"REVIEWED"

THE RISE AND FALL OF FEDERAL WEATHER MODIFICATION POLICY

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Abstract. Three hundred million dollars in federal funds have been expended since 1960 to conduct research and to develop weather modification capabilities. This has resulted in techniques to operationally eliminate fogs, to reduce or enhance stratus clouds, and to increase snowfall and rainfall during certain conditions (American Meteorological Society, 1985). But, the annual R and D funding has been halved since 1978, and the general public, many scientists, and most government decision makers now believe, rightly or wrongly, that major scientific uncertainties and policy problems exist in the field. Rather than serving as spurs to heightened federal efforts, these beliefs have had a dampening effect. Support for the field is decreasing and weather modification R and D is in trouble. Why?

Several reasons for the current state of affairs have been offered including poor experimental designs, widespread use of uncertain modification techniques, inadequate management of projects, unsubstantiated claims of success, inadequate project funding, and wasteful expenditures. This review of federal policies relating to the management of the R and D of weather modification concludes that after several policy decisions in the 1950's and early 1960's which had a positive impact, certain federal policy decisions since the late 1960's combined to be a primary reason for the lack of a coordinated, cost-effective national research program. These policy failures are seen as one cause for the slower than expected scientific and technical advances in the weather modification field, as well as the recent decrease in interest in its research, development, and usage.

Congress' decision to end the lead agency role of NSF in 1968 appears unfortunate, and then in 1971 NSF leaders shifted the research program into the applied research and technology-oriented RANN Directorate, a questionable decision. The USDA, representing the U.S. sector with the greatest potential benefits from most capabilities to modify the weather, failed to significantly participate in the R and D of weather modification. NOAA scientists tackled difficult weather modification phenomena. Ironically, however, considering its role as the nation's weather agency, NOAA did not assume the lead agency role for R and D, although it has been recommended for that status by most independent assessments done over the past 20 years. DOD agencies supported key early research but then performed surreptitious cloud seeding programs to make rain to interdict enemy troops during the Vietnam conflict. This led to congressional condemnation and the end of large-scale R and D in weather modification by DOD. The Bureau of Reclamation program, based solidly on its western constituency and congressional support, has been the major effort sustaining the field during the past decade. However, the agency's focused mission (water) made it unable to embrace R and D of all other weather forms (fog, hail, winds, etc.). Hence it was unwilling to assume the lead agency role.

The summation of these mistakes, omissions and limitations has led to an ineffective national policy. Virtually every study of the field has indicated that the societal benefits of weather modification are too great to be ignored. The field and nation need a stated policy that is based on the view that weather modification capabilities are in the national interest, and that a well planned and well coordinated federal R and D effort should be conducted to ensure the ultimate achievement of that goal. This effort requires a balanced program in basic research and applied field projects, and it requires coordination across agencies. One agency should be given lead status and resources for generic technological development across weather modification application areas. These calls for policy change have been made before, but the current state of affairs requires they be made again. Federal policy has retrogressed rather than progressed, and the field and nation have suffered accordingly.

1. INTRODUCTION

The nation's efforts to learn how to modify the weather and to develop weather modification capabilities to protect lives and property and to enhance water supplies, agricultural production, and transportation have largely been a federal responsibility since World War II. To a much lesser extent, certain states and the private sector have supported weather modification research and development, but the state role has typically been to regulate and/or support operational weather modification programs (Changnon, 1983).

The federal government's early weather modification research concerned efforts by the Armed Forces to alter conditions limiting visibility. Military agency funding of General Electric scientists (under Project Cirrus) led to post-war discoveries of the effects of dry ice and silver iodide to change certain fogs and layer clouds (Schaefer, 1951), and these findings set the foundation and high expectations for the fledgling field (Bergeron. 1949). Subsequent research by Dr. Irving Langmuir and his associates led to scientific questioning, and the U.S. Weather Bureau launched two modification projects in the early 1950's. These and other Air Force-sponsored projects had turned to precipitation modification as a goal with assessments indicating generally uncertain outcomes (American Meteorological Society, 1957). Controversies generated within the scientific community, coupled with failure of meteorologically-unskilled private pilots and crop dusters to increase rain in the severe droughts of the early 1950's, helped lead Congress (PL83-256) to establish in 1953 an Advisory Committee on Weather Control (1957). Its report stated that weather modification capabilities were in the national interest and that the National Science Foundation (NSF) should establish a weather modification research program (effectively also acting as a lead agency), a recommendation which set forth a new national policy.

