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Fixing the Weather and Climate: Military and Civilian Schemes for Cloud Seeding and Climate Engineering

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Cloud Wars

> 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
>
> General George C. Kennedy,
> *Commander of the Strategic Air Command, 1947*

In 1947 meteorologists in the Joint Research and Development Board advised the U.S. Defense Department that weather control by cloud seeding was "entirely feasible" and that the perfection of this technique would have major tactical, strategic, and economic implications. If researchers were right, a small amount of nucleating agent could cause a chain reaction in clouds that would release as much energy as an atomic bomb. Such a weather weapon could be used surreptitiously and without radioactive fallout; moreover, it would be unidirectional in that clouds seeded over Europe would be carried by the westerly winds over the Soviet Union. Note the analogies to atomic weapons: cloud seeding nuclei, cause chain reactions forming a destructive mushroom-shaped cumulonimbus cloud with the energy of an atomic bomb; the fall-out — precipitation — is clean however (not radioactive). Such weapons might also be deployed surreptitiously.[1]

Military 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, using controlled precipitation as a delivery system for biological or radiological agents, diverting precipitation from one large geographic area to another to disrupt (or improve) the agricultural economy of the nation concerned, and altering the global climate for military purposes. 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 conditions. In military circles cloud seeding was seen 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. Based on the military and economic implications of the technique and the powers it promised its masters, meteorologists advised the military to launch an "intensive research and development effort."[2] For three decades, until 1977 when the United States signed a United Nations' Convention condemning the use of environmental modification as a weapon of war, the U.S. military enthusiastically supported research on new technologies of weather modification and control.

Such patronage should come as no surprise for indeed, modern meteorology has overwhelming ties to the military.[3] During World War II the U.S. Army Air Forces and the U. S. Navy trained approximately 8,000 weather officers. Personnel of the army's Air Weather Service (AWS), an agency nonexistent in 1937, numbered 19,000 in 1945. About 4,500 of this total were officers. Even after demobilization the AWS averaged approximately 11,000 soldiers during the Cold War and Vietnam eras.[4] In 1954 an NSF (National Science Foundation) survey of 5,273 professional meteorologists in America revealed that 43 percent of them were still in uniform on active duty, 25 percent held U. S. Air Force reserve commissions, and 12 percent were in the naval reserve. Thus almost a decade after the war, 80 percent of American meteorologists still had military ties.[5] Most of them were operational forecasters who had received their basic training in meteorology during the war. In 1958 the Committee on Meteorology of the National Academy of Sciences observed that, "the percentage of meteorologists with doctor's degrees was the lowest of any major scientific group, while the percentage of persons with no degree at all who were designated as meteorologists was the highest of any major scientific group."[6] In 1965, two decades after the war, the military had a larger budget than the Weather Bureau ($189 million compared to $104 million) and three times as many people (14,300 compared to 4,500) in weather service and research. The total meteorological budget of the U. S. Department of Defense (DoD) was $188.9 million in 1965. This was larger than that of any other government agency.

The General Electric (GE) Experiments and Project Cirrus

The modern era of weather modification began in the summer of 1946 at the General Electric Research Laboratory in Schenectady, New York, when

Vincent Schaefer dropped a block of dry ice into a home freezer unit and, to his surprise, instantly transformed a cold vapor cloud into millions of tiny ice crystals. After some rough calculations, Schaefer tossed six pounds of dry ice out the window of a rented plane and seeded a cold cloud over Greylock peak in the Berkshires, creating ice crystals and fall streaks of snow.[7] According to Schaefer's laboratory notebook, "It seemed as though [the cloud] almost exploded, the effect was so widespread and rapid ..."[8] Within a year Bernard Vonnegut (yes Kurt's brother) of the Massachusetts Institute of Technology (MIT), who had come to GE to count the crystals, discovered that silver iodide smoke also *seeded* supercooled clouds. Completing the cloud seeding triumvirate at GE was Nobel prize winner Irving Langmuir, senior scientist and an outspoken, enthusiastic promoter and popularizer of large-scale weather control.[9] In the press and before the meteorological community, Langmuir expounded his sensational vision of large-scale weather control: of the arid Southwest being changed into fertile farmland and of cloud seeding preventing "all ice storms, all storms of freezing rain, and icing conditions in clouds."[10]

An extremely optimistic announcement of progress in weather modification appeared in the *General Electric Annual Report* for 1947: "Further experiments in weather control led to a new knowledge which, it is believed now, will result in *inestimable* benefits for mankind."[11] But cloud seeding was becoming a controversial issue and Langmuir's exaggerated claims threatened to take the company into litigious territory, far beyond the limits of normal corporate support for research.[12] When one of Schaefer's cloud seeding attempts coincided with an eight-inch snowfall in upstate New York (earlier the Weather Bureau had forecast "fair and warmer"), Langmuir was quick to claim that cloud seeding had triggered the storm. He further claimed that chain reactions could be set off in warm cumulus clouds, that in one field trial a hurricane had changed direction within six hours because of seeding, and that in general all meteorologists needed to do was find the proper trigger to release the immense amounts of energy stored in the atmosphere.[13]

GE lawyers, fearing a deluge of property damage and personal inconvenience suits, tried to silence Langmuir.[14] C. Guy Suits, the director of research at GE, hurriedly halted outdoor experimentation on cloud seeding. He instructed Langmuir's team to work with Project Cirrus, a classified project conducted by the U. S. Army Signal Corps, the Office of Naval Research and the U. S. Air Force over a 1,000-square-mile area north of Schenectady. As stated in the GE contract, the general purposes of the project were (a) "to search for fundamental knowledge and a better understanding of the physics and chemistry of hydrometeor formation as an aid in operational forecasting of both local and long range weather conditions" and (b) "to investigate the practicability of and the means for cloud modification for military purposes."[15] The *Harvard Law School Record* reported, "Today 'Project Cirrus' has an annual budget of $750,000 from

military and naval funds because of its war implications — bogging down enemy troops in snow and rain, clearing airfields of fog at lowest cost, and infecting induced storms with bacteriological and radiological materials. The Battle of the Bulge, in which the Nazis mobilized and attacked under supercooled fog, could have been much altered by a few pounds of dry ice."[16]

Langmuir and Schaefer served only in advisory roles in Project Cirrus. GE's contract stipulated that, "the entire flight program shall be conducted by the government, using exclusively government personnel and equipment, and shall be under the exclusive control of such government personnel." Suits notified his staff, "that it is essential that all of the G.E. employees who are working on the project refrain from asserting any control or direction over the flight program. The G.E. research laboratory responsibility is confined *strictly* to laboratory work and reports."[17] GE's corporate posture was that the whole matter properly belonged to the government, and that the government, by suitable legislation, should both regulate the inducing of rainfall and indemnify for loss any contractor acting on the government's behalf — especially themselves. Secretary of Defense James Forrestal asked Congress for a law "to protect contractors engaged in cloud modification experiments against claims for damages by third parties."[18] No legislation to this effect, however, was forthcoming.

Under Project Cirrus, between 1947 and 1952, scientists carried out about 180 field experiments involving modification of cold stratus clouds, warm and cold cumulus clouds, and a tropical storm. Although mountains of photographic and other data were collected and analyzed, the response of the atmosphere to seeding was erratic and no definitive measure of the efficacy of artificial nucleating agents was obtained.[19] The results from several experimental runs were spectacular, however, and the DoD decided to continue funding projects, which continued and expanded the work of Project Cirrus.

