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The pathological history of weather and climate modification: Three cycles of promise and hype

WE HAVE ALREADY experienced two major cycles of promise and hype in the history of weather modification, and they have both demonstrated large-scale pathological features. The first cycle, initiated by James Espy's speculative proposal in the 1830s to enhance precipitation by lighting huge fires, thus stimulating convective updrafts, preceded the pseudo-scientific hype of the western rainmakers, or so-called "pluviculturalists." The second cycle, dating to the 1940s, began with promising discoveries in "cloud seeding" by Irving Langmuir and his associates at the General Electric Corporation, but rapidly devolved into a suite of unsupportable claims by cold warriors and again, western rainmakers. A third cycle has begun recently.[1] In October 2003 the U.S. National Research Council issued a report titled, "Critical issues in weather modification research." In the same month the U.S. Pentagon released a controversial report, "An abrupt climate change scenario and its implications for United States national security," that explored how global warming could lead to rapid and catastrophic global cooling.[2] Only three months later, in January 2004, a symposium on "Macro-engineering Options for

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The following abbreviations are used: AWS, Air Weather Service; NRC, National Research Council; *NYT, New York Times*; *PT, Physics today*.

1. The third cycle has begun so recently that it has gone largely unnoticed; for example, Chunglin Kwa, "The rise and fall of weather modification: Changes in American attitudes toward technology, nature, and society," in C.A. Miller and P.N. Edwards, eds., *Changing the atmosphere: Expert knowledge and environmental governance* (Cambridge, 2001), 135-165 has no mention of this.

2. U.S. National Research Council, *Critical issues in weather modification research* (Washington, DC, 2003); Peter Schwartz and Doug Randall. "An abrupt climate change

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Climate Change Management and Mitigation" was held in Cambridge, England under the joint sponsorship of the Tyndall Centre for Climate Change Research and the business-oriented Cambridge-MIT Institute.[3] The NRC study 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 new national and international initiatives in weather modification research. On a grander, planetary scale, the authors of the DoD report recommended that the government should "explore geo-engineering options that control the climate," while the Tyndall Centre symposium set out to "identify, debate, and evaluate" possible, but highly controversial options for the design and construction of engineering projects for the management and mitigation of global climate change. These policy initiatives were surrounded by a modicum of promise and an excess of hype, but none had adequate recourse to historical analysis. In November 2006 I participated in a conference sponsored by the NASA-Ames and the Carnegie Institution on "Managing Solar Radiation," one of the many euphemisms for geoengineering. I was the sole historian. This paper brings the checkered history of weather modification to bear on these very recent initiatives and asks, are we at the start of a third cycle—this time involving both weather and climate modification?

1. ROUND 1: THE "PLUVICULTURALISTS"

In the United States, the first glimmer of promise in scientific weather modification originated with James Pollard Espy (1785-1860), who advanced a theory of storms driven by inrushing winds, thermally induced vertical convection, and the condensation of moisture releasing the "steam power" of the atmosphere.[4] Espy, a frontier schoolmaster and lawyer, moved to Philadelphia in 1817 where he taught mathematics and classics, part-time, at the Franklin Institute. Later in life, as chair-

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scenario and its implications for United States national security," 2003, available at http://www.environmentaldefense.org/documents/3566_AbruptClimateChange.pdf (2 Jan 2006).

3. The Tyndall Centre for Climate Change Research http://www.tyndall.ac.uk (2 Jan 2006) is a consortium of UK research institutions drawing support from the National Environment Research Council, Engineering and Physical Sciences Research Council, Economic and Social Research Council, and the Department of Trade and Industry. The Cambridge-MIT Institute http://www.cambridge-mit.org (2 Jan 2006) is a partnership between the University of Cambridge and MIT to undertake education and research designed to improve competitiveness, productivity, and entrepreneurship in the UK, and to forge stronger links between academic research and business. The on-line proceedings of the Tyndall Centre conference are at http://www.tyndall.ac.uk/events/past_events/cmi.shtml.

4. James Rodger Fleming, *Meteorology in America, 1800-1870* (Baltimore, 1990), 24-31, and *American national biography*, s.v. Espy.

man of the Joint Committee on Meteorology of the American Philosophical Society and Franklin Institute, he was successful in gaining support from the legislature of Pennsylvania to establish a system of weather observers in each county and to supply them with standard instruments. He also maintained a national network of volunteer observers.

Espy viewed the atmosphere as a giant heat engine. According to his thermal theory of storms, all atmospheric disturbances, from thunderstorms to winter storms, are driven by heated updrafts, inwardly rushing air currents, and the release of latent heat. His theory, published as *The philosophy of storms* (Boston, 1841), was well received by many scientists of his time, including a committee of the French Academy of Sciences.

Espy moved to Washington, D.C. in 1842 as the first federally funded meteorologist. In his first government appointment, he served as professor of mathematics in the navy. He was also appointed national meteorologist in the Army Medical Department, a position that supported his storm studies and provided him access to the meteorological reports of the army post surgeons. During his years with the army, Espy issued several reports, the most significant being his *First report on meteorology to the Surgeon General of the United States Army* (1843). From 1847 to 1857 Espy was again assigned to the navy with a salary provided by annual appropriations from Congress. With Joseph Henry, he established the Smithsonian meteorological system of observers and experimented with telegraphic weather reports, placing Espy at the national center for atmospheric research in the mid-19th century.

The meteorological literature of the time indicates that Espy's ideas on the steam power of the atmosphere and on the importance of latent caloric were widely accepted by such influential scientists as Joseph Henry, Elias Loomis, and James Coffin. William Ferrel, perhaps the greatest theoretical meteorologist of the late 19th century was a supporter, with modifications, of "Espian thermal processes." His colleagues respected his basic physical insights, but not his presentation of them. His credibility was reduced by his tendency to offend other investigators and challenge their findings during the "great American storm controversy" and by his unbridled enthusiasm for his scheme, loosely linked to his theoretical insights, to enhance thermal updrafts by lighting huge fires across the country to generate artificial rains.[5]

In 1839, a committee of Pennsylvania lawmakers issued a promising report on Espy's proposed method of generating rain by fire. This led to an amendment, annexed to a House bill regulating "hawkers and pedlars," to provide a reward of up to $50,000 if Espy could keep the Ohio River navigable from Pittsburgh to its confluence with the Mississippi River during the summer season. The Senate, however, defeated the measure by a ratio of 2 to 1. "Magnificent Humbug," opined

5. Fleming (ref. 4), 43-45, and Clark C. Spence, *The rainmakers: American "pluviculture" to World War II* (Lincoln, NE, 1980), 9-21.

the *Genesee farmer* concerning the entire incident.[6] Undaunted, Espy continued his attempts to generate artificial rain by setting fire to large tracts of forest. In the summer of 1849 he contracted for twelve acres of timber in Fairfax County, Virginia, "with pines as thick as a man's leg or arm," to be cut and burned in the hope of producing an intense column of heated air, clouds, and artificial rain. He asked his friend Joseph Henry to guarantee the owner of the woodlot $60 for supervising the experiment in his absence. Henry did not expect much: "The conditions necessary to success are too many to occur simultaneously unless by unhoped for good luck." Nevertheless, Espy tried the experiment in the last week of July 1849 but made sure that if rain was not produced, the failure could be attributed to unfavorable ambient conditions and not to any deficiency in his theory. The experiment ended in failure.[7]