The recommendation for NSF leadership was followed under PL85-510, enacted in 1958 and major field experiments were launched in Arizona, Colorado, and Missouri. The Act was later rescinded (PL90-407, 1968) at a time when several other federal agencies had developed major programs addressing weather modification. Federal funding for weather modification R and D grew from $2.7 million in FY63 to $18.7 million by FY72, a six-fold increase in ten years. The efforts of these other agencies were more mission oriented and more developmental than the basic research efforts at NSF. The program at the Bureau of Reclamation had developed a strong congressional interest and support. Annual reporting of all weather modification projects (which had been done by NSF) also ended in 1968, but was resumed in 1971 (PL92-205) by the National Oceanic and Atmospheric Administration (NOAA), in recognition of federal monitoring responsibilities.

As the federal R and D effort grew, a series of reviews of the federal and private weather modification efforts were performed in the 1963-1979 period by National Academy Science Panels on Weather Modification (1966 and 1973); the Interdepartmental Committee on Atmospheric Sciences in 1968 and 1971 (ICAS, 1966-1978); the Domestic Council (1975); the National Advisory Committee on Oceans and Atmosphere (1973, 1976); the Government Accounting Office, GAO (1974); and the Congressional Research Service (1979). All these reports pointed to two different federal policy directions, generally critical of the one actually being pursued, and another being recommended but not followed. The federal programs over time had become strongly oriented to each agency's mission, focusing on field research projects that concerned their interests and constituencies, with loose federal programmatic coordination through ICAS. Conversely, the external assessments by NAS Panels, NACOA, and GAO saw the federal program becoming fragmented from the mid-1960's through the 1970's; poorly planned and coordinated; too developmental (too little basic research); and requiring a lead agency for proper management (with NOAA the oft-recommended agency for this effort).

The most recent major effort to assess and recommend a total refocus of the national effort resulted from PL94-490 of 1976 which directed the Secretary of Commerce to establish an external group to assess the national effort. The Weather Modification Advisory Board (1978) recommended a restructured national program with a director in a lead agency (NOAA) and a sizable budget. But whatever efforts NOAA and others made to implement the recommendation fell short, and no legislation was enacted.

A major decrease of federal support for weather modification occurred after 1980, from a peak of $18.7 million in FY77 to $8.1 million in FY84. There is no particular interest in the R and D of weather modification in the current administration, with no internally supported research in NOAA and relatively small identifiable funds for modification R and D in only two agencies, Bureau of Reclamation (BR) and NSF. Congress continues into the 1980's exhibiting interest in the subject by additions of funds for research to the NOAA and BR budgets. This paper examines some of the dynamics behind past federal policies; reasons for the fluctuations in federal interest and support of weather modification; and what these factors imply for the future.

2. POLICY DEVELOPMENT, 1953-1985

Why did the diversified mission-agency policy approach develop with its strong resistance to a lead agency (and an inherent singular direction in the planning and conduct of the nation's R and D program) for weather modification? It can be hypothesized from a policy viewpoint, that failures of the federal government to draft a national plan, to adopt a lead agency, and to establish a strongly coordinated program with a single budget-making approach are among the most critical factors limiting progress in development of weather modification capabilites over the last 20 years. Was the multi-agency approach to weather modification R and D the most likely outcome, given the very nature of the subject (weather)

and the pluralistic structure of our government? To examine what happened requires inspection of the main activities of the individual agencies since the 1940's (Lambright, 1972). The annual budgets of the agencies are shown in Table 1 for FY63 through FY85. Fleagle (1977) concluded that growth in federal funding from 1966 to 1977 was largely in response to what was perceived (by policy makers) to be needs for prompt application of the technology. The reductions in the early 1970's were attributed to budget cuts and to growing debates within the scientific community (Changnon, 1973, 1975). The trends and fluctuations in funding by the three major agencies (NOAA, BR, and NSF) were alike from FY63 to FY76; thereafter, major dissimilarities occurred for reasons presented in the following pages. This loss of agreement also is a useful indicator of the breakdown in the loose confederation of coordinated federal agency programs. What has occurred since FY77 has been determined essentially by each agency with little or no effort to justify its program as part of a coordinated national R and D program (the policy theme of the 1968-1976 period). This latest policy of "everyone goes his own way" is certainly a candidate as a cause for major loss of initiative and interest in the field since the late 1970's. Divided, the individual agencies have seen their budgets fall.