One such project, the joint Air Force-Weather Bureau Cloud Physics Research Project, designed to study the synoptic aspects of cloud physics and test the results of Project Cirrus, found that seeding did indeed produce striking visual changes in clouds, including dissipation of cold stratus decks. However, experiments with clouds over Ohio in 1948 and over California and the Gulf states in 1949 led the researchers to conclude that cloud seeding could not initiate self-propagating storms or relieve drought. The Weather Bureau spent $85,000 on the project in 1948 and $100,000 in 1949. The U. S. Air Force supplied aircraft, personnel, and ground radar facilities.[20]

Experiments in New Mexico and Secret Military Projects

Langmuir's most fantastic claim was that changes in the weather across the continent had been caused by a single silver iodide generator in New Mexico in 1950.[21] The experiment, which coincided with severe flooding in the Ohio Valley and resulted in widespread property damage and fatalities, came to the attention of the highest echelons in the government and resulted in a number of secret projects. Noted meteorologist Sverre Petterssen of the University of Chicago explained the situation as follows:

For no profound reason [Langmuir] had left a silver-iodide generator somewhere in New Mexico and made arrangements with a local person to "burn" the generator on a weekly schedule. Using a set of readily available weather reports, Langmuir found that the rainfall had begun to vary in a weekly rhythm. The amazing thing was that the response was not just local; it was nationwide and might well be of hemispheric proportions. Langmuir, and many with him, concluded that the weekly injection of silver iodide from a single generator in New Mexico had excited a hitherto undiscovered natural rhythm of the atmosphere ...[22]

Langmuir had forgotten, or perhaps was unaware, that the atmosphere frequently exhibits a *natural* seven-day periodicity.

Nevertheless, the technology seemed of such great potential, especially to military aviation, that Vannevar Bush, former head of the Office of Scientific Research and Development (OSRD) in 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. Bradley immediately convened a "cushion committee" to serve as a buffer between the defense establishment and the scientific community. This committee, consisting of an admiral, a general, and the chief of the U.S. Weather Bureau, Francis F. W. Reichelderfer, in turn appointed a special scientific committee chaired by Sverre Petterssen, director of scientific weather services for the U.S. Air Force, called the "Ad hoc Committee on Artificial Cloud Nucleation" — a name, according to Petterssen, "that did not suggest interest in secret weapons. To add camouflage, Dr. Alan T. Waterman, Director of the National Science Foundation, was appointed a member."[23]

At the direction of the cushion committee, and with the secret hope that a secret weapon might emerge from this technology, Petterssen's ad hoc group conducted a brief survey of the state of the field and recommended a program of five statistically controlled experiments to begin in 1952 "to clarify major uncertainties."

1. The seeding of extratropical cyclones, designated Project Scud, was sponsored by the Office of Naval Research, with flight operations performed by the Navy Hurricane Reconnaissance Squadron, and data analysis under the direction of Dr. Jerome Spar of New York University. The project sought to evaluate Langmuir's claim that large-scale weather systems could be controlled, but the experimenters concluded that, "the seeding in this experiment failed to produce any effects which were large enough to be detected against the background of natural meteorological variance ."[24]

2. Modification of convective clouds was sponsored by the Air Force Cambridge Research Center, under contract with the University of Chicago. The Air Force Research and Development Command supplied flight services. Dr. Horace R. Byers, head of the well-developed and essentially permanent cloud physics laboratory at the Chicago Midway Laboratory of the University of Chicago, led the research team.[25] Because of ongoing funding from DoD, his physics lab was one of the better-equipped and more completely staffed facilities in the world. The stated purpose of this investigation was to determine to what extent cold and warm cumulus and cumulonimbus clouds could be modified by artificial nucleation. To obtain as many cumulus clouds as possible for testing, the group worked in the Caribbean in the winter and in the Midwest in the summer. Caribbean clouds were seeded with water from a 450-gallon tank in the bomb bay of an air force B-17. Statistical analysis indicated that many more seeded clouds had radar echoes than unseeded ones, and the probability of occurrence of an echo in a cloud was approximately doubled by seeding. Both water and dry ice were used as seeding agents in Illinois and Missouri during the summers of 1953 and 1954, but the numbers of clouds seeded were deemed too small to yield significant results.
3. The U.S. Air Force, under contract with Stanford Research Institute, also examined the physics of ice fogs and their relation to weather conditions at air bases in Alaska. The study showed that most ice fogs developed from local sources of water and pollution, such as chimneys, smoke stacks, power plants, motor vehicles, and aircraft during warming-up operations.
4. Experiments in the dissipation of cold stratus and fog, sponsored by the Army Signal Corps Engineering laboratories, in large part substantiated the results of Project Cirrus.
5. The Army also hired Arthur D. Little, Inc. to explore techniques for modifying warm stratus and fog. Under Vonnegut's leadership, attempts were made to cause precipitation of suspended cloud droplets by generating electrostatic forces or by adding chemical agents to the fogs to increase their drop sizes. Vonnegut worked for Little from 1952 to 1967 on meteorological and other problems. Apparently, controversies surrounding weather modification were so great that the company, like GE, did not emphasize this line of research.[26]

Although this series of experiments had better statistical controls than did Project Cirrus, they did not receive much attention and they most

definitely did not lead to new military applications. The experiments ended in 1954, but the final report was not published until 1957 when it appeared in a limited circulation monograph of the American Meteorological Society. All of the reports needed to pass a security review; most of the delay, however, was caused by the Petterssen committee itself, which collected all five reports and insisted on revisions before publishing any of them. The reports were out of date as they left the press.[27] Moreover, the meteorological community discounted the experiments because of their brevity, their inconclusive results, and the primitive state of the art of instrumentation. It seemed that the design of the experiments was not sufficiently sophisticated to filter out the natural variability of the atmosphere.[28] The optimistic position on the topic adopted by the Council of the American Meteorological Society in 1950 was no longer supported by the meteorological community.[29] According to noted meteorologist J. Murray Mitchell, the negative results of the Artificial Cloud Nucleation Committee, "encouraged the meteorological profession to 'go underground' in weather control research," and concentrate "on fundamental studies of cloud and precipitation physics."[30]

The Controversies Continue

While the military and Weather Bureau projects were struggling for results, a determined and enthusiastic band of private meteorological entrepreneurs, operating primarily in the West and Midwest, succeeded in placing nearly 10 percent of the land area of the country under commercial cloud seeding at an annual cost to farmers and municipal water districts of $3 to $5 million.[31] 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 law suits 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 that ceased further cloud seeding activities; further litigation stopped just short of the Supreme Court.[32]

During the western drought in the early 1950s, Irving Krick,[33] 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 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, Krick was credited by the Bureau of Reclamation 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 his operations, Krick's company was conducting seeding operations covering 130 million acres of western lands.

Of greatest concern to the military was the possibility that such unregulated civilian cloud seeding could contaminate the atmosphere and render military tests inconclusive or worse, that it could generate such controversy that all testing could be stopped by litigation. In the opinion of military legal counsel, it was "considered essential to protect the research program from stoppage by injunction or other pressure."[34] F. W. Reichelderfer, head of the U.S. Weather Bureau, advised the DoD that control of weather could be even more controversial than control of atomic energy and might offend some religious groups; unbridled controversy could threaten "further development and progress in this field." Vannevar Bush thought civilian requests for participation in application of cloud and weather modification should be referred to the Weather Bureau as the coordinating agency.[35] Suits suggested the creation of a central governmental agency to control weather modification. A Harvard study group agreed and advocated spending a portion of the Atomic Energy Commission's budget on weather modification research.[36] A bill (S. 222) introduced in the 81st Congress proposed a "Weather Control Commission," to be established and organized substantially along the lines of the Atomic Energy Commission, with advisory and liaison committees. The DoD, seeing this as a threat to its autonomy, was strongly opposed to any laws creating such a new agency or centralizing authority in an existing agency.[37]

The debate over private and public experiments in weather control prompted Congress to establish an Advisory Committee on Weather Control in 1953. It was chaired by a presidential appointee, retired U.S. Navy Captain Howard T. Orville.[38] The committee's report, issued in 1958, was cautiously optimistic, concluding that increases of 10 to 15 percent in rainfall were induced by seeding spring and winter storms in the mountainous areas of the western United States. The committee recommended more vigorous government support for basic meteorological research, specifically in solar influences, global air circulation, dynamics of cloud motion, and the origin and movement of large-scale storms. It also recommended a dramatic increase in manpower. In the light of these recommendations, NSF became, in 1958, the lead agency for federally supported research on weather modification.[39]

The Cold War Era: Strategy and Tactics

Although the time scales are different by many orders of magnitude, the total amount of energy released by a single thunderstorm is equal to that

of a twenty-kiloton atomic bomb. Moreover, a mature hurricane of moderate strength and size releases as much energy in a day as that of about 400 twenty-megaton hydrogen bombs. Such impressive numbers, despite the technical uncertainties involved in large-scale weather modification, made comparisons between weather modification and nuclear weapons very popular.[40] Since weather warfare could perhaps be conducted cheaply, surreptitiously, and without polluting the environment with fallout, and since the Russians were probably going to master the technology anyway, it made good sense to military planners to attempt to control it (see Figure 9.1).

