minh Trail, which Hanoi used to move men and materiel to South Vietnam. Operating out of Udorn Air Base, Thailand, without the knowledge of the Thai government or almost anyone else, but with the full and enthusiastic support of presidents Lyndon B. Johnson and Richard M. Nixon, the Air Weather Service flew more than 2,600 cloud seeding sorties and expended 47,000 silver iodide flares over a period of approximately five years at an annual cost of some $3.6 million. The covert operation had several names, including "POPEYE" and "Intermediary-Compatriot."

In March 1971, nationally syndicated columnist Jack Anderson broke the story about Air Force rainmakers in Southeast Asia in *The Washington Post*, a story confirmed several months later with the leaking of the Pentagon Papers and splashed on the front page of *The New York Times* in 1972 by Seymour Hersh. By 1973, despite stonewalling by Nixon administration officials, the U.S. Senate had adopted a resolution calling for an international treaty "prohibiting the use of any environmental or geophysical modification activity as a weapon of war." The following year, Senator Claiborne Pell (D.-R.I.), referring to the field as a "Pandora's box," published the transcript of a formerly top-secret briefing by the Defense Department on the topic of weather warfare. Eventually, it was revealed that the CIA had tried rainmaking in South Vietnam as early as 1963 in an attempt to break up the protests of Buddhist monks, and that cloud seeding was probably used in Cuba to disrupt the sugarcane harvest. Similar technology had been employed, yet proved ineffective, in drought relief efforts in India and Pakistan, the Philippines, Panama, Portugal, and Okinawa. All of the programs were conducted under military sponsorship and had the direct involvement of the White House.

Operation POPEYE, made public as it was at the end of the Nixon era, was dubbed the "Watergate of weather warfare." Some defended the use of environmental weapons, arguing that they were more "humane" than nuclear weapons. Others suggested that inducing rainfall to reduce trafficability was preferable to dropping napalm. As one wag put it, "Make mud, not war." At a congressional briefing in 1974, military officials downplayed the impact of Operation POPEYE, since the most that could be claimed were 10 percent increases in local rainfall, and even that result was "unverifiable." Philip Handler, president of the National Academy of Sciences, represented the mainstream of scientific opinion when he observed, "It is grotesquely immoral that scientific understanding and technological capabilities developed for human welfare to protect the public health, enhance agricultural productivity, and minimize the natural violence of large storms should be so distorted as to become weapons of war."

At a time when the United States was already weakened by the Watergate crisis, the Soviet Union caused considerable embarrassment to the Ford administration by bringing the issue of weather modification as a weapon of war to the attention of the United Nations. The UN Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques (ENMOD) was eventually ratified by nearly 70 nations, including the United States. Ironically, it entered into force in 1978, when the Lao People's Democratic Republic, where the American military had used weather modification technology in war only six years earlier, became the 20th signatory.

The language of the ENMOD Convention may become relevant to future weather and climate engineering, especially if such efforts are conducted unilaterally or if harm befalls a nation or region. The convention targets those techniques having "widespread, longlasting or severe effects as the means of destruction, damage, or injury to any other State Party." It uses the term "environmental modification" to mean "any technique for changing—through the deliberate manipulation of natural processes—the dynamics, composition, or structure of the Earth, including its biota, lithosphere, hydrosphere, and atmosphere, or of outer space."

A vision of perfect forecasting ultimately leading to weather and climate control was present at the birth of modern computing, well before the GE cloud seeding experiments. In 1945 Vladimir Zworykin, an RCA engineer noted for his early work in television technology, promoted the idea that electronic computers could be used to process and analyze vast amounts of meteorological data,

issue timely and highly accurate forecasts, study the sensitivity of weather systems to alterations of surface conditions and energy inputs, and eventually intervene in and control the weather and climate. He wrote:

> The eventual goal to be attained is the international organization of means to study weather phenomena as global phenomena and to channel the world's weather, as far as possible, in such a way as to minimize the damage from catastrophic disturbances, and otherwise to benefit the world to the greatest extent by improved climatic conditions where possible.