National Science Foundation. The National Science Foundation played an extremely pivotal role in the history of weather modification R and D from the late 1950's to the late 1970's. The Advisory Committee on Weather Control recommended in 1957 the establishment of a national research program at NSF and in effect made the NSF the "lead agency" for the federal R and D effort. In this unusual circumstance, NSF responded by funding a mixture of research efforts in the laboratory and in the field including major field experiments in Missouri and Arizona during the early 1960's. NSF Directors Waterman and Hayworth were supportive of weather modification but limited the NSF role to primarily one of promoting basic research. It would "bend," but in a traditional "NSF-type" way. Other agencies did in fact work on the applied aspects, especially the Bureau of Reclamation. There was

Table 1. Federal Support of Weather Modification Research[1], 1963 to 1985.

In Millions of Dollars

Fiscal Year	NSF	Interior	Commerce	DOD	Agriculture	Other	Total
1963	1.3	0.1	0.2	1.0	0.1	0.0	2.7
1964	1.6	0.2	0.2	1.4	0.1	0.1	3.6
1965	2.0	1.3	0.1	1.5	0.1	0	5.0
1966	2.0	2.9	0.7	1.3	0.1	0.1	7.1
1967	3.3	3.7	1.2	1.3	0.3	0.1	9.9
1968	3.4	4.6	1.5	1.4	0.2	0.2	11.3
1969	2.7	4.3	1.1	1.6	0.3	0.2	10.2
1970	3.2	4.8	1.3	1.9	0.3	0.2	11.7
1971	3.8	6.5	3.0	1.4	0.4	0.7	15.8
1972	5.5	6.7	3.9	1.8	0.4	0.4	18.7
1973	6.2	6.4	3.8	1.2	0.4	0.4	18.4
1974	4.7	3.9	3.3	1.2	0.3	0.1	13.5
1975	4.7	4.0	2.5	1.1	0.1	0	12.4
1976	5.6	4.9	4.6	1.1	0.1	0	16.3
1977	4.4	6.8	4.6	2.8	0.1	0	18.7
1978	2.0	7.6	4.6	0.1	0	0	14.3
1979	2.0	9.6	5.3	0	0	0	16.9
1980	1.5	9.4	5.8	0	0	0.1	16.8
1981	1.5	8.5	5.4	0	0	0	15.4
1982	1.2	5.7	5.4	0	0	0	11.9
1983	1.2	4.5	3.4	0	0	0	9.1
1984	1.2	5.4	1.5	0	0	0	8.1
1985	1.3	5.6	2.1	0	0	1.0	10.0

[1] Defined as the functions: (1) intended to modify the atmosphere through artificial means, including, but not limited to, seeding of clouds and fog to influence the natural development cycle, intentional initiation of large heat sources or fires to influence convective circulation or evaporate fog, intentional modification of solar radiation exchange of the earth or clouds through the release of gases, dusts, liquids or aerosols in the atmosphere, intentional modification of the energy transfer characteristics of the earth's land or water surface by dusting with powders, liquid sprays or dyes, etc., (2) of research which does not directly involve intentional modification but is carried on with the primary intent to apply its results to such activities, and (3) of research in inadvertent modification such as the monitoring of atmospheric constituents and studies of their modifying influences on the weather.

a measure of coordination by NSF and the Interagency Committee for Atmospheric Sciences (ICAS), an interagency body established under auspices of the existing White House Science Advisory System. As other federal agency programs grew during the 1960's, for reasons which will be described under each agency, congressional leaders decided that the national effort was well launched, and that NSF was not needed as lead agency, a decision consummated in 1968 (PL90-407). One ensuing effect was to focus ever more of the nation's R and D efforts on performing major field projects and less on analysis of the physics and dynamics of the atmosphere.