The classic Cold War pronouncement on weather prediction and control belongs to General George C. Kennedy, commander of the Strategic Air Command: "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."[41] Kennedy was not alone. 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."[42]

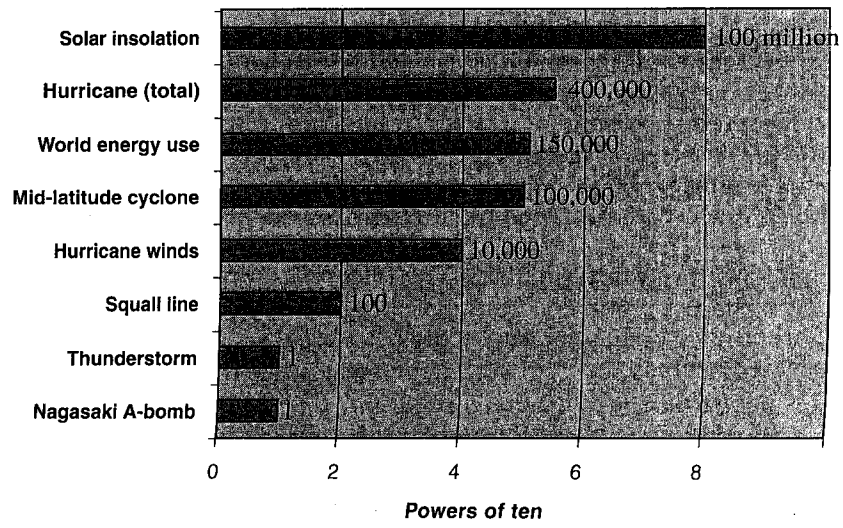

Fig. 9.1 *Energy of Selected Phenomena Expressed in A-bomb Equivalents.*

Pursuing this theme, Orville, Eisenhower's weather advisor, published an influential article in *Collier's* in 1954 that included scenarios for meteorological 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 another technique: loading silver iodide and carbon dioxide into fifty-caliber tracer bullets that pilots could fire into clouds.[43] A more insidious technique would strike at the enemy's food supply by seeding clouds to rob them of moisture before they reached enemy agricultural areas:

> It is ... conceivable that we could use weather as a weapon of warfare, creating storms or dissipating them as the tactical situation demands. We might deluge an enemy with rain to hamper a military movement or strike at his food supplies by withholding needed rain from his crops. ... But before we can hope to achieve all the *benefits* I have outlined, hundreds of meteorological unknowns must be solved at a cost of possibly billions of dollars.[44]

Although in Orville's assessment, total weather mastery would be possible only after four 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.'"[45] This sort of accuracy of prediction, 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 the rapid expansion of meteorological research in all areas during the Cold War era. With the support of Waterman at NSF, the atmospheric sciences began a period of rapid growth. This is especially noticeable in the founding of many new university departments of atmospheric science and the University Corporation for Atmospheric Research, and in the building of the National Center for Atmospheric Research, a national laboratory in Boulder, Colorado.[46]

A Geophysical Arms Race

In January 1958, while Americans were still reeling from the psychological impact of the launch of the Soviet's first earth satellite, *Newsweek* informed its readers that there was a "new race with the reds" in the form of weather warfare. In the article, Orville indicated the need to keep ahead of the Russians was clearer than ever: "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."[47] The article also quoted hot heads such as Edward Teller, an expert on hydrogen bombs but not on weather control, who told the Senate Preparedness Subcommittee: "Please imagine a world ... where [the Soviets] can change the rainfall over Russia ... and influence the rainfall in our country in an adverse manner. They will say, 'we are sorry if we hurt you. We are merely trying to do what we need to do in order to let our people live'."[48] Cooler heads, such as Professor Henry G. Houghton, chairman of the Department of Meteorology at MIT, expressed the same concerns: "I shudder to think of the consequences of a prior Russian discovery of a feasible method of weather control ... An unfavorable 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."[49]

According to the Soviet academician Ye. K. Fedorov, the Soviet Union was engaged in a "struggle for meteorological mastery" over nature and, by analogy to the space race, over the United States:

> mankind is ever more rapidly approaching that stage in its interaction with nature in which it will require practically all the natural resources of the earth and will need the capability to cope with elemental phenomena on a large scale over the entire globe. In other words, man is becoming master of the earth. It is evidently no accident that our entry into space coincides with this development. There is hardly any need to argue that under these conditions all mankind must present a united front to the world around it. There is no other alternative. There is nothing absurd in dreams of a 'struggle for meteorological mastery.'[50]

Such mastery was but one aspect of the Soviet's "Great Plan for the Transformation of Nature," announced by Stalin in 1948. Under this plan the Soviet State Planning Commission controlled all activities devoted to expanding the Soviet economy by harnessing nature: opening new farmland, building new cities and hydroelectric installations, establishing shelter belts, and attempting to control the weather and climate. Science was seen as a useful ally in what was considered a "war against nature on a far-flung front"; in such a struggle, the ability to control the weather and climate was considered particularly useful.[51]

By some estimates, the Soviet Union had three or four times more meteorologists than the United States. As noted earlier, in 1965 the U.S. military employed 14,300 meteorologists and the Weather Bureau, 4,500. In 1969 the president of the American Meteorological Society was informed by official Soviet representatives that the total number of employees in the Soviet Hydrometeorological Service was in excess of 70,000. An estimate published in 1974 placed the number of employees of

the U.S. National Weather Service at 6,000 and the number of Soviet meteorologists at 75,000.[52]

The issue of a geophysical arms race did not go away. In the late 1960s Gordon MacDonald, professor of geophysics at the University of Southern California, Los Angeles (UCLA), Pentagon confidant, and member of President Johnson's Science Advisory Committee, saw weather control, even of severe storms such as hurricanes and typhoons, as just the beginning step in an escalating game of environmental and geophysical warfare. Potentially, belligerents could, for example, cut a hole in the ozone layer over a target area to let in lethal doses of ultraviolet radiation, manipulate the Arctic ice sheet to cause climatic changes or massive tidal waves, trigger earthquakes from a distance, and in general manipulate the planetary environment and its geophysics on a strategic scale.[53]

Nor was the discussion total science fantasy. Military planners, perhaps oversimplifying the problems involved, were interested in improved weather observations, understanding, prediction, and control to support both current and future operational capabilities. Weather and climate modification research included both computer modeling of the atmosphere and new weather satellites. Nile Blue, a computer model developed by Advanced Research Projects Agency (ARPA), was used to test the sensitivity of the climate to major perturbations, including Soviet tinkering and those caused by a major environmental war. *Newsweek* reported that the United States would soon have a series of "baby moons" of its own, and that one of the "eye-in-the-sky" satellites, designed by the Army Signal Corps, would be used to monitor the Earth's weather from space. Military weather satellites would be useful in routine operational forecasting, as support for the climate modelers, and for more esoteric missions such as monitoring changes in global weather patterns and heat budgets, and tracing the effects of nuclear tests. But while most Americans worried about the race with the reds and the military speculated about the use of climatic and geophysical modification techniques as strategic weapons in future wars, operational cloud seeding was being used tactically and covertly in a real war — over the jungles of Vietnam.[54]

Cloud Seeding in Indochina

In March 1971, nationally syndicated columnist Jack Anderson broke a story about air force rainmakers in Southeast Asia.[55] Several months later a document published in the *Pentagon Papers* confirmed that the government, after field trials in Laos, had begun cloud seeding operations in Vietnam in 1967 to reduce trafficability along enemy infiltration routes. This was done with the full and enthusiastic support of President Johnson. The code name of the operation was POPEYE.[56]

Between 1967 and 1972, during the rainy southwest monsoon season, Operation POPEYE attempted to create rain over portions of the Ho Chi Minh Trail in North Vietnam, Laos, Cambodia, and South Vietnam.[57] The AWS conducted the mission out of Udorn Air Base, Thailand. Employing C-130 and other aircraft equipped with racks of up to 104 silver or lead iodide flares, the AWS flew over 2,600 sorties and expended almost 50,000 flares over a period of approximately five years at an annual cost of approximately $3.6 million. This information, from a top secret Defense Department briefing in 1974, was made public several days later by Senator Claiborne Pell.