Espy's scientific friends worried about the "strange course" he had taken, his overly sanguine expectations, and his tendency to exhibit "a want of prudence."[8] Henry warned him not to make extravagant claims about rainmaking and confided to Alexander Dallas Bache that Espy's "old proposition" of producing rain by firing patches of woods up to seven miles long, was "in my mind so entirely impractical that, as I informed him, should one of his enemies get hold of it, the influence of yourself, myself and all his other friends, would not be sufficient to sustain him."[9]

But that was just the beginning of the cycle. After studying Civil War battles, Edward Powers wrote a book, *War and the weather, or, the artificial production of rain* (1871), in which he contended that rain followed artillery engagements—usually within several days. The following year Congress authorized $2,500 to test his plan under the direction of the secretaries of war and the navy.[10] Observers hastened to point out that the connection was an ancient one. According to Plutarch, "It is an observation… that extraordinary rains pretty generally fall after great battles; whether it be that some divine power thus washes and cleanses the polluted earth with showers from above, or that moist and heavy evaporations, steaming forth from the blood and corruption, thicken the air, which naturally is subject to alteration

6. *The Genesee farmer* (3 Mar 1839), 99.

7. Espy to Henry, 30 Apr 1849; Espy to Henry, 29 May 29 1849; Henry to Edward Foreman, 10 Aug 1849; Henry Desk Diary, 21 Jul 1849; and Henry to Foreman, 9 Sep 1849; all documented in Fleming (ref. 4), 99.

8. Alexander Dallas Bache to Humphrey Lloyd, 4 May 1839; Sears C. Walker to W.H. White, 10 Jul 1839; and Joseph Henry to William C. Redfield, 17 Dec 1838; all documented in Fleming (ref. 4), 44.

9. Henry to Alexander Dallas Bache, 10 Jul 1851, documented in Fleming (ref. 4), 99-100.

10. Edward Powers, *War and the weather, or, the artificial production of rain* [1871]. (Delavan, WI, 1890): "A bill appropriating two thousand five hundred dollars to test a plan for the artificial production of rain, and so forth," H.R. 2930, 27 May 1872, in Spence (ref. 5), 24-29.

from the smallest causes." Most likely there was no correlation between battles and storms, but generals chose to fight during breaks in the weather.[11]

Nevertheless, the theory persisted that rains can be formed artificially by large explosions. In 1880 former Confederate General Daniel Ruggles obtained a patent and federal funding for his so-called "concussion theory" of rainmaking. A decade later a severe and prolonged Western drought prompted a Congressional appropriation of $10,000 for a new series of field experiments in Texas in 1891. The Secretary of Agriculture, nominally in charge of the project, chose Robert St. George Dryenforth, a flamboyant patent lawyer from Washington, D.C. and a man with no scientific or military background, as the lead investigator. Arriving in Texas in August at the onset of the rainy season with an arsenal of explosives, including balloons and kites to be detonated at various altitudes, Dryenforth engaged in what one observer called, "a beautiful imitation of a battle." He concluded that his practical skills, combined with his use of special explosives "to keep the weather in an unsettled condition," could indeed cause precipitation—when conditions are favorable! Dryenforth warned the farmers that bombarding the sky in dry weather, however, would be fruitless. *The Nation* criticized the government for wasting tax dollars, duping unsophisticated farmers, and indulging in "the silliest performance that human ingenuity could devise." It observed that the effect of the explosion of a ten-foot 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."[12]

F.W. Clarke's humorous "Ode to pluviculture" was undoubtedly inspired by the Dryenforth experiments. In the poem, the hapless farmer, Jeremy Jonathan Joseph Jones seeks to break a drought using "cannon, and mortars, and lots of shells, and dynamite by the ton, with a gas balloon and a chime of bells, and various other mystic spells to overcloud the sun." His third shot into a cloudless sky "brought a heavy dew," his fourth, "thunder, rain and hail." Jeremy drowned in the ensuing flood and his farm is now a lake. All efforts to stop the deluge were in vain, "Until the Bureau at Washington stirred, and stopped the storm with a single word, by just predicting—Rain!"[13]

A final episode (there are many more stories) brings the first cycle into the 20th century. By 1904 Charles M. Hatfield had established his reputation out west as a prodigious rainmaker. The following appeal was addressed to him concerning the weather in Pasadena on January 2, 1905, the day of the Tournament of Roses Parade: "Great moistener, if you will listen now, and make this vow: Oh, please,

11. *The nation, 52* (5 Feb 1891), 117. Plutarch, "Life of Marius," at http://ancienthistory.about.com/library/bl/bl_text_plutarch_cmarius.htm (2 Jan 2006).
12. "Government rainmaking," *The nation, 53* (22 Oct 1891), 309-10, in Spence (ref. 5), 30-44.
13. F.W. Clarke, "An ode to pluviculture, or, the rhyme of the rain machine" (1891), at http://www.history.noaa.gov/art/rainmachine.html (2 Jan 2006).

kind sir, don't let it rain on Monday!" Hatfield's technique involved building tall mysterious towers equipped with large shallow pans from which he patiently evaporated a proprietary fluid until it rained. He is largely remembered because his rainmaking activities in January 1916 coincided with a severe flood in San Diego. According to city water department records, over 28 inches of rain fell that month, the Morena Reservoir overflowed, and the Lower Otay Dam burst, sending a wall of water into downtown San Diego killing dozens of people, leaving many others homeless, and destroying all but two of the city's 112 bridges. Seeking to avoid lawsuits, the city of San Diego denied its connection to Hatfield, who had a vague contract for rain enhancement, and never paid him the $10,000 he claimed it owed him. Hatfield's suit against the city was finally dismissed in 1938.[14]

The first cycle of promise and hype began in the 1840s and lasted about a century. Clark Spence encapsulates this era in his entertaining book *The rainmakers: American "pluviculture" to World War II,* an episodic, sometimes fantastic, and always quixotic history of weather modification in America to 1940. But a piece of fiction written in 1842 also captured the essence of the century ahead and the dangers of attaining weather on demand. Only one year after the publication of Espy's *Philosophy of storms,* Eliza Leslie wrote an article in *Godey's magazine* entitled the "The rain king, or, A glance at the next century," a fanciful account of rainmaking set in 1942 in Philadelphia, where Espy's great, great, grand-nephew, "the rain king," offered weather on demand. In the story, various factions vie for the weather they desire. Three hundred washerwomen and the parasol makers petition the rain king for fine weather forever, while others, the cabmen and the umbrella makers, want perpetual rain. Although an equal number of applications were received from both the fair- and foul-weather factions, the balance was tipped by a late request from a winsome high-society matron desperately wanting a hard rain to prevent a visit from her country-bumpkin cousins who threatened to spoil her fancy party. Of course, when the artificial rains came, they satisfied no one and raised widespread suspicions. As Miss Leslie put it, "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. But these artificial rains were taken more in anger than in sorrow, by all who did not want them."[15]