As the federal leadership by NSF ended in the late 1960's, the general ensuing policy of each agency was to assume R and D responsibility for modification of one or more weather condition. At the same time, NSF became a dominant source of funding for research on inadvertent weather modification, taking the lead in funding the sizable Metropolitan Meteorological Experiment (METROMEX) effort at St. Louis during 1971-1976 (Changnon et al., 1981). NSF also assumed the leadership role in hail suppression research which focused on the National Hail Research Experiment (NHRE) designed and directed by the National Center for Atmospheric Research (NCAR) and conducted in northeastern Colorado (Changnon et al., 1977). The conduct of this massive and expensive effort ($20+ million over 6 years) involved NCAR, many universities and private concerns with major funding from NSF and minor support from other federal agencies.

NHRE had just begun when NSF made an important decision that, in retrospect, hurt the field. Management of its weather modification research program involving NHRE, METROMEX, and other basic research efforts was shifted from the Meteorology Program to the new Research Applied to National Needs (RANN) Program. RANN was an endeavor to enhance applied research and technology development. The attempt to reorient weather modification to suite the RANN mission helped detract from exploratory, research-oriented work that weather modification needed at that time. It also contributed to scientific debates that helped bring about an early demise of NHRE, (RANN-UCAR Panel, 1974; Atlas, 1975; Changnon, 1976), aided by the critical recommendations of a major technology assessment of hail suppression (Changnon et al., 1977). The termination of NHRE in 1976 as a field program of consequence and the 1978 reorganization of the RANN program inside NSF greatly diminished interest in weather modification research generally at NSF (Bierly, 1986). The NSF weather modification research program rapidly dwindled from $5.4 million in FY76 to $2.0 million in FY78 (Table 1), and the program again became oriented to basic research, funded at about $1.0 million annually since FY82 (Bierly, 1986). As NSF assumed a lower profile, this represented a major change in the amount of funding and in programmatic leadership that NSF had provided the field from 1958 through the mid-1970's.

U.S. Department of Agriculture. Most studies of the value of weather modification have shown that U.S. agriculture is the single greatest beneficiary from most envisioned capabilities of weather modification (Sonka, 1979). Hence, one would conclude that the USDA should have played an important role in weather modification research and development, including studies of the value of weather modification. This was not the case.

In the 1950's a research program called Project Skyfire developed in the U.S. Forest Service. It focused on the potential for reducing forest fires through cloud seeding to decrease lightning. Experimentation in Montana during the 1960's and in Alaska in the early 1970's (with the Bureau of Land Management) suggested that the seeded storms had less cloud-to-ground lightning, but the research findings were never conclusive (Fuquay, 1974). As concerns developed over potential complementary decreases in rainfall and cost effectiveness, field efforts ended after 1973 and agency interest in further research dwindled to a zero budget level by FY77 (Table 1).

Other, more relevant forms of weather modification such as the enhancement of rainfall for crop growth, or added snowfall and rain in the west to provide more irrigation water were never addressed by the USDA. Other agencies had begun studies into these topics in the 1960's. It appears that leaders of this agency were never strongly convinced of the value of weather modification, and, in essence, its interests in weather modification research and development were being served by the work of other federal agencies. In recent years a series bumper yields of wheat, corn, and soybean crops have brought supplies and attendant economic problems to U.S. agriculture. Obviously a costly technology like weather modification aimed at increasing yields is not given a high federal research priority, but for the individual farmer, desires to optimize yields remain high. Hence, one finds local interest in the use of the existing techniques but little national pressure for R and D through USDA.

Department of Interior/Bureau of Reclamation. The early hopes of certain western senators in the potential for precipitation modification to help address water needs in the arid west helped lead to the formation of a weather modification program within the Bureau of Reclamation (BR). Congressional interest and agency support for this program began in 1962. The program grew rapidly from $0.1 million in FY63 to $3.7 million by FY67. By 1966 the BR program, called Project Skywater, funded sizable research and development efforts at universities and institutes in all 17 western states. As shown in Table 1, the BR program became the largest of all the federal programs by FY66 and has remained the largest except for FY74-76 when the NHRE and METROMEX efforts produced greater annual expenditures at NSF.

Increasing water supplies in the west is central to the mission of the BR which had the philosophy that programs and funding were constituency oriented with funding used to support R and D at universities, the states, and the private sector in its western area of responsibility. Important to the program of the Bureau of Reclamation was the fact that it was

strongly supported by the Congress (Congressional Research Service, 1979). The program funding became a part of the base budget of the agency, but when various fluctuations of the agency budget occurred, state interests exerted through Congress frequently protected and enhanced the budget of the BR program.