Although by some reports, Operation POPEYE induced from one to seven inches of additional rain along the Ho Chi Minh Trail, no scientific data were collected to verify the claim.[58] General William Westmoreland thought there was "no appreciable increase" in rain from the project.[59] Even if the cloud seeding had produced a tactical victory or two in Vietnam (it did not), the extreme secrecy surrounding the operation and the subsequent denials and stonewalling of Congress resulted in a major strategic defeat for military weather modification. To illustrate the point, Westmoreland was one of only four general officers in Southeast Asia privy to the details of Operation POPEYE. Even the squadron commander at Udorn whose planes were being used was not informed of the mission.[60] The governments of Thailand, Laos, and South Vietnam were not informed, nor were the American ambassadors to those countries. Typical of the cover-up during this period was the AWS annual survey report on weather modification for 1971, which documented five fog dispersal projects in the United States and Germany, and a rainmaking effort in Texas, but contained no mention of Operation POPEYE.[61] The prime example of stonewalling came from Secretary of Defense Melvin Laird who told the Senate Foreign Relations Committee in 1972 that there was no cloud seeding going on over *North Vietnam,* but never mentioned that Operation POPEYE was still functioning over Laos, Cambodia and South Vietnam.[62]

Operation POPEYE, made public as it was at the end of the Nixon era, was called the Watergate of weather warfare.[63] But it was neither the first use of weather modification as a weapon of war, nor the first in Southeast Asia. On April 22, 1954 the French High Command announced, in connection with the besieged French forces at Dien Bien Phu that, "it will try to wash out Vietminh communication routes from Red China with man-made rainstorms as soon as cloud conditions permit."[64] Moreover, according to the testimony of a former CIA agent, the agency seeded clouds in South Vietnam as early as 1963 in an attempt to disperse demonstrating Buddhist monks when they noticed that the monks resisted tear gas but disbanded when it rained.[65] Some former DoD consultants were politicized by the revelations. One alleged (but Pentagon sources denied) that weather modification was also attempted against Cuba during 1969 and 1970 in an attempt to cause a damaging drought.[66] Another observed 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 without the knowledge of the people."[67] 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 techniques used in Vietnam.[68]

Some argued that environmental weapons 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." Philip Handler, president of the National Academy 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."[69] Nevertheless, for every prophetic call to beat "swords into plowshares" (Isaiah 2:4), there were many more who advocated that plowshares should be beaten into swords (Joel 3:10).

The weather modification budget as reported by DoD averaged about $1.5 million per year in constant 1967 dollars and reached zero by 1979. In 1962, however, the only year ARPA reported its budget, the expenditures reported were an additional $1.8 million.[70] A request for the weather modification and cloud physics budgets of ARPA and its successor Defense Advanced Research Projects Agency (DARPA) from 1961 to 1978 filed under the Freedom of Information Act resulted in a "no record" response.[71] One unofficial source estimated that ARPA's budget averaged $3.3 million per year for weather modification research during the entire period.[72] The cost of operational rainmaking in Vietnam, hidden from official reports but included here, averaged another $3.6 million per year from 1967 to 1972, or more than double the reported military research budget. The cost of operating and maintaining the aircraft (estimated at $1 to 1.5 million per year) and salaries and support of military personnel engaged in cloud seeding are not included in these figures.

Outlawing Environmental Modification as a Weapon of War, 1972 to 1977

In 1972 Senator Claiborne Pell, prompted in large part by unofficial reports that the United States was modifying weather conditions in Southeast Asia as a part of its military operations, introduced a resolution calling upon the United States government to negotiate a convention prohibiting the use of environmental or geophysical modification activities as weapons of war.[73] Testifying at the Senate hearings, Richard J. Reed, president of the American Meteorological Society, cited earlier bans on chemical and biological warfare and atmospheric nuclear testing, and

urged the government," to present for adoption by the United Nations General Assembly a resolution pledging all nations to refrain from using weather modification for hostile purposes." Citing a 1972 public policy statement of the society, he referred to the "present primitive state of knowledge" in the field and the difficulties of controlled experimentation during military operations. The testimony of other prominent atmospheric scientists stressed the need to protect open and peaceful international scientific cooperation.[74] Despite the opposition of the Nixon administration, the Senate adopted the resolution within a year by a vote of 82 to 10.[75] Representative Donald Fraser led a parallel effort in the House.

Feeling the growing pressure from Congress and the press, President Nixon directed a committee of the National Security Council (NSC) to undertake a study of possible international restraints on environmental warfare. In May 1974 the committee presented the following options to the president: (1) no restraints; (2) restraints on military use of environmental modification techniques having long-term, widespread or especially severe effects; (3) a comprehensive prohibition of hostile use.[76] The administration favored option two.

At the Moscow summit on July 3, 1974, just after Senator Pell had placed the top secret DoD briefing on cloud seeding in Vietnam in the public record, President Nixon and Soviet General Secretary Brezhnev signed a "Joint Statement Concerning Future Discussion on the Dangers of Environmental Warfare" expressing their desire to limit the potential danger to mankind from the use of environmental modification techniques for military purposes whose effects would be "widespread, long-lasting and severe."[77] This was essentially option number two of the NSC. Military restraint was limited to conjectural and highly impractical techniques of climatic and environmental modification having long-term, widespread or especially severe effects. By that language, more or less operational techniques of weather modification such as rainmaking and fog dispersal, whose effects were considered limited in time, place and effect, were excluded from the discussion; their use in warfare was implicitly legitimized.[78]

Within a month 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 by unilaterally bringing the issue of weather modification as a weapon of war to the attention of the United Nations. The Soviet proposal did not limit the treaty to a bilateral agreement, nor did it limit it to effects that were "widespread, long-lasting and severe." According to the Soviets, "It is urgently necessary to draw up and conclude an international convention to outlaw action to influence the environment for military purposes."[79] The draft convention unveiled by the Soviet Union in September of 1974 forbid contracting parties from using:

> meteorological, geophysical or any other scientific or technological means of influencing the environment, including weather and climate, for military and other purposes incompatible with the maintenance of international security, human well-being and health, and, furthermore, never under any circumstances to resort to such means of influencing the environment and climate or to carry out preparation for their use.[80]

The General Assembly, taking note of the Soviet draft convention, decided that the subject deserved further attention and, with the United States abstaining, voted to turn it over to the Conference of the Committee on Disarmament.[81] To avoid further embarrassment, President Ford insisted on the language of NSC's option number two. The final treaty, the U.N. Convention on the Prohibition of Military or any other Hostile Use of Environmental Modification Techniques, applied only to environmental modification. The qualifiers "widespread, long-lasting or severe" had found their way back into the convention.

The convention was opened for signature on May 18, 1977 in Geneva. It was signed initially by thirty-four states, including the United States and the Soviet Union, but did not enter into force until October 5, 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.[82]

As the United States had hoped, the convention was vague and unenforceable. The AWS was of the opinion that the treaty's language was so vague that it did not affect its capabilities in weather modification at all, and Military Airlift Command was instructed to retain its capabilities in this area. For the military, the deciding factor was not the U.N. convention, but the fact that weather modification technology had "little utility" or "military payoff" as a weapon of war.[83] By 1978, the DoD claimed that its operational programs were directed solely at fog and cloud dispersal, while research funding continued in cloud physics, computer modeling, and new observational systems.

Yet Operation POPEYE was the mouse that roared, causing international embarrassment as the United States fought to tone down the wording of the convention. The close links between the meteorological community and the military, forged during World War II and the early Cold War, eroded over time. Faced with the complexities of the atmosphere, meteorologists did not develop reliable technologies of weather modification and control. Moreover, a new generation of university-trained meteorologists feared that the atmosphere of secrecy surrounding military projects would ultimately poison the atmosphere of international cooperation needed in meteorological research. Although military patronage since World War II had provided consistent support for several generations of meteorologists, approximately two-thirds had gone to basic

weather analysis and forecasting, while only one-third had supported the various research specialties.