Zworykin imagined that a perfectly accurate machine forecast combined with a paramilitary rapid deployment force able literally to pour oil on troubled ocean waters or even set fires or detonate bombs might someday provide the capacity to disrupt storms before they formed, deflect them from populated areas, and otherwise control the weather.

John von Neumann, the multi-talented mathematician extraordinaire at the Institute for Advanced Study in Princeton, New Jersey, endorsed Zworykin's view, writing to him, "I agree with you completely. . . . This would provide a basis for scientific approach[es] to influencing the weather." Using computer-generated predictions, von Neumann wrote, weather and climate systems "could be controlled, or at least directed, by the release of perfectly practical amounts of energy" or by "altering the absorption and reflection properties of the ground or the sea or the atmosphere." It was a project that neatly fit von Neumann's overall philosophy: "All stable processes we shall predict. All unstable processes we shall control." Zworykin's proposal was also endorsed by the noted oceanographer Athelstan Spilhaus, then a U.S. Army major, who ended his In weather control meteorology has a new goal worthy of its greatest efforts."

In a 1962 speech to meteorologists, "On the Possibilities of Weather Control," Harry Wexler, the -MIT-trained head of meteorological research at the U.S. Weather Bureau, reported on his analysis of early computer climate models and additional possibilities opened up by the space age. Reminding his audience that humankind was modifying the weather and climate "whether we know it or not" by changing the composition of the earth's atmosphere, Wexler demonstrated how the United States or the Soviet Union, perhaps with hostile intent, could alter the earth's climate in a number of ways. Either nation could cool it by several degrees using a dust ring launched into orbit, for example, or warm it using ice crystals lofted into the polar atmosphere by the explosion of hydrogen bombs. And while most practicing atmospheric chemists today believe that the discovery of ozone-destroying reactions dates to the early 1970s, Wexler sketched out a scenario for destroying the ozone layer using chlorine or bromine in his 1962 speech.

"The subject of weather and climate control is now becoming respectable to talk about," Wexler claimed, apparently hoping to reduce the prospects of a geophysical arms race. He cited Soviet premier Nikita Khrushchev's mention of weather control in an address to the Supreme Soviet and a 1961 speech to the United Nations by John F. Kennedy in which the president proposed "cooperative efforts between all nations in weather prediction and eventually in weather control." Wexler was actually the source of Kennedy's suggestions, and had worked on them behind the scenes with the President's Science Advisory Committee and the State Department. But if weather control's "respectability" was not in question, its attainability—even using computers, satellites, and

100-megaton bombs—certainly was.

In 1965, the President's Science Advisory Committee warned in a report called *Restoring the Quality of Our Environment* that increases in atmospheric carbon dioxide due to the burning of fossil fuels would modify the earth's heat balance to such an extent that harmful changes in climate could occur. This report is now widely cited as the first official statement on "global warming." But the committee also recommended geoengineering options. "The possibilities of deliberately bringing about countervailing climatic changes . . . need to be thoroughly explored," it said. As an illustration, it pointed out that, in a warming world, the earth's solar reflectivity could be increased by dispersing buoyant reflective particles over large areas of the tropical sea at an annual cost, not considered excessive, of about $500 million. This technology might also inhibit hurricane formation. 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. The committee also speculated about modifying high-altitude cirrus clouds to counteract the effects of increasing atmospheric carbon dioxide. It failed to mention the most obvious option: reducing fossil fuel use.

After the embarrassment of the 1978 ENMOD Convention, federal funding for weather modification research and development dried up, although freelance rainmakers continued to ply their trade in the American West with state and local funding. Until recently, a 1991 National Academy of Sciences report, *Policy Implications of Greenhouse Warming,* was the only serious document in decades to advocate climate control. But the level of urgency and the number of proposals have increased dramatically since the turn of the new century.

In September 2001, the U.S. Climate Change Technology Program quietly held an invitational conference, "Response Options to Rapid or Severe Climate Change." Sponsored by a White House that was officially skeptical about global warming, the meeting gave new status to the control fantasies of the climate engineers. According to one participant, "If they had broadcast that meeting live to people in Europe, there would have been riots."