Under its R and D policy, the BR has funded a variety of basic research efforts, but the program has focused on applied research aimed to add precipitation. The agency since 1966 has conducted a series of major field experiments dealing with either snow enhancement in the Sierra or Rocky Mountains, or rain increases in various portions of the High Plains (Bureau of Reclamation, 1977). The program budget grew from FY77 to FY80 (Table 1), while most other agency programs were decreasing, because of new funding for the Sierra Cooperative Pilot Project and the High Plains Experiment (HIPLEX), a series of rain modification experiments in Texas, Kansas, and Montana that also involved state funding. After a major field effort in Montana in 1981 involving NCAR and several institutions, BR funding dropped presumably due to lack of internal agency interest. In recent years, the BR has become involved in international programs. Since 1983 it has acted for the U.S. Agency for International Development to design and assist Morocco in conducting a major ($10 million, 5-year) snow enhancement field experiment that began in Morocco in 1984.

The water-oriented mission of the Bureau meant there could be little priority in weather modification R and D relating to severe storms, such as hail, hurricanes, or tornadoes. Thus, BR has not sought to assume the national "lead agency" role which requires an all encompassing stature. Further, in defense of its own niche in the field, it was frequently in opposition to the oft-recommended centralized lead agency type of national program. With the largest weather modification budget of any agency (Table 1), its views and policies have often dominated the de facto national policy. The water management philosophy of the Bureau has frequently acted to direct the program efforts toward the development and application of weather modification as a water management tool (Silverman, 1986).

Department of Defense. The initial interest of the armed forces in altering visibility conditions led to sponsorship of weather modification R and D during the 1940's and 1950's. These and other weather changes had obvious benefits to military operations and therefore benefits to national security; thus early federal policy was linked with potential military applications. The Navy, Air Force, and Army each began R and D programs in weather modification in the late 1940's. In addition to the control of visibility (fogs and clouds), the potential for precipitation alterations that could help or hinder field operations, attracted the attention of all three branches of the armed forces. Military funding of Project Cirrus conducted by scientists at General Electric led to important post-war discoveries of the effects of dry ice in changing certain fogs and stratus clouds (Schaefer, 1951). Such early findings set the foundation for high expectations in both the military and general public, for many other capabilities to modify weather conditions.

For many years the Air Force, through the Air Weather Service (AWS), pursued a program in fog suppression (Chary, 1974). Its findings, coupled with those of the privately supported United Airlines research program, led to workable techniques to suppress cold fogs by the 1960's that are operationally utilized at several military and U.S. airports. The Air Force continues to utilize fog dispersal at certain military airports in Alaska and Germany, and in the early 1970's the AWS pursued research into stratus cloud and precipitation modification. In 1971, AWS joined the Bureau of Reclamation in cloud-seeding operations in Texas to try to alleviate a drought. The Army focused on warm fog dispersal techniques.

The Navy also had a research program on weather modification. It too focused on fog dispersal and cloud modification with an emphasis by the late 1960's on precipitation enhancement. Scientists with the Naval Weapon Center (NWC) and Air Force facilities performed exploratory-assistance seeding projects in the Philippine Islands, Panama, India, Portugal, and Okinawa during the late 1960's. The DOD philosophy was that a technology to increase rainfall was sufficiently developed to be employed for foreign drought alleviation. This view was apparently one basis for the military's extensive use of cloud seeding during the Vietnamese conflict from 1967 to 1972 in attempts to increase rainfall so as to hinder movement of enemy troops and supplies. When this information, which had been classified and kept secret from the Congress and general public, became public in 1974 (Committee on Foreign Relations, 1974), it created a backlash in Congress and in DOD, quickly reducing weather modification R and D by the armed forces and terminating it by FY78 (Table 1).

National Oceanic and Atmospheric Administration (Department of Commerce). The history of this agency's involvement in weather modification is particularly relevant to the evolution of national policy. Claims of weather modification capabilities in the 1940's and 1950's, such as those by Dr. Irving Langmuir and other scientists, were investigated, and the claims of success by some early investigators were strongly challenged by the U.S. Weather Bureau (predecessor of today's NOAA). One reaction was the conducting of two relatively short field projects in the early 1950's by the Weather Bureau. Their uncertain outcomes, plus obviously unsubstantiated claims of modification from untrained cloud seeders in the droughts of the early 1950's, promoted a philosophy among many leaders in the Weather Bureau in the 1950's and that "weather modification of any type cannot be done."