By the 1970s the atmospheric science community, no longer dominated by the veterans of World War II, had trained a new generation of civilian Ph.D.s who increasingly were funded by NSF and NASA. Their primary interest was in the advancement of the discipline, not in national and international political controversies. Many of them were aghast that the unproven weather modification technologies were garnering adverse publicity and generating such a high-level debate. They found it all quite threatening to the free international exchange of meteorological data, to ongoing international research programs such as GARP (the Global Atmospheric Research Programme), and to the future of peaceful international scientific cooperation.[84]

The Current Situation

Climate modification proposals have returned in force recently due to growing apprehension that global warming is real and will have real consequences. As the logic goes, if everyone is unwilling or unable to limit their greenhouse gas emissions, perhaps a few smart people can provide a technological fix for the climate.

In 1992 the Intergovernmental Panel on Climate Change concluded that "the unequivocal detection of the enhanced greenhouse effect from observations is not likely for a decade or more," a widely cited conclusion of the 1995 report was that "The balance of evidence suggests a discernible human influence on global climate."[85] On the social end, the United Nations Environmental Programme recently asked, "Are we overlooking the social and political implications of climate change?" pointing out that if scientific predictions about climate change hold true, it seems likely that political structures and social bonds will be subjected to additional stresses.[86] Several strategies of climate intervention are being pursued. The Montreal Protocol and the United Nations Framework Convention on Climate Change represent geopolitical interventions in the climate system. Many more policy initiatives are underway. Economics has also begun to play a role as taxes and incentives are put in place to reduce unwanted emissions. Meanwhile, green social engineers are attempting to convince the general public to save the planet by reducing, reusing, and recycling.

The most immodest of the new intervention strategies involves *geoengineering* massive technical fixes for the climate system. A 1991 National Academy of Sciences report, *Policy Implications of Greenhouse Warming*, 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 into space, turning the oceans into soupy green algae blooms to sequester excess carbon, or setting up gigantic "soot

generators" to shade the Earth. Other scholars have taken a recent 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."[87] If this does not invoke apprehension, I don't know what will. As Jerome Namias pointed out in 1989, "the greenhouse effect is now firmly part of our collective angst, along with nuclear winter, asteroid collisions, and other widely bruited global nightmares."[88]

Lest we forget, agricultural, water conservation, and hydropower interests are conducting routine cloud seeding operations over about one-third of the area of the American West (see Figure 9.2).

On a more speculative level, three announcements were recently in the news: Beijing's Study Institute of Artificial Influence on the Weather has announced its intention of manipulating the weather to ensure optimum conditions for the 2008 Olympics; a private weather company in Florida has announced a new powder called Dyno-Gel that has the power to "suck the moisture out of a thunderstorm or weaken a hurricane"; and finally, a recent study by the U.S. Air Force claims that "in 2025, US 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 U.S. 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 developing these clouds is 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."[89]

Epilogue

As an episode in the history of science in the Cold War era, the story of weather control contains tragic, comedic, and heroic elements. Was weather modification a military boondoggle? an unconscionable misuse of public funds? a political and diplomatic embarrassment? a scientific dead end? a way of making money by taking advantage of drought-stricken farmers? Although weather control possesses some of these attributes, and no serious weapons were developed during the Cold War, it remains under discussion today as a special fantasy of military planners. Weather modification's intellectual offspring, cloud physics, has developed into a distinguished specialty niche among atmospheric scientists. In the private sector, routine cloud seeding by private companies, although providing at best a 10 percent enhancement of precipitation, is still a flourishing business, especially in the American West. Moreover, purposeful climate modification, as a response to inadvertent climate change, remains a speculative, and to some a terrifying possibility.

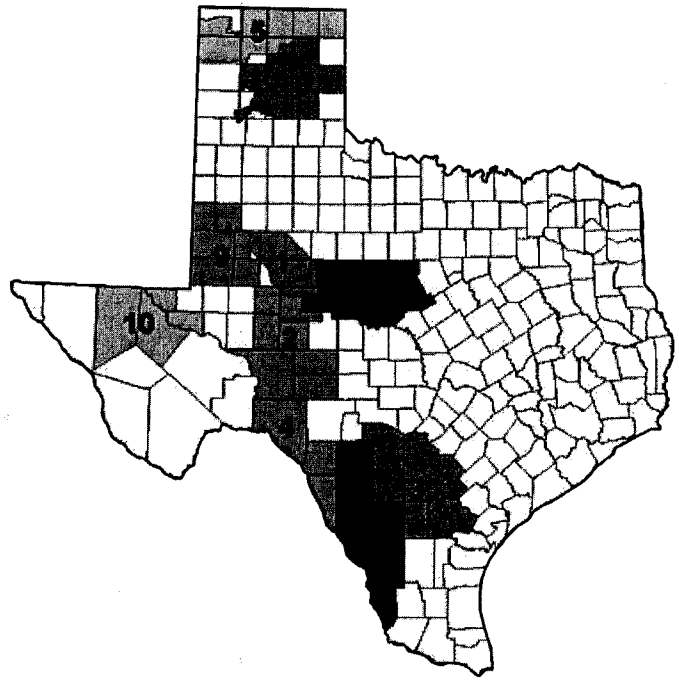

Fig. 9.2 Texas Weather Modification Programs as of December 2002 cover approximately one-third of the area of the state. The Texas Department of Agriculture provided funding of $2.4 million for cloud seeding activities in 2002 – equivalent to about 7 to 9 cents per acre. Areas with ongoing weather modification programs (and date of founding) include: 1. Colorado River (1971); 2. West Texas (1996); 3. South Texas (1997); 4. Texas Border (1998); 5. North Plains (2000); 6. Panhandle (2000); 7. South West Texas (1999); 8. West Central Texas (2001); 9. Southern Ogallala Aquiver Rain-Enhancement (2002); 10. Trans-Pecos (2002). Courtesy of Texas Department of Agriculture http://www.agr.state.tx.us/iga/grants_funding/iga_weathermod.htm (28 May 2003). Similar projects are ongoing throughout the American West. See, for example, Nevada, http://cloudseeding.dri.edu/HomePage.html (28 May 2003).

The next time a line of thunderstorms rumbles out of West Texas across the Dallas-Fort Worth area, or a hurricane veers offshore, or a sporting event or military operation is favored with good weather, perhaps you will remember the story of military and civilian schemes for cloud seeding and climate engineering. Perhaps your local weather or the climate of your region, continent, or the globe is far from natural. Perhaps someone has already "fixed" it.

Notes

1. C. G. Rossby, Chair, Panel on Meteorology, Joint Research and Development Board, Department of Defense, "Interim Report on Artificially Induced Precipitation," April 21, 1947, cited in secret memo, L. R. Hafstad to the Joint Staff, February 5, 1948, Subject-Numeric Files 1947–1953, 100-GG-GAT--Weather Control, Defense Research and Development Board, Office of Secretary of Defense, RG 330, National Archives and Records Administration (hereafter: RDB Weather Control Files, NA). In the same file see also confidential memo, C. G. Rossby, chairman of Panel on Meteorology to Committee of Geophysical Sciences, Joint Research and Development Board, n.d. but ca. January 1947; and secret memo, D. B. Langmuir, director, Planning Division to chairman, Committee on Geophysical Sciences, February 21, 1947.
2. See confidential memo, P. F. Lee, chief of Naval Research to assistant secretary of the Navy for Air, January 14, 1948, File CD 3-1-46, Cloud Modification Experiments, Office of the Secretary of Defense, September 1947–June 1950, RG 330, National Archives and Records Administration (hereafter: OSD Cloud Modification File, NA). On the U.S. Army's interest see confidential memo, "Process of Artificial Production of Precipitation," John L. Pfeiffer to director of Research and Development, War Department General Staff, September 17, 1947, RDB Weather Control Files, NA.
3. In support of this assertion, see Charles C. Bates and John F. Fuller, *America's Weather Warriors, 1814–1985* (College Station: Texas A&M University Press, 1986), 52 and passim. Early rainmaking, including its military connections is treated in Clark C. Spence, *The Rainmakers: American "Pluviculture" to World War II* (Lincoln: University of Nebraska Press, 1980). James P. Espy, employed by the army and the navy in the 1840s and 1850s was the first federal employee to advocate weather modification; on Espy's military connections see James Rodger Fleming, *Meteorology in America, 1800–1870* (Baltimore, MD: The Johns Hopkins University Press, 1990).
4. Col. Donald Yates, AWS commander in 1946 is quoted as saying, "I'm tired of consultants. In the next war, we're going to have our own damned Ph.D.'s already in uniform." He encouraged promising young officers to apply for permanent military commissions, and indicated that assignments to leading universities for graduate study were likely; Donald Yates to Charles Bates, January 29, 1946, cited in Bates and Fuller, *Weather Warriors*, 134.
5. See Bates and Fuller, *Weather Warriors*, 134 and 299 (note 6). The authors claimed that 80 percent of U.S. *civilian* meteorologists still had military ties. The numbers cited are as follows: 5,273 total, 2,267 in uniform, 1,325 U.S. Air Force reserve, 650 naval reserve, 1,031 civilians. This means that 4,242 individuals, or 80 percent of *all* U.S. meteorologists in 1954, had military ties.