Two years later, the Pentagon released a controversial report titled *An Abrupt Climate Change Scenario and Its Implications for United States National Security*. The report explained how global warming might lead to rapid and catastrophic global cooling through mechanisms such as the slowing of North Atlantic deep-water circulation—and recommended that the government "explore - geoengineering options that control the climate." Noting that it is easier to warm than to cool the climate, the report suggested that it might be possible to add various gases, such as hydro-fluorocarbons, to the atmosphere to offset the effects of cooling. Such actions would be studied carefully, of course, given their potential to exacerbate conflict among nations.

With greater gravitas, but no less speculation, the National Research Council issued a study, *Critical Issues in Weather Modification Research,* in 2003. It cited looming social and environmental challenges such as water shortages and drought, property damage and loss of life from severe storms, and the threat of "inadvertent" climate change as justifications for investing in major new national and international programs in weather modification research. Although the NRC study included an acknowledgment that there is "no convincing scientific proof of the efficacy of intentional

weather modification efforts," its authors nonetheless argued that there should be "a renewed commitment" to research in the field of intentional and unintentional weather modification.

The absence of such proof after decades of efforts has not deterred governments here and abroad from a variety of ill-advised or simply fanciful undertakings. The NASA Institute for Advanced Concepts, for example, has provided $475,000 for atmospheric scientist Ross Hoffman's research on beaming satellite-based microwaves at hurricanes as a means of redirecting them—as if it were possible to know where a storm was originally headed or that its new path would not lead straight to calamity. In 2005, Senator Kay Bailey Hutchison (R.-Texas) introduced legislation "to develop and implement a comprehensive and coordinated national weather modification research policy and a national cooperative Federal and State program of weather modification and development." (Significantly, the Texas Department of Agriculture already supports weather modification programs covering one-fifth of the state.) And China has announced that its Study Institute for Artificial Influence on the Weather will attempt to manipulate Beijing's weather by cloud seeding in order to ensure optimum conditions for the 2008 Olympics.

With great fanfare, atmospheric chemist Paul J. Crutzen, winner of a 1995 Nobel Prize for his work on the chemistry of ozone depletion, recently proposed to cool the earth by injecting reflective aerosols or other substances into the tropical stratosphere using balloons or artillery. He estimated that more than five million metric tons of sulfur per year would be needed to do the job, at an annual cost of more than $125 billion. The effect would emulate the 1991 eruption of Mount Pinatubo in the Philippines, which covered the earth with a cloud of sulfuric acid and other sulfates and caused a drop in the planet's average temperature of about 0.5°C for roughly two years. Unfortunately, Mount Pinatubo may also have contributed to the largest ozone hole ever measured. The volcanic eruption was also blamed for causing cool, wet summers, shortening the growing season, and exacerbating Mississippi River flooding and the ongoing drought in the Sahel region of Africa.

Overall, the cooling caused by Mount Pinatubo's eruption temporarily suppressed the greenhouse warming effect and was stronger than the influence of the El Niño event that occurred at the same time. Crutzen merely noted that if a Mount Pinatubo–scale eruption were emulated every year or two, undesired side effects and ozone losses should not be "as large," but some whitening of the sky and colorful sunsets and sunrises would occur. His "interesting alternative" method would be to release soot particles to create minor "nuclear winter" conditions.

Crutzen later said that he had only reluctantly proposed his planetary "shade," mostly to "startle" political leaders enough to spur them to more serious efforts to curb greenhouse-gas emissions. But he may well have produced the opposite effect. The appeal of a quick and seemingly painless technological "fix" for the global climate dilemma should not be underestimated. The more practical such dreams appear, the less likely the world's citizens and political leaders are to take on the difficult and painful task of changing the destiny that global climate models foretell.