2. ROUND 2: CLOUD SEEDING IN THE COLD WAR AND VIETNAM WAR ERAS

The second cycle of promise and hype began at the General Electric Research Laboratory in Schenectady, New York where, on a warm, humid day in 1946 Vincent Schaefer dropped dry ice into a home freezer unit he was using as a cloud

14. Thomas W. Patterson, "Hatfield the rainmaker," *Journal of San Diego history, 16* (Summer 1970), http://www.sandiegohistory.org/journal/70winter/hatfield.htm (2 Jan 2006); Spence (ref. 5), 80-99.
15. Eliza Leslie, "The rain king, or, A glance at the next century," *Godey's magazine, 25* (New York, 1842), 7-11.

chamber in an attempt to cool it off.[16] To his surprise, he instantly saw his breath transform into a cloud of millions of tiny ice crystals. 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."[17] Within a month of Schaefer's experiment Bernard Vonnegut, who had recently transferred into Langmuir's research group, discovered that silver iodide smoke also "caused explosive ice growth in" supercooled clouds.[18] When their mentor, associate director of the laboratory Irving Langmuir saw these effects he remarked excitedly, "Well, we've got to get into the atmosphere and see if we can do things with natural clouds."

In November Schaefer rented an airplane and dropped six pounds of dry ice pellets into a cold cloud over Greylock peak in the 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."[19] Langmuir, watching the experiment unfold from the control tower of the airport, was on the phone to the *New York Times* before Shaefer landed. According to the article, "a single pellet of dry ice, about the size of a pea… might produce enough ice nuclei to develop several tons of snow," thus, "opening [the] vista of moisture control by man."[20] Langmuir may have been thinking of an analogy to nuclear power. 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, generating artificial snow storms, changing the arid Southwest into fertile farmland, and suppressing icing conditions to enhance aviation safety.[21]

Fear of lawsuits due to unanticipated side effects caused GE to transfer its research on cloud seeding to the military. If Langmuir was right, a small amount

16. This section is based on James R. Fleming, "Fixing the weather and climate: Military and civilian schemes for cloud seeding and climate engineering," in Lisa Rosner, ed., *The technological fix: How people use technology to create and solve problems* (Hagley Center Studies in the History of Business and Technology) (New York, 2004), 175-200; and James R. Fleming, "Distorted support: Pathologies of weather warfare," Barton C. Hacker and Margaret Vining, eds., *Science in uniform: Science, technology, and American military institutions, from the Revolutionary War to the present* (Lanham, MD., in press).

17. Earl Droessler, "Interview with Vincent Schaefer, 8-9 May 1993," Tape-recorded interview project, American Meteorological Society and University Corporation for Atmospheric Research; Vincent Schaefer, "The production of ice crystals in a cloud of supercooled water droplets," *Science, 104* (1946), 459.

18. Bernard Vonnegut, "The nucleation of ice formation by silver iodide," *Journal of applied physics, 18* (1947), 593-595.

19. "Project Cirrus—The story of cloud seeding," *G.E. review* (Nov 1952), 12.

20. *NYT* (15 Nov 1946), 24. Many other stories about Langmuir and weather control appeared in the *Times*.

21. Irving Langmuir, "Summary of results thus far obtained in artificial nucleation of clouds," in Final report: Project Cirrus, G.E. report No. RL-140 (Schenectady, NY, 1948), 18.

of "nucleating" agent such as dry ice, silver iodide, or even water, could cause a "chain reaction" in clouds that would release as much energy as an atomic bomb, but without radioactive fallout. As a weapon it favored the west, since clouds seeded over Europe would be carried by the prevailing winds over the Soviet Union. It could also be done surreptitiously. Planners generated scenarios that included hindering the enemy's military campaigns by causing heavy rains or snows to fall along lines of troop movement and on vital airfields, taming the winds in the service of an all-weather air force, or, on a larger scale, perhaps disrupting (or improving) the agricultural economy of nations and altering the global climate for strategic purposes. Other possibilities included dissipating cloud decks to enable visual bombing attacks on targets, opening airfields closed by low clouds or fog, relieving aircraft icing conditions, or using controlled precipitation as a delivery system for chemical, biological, or radiological agents. The military regarded cloud seeding as the trigger that could release the violence of the atmosphere against an enemy or tame the winds in the service of an all-weather air force.

The technology seemed of such great potential, especially to military aviation, that Vannevar Bush, a friend of Langmuir and, as the chief mobilizer of American science during World War II, the country's leading science policy man, brought the issue to the attention of Secretary of Defense George C. Marshall and Chairman of the Joint Chiefs of Staff General Omar Bradley. Bradley immediately convened a committee headed by meteorologist Sverre Petterssen to serve as a buffer between the defense establishment and the scientific community as research proceeded on secret weather weapons.[22]

The classic cold-war pronouncement on weather control belongs to General George C. Kenney, commander of the Strategic Air Command: "The nation that first learns to plot the paths of air masses accurately and learns to control the time and place of precipitation will dominate the globe."[23] Nor was Kenney alone in holding this view. The distinguished aviator-engineer Rear Admiral Luis De Florez, who developed synthetic training devices for navy fliers during World War II, had a similar opinion: "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." De Florez advocated that government "start now to make control of weather equal in scope to the Manhattan District Project which produced the first A-bomb."[24]

Pursuing this theme, Harold Orville, President Eisenhower's weather advisor, published an influential article in *Collier's* in 1954 that included scenarios for

22. Sverre Petterssen, "CHAPTER TITLE," in James Rodger Fleming, *Weathering the storm: Sverre Petterssen, the D-Day forecast and the rise of modern meteorology* (Boston, 2001).
23. *NYT* (15 June 1947), 46, 1.
24. Arthur Krock, "An inexpensive start at controlling the weather," *NYT* (23 Mar 1961), 32.

using weather as a weapon of warfare. Planes would drop hundreds of balloons containing seeding crystals into the jet stream. Downstream, when fuses on the balloons exploded, the crystals would fall into the clouds, initiating rain and miring enemy operations. The Army Ordnance Department was investigating a technique to load silver iodide and carbon dioxide into fifty-caliber tracer bullets that pilots could fire into clouds. A more insidious plan would strike at the enemy's food supply by seeding clouds to rob them of moisture before they reached enemy agricultural areas.[25]

Although in Orville's assessment, total weather mastery would be possible only after several decades of intensive research, the spin-offs from this work, when combined with the maturation of electronic computers, would provide a *completely accurate* system of weather forecasting, perhaps within a decade: "I think it entirely probable that, in 10 years, your daily weather forecast will read something like this: 'Freezing rain, starting at 10:46 A.M., ending at 2:32 P.M.' or 'Heavy snowfall, seven inches, starting today at 1:43 A.M., continuing throughout day until 7:37 P.M.'"[26] Such accurate predictions, even without weather control, would have major consequences for military operations. Although speculative and wildly optimistic, ruminations such as these from an official source and threats that the Soviets were aggressively pursuing weather control helped fuel a weather race with the Russians and the rapid expansion of meteorological research in all areas, but especially in weather modification.