   Naming names, Robert M. White, a lieutenant in the wartime U.S. Army Air Forces who received his doctorate through the GI Bill, went on to high-level administrative work as head of the Air Force Cambridge Research Center's Meteorology Development Lab from 1952 to 1959. He was also chief of the Weather Bureau, first director of ESSA (Environmental Science Services Administration), then NOAA (National Oceanic and Atmospheric Administration, and "meteorological czar" of the interagency Office of the Federal Coordinator for Meteorological Services and Supporting Research. In 1983 he was elected president of the National Academy of Engineering. The three immediate past directors of the National Weather Service, George P. Cressman, Richard E. Hallgren and Elbert (Joe) Friday, were all former military meteorologists. The list could go on almost indefinitely: Brig. Gen. Kenneth C. Spengler (AWS reserve) served as executive secretary of the American Meteorological Society from 1946 to 1988; Hallgren is now executive director emeritus of the society. U.S. Air Force General and former director of AWS Albert J. Kaehn, Jr. was the society's president in 1987; and Norman A. Phillips, who served as a lieutenant in the AWS, became a pioneer in numerical weather prediction.

   ESSA was established in the Department of Commerce in 1965 by a consolidation of the Coast and Geodetic Survey and the Weather Bureau. ESSA was renamed the National Oceanic and Atmospheric Administration (NOAA) in 1970.
6. National Academy of Sciences, *Research and Education on Meteorology: An Interim Report of the Committee on Meteorology*, January 25, 1958 (Washington, DC, 1958).

7. Vincent Schaefer, "The Production of Ice Crystals in a Cloud of Supercooled Water Droplets," *Science* 104 (1946): 459. See Horace Byers, "History of Weather Modification," in Wilmot N. Hess (ed.), *Weather and Climate Modification* (New York: Wiley, 1974), 9.
8. "Project Cirrus — The Story of Cloud Seeding," G.E. Review (November 1952), 12.
9. During World War II the National Defense Research Council, the Office of Scientific Research and Development, the Chemical Warfare Service, the secretary of war, and the U.S. Army Air Forces sponsored research on gas mask filters, screening smokes, precipitation static, and aircraft icing studies. Langmuir and Shaefer were involved in this work. See Irving Langmuir, "The Growth of Particles in Smokes and Clouds and the Production of Snow from Supercooled Clouds," *Proceedings of the American Philosophical Society* 92 (1948): 167.
10. 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, N.Y., 1948), 18.
11. *General Electric 56th Annual Report and Yearbook* (Schenectady, N.Y., 1947), 27.
12. James R. Fleming, "Irving Langmuir's Weather Modification Experiments for General Electric and Project Cirrus: A Case Study of the Limits of Private Support for Science," paper presented at the annual meeting of the American Meteorological Society, 1984.
13. Irving Langmuir, "The Production of Rain by a Chain Reaction in Cumulus Clouds at Temperatures above Freezing," *Journal of Meteorology* 5, no. 5 (1948): 110ff. This theory considers the development of precipitation in warm clouds by the collision-coalescence of drops that grow so large they break up into smaller drops and are carried upward to repeat the cycle, forming a so-called chain reaction. Although accounts of these developments exist in the scientific and journalistic literature, until now they have not attracted the attention of professional historians of science and technology. See, for example, Byers, "History of Weather Modification," 3-24; and Barrington S. Havens (comp.), "History of Project Cirrus," *General Electric Research Laboratory Report No. RL-756* (Schenectady, N.Y., 1952). Archival materials are found in the Irving Langmuir Papers in the Library of Congress, and in the archives of the General Electric Company at the Schenectady Museum and in the archives of the State University of New York (SUNY) Albany.
14. Eli Goldston, "Legal Entanglements for the Rain-maker," *Case and Comment* 54, no. 1 (1949): 3–6.
15. A contract was signed by the Army Signal Corps and General Electric Company on February 24, 1947. The Office of Naval Research participated in the program on an equal basis under government order NA ONR 19-47. The U.S. Air Force furnished airplanes and support personnel for the project. "Interim Report on Artificially Induced Precipitation," RDB Weather Control Files, NA.
16. Harvard Law School Record, "Many Legal Entanglements Forecast for Man in New Role as Rain-Maker," clipping in File CD 3-1-46, RG 330, NA.
17. "Project Cirrus — The Story of Cloud Seeding," 13.
18. *New York Times*, January 13, 1949, 25.
19. Earl G. Droessler, "Federal Government Activities in Weather Modification and Related Cloud Physics," in *Final Report of the United States Advisory Committee on Weather Control*, Vol. 2, Howard T. Orville, chairman (Washington, DC, 1957), 253.
20. F. W. Reichelderfer, "General Statement of the Chief of the Weather Bureau with Reference to H.R. 4582," Hearings — Committee on Interstate and Foreign Commerce, March 18, 1948, in File CD 3-1-46, RG 330, NA. See also memo "Air Force Activities in Cloud Physics Research Program," D. C. Doubleday to Office of the Air Judge Advocate, March 31, 1948, and other documents in ibid.; also Byers, "History of Weather Modification," 16–17.
21. Irving Langmuir, "A Seven-day Periodicity in Weather in United States during April 1950," *Bulletin of the American Meteorological Society* 31 (1950): 386ff.
22. Cited in *Weathering the Storm: Sverre Petterssen, the D-Day Forecast and the Rise of Modern Meteorology*, ed. James Rodger Fleming (Boston: American Meteorological Society, 2001), 294.