These issues are not new. In 1956, F. W. Reichelderfer, then chief of the U.S. Weather Bureau, delivered an address to the National Academy of Sciences, "Importance of New Concepts in Meteorology." Reacting to the widespread theorizing and speculation on the possibilities of weather and climate control at the time, he pointed out that the crucial issue was "practicability" rather than "possibility." In 1956 it was possible to modify a cloud with dry ice or silver iodide, yet it was

impossible to predict what the cloud might do after seeding and impracticable to claim any sense of control over the weather. This is still true today. Yet thanks to remarkable advances in science and technology, from satellite sensors to enormously sophisticated global climate models, the fantasies of the weather and climate engineers have only grown. Now it is possible to tinker with scenarios in computer climate models—manipulating the solar inputs, for example, to demonstrate that artificially increased solar reflectivity will generate a cooling trend in the model.

But this is a far cry from conducting a practical global field experiment or operational program with proper data collection and analysis; full accounting for possible liabilities, unintended consequences, and litigation; and the necessary international support and approval. Lowell Wood blithely declares that if his proposal to turn the polar icecap into a planetary air conditioner were implemented and didn't work, the process could be halted after a few years. He doesn't mention what harm such a failure could cause in the meantime.

There are signs among the geoengineers of an overconfidence in technology as a solution of first resort. Many appear to possess a too-literal belief in progress that produces an anything-is-possible mentality, abetted by a basic misunderstanding of the nature of today's climate models. The global climate system is a "massive, staggering beast," as oceanographer Wallace Broecker describes it, with no simple set of controlling parameters. We are more than a long way from understanding how it works, much less the precise prediction and practical "control" of global climate.

Assume, for just a moment, that climate control were technically possible. Who would be given the authority to manage it? Who would have the wisdom to dispense drought, severe winters, or the effects of storms to some so that the rest of the planet could prosper? At what cost, economically, aesthetically, and in our moral relationship to nature, would we manipulate the climate?

These questions are never seriously contemplated by the climate wizards who dream of mastery over nature. 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? Have you noticed all the cannons? From Dyrenforth's cannonading in Texas to Crutzen's artillery barrage of the stratosphere, military means and ends have been closely intertwined with thinking about control of the weather and climate. In 1996 the U.S. Air Force resurrected the old Cold War speculation about using weather modification for military purposes, claiming that "in 2025, U.S. aerospace forces can 'own the weather' by capitalizing on emerging technologies and focusing development of those technologies to war-fighting applications." In addition to conventional cloud seeding methods, the Air Force visionaries proposed computer hacking to disrupt an enemy's weather monitors and models and the use of emerging technologies to create clouds of particles that could block an enemy's optical sensors. Hurricanes were also fair game for weaponization. The Air Force pointed out that weather modification, unlike other approaches, "makes what are otherwise the results of deliberate actions appear to be the consequences of natural weather phenomena."

Given such mindsets, it is virtually impossible to imagine governments resisting the temptation to explore military uses of any potentially climate-altering technology.

When Roger Angel was asked at the NASA meeting last November how he intended to get the massive amount of material required for his space mirrors into orbit, he dryly suggested a modern

cannon of the kind originally proposed for the Strategic Defense Initiative: a giant electric rail gun firing a ton or so of material into space roughly every five minutes. Asked where such a device might be located, he suggested a high mountaintop on the Equator.

I was immediately reminded of Jules Verne's 1889 novel *The Purchase of the North Pole.* For two cents per acre, a group of American investors gains rights to the vast and incredibly lucrative coal and mineral deposits under the North Pole. To mine the region, they propose to melt the polar ice. Initially the project captures the public imagination, as the backers promise that their scheme will improve the climate everywhere by reducing extremes of cold and heat, making the earth a terrestrial heaven. But when it is revealed that the investors are retired Civil War artillerymen who intend to change the inclination of the earth's axis by building and firing the world's largest cannon, public enthusiasm gives way to fears that tidal waves generated by the explosion will kill millions. In secrecy and haste, the protagonists proceed with their plan, building the cannon on Mount Kilimanjaro. The plot fails only when an error in calculation renders the massive shot ineffective. Verne concludes, "The world's inhabitants could thus sleep in peace." Perhaps he spoke too soon.

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"One cool judgement is worth a thousand hasty counsels.
The thing to be supplied is light, not heat."
–WOODROW WILSON, ADDRESS ON PREPAREDNESS, PITTSBURGH, PENNSYLVANIA, 1916

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