In 1953, at the time he was making highly dubious claims for the efficacy of weather modification and even climate modification, Langmuir presented a seminar at GE on "Pathological science" or "the science of things that aren't so."[27] Utilizing his own criteria for pathology, Langmuir's claims for cloud seeding qualified on several counts: they rested on observations close to the threshold of detectability, on apparently meaningful patterns generated in field trials; on the inability of critics to reproduce the experiments; on the intervention of the courts, legislature, and the press; and on overreliance on the credentials of a Nobel laureate rather than proof.

Distinguished meteorologist Charles Hosler tells of an encounter with Langmuir in a symposium at MIT in 1951 where the 72-year old Nobel laureate was describing how cloud seeding had apparently changed the course of a hurricane off the coast of Florida it to veer westward into Georgia. When the 27-year old Hosler, with a newly-minted Ph.D. in meteorology, pointed out that forecasters had

25. Howard T. Orville, "Weather made to order?" *Collier's* (28 May 1954), 25-29, on 25-26.

26. Ibid., 26.

27. The Irving Langmuir Papers in the Manuscript Division of the Library of Congress contain the original lecture note cards, "Pathological Science," dated 18 Dec 1953, as well as a sound recording and transcript of this seminar. Irving Langmuir, "Pathological science," Robert N. Hall, ed., *PT* (Oct 1989), 36-48. See also Robert G. Fleagle, "Second opinions on 'pathological science'," *PT* (Mar 1990), 110.

predicted the change in the hurricane's direction based on steering currents in the larger-scale circulation, and that the small amount of ice generated by cloud seeding would have been overwhelmed by naturally-occurring ice in the storm, Langmuir, in essence, replied that Hosler "was so stupid that [he] didn't deserve an explanation and that [he] should figure it out." During a meeting break, Henry Houghton, the chair of the department at MIT, took Hosler aside and explained to him that Langmuir's attitude stemmed from his belief that cloud seeding was his greatest scientific discovery and he had no time or patience to listen to objections.[28]

While the military and Weather Bureau projects were struggling for results and the scientific community was beginning to look askance at Langmuir, a determined and enthusiastic band of private meteorological entrepreneurs, operating primarily in the West and Midwest, succeeded in placing nearly ten percent of the land area of the country under commercial cloud seeding at an annual cost to farmers and municipal water districts of three to five million dollars.[29] The spread of this technique generated numerous public controversies that pitted Langmuir, the entrepreneurs, and their clients against Weather Bureau skeptics and parties claiming damages purportedly caused by cloud seeding.

For example, in 1951 New York City was facing 169 claims totaling over $2 million from Catskill communities and citizens for flooding and other damages attributed to the activities of a private rainmaker, Wallace Howell. The city had hired Howell to fill its reservoirs with rain, and, at least initially, claimed that Howell had succeeded. When faced with the lawsuits, however, city officials reversed their position and commissioned a survey to show that the seeding was ineffective. Although the plaintiffs were not awarded damages, they did win a permanent injunction against New York City, which ceased further cloud seeding activities; further litigation stopped just short of the Supreme Court.[30]

During the western drought in the early 1950s, Irving Krick,[31] private weather consultant and promoter of a controversial system of ultra-long-range forecasting, began cloud seeding operations for large agricultural concerns. His clients included

28. Charles Hosler, "Weather modification and science and government," unpub. ms. and personal communication, 22 Mar 2005. Hosler served as professor, dean of the College of Earth and Mineral Sciences, and dean of the graduate school at the Pennsylvania State University. He is also featured in Theodore Steinberg, *Slide mountain, or the folly of owning nature* (Berkeley, 1995), 106-134 and 191-194.

29. Robert D. Elliott, "Experience of the private sector," in W.N. Hess, ed., *Weather and climate modification* (New York, 1974), 45-89.

30. "City flip-flop on rainmaking," *Daily news* (5 Nov 1951), unpaginated clipping; H. Victor Crawford to John C. Morrissey, 21 June 1951; bibliography on legal and historical aspects, included in Helmut E. Landsberg, "Memorandum for the record—Briefing on weather control," 5 Nov 1951. These and related items are in Research and Development Board Weather Control Files, U.S. National Archives.

31. Victor Boesen, URL: http://www.weathersage.com/texts/boesen/chapter8.htm (2 Jan 2006).

wheat farmers, ranchers, and stream-flow enhancement projects on the Salt River in Arizona and the Columbia River in the Pacific Northwest. In the later project, the Bureau of Reclamation credited Krick with an 83 percent enhancement of the river flow while the Weather Bureau considered this claim meaningless and sought to discredit him whenever possible. At the height of its operations, Krick's company was conducting seeding operations that covered 130 million acres of western lands.

Weather modification took a macro-pathological turn between 1967 and 1972 in the jungles over North and South Vietnam, Laos, and Cambodia.[32] Under operation POPEYE, the Air Weather Service conducted secret cloud seeding operations to reduce traffic along portions of the Ho Chi Minh Trail. Flying 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 President Johnson,[33] the AWS flew over 2,600 cloud seeding sorties and expended 47,000 silver iodide flares over a period of five years at an annual cost of approximately $3.6 million.

In March 1971, nationally syndicated columnist Jack Anderson broke the story about Air Force rainmakers in Southeast Asia in the *Washington post*; several months later the *Pentagon papers* confirmed his information.[34] A year later Secretary of Defense Melvin Laird stonewalled the Senate Foreign Relations Committee when he stated that no cloud seeding was taking place over North Vietnam, never mentioning that Operation POPEYE still operated elsewhere in the region.[35] Nevertheless by

32. Senate committee on foreign relations, Subcommittee on oceans and international environment, Weather modification: Hearings, 93rd Cong., 2nd sess., 1974, 87ff. The operational phase of POPEYE began on 20 Mar 1967 and was conducted each year during the monsoon season (Mar-Nov). The project was also known as "Intermediary Compatriot," and, as "Motorpool." See John F. Fuller, Air weather service support to the United States army: Tet and the decade after [AWS] *Historical Study No. 8* (Scott AFB, IL, 1979), 30-32.

33. As early as 1957, then Senator Johnson had speculated on controlling the earth's weather from space for military purposes; Lowell Ponte, "Weather warfare forecast: Partly cloudy —UN treaty would permit 'peaceful' environmental research by military," *Los Angeles times* (29 Jan 1976), reprinted in Senate committee on foreign relations, Subcommittee on oceans and international environment, Prohibiting hostile use of environmental modification techniques: Hearing, 94th Cong, 2nd sess., 1976.

34. Jack Anderson, *Washington post* (18 Mar 1971). Memorandum from the Deputy Secretary of Defense to the Hon. Nicholas deB. Katzenbach, Under Secretary of State, Subject: "Military action program for SE Asia," 21 Feb 1967; cited in Department of Defense, United States—Vietnam relations, 1945-1967: Study prepared by the Department of Defense, Book 5, Vol. 2, *U.S. ground strategy and force deployments: 1965-1967* (Washington, DC, 1971), 50-51. See also Charles C. Bates and John F. Fuller, *America's weather warriors, 1814-1985* (College Station, TX, 1986), 229-232.