23. Ibid., 294–95. Sverre Petterssen, et. al., *Cloud and Weather Modification: A Group of Field Experiments* (Boston, MA: American Meteorological Society, 1957), *Meteorological Monographs* 2, No. 11. The composition of the Advisory Group was as follows: E. R. Biel, climatologist, Rutgers University; C. L. Critchfield, physicist, Convair; S. Petterssen, chairman, meteorologist, University of Chicago; A. Spilhaus, meteorologist, University of Minnesota; H. J. Stewart, aerodynamicist, California Institute of Technology; A. T. Waterman, physicist, National Science Foundation; M. A. Woodbury, statistician, University of Pennsylvania; Thomas S. Malone, special assistant.
24. Droessler, "Federal Government Activities," 253–54; Byers, "History of Weather Modification," 25–27; and Special Steering Group on Artificial Cloud Nucleation, "Report of Aspects of Artificial Cloud Nucleation Program," MS, n.d., but ca. December 1952, RDB Weather Control Files, NA.
25. Byer's associates in the cloud physics group were Roscoe R. Braham Jr., Louis J. Battan, James P. Lodge, Guy Goyer, and James E. McDonald. See Roger A. Prior, confidential memo, "Report on Aspects of the Air Force ACN Project at the University of Chicago," January 22, 1953, RDB Weather Control Files, NA.
26. Vonnegut is mentioned briefly in E. J. Kahn Jr., *The Problem Solvers: A History of Arthur D. Little, Inc.* (Boston: Little, Brown & Co., 1986), 203.
27. Petterssen et. al., "Cloud and Weather Modification"; see also Droessler, "Federal Government Activities," 254; and Byers, "History of Weather Modification," 28.
28. See "Excerpt from First Annual Report to the President and the Congress by the National Advisory Committee on Oceans and Atmosphere, dated June 30, 1972"; reprinted in Senate Committee on Foreign Relations, Subcommittee on Oceans and International Environment, *Prohibiting Military Weather Modification: Hearings on S.R. 281*, 92d Cong., 2d sess., 1972, 156 (hereafter: *Prohibiting Military Weather Modification*).
29. American Meteorological Society, "Statement on Weather Modification and Control," ca. 1950, Appendix III of "Second Report of the Special Committee on Cloud Physics," RDB Weather Control Files, NA.
30. J. Murray Mitchell Jr. to Luis de Florez, April 24, 1961 (copy), Harry Wexler Papers, Manuscript Division, Library of Congress (hereafter: Wexler Papers, LC).
31. See Robert D. Elliott, "Experience of the Private Sector," in Hess (ed.), *Weather and Climate Modification*, 45–89.
32. "City Flip-Flop on Rainmaking," *Daily News*, November 5, 1951 (clipping); H. Victor Crawford to John C. Morrissey, June 21, 1951; a bibliography on legal and historical aspects is included in Helmut E. Landsberg, "Memorandum for the Record — Briefing on Weather Control," November 5, 1951; these and related items are in RDB Weather Control Files, NA.
33. Victor Boesen, *Storm*, chapter 8. URL: http://www.weathersage.com/texts/boesen/chapter8.htm (30 May 2003).
34. Confidential memo, "The Legal Implications of Artificially Induced Precipitation," to the Secretaries of War and the Navy, n.d., but ca. 1950, RDB Weather Control Files, NA.
35. F. W. Reichelderfer, chief of the Weather Bureau to Helmut E. Landsberg, Joint Research and Development Board, July 30, 1947; Vannever Bush to James Forrestal, January 15, 1948; both RDB Weather Control Files, NA.
36. Kenneth M. Arenberg, et al., *Weather Modification: Past, Present and Future* (Weymouth, MA, 1954), 40.
37. "Weather Control," MS, n.d., but ca. 1950, RDB Weather Control Files, NA. Other bills included H.R. 4864, S. 798, H.R. 3672, H.R. 4887 and House Joint Resolution No. 56.
38. The committee was created by act of Congress, August 13, 1953 (67 Stat. 559), as amended July 9, 1956 (70 Stat. 509). Orville and four others were appointed by President Eisenhower on December 9, 1953, and were confirmed by the Senate on January 25, 1954. Six other members of the committee represented government agencies.
39. Public Law 85-510, dated July 10, 1958 directed NSF to initiate and support a program of study, research, and evaluation in the field of weather modification; the foundation did so until 1968 when Public Law 90-407 removed this role. See National Science Foundation, *First Annual Report on Weather Modification 1959*, NSF-60-24 (Washington, DC, 1960), and subsequent annual reports, 1960–68.

40. The analogy between hydrogen bombs and hurricanes is from R. H. Simpson and J. Simpson, "Why Experiment on Tropical Hurricanes?" *Transactions of the New York Academy of Sciences* 28, no. 8 (1966): 1045–62; reprinted in Geoffrey McBoyle (ed.), *Climate in Review* (Boston: Houghton Mifflin, 1973), 193–205. Table 9.1 is adapted from ibid., and from W. D. Sellers, *Physical Climatology* (Chicago: University of Chicago Press, 1965), 106. From 1962 until the early 1970s, the U.S. Navy was a cosponsor of Project STORMFURY, an attempt to dissipate hurricanes by seeding them. See H. E. Willoughby, et. al., "Project STORMFURY: A Scientific Chronicle, 1962–1983," *Bulletin of the American Meteorological Society* 66 (1985): 505–14.
41. *New York Times* (June 15, 1947) 46, 1; quoted in Bruce Bliven, "The Rainmakers," *Challenge Magazine* (May 1953): 45. For other general concerns of the era, see D. J. Ritchie, "Reds May Use Lightning as a Weapon," *Missiles and Rockets* 5, no. 35 (1959): 13–14.
42. The quotations are from an editorial by Arthur Krock, "An Inexpensive Start at Controlling the Weather," *New York Times* (March 23, 1961); copy in Wexler Papers. LC.
43. See confidential memos, "Cloud Seeding Ammunition Development Project," C. P. Vansant to R. C. Coupland, January 26, 1949; "Ammunition for Cloud Seeding," Edwin R. Patzing to Chief of Ordnance, March 23, 1949; "Minutes of Meeting on Cloud Seeding Ammunition," Frances L. Whedon to R. B. Simpson, March 28, 1949; all in RDB Weather Control Files, NA.
44. Howard T. Orville, "Weather Made to Order?" *Collier's* (May 28, 1954): 25–26, emphasis added.
45. *Ibid.*, 26; original emphasis preserved.
46. University Corporation for Atmospheric Research, Preliminary Plans for a National Institute for Atmospheric Research (1959); Elisabeth Lynn Hallgren, *The University Corporation for Atmospheric Research and the National Center for Atmospheric Research, 1960–1970: An Institutional History* (Boulder, CO, 1974).
47. Quoted in "The Weather Weapon: New Race with the Reds," *Newsweek* (January 13, 1958): 54. There was also concern about Chinese capabilities in this area; see Department of Commerce, "Chinese Communist Weather Control Experiments," USDOC 60-21921, 21 August 1959 (Washington, DC, 1960).
48. *Newsweek* (January 13, 1958): 54.
49. 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; also quoted in *Newsweek* (January 13, 1958): 54.
50. E. K. Fedorov, "Modification of Meteorological Processes," ibid., 401. On other Soviet weather and climate modification projects see Nikolay T. Zikeev and George A. Doumani (comps.), *Weather Modification in the Soviet Union, 1946–1966: A Select Annotated Bibliography* (Washington, D.C., 1967).
51. 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: University of Chicago Press, 1956), 1036 and 1049–50; see also John Maynard, *Russia in Flux* (New York: MacMillan Co., 1948), 14–15.
52. George S. Benton, "Some General Comments on Meteorological and Weather Modification Activities in the Soviet Union," *Bulletin of the American Meteorological Society* 50 (1969): 918–22; Hess (ed.), *Weather and Climate Modification*, 385. According to Louis J. Battan, in 1976 Soviet investments in cloud physics and weather modification research were "substantially greater" than in the United States. Battan, "Weather Modification in the Soviet Union – 1976," *Bulletin of the American Meteorological Society* 58 (1977): 19.
53. Gordon J. F. MacDonald, "How to Wreck the Environment," in Nigel Calder (ed.), *Unless Peace Comes* (New York: Viking, 1968), 181–205; reprinted in Senate Committee on Foreign Relations, Subcommittee on Oceans and International Environment, *Weather Modification: Hearings*, 93rd Cong., 2d sess., 1974, 55ff. (hereafter: *Weather Modification Hearings*. A similar analysis was conducted by J. O. Fletcher, *Managing Climatic Resources*, RAND Report No. P-4000-1) (Santa Monica, CA: RAND Corporation, 1969).
54. 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, 3 (hereafter: *Prohibition of Weather Modification*).