35. Testimony of Melvin R. Laird before the Senate Foreign Relations Committee, 18 Apr 1972, cited in Weather modification hearings (ref. 32), 109-110; Daniel S. Greenberg, "Vietnam rainmaking: A chronicle of DoD's snowjob," *Science and government report, 2* (1972), 1-4.

1973 the Senate had adopted a resolution (S. 71) "to prohibit and prevent, at any place, any environmental or geophysical modification activity as a weapon of war," and in 1974 Senator Claiborne Pell forced the declassification of the transcript of a top-secret briefing by the Defense Department on the topic.

Operation POPEYE, made public at the end of the Nixon era, was called the Watergate of weather warfare.[36] Some argued that environmental weapons were more "humane" than nuclear weapons, and that inducing rainfall was preferable to dropping napalm; as one wag put it, "make mud, not war." Philip Handler, president of the National Academy of Sciences, represented the mainstream of scientific opinion, however, 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."[37]

The Soviet Union, realizing the weakness of the U.S. position on cloud seeding in Vietnam and taking full advantage of the Watergate crisis, seized the diplomatic initiative and 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 entered into force in 1978, ironically, when the Lao People's Democratic Republic, where the American military had used weather modification technology in war only six years earlier, became the twentieth nation to ratify it.[38] Thus ended the second cycle of promise and hype.

What lessons can we draw? Cold warriors presumed that clouds, storms, and even the climate, like any other natural phenomenon, could be controlled and weaponized. They further supposed as usual, that the Soviets were probably ahead in this novel warfare. Western farmers, still susceptible to drought, remained at the mercy of private, sometimes unscrupulous rainmakers. During the Johnson and Nixon administrations—the era of generation gaps and credibility gaps—planners assumed that the surreptitious use of environmental warfare was acceptable. One observer noted that the lesson of the Vietnam experience was not that rainmaking is an inefficient means for slowing logistical movement in jungle trails, but "that one can conduct covert operations using a new technology in a democracy

36. Cristine Russell, "The weather as a secret weapon: From Vietnam to Geneva," *Washington star* (23 Aug 1975), reprinted in Senate committee on foreign relations, Subcommittee on oceans and international environment, Prohibiting military weather modification: Hearings on S.R. 281, 92nd Cong., 2nd sess., 1972, 47.

37. Philip Handler to Claiborne Pell, 25 Jul 1972, in *Hearings* (ref. 36), 153.

38. United Nations, *Multilateral treaties deposited with the Secretary-General: Status as of 31 December 1982* (New York, 1983), 667. The text of the UN convention (A/RES/31/72) is reprinted as appendix C in Congressional Research Service, "Weather modification: Programs, problems, policy, and potential," 95th Cong., 2nd sess., 1978, 510-13.

without the knowledge of the people."[39] The dominant opinion, however, was that seeding clouds—like using Agent Orange or the Rome Plow, setting fire to the jungles or bombing the dikes over North Vietnam—was but one of many sordid genocidal and ecocidal techniques used in Vietnam.[40] Since 1979 federal funding for applied weather modification has literally dried up. Today limited state and local funds support agricultural, water conservation and hydropower interests as they conduct routine cloud seeding operations over about one-third of the area of the American West.

3. ROUND 3: WEATHER MODIFICATION IN THE 21ST CENTURY

Recently, three speculative announcements concerning weather modification were in the news: Beijing's Study Institute of Artificial Influence on the Weather announced its intention of manipulating the weather to ensure optimum conditions for the 2008 Olympics; a private weather company in Florida advertised a new powder called Dyn-O-Gel with the power to "suck the moisture out of a thunderstorm or weaken a hurricane"; and the U.S. Air Force claimed 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 traditional cloud seeding methods, the Air Force visionaries propose computer hacking to disrupt an enemy's weather monitors and models, and using "nanotechnology" to create clouds of microscopic computer particles that could block an enemy's optical sensors or guide smart weapons to their targets; the cost of developing these clouds to be borne by the private sector. In a recurring theme, the military points 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."[41]

With greater gravitas, but with no less speculation, in October 2003 the NRC issued its report, "Critical issues in weather modification research." The study cites 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

39. Gordon J.F. MacDonald, statement in House Committee on International Relations, Subcommittee on International Organizations, Prohibition of Weather Modification as a Weapon of war: Hearings on H.R. 28, 94th Cong., 1st sess., 1975, 5.
40. Stockholm International Peace Research Institute, *Ecological consequences of the second Indochina war* (Stockholm, 1976); Ruth Russell, "The nature of military impacts on the environment," in Sierra Club, *Air, water, earth, fire* (San Francisco, 1974), 1-14.
41. Melinda Liu, "Rain called on account of games," *Newsweek* (5 Aug 2002); Amanda Riddle, "Powder dries up Florida thunderstorms," *AP News* (19 Jul 2001); "Florida inventor believes he can suck the power out of hurricanes," *USA today* (1 June 2003); Col. Tamzy J. House et al., "Owning the weather in 2025," *Air Force 2025* (1996), http://www.above-topsecret.com/pages/af2025.html (2 Jan 2006).

and international programs in weather modification research. In essence, these amount to engineering solutions for nature's wrath by techniques such as cloud seeding and aerosol modification. Although the NRC study acknowledges that there is no "convincing scientific proof of efficacy of intentional weather modification efforts," its authors nonetheless believe that there should be "a renewed commitment" in the field of intentional and unintentional weather modification. In fact, no one has demonstrated a reliable, controllable method to modify weather, and the report admits as much: "Evaluation methodologies vary but in general do not provide convincing scientific evidence for either success or failure."[42] This has been true for the last 165 years, and it remains true today.

The NRC report suggests a new long-range research program in weather modification, although, as it acknowledges the time frame for meaningful results "may be measured in decades." In other words, we won't know if weather modification can help solve our problems until 2030, 2040 or beyond—and we may never know. Can we allow an unproven technology—a technological fix—such as cloud seeding to replace a fully coordinated and integrated water policy? Could this approach lead to even more speculative proposals to redirect storms or to engineer the climate, in effect replacing common sense and socially responsible policies that reduce weather and climate vulnerability? Can we allow weather modification to overshadow more reasonable and sustainable approaches to public resource problems? Would a proposed new institute and big field programs with large-scale cloud seeding really serve the needs of basic cloud physics?

According to meteorology professor Hans Verlinde of Penn State, one of the authors of the NRC report, the basic problems in cloud microphysics "haven't really changed much over the years."[43] Scientists do not have the ability to characterize the background concentration, sizes, and chemical composition of aerosols, the very smallest particles that participate in cloud processes. This is particularly true for ice nuclei. Additionally, the mass accommodation coefficient, a factor that determines the activated drop spectrum at cloud base and the maximum supersaturation attained within the cloud, is not known within an order of magnitude. Taken together, this means that atmospheric scientists cannot with confidence predict the droplet distribution and its variation within any particular cloud. Moreover, factors such as chemical surfactants and radiation influence the evolution of the droplets over time.

Concerning the formation of precipitation, the traditional view of the collision-coalescence process as a purely gravitational interaction is wrong, since cloud particles have three dimensional relative velocity differences and hence can approach each another from arbitrary directions. This has a profound impact on the collision and coalescence probabilities. The solution requires a greater understanding of turbulence than is currently available among cloud physicists. Also not well

42. NRC (ref. 2), 3-4.
43. Personal communication from Professor Johannes Verlinde, 9 Jan 2004.

understood is the behavior of complicated ice structures—in clouds and their density transitions, which are critical for precipitation formation. Realistic microphysical processes elude numerical weather models. Since cloud and precipitation formation are the bases for all larger scale weather phenomena, and since they occur at sub-grid scales with great spatial and temporal variability, microphysical processes are treated by modelers as at best unrealistic parameterizations with no theoretical basis. What is a cloud? is then both a philosophical and a scientific question.

The military's plan to control the weather and to redirect hurricanes calls to mind the immodesty of planetary scale macro-engineering, "geoengineering" massive technical fixes for the Earth's climate system. Jules Verne's novel *The purchase of the north pole*, can set the stage. A group of American investors had recently gained 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 captured the public imagination and was publicized as a means of improving the climate everywhere by reducing extremes of both cold and heat, making the Earth a terrestrial heaven. When it is revealed that the investors (modern Titans)—retired Civil War artillerists from the Baltimore Gun Club who had previously fired a manned projectile at the moon—intend to change the inclination of the earth's axis by constructing and firing the world's largest cannon, public support and enthusiasm give way to fears that tidal waves generated by the explosion would flood coastal cities and kill millions of people. In secrecy and haste (but aware of the cost-benefit calculus), the protagonists proceed with their plan, building the cannon in the side of Mount Kilimanjaro, but ultimately fail when an error in calculation renders the massive shot ineffective. "The world's inhabitants could thus sleep in peace. To modify the conditions of the Earth's movement [and by implication its climate] is beyond the power of man.."[44] Or is it?

In 1948 Joseph Stalin announced his "Great plan for the transformation of nature," a futile attempt to expand the Soviet economy by harnessing nature and controlling the weather and climate.[45] Even after Stalin's demise, in the era of Nikita Khrushchev, prominent meteorologists such as Howard Orville warned, "If an unfriendly nation gets into a position to control the large-scale weather patterns before we can, the result could even be more disastrous than nuclear warfare."[46] Professor Henry G. Houghton of MIT "shudder[ed] to think of the consequences of a prior Russian discovery of a feasible method of weather control….An unfavorable

44. Jules Verne, *The purchase of the north pole* (London, 1891), 173.

45. Albert E. Burke, "Influence of man upon nature—the Russian view: A case study," in William L. Thomas, Jr., ed., *Man's role in changing the face of the earth* (Chicago, 1956), 1035-1051, on 1036, 1049-1050.

46. Howard Orville, quoted in "The weather weapon: New race with the reds," *Newsweek* (13 Jan 1958), 54. There was also concern about Chinese capabilities in this area; Department of Commerce, "Chinese communist weather control experiments," U.S. DOC 60-21921, 21 Aug 1959 (Washington, D.C., 1960).

modification of our climate in the guise of a peaceful effort to improve Russia's climate could seriously weaken our economy and our ability to resist."[47]

In the cold war era, authors from at least nineteen research institutions in the Soviet Union published books, articles and reports on weather and climate modification.[48] Several popularizations of this literature are notable for their geoengineering fantasies.[49] In *Soviet electric power* (1956), Arkadiaei Bovisovich Markin outlines the progress of electrification in the Soviet Union and provides a forecast to the year 2000 when, he supposes, electrical power output will be one hundred times greater that at the time of writing. Markin gives special emphasis to the future role of nuclear power, including—reminiscent of Edward Teller's Project Plowshare—using nuclear explosions for geo-engineering purposes:

> Gigantic atom explosions in the depths of the earth will give rise to volcanic activity. New islands and colossal dams will be built and new mountain chains will appear. Atom explosions will cut new canyons through mountain ranges and will speedily create canals, reservoirs, and seas, carry[ing] out huge excavation jobs. At the same time we are convinced that science will find a method of protection against the radiation of radioactive substances.

Surely, Markin concludes, the power engineer can achieve "magnificent results" when inspired by the "omnipotence of human genius."[50]

In *Man versus climate* (1960), Nicolai Petrovich Rusin and Lila Abramovna Flit admit that "we are merely on the threshold of the conquest of nature," and go on to describe "those mysteries of nature already penetrated by science, the daring projects put forward for transforming our planet, and the fantastic dreams to be realized in the future." Invoking the Jules Verne fantasy, the book's cover shows the Earth surrounded by a Saturn-like ring of dust particles intended to illuminate the Arctic Circle, increase solar energy absorption, and melt the polar ice caps. The book describes mega-engineering projects such as damming the Congo River to irrigate the Sahara with a "Second Nile," diverting the Gulf Stream with a dam between Florida and Cuba, and P.M. Borisov's proposal to dam the Bering Straits to divert Atlantic waters into the Pacific and melt the Arctic sea ice. The authors' ultimate goal is to convince the reader, that "man can really be the master of this planet and that the future is in his hands."[51]

47. Henry G. Houghton, "Present position and future possibilities of weather control," in *Final report of the United States advisory committee on weather control,* Vol. 2, 288; quoted in *Newsweek* (13 Jan 1958), 54.
48. Nikolay T. Zikeev and George A. Doumani, *Weather modification in the Soviet Union, 1946-1966: A selected annotated bibliography* (Washington, D.C., 1967).
49. The American literature includes Willy Ley, *Engineer's dreams* (New York, 1954) and David Nye, *American technological sublime* (Cambridge, 1994).
50. A. Markin, *Soviet electric power: Developments and prospects* (Moscow, 1956), 133-35.
51. N. Rusin and L. Flit, *Man versus climate* (Moscow, 1960); P.M. Borisov, "Can we con-

Igor Adabashev discusses many of the same projects in his book *Global engineering* (1966), but his utopian hopes are tinged by stronger ideological commitments.[52] Concerning the "Second Nile" project in Africa: "The great new man-made inland seas would transfigure the Sahara…and create a new climate in Northern Africa….Millions and millions of fertile acres would be made to yield two and even three crops a year for the benefit of mankind." This would enhance the "struggle of African peoples for national liberation" against the vested interests of American and European capitalists seeking to control the African economy. Referring to Borisov's proposal to melt the polar ice by building a dam across the Bering Strait, Adabashev declares that "What mankind needs is war against cold, rather than a 'cold war'." Of little concern to the Soviets was the possibility that warming of the Arctic "may mean another ice age in Europe, America, and Asia." Adabashev forsees a new global hydrologic era "of gigantic dams and dykes, pumping stations capable of handling entire seas, and other facilities which will 'trigger' various meteorological processes. We shall work out a better 'heating system' for our planet, better able to serve all five continents." Confronted with world population increase and energy concerns, a visionary engineer need not stop at the surface of the Earth. Adabashev concludes his book with a fanciful account of a "Dyson sphere," one astronomical unit in radius, a new home for humanity roughly a trillion times greater than that of Earth, synthesized from the remains of the outer planets and capturing all the incident solar energy—"sustainable development" in action—at least for the next several billion years![53]

These were not just Russian pipe dreams, for in 1965 President Johnson's Science Advisory Committee issued a report called "Restoring the quality of our environment." After estimating the future increase of anthropogenic CO_2 from fossil fuel and its likely negative impact on climate, the report suggested that geoengineering options or, as they put it, "the possibilities of deliberately bringing about countervailing climatic changes…need to be thoroughly explored." As an illustration, they pointed out that the Earth's albedo could be increased by one percent by dispersing buoyant reflective particles on the sea surface at an annual cost, not considered excessive, of about $500 million. Reducing fossil fuel use was not mentioned as an option.[54] In 1977 Cesare Marchetti tackled the problem of CO_2 control in the atmosphere by proposing a kind of "fuel cycle" to collect and inject it into the Mediterranean at the Straits of Gibraltar. About the same time, M.I. Budyko emphasized modification of the aerosol layer of the stratosphere.[55]

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trol the Arctic climate?" *Priroda, 12* (1967), 63-73, transl. Defence Scientific Information Service, DRB, Canada (1968).