55. Jack Anderson, *Washington Post* (March 18, 1971) "Air Force Turns Rainmaker in Laos," F7. See also Seymour Hersh, "Rainmaking is Used as a Weapon by U.S ... ," *New York Times* (July 3, 1972); reprinted in *Prohibiting Military Weather Modification*, 14; and Bates and Fuller, *Weather Warriors*, 229–32.
56. See memorandum from the deputy secretary of Defense to the Hon. Nicholas deB. Katzenbach, undersecretary of state, Subject: "Military Action Program for SE Asia," February 21, 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* (Pentagon Press) (Washington, DC, 1971), 50–51. As early as 1957, then Senator Johnson had speculated on controlling the Earth's weather from space for military purposes; see Lowell Ponte, "Weather Warfare Forecast: Partly Cloudy — U.N. Treaty Would Permit 'Peaceful' Environmental Research by Military," *Los Angeles Times* (January 29, 1976); reprinted in Senate Committee on Foreign Relations, Subcommittee on Oceans and International Environment, *Prohibiting Hostile Use of Environmental Modification Techniques: Hearing*, 94th Cong, 2d sess., 1976.
57. *Weather Modification Hearings*, 87ff. The operational phase began on March 20, 1967, and was conducted each year during the monsoon season (March–November) until July 5, 1972. The project was also known as Intermediary Compatriot, and by AWS 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, Ill.: Military Airlift Command, 1979), 30–32.
58. Deborah Shapley, "Weather Warfare: Pentagon Concedes 7-Year Vietnam Effort," *Science* 184 (June 7, 1974); reprinted in House Committee on International Relations, Subcommittee on International Organizations and Movements, *Weather Modification as a Weapon of War: Hearing on H.R. 116 and 329*, 93rd Cong., 2d sess., 1974, 35 (hereafter: *Weather Modification as a Weapon.*)
59. Westmoreland, *A Soldier Reports* (New York: Doubleday, 1976), 342. See also Tad Szulc, *The Illusion of Peace: Foreign Policy in the Nixon-Kissinger Years* (New York: Viking, 1978), 39.
60. Fuller, *Air Weather Service Support to the United States Army*, 30-32.
61. Air Weather Service, Fourth Annual Survey Report on the Air Weather Service Weather Modification Program [FY 1971], *AWS Technical Report* 244 (Scott AFB, Ill.: Military Airlift Command, 1972).
62. Testimony of Melvin R. Laird before the Senate Foreign Relations Committee, April 18, 1972; cited in Weather Modification Hearings, 109–10; see also Daniel S. Greenberg, "Vietnam Rainmaking: A Chronicle of DoD's Snowjob," *Science and Government Report* 2 (May 1, 1972): 1–4.
63. Cristine Russell, "The Weather as a Secret Weapon: From Vietnam to Geneva," *Washington Star* (August 23, 1975); reprinted in *Prohibition of Weather Modification*, 47.
64. "French Fight Off Dienbienphu Blow," *New York Times* (April 23, 1954), 2; cited in Arenberg, et al., *Weather Modification: Past, Present and Future*, 39. Cloud seeding also may have been used in Korea, especially to clear cold fogs, see e.g., Helmut E. Landsberg to H. C. Schweinler, July 20, 1950, "Use of Cloud Seeding in the Korean War," RDB Weather Control Files, NA; and personal communication Earl G. Droessler to the author, December 14, 1990.
65. Hersh, "Rainmaking is Used as a Weapon by U.S ..."
66. Lowell Ponte, *International Herald Tribune* (June 29, 1976): 2.
67. Gordon J. F. MacDonald, statement in *Prohibition of Weather Modification*, 5.
68. For a detailed account of American environmental war efforts and their effects in Indochina, see Stockholm International Peace Research Institute, *Ecological Consequences of the Second Indochina War* (Stockholm: Almquist & Wiksell International, 1976). For background see Ruth Russell, "The Nature of Military Impacts on the Environment," in Sierra Club, *Air, Water, Earth, Fire* (San Francisco: Sierra Club, 1974), 1–14.
69. Philip Handler to Claiborne Pell, July 25, 1972 in *Prohibiting Military Weather Modification*, 153.
70. This data is from the NSF annual report report on weather modification for 1962; data for 1969 to 1979 are taken from Department of Commerce, *National Weather Modification Policies and Programs: A Report to the President and the Congress* (Washington, DC, 1979).

71. The request was filed with the Freedom of Information Act and Security Review Office at the Pentagon on October 9, 1990; the "no record" response was dated November 21, 1990; W. M. McDonald to author, November 21, 1990, author's personal files.
72. Georg Breuer, *Weather Modification: Prospects and Problems* (Cambridge: Cambridge University Press, 1979); transl. by Hans Mörth of *Wetter Nach Wunsch?* (Stuttgart: Deutsche Verlanganstalt, 1976), 144–45.
73. S. Res. 281, 92nd Cong., 2d sess., 1972.
74. "Hearing on Senate Resolution 281," *Bulletin of the American Meteorological Society* 53 (1972): 1185–91.
75. *Congressional Record* (11 July 1973): 233303-05. As adopted by the 93rd Congress the resolution was designated S. Res. 71. See Lawrence Juda, "Negotiating a Treaty on Environmental Modification Warfare: The Convention on Environmental Warfare and Its Impact upon Arms Control Negotiations," *International Organization* 32 (autumn 1978); reprinted in Senate Committee on Foreign Relations, *Environmental Modification Techniques: Hearing*, 96th Cong., 1st sess., 1979, 24–29.
76. Senate Committee on Foreign Relations, *Environmental Modification Treaty: Hearings*, 95th Congress, 2d sess., 1978, 87ff.
77. "Joint Statement on Environmental Warfare," in *Weather Modification as a Weapon*, 11. The text of the statement is as follows: "The United States of America and the Union of Soviet Socialist Republics: Desiring to limit the potential danger to mankind from possible new means of warfare; Taking into consideration that scientific and technical advances in environmental fields, including climate modification, may open possibilities for using environmental modification techniques for military purposes; Recognizing that such use could have widespread, long-lasting, and severe effects harmful to human welfare; Recognizing also that proper utilization of scientific and technical advances could improve the interrelationship of man and nature; 1. Advocate the most effective measures possible to overcome the dangers of the use of environmental modification techniques for military purposes. 2. Have decided to hold a meeting of United States and Soviet representatives this year for the purpose of exploring this problem. 3. Have decided to discuss also what steps might be taken to bring about the measures referred to in paragraph 1." Moscow, July 3, 1974.
78. Stephen S. Rosenfeld, "Weather as a Weapon," *Washington Post* (February 28, 1975), and "Weather Warfare," *Washington Post* (June 26, 1975); both reprinted in *Prohibition of Weather Modification*, 40. Both news accounts are based on the statement of Dr. Edith Brown Weiss, Brookings Institution, in *Weather Modification as a Weapon*, 21.
79. A. Gromyko to the secretary general of the United Nations, August 7, 1974, in *Weather Modification as a Weapon*, 11–12.
80. Juda, "Negotiating a Treaty," 28.
81. *Ibid.*, 24–29.
82. United Nations, *Multilateral Treaties Deposited with the Secretary-General: Status as of 31 December 1982* (New York, 1983), 667. The Text of the U.N. Convention (A/RES/31/72) is reprinted as Appendix C in Congressional Research Service, *Weather Modification: Programs, Problems, Policy, and Potential*, 95th Cong., 2d sess., 1978, 510–13.
83. Department of Defense, "Statement on Position on Weather Modification," [1978], Appendix B in *Weather Modification: Programs, Problems, Policy, and Potential*, 509. The statement, from the Office of the Under Secretary of Defense for Research and Engineering, was provided by Col. Elbert W. (Joe) Friday, former director of the National Weather Service.
84. See Stanley A. Changnon Jr., "Weather Modification in 1972: Up or Down?" *Bulletin of the American Meteorological Society* 54 (1973): 642–46; "Hearing on Senate Resolution 281"; and Gordon J. F. MacDonald, statement in *Prohibition of Weather Modification*, 4.
85. *Climate Change 1992: The Supplementary Report to the IPCC Scientific Assessment*, ed. J. T. Houghton, B. A. Callander, and S. K. Varney (Cambridge: Cambridge University Press, 1992), 5; Intergovernmental Panel on Climate Change, "Summary for Policy Makers: The Science of Climate Change," Working Group 1, 1995, <http://www.unep.ch/ipcc/wg1.html> (December 5, 1996).
86. United Nations, Information Unit on Climate Change, "Are We Overlooking the Social and Political Implications of Climate Change?" <http://www.unep.ch/iucc/fs108.html> (September 26, 1996).

87. David Keith and Hadi Dowlatabadi, "A Serious Look at Geoengineering," *EOS, Transactions of the American Geophysical Union* 73 (1992): 289, 292–93.
88. Jerome Namias, "The Greenhouse Effect as a Symptom of Our Collective Angst," *Oceanus* 32 (summer 1989): 66.
89. Melinda Liu, "Rain Called on Account of Games," *Newsweek* (August 5, 2002); Amanda Riddle, "Powder Dries Up Fla. Thunderstorms," *AP News*, July 19, 2001; "Florida Inventor Believes He Can Suck the Power out of Hurricanes," http://web1.wsvn.com/news/articles_p/local/C21236/ (1 June 2003); Col. Tamzy J. House, et al., "Owning the Weather in 2025," *Air Force 2025* (August 1996) available at the following URL: http://www.au.af.mil/au/2025/volume3/chap15/v3c15-1.htm (1 June 2003).