52. I. Adabashev, *Global engineering* (Moscow, 1966).

53. Ibid., 161, 192, 201, 236.

54. President's Science Advisory Council, *Restoring the quality of our environment, Report of the environmental pollution panel* (Washington, D.C., 1965).

55. Cesare Marchetti, "On geoengineering and the CO2 problem," *Climatic change, 1*

Technical proposals continue to dominate. The report of the National Academy of Sciences, *Policy implications of greenhouse warming* (1992), advised that the United States should conduct research in schemes to cool the Earth if global warming gets out of hand. Proposals included orbiting a fleet of space mirrors or spraying sulfur dioxide into the stratosphere to reflect solar radiation back to space, turning the oceans into soupy green algae blooms to sequester excess carbon, or setting up gigantic "soot generators" to shade the Earth.[56] Other scholars have taken a "serious look" at geoengineering and find it attractive because, in their words, "Doubt about the prospects for cooperative abatement of global greenhouse gas emissions is a pragmatic reason to consider geoengineering, whose implementation requires fewer cooperating actors than abatement."[57]

Today's geoengineering schemes typically are ocean-based (diverting currents, iron fertilization, ocean carbon sequestration), land-based (biological or geological carbon sequestration, alternative energy generation), or radiation-based (space mirrors, enhancing cloud reflectivity, eliminating trace gases). Writing in the past and conditional tenses, but clearly pointing to the future beyond the Kyoto Protocol, a recent history of global warming pointed to the probable failure of voluntary reductions of emissions and alluded to a possible dystopian future when the geoengineering option was exercised:[58]

> Global warming might require the international system to forge entirely new mechanisms of cooperation, and some questioned whether people could rise to the challenge. Many leaders nevertheless felt it worthwhile to keep on developing regulation and monitoring mechanisms. The experience would be essential if the day came when dire need forced the world to truly commit itself to halt global warming.

For surely macro-scale or planetary-scale climate engineering—the study, preparation, and execution of the largest possible engineering works—also requires macrosocial planning, implying fundamental changes to the world's economic and political systems, social and cultural institutions, and even ethnic and demographic groupings. Nevertheless the macro-engineers were gathering—without the perspectives of historians or ethicists!

During the hot summer of 1988 the Government of Canada hosted a major scientific conference in Toronto on "The changing atmosphere: Implications for

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(1977), 59-68; M.I. Budyko, *Climatic changes* (1974, transl. American Geophysical Union, 1977), 236-246.

56. National Academy of Sciences, *Policy implications of greenhouse warming: Mitigation, adaptation, and the science base* (Washington, D.C., 1992); Edward Teller, "The planet needs a sunscreen," *Wall street journal* (17 Oct 1997), 1.

57. David Keith and Hadi Dowlatabadi, "A serious look at geoengineering," EOS, American Geophysical Union, *Transactions, 73* (1992), 289, 292–293.

58. Spencer Weart, *The discovery of global warming* (Cambridge, 2003), 190.

global security" in collaboration with the United Nations and the World Meteorological Programme. Scientists from all over the world agreed on a consensus statement and a target for emission reductions. The statement opened, "Humanity is conducting an unintended, uncontrolled, globally pervasive experiment, whose ultimate consequences could be second only to global nuclear war." The target: global reductions of carbon dioxide emissions to twenty percent below 1988 levels by 2005.

That was 1988. By 2005 we were nowhere near this goal and popular cries to "Stop global warming" and "Control climate change" have become more and more widespread. The scientific community is also moving in this direction. In October 2003 the U.S. Pentagon released a controversial report, "An abrupt climate change scenario and its implications for United States national security," that explored how global warming could lead to rapid and catastrophic global cooling, "and how such an abrupt climate change scenario could potentially de-stabilize the geo-political environment, leading to skirmishes, battles, and even war due to resource constraints." This relied on the more scientific and significantly less dramatic report by the NRC, "Abrupt climate change: Inevitable surprises" (2002).

While the NRC report focused its modest set of recommendations on improved impact assessments, data collection, modeling, and what it called "no regrets" strategies to reduce climate vulnerabilities, the Pentagon report concluded with the more aggressive recommendation that the government "explore geo-engineering options that control the climate." The authors made the following dubious claim about *warming a cooling climate*: [59]

> Today, it is easier to warm than to cool the climate, so it might be possible to add various gases, such as hydro-fluorocarbons, to the atmosphere to offset the affects [sic] of cooling. Such actions, of course, would be studied carefully, as they have the potential to exacerbate conflicts among nations.

In January 2004, in Cambridge, England, the Tyndall Centre for Climate Research and the Cambridge-MIT Institute held a joint symposium on "Macro-engineering options for climate change management and mitigation."[60] Citing as their rationale the urgent need to reduce greenhouse emissions by fifty percent globally and up to ninety percent in the United States and Europe in order to avoid excessive climate change, and the *un-likelihood* of such reductions being accomplished by conventional means such as renewable energy sources and energy efficiency, the conference set out to "identify, debate, and evaluate" possible, but highly controversial macro-engineering options for the management and mitigation of climate change. This was no mere academic exercise, but a fully vested rehearsal, ranking, and evaluation, by the research community and their government sponsors, of the panoply of geoengineering options prior to their implementation.

59. Schwartz and Randall (ref. 2).
60. Tyndall Centre conference (ref. 3).

Although couched in the language of uncertainty and swathed in caveats, the conference's proposals coincided with the initiation of pilot projects and served to move the speculative geoengineering agenda closer to the mainstream. In the language of the organizers, "At the very least, such options may be considered as emergency policy options in the event of more adverse climate change impacts than expected, or less effective carbon reduction measures than anticipated." The conference did not specify "adverse climate change impacts" nor how much climate change would be needed to trigger a geoengineering option. Less-than-effective carbon reduction measures are just about certain to occur.

Among the technical options considered, were (1) *carbon sequestration* (capture and storage) by geological disposal in landforms or in the oceans, atmospheric scrubbing, ocean fertilization, and enhancement of terrestrial sinks; (2) *albedo modification* on a planetary scale, for example, by launching mirrors or reflective particles into orbit, adding aerosols to the stratosphere, enhancing cloud reflectivity, and modifying land surfaces; (3) *climate design* (also known as terra-formation) by attempting to control trace gas concentrations, glaciers, and photosynthesis; and (4) *reducing impacts* by constructing animal migration corridors and by diverting rivers and glacial melt water in an attempt to stabilize ocean currents and sea level.[61]

A paper on "Active climate stabilization albedo control," by Edward Teller (now deceased) and his protégés at Lawrence Livermore National Laboratory proposed that *both* global warming *and* the onset of an ice age could be prevented by injecting appropriate sub-microscopic chaff particles into the Stratosphere.[62] In the case of excess warming, the chaff would reflect about two percent of incoming solar radiation to cool the planet by up to four degrees; in the case of unwanted cooling, a different kind of chaff could be used to enhance the natural greenhouse effect by the same amount. In either case, the authors estimated that "albedoengineering" or active technical management of radiative forcing would cost less than $1B per year or much less than one percent of the cost of "bureaucratic management" of greenhouse gases. Moreover, in their reading, the UN Framework Convention on Climate Change (Art. 3.3) requires reducing bureaucratic management, since it calls for "ensur[ing] global benefits at the lowest possible cost."[63] Notwithstanding the

61. Technical aspects have dominated the discussion. Robert G. Watts, ed., *Engineering response to global climate change: Planning a research and development agenda* (Boca Raton, FL, 1997); M.I. Hoffert, et al., "Advanced technology paths to global climate stability: Energy for a greenhouse planet," *Science, 298* (2002), 981-988.

62. Edward Teller, Roderick Hyde, Muriel Ishikawa, John Nuckolls and Lowell Wood, "Active climate stabilization: Presently-feasible albedo-control approaches to prevention of both types of climate change," in Tyndall Centre conference (ref. 3). Wood was an active participant in the 2006 NASA/Carnegie conference as well.

63. The text of the Framework Convention on Climate Change, Article 3.3, which does not mention geoengineering, reads as follows: "The Parties should take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects. Where there are threats of serious or irreversible damage, lack of full scientific cer-

authors' hopes of generating more colorful sunsets, their proposal to control global warming would probably turn the blue sky white while reducing direct beam solar radiation by about twenty percent.[64]

At the Tyndall Centre meeting two other scientists from Lawrence Livermore National Laboratory, Bala Govindasamy and Ken Caldira, provided a valuable counterpoint to the enthusiasm of Teller et al.[65] They argued that the technical, environmental, political, and economic challenges of geoengineering schemes demand further investigation. Even on the merely technical level, they warned that geoengineering could subject ecosystems to unknown and possibly adverse impacts, and that the failure of a geoengineering system could expose the Earth to extremely rapid climate change. They thought the better way to reduce the effects of greenhouse gas emissions is by reducing greenhouse gas emissions, an eminently reasonable conclusion echoing that of D. Whitney King over a decade ago.[66]

The vision of the organizers of the Tyndall Centre conference took in a full range of participants. These included scientists, engineers, economists, and representatives of governments and NGOs, but did not extend to historians of science and technology or to ethicists, although one valuable paper by David Keith presented a policy history of geoengineering. Keith argued that the discourse had been largely pragmatic, based on risk assessment and cost-benefit analysis, and that "serious ethical arguments about geoengineering are almost nonexistent." Ethically, a large-scale environmental tech fix would be imposed on others, typically by the will of the few; in contrast, a medical tech fix, for example like heart surgery, is at

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tainty should not be used as a reason for postponing such measures, taking into account that policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost. To achieve this, such policies and measures should take into account different socio-economic contexts, be comprehensive, cover all relevant sources, sinks and reservoirs of greenhouse gases and adaptation, and comprise all economic sectors. Efforts to address climate change may be carried out cooperatively by interested Parties." http://unfccc.int/essential_background/convention/background/items/2853.php (2 Jan 2006).

64. Personal communication from Michael MacCracken, former director of the U.S. Global Change Research Program (12 Feb 2005).

65. Bala Govindamay and Ken Caldeira, "Geoengineering earth's radiation balance to mitigate CO2-induced climate change," *Geophysical research letters, 27* (2000), 2141-2144, in Tyndall Centre conference (ref. 3). Caldeira, now with the Carnegie Institution, was the organizer of the 2006 NASA/Carnegie meeting, a meeting inspired by Nobel Laureate and atmospheric chemist Paul J. Crutzen's recent proposal to inject sulfates into the stratosphere to reduce global warming.

66. "The search for the elusive silver bullet just provides us with an excuse to postpone dealing with the CO_2 production problem;" D. Whitney King, "Can adding iron to the oceans reduce global warming? An example of geoengineering," in James R. Fleming and Henry A. Gemery, eds., *Technology and the environment: Multidisciplinary perspectives* (Akron, 1994), 112-135, on 135.

the appropriate choice of the individual patient. Recent sessions at the American Geophysical Union and the American Association for the Advancement of Science examined geoengineering history, ethics, and policy, but more work is needed.[67]

4. CONCLUSION

Understanding, prediction, and control are the fantasies of both science and science fiction. For some, controlling the weather, climate, or chemical composition of the atmosphere, is more desirable than merely understanding it or predicting its behavior. We have examined two past cycles of promise and hype involving manufactured weather and climate in an attempt to illuminate what appears to be the start of a third rhetorical cycle. Fantasies are again giving way to seemingly rational, technical proposals. But they are only rational without their histories. In the recent flurry of activity beginning in 2003, as well as in the past cycles, massive and immodest proposed interventions served to subvert or at least submerge more fundamental and perhaps more reasonable aspects of cloud physics and climate dynamics. Instead they came to reflect larger social tensions, values, and public apprehensions.

James Espy was the leading meteorologist of his day; Irving Langmuir and his team at GE developed many of the basic techniques of cloud physics. However, in both historical cycles, the promise of weather control soon gave way to excessive hype and pathology. No one doubts the competence of the scientists and engineers involved in the recent NRC and DoD reports or the Tyndall Centre and NASA/Carnegie conferences. However, by emphasizing the purely technical or economic aspects of strategies of weather and climate control, bypassing understanding and prediction, and neglecting the historical, ethical, and social dimensions, we are in danger of entering a new cycle of discourse saturated with hype, the heirs of an impoverished debate.

67. James R. Fleming, convener, "Geoengineering: Historical, ethical, and policy perspectives," American Geophysical Union Session U54A, San Francisco (9 Dec 2005) and "Sustaining the global climate: Science, ethics, and public policy," American Association for the Advancement of Science, San Francisco (16 Feb 2007)..

JAMES RODGER FLEMING

The pathological history of weather and climate modification: Three cycles of promise and hype

ABSTRACT

The chequered history of weather and climate modification exhibits a modicum of promise and an excess of hype. This paper examines two completed historical cycles: the first, dating from 1839, involved western proprietary rainmaking or "pluviculture"; the second, from 1946 to 1978 involved "cloud seeding," commercial rainmaking, and the attempted weaponization of the clouds. Recently, discussion of weather and climate modification has returned to the science-policy agenda, framed as seemingly inevitable responses to killer storms and global warming. The long history of deceptive and delusional attempts to "control" nature, however, raised serious questions about the rationality of these options.

KEY WORDS: climate control, climate modification, cloud seeding, geoengineering, pathological science, weather control, weather modification