However, leadership changed in 1961 and in 1965 the Weather Bureau leader enunciated an aggressive policy for R and D in weather modification (Gilman et al., 1965). The Weather Bureau began studies of the modification of clouds in hurricanes to diminish winds known as Project Stormfury. This effort was funded jointly by the Weather Bureau, DOD, and NSF.[1] Project Stormfury personnel seeded four

[1]General Electric scientists had tried to modify a hurricane in 1947.

hurricanes between 1961 and 1971. Thereafter, concerns over international ramifications of such actions, an absence of sufficient funding, and a lack of suitable storms when funding existed resulted in no more seeding and the Stormfury effectively ended in 1978.

This re-entry of NOAA into weather modification R and D included involvement in other projects. Experimentation to modify individual cumulus clouds in Florida began in 1965, and the Florida Area Cumulus Experiment (FACE) was launched in 1970, an effort that continued through the 1970's (Woodley et al., 1977). In the 1970's NOAA scientists worked on a project to re-distribute lake-induced heavy snowfalls on Lake Erie. They also experimented with lightning suppression in Arizona, and evolved with scientists in midwestern states the design of an experiment to address increasing summer rainfall in the Midwest, the Precipitation Augmentation for Crops Experiment (Congressional Research Service, 1979). However, NOAA leadership in the late 1970's, decided to shift to more basic research on cloud physics and dynamics. The FACE-2 confirmatory experiment in 1978-1980 ended (prematurely in the view of some observers) with the wide perception of a negative outcome (Kerr, 1982), and NOAA's weather modification research program was virtually discontinued in 1982, as reflected in general funding reductions (Table 1). This came at a time of general major funding reductions for NOAA by the Reagan administration (Fleagle, 1986). The post-1980 period has seen NOAA buffeted by bureaucratic troubles as it became an agency "targeted" by administration budgets cutters.

The only continuing NOAA effort, due to the support of Congress, has been the Federal-State Cooperative Weather Modification Program which began in 1979. NOAA leaders recognize its scientific value (Fletcher, 1986), but it has been removed by NOAA from its base budget each year since FY82 only to be reinstated by Congress every year. The annual theme of "the administration cuts and Congress restores" leads to an inability to do effective long-range planning in weather modification research, as well as in other programs (Fleagle, 1986).

Certain NOAA leaders recognized from the early 1960's through about 1980 that it should have a major role in weather modification research and development. It fit within NOAA's missions of public welfare and resource development. Agency leadership proved unable or unwilling to respond to, and seek the lead agency role that numerous external review groups repeatedly recommended for NOAA (or its predecessors) during that 20-year period. NOAA appears to have been content with a role in basic research at times, and applied, mission-oriented project experimentation at locales in the eastern half of the United States at other times. NOAA has long lacked a strong constituency, a condition that has made it difficult for the agency to assert its presence, even when it has had an inclination to do so.

Other Federal Agencies. At times other federal agencies have expended funds on planned and inadvertent weather modification research (see Table 1). The Department of Transportation Federal Aviation Agency (FAA) invested limited funds during 1970-1975 in warm fog abatement research. The Department of Energy and its predecessors (Energy Research and Development Agency and the Atomic Energy Commission) during the 1970's funded studies relating to inadvertent weather modification including part of the METROMEX program at St. Louis. In FY85 the U.S. Agency for International Development expended $1.0 million (via intergovernmental transfer) as U.S. input to the first year of a 5-year modification experiment in Morocco.

3. RAMIFICATIONS OF FEDERAL POLICIES

A review of these histories of the federal agencies involved in the nation's weather modification research and development effort reveals that even without a national plan, most early policy decisions appear efficacious for the encouragement and management of the early research phases of a complex scientific problem and emerging technology. After a period of scientific and bureaucratic controversy in the 1940's and 1950's, scientists and government settled down in the 1960's, to a relatively coordinated and forward looking effort. There were disputes (especially between BuRec and ESSA), but these were examples more of creative competition between agencies striving to build strong programs, than of bureaucratic in-fighting harmful to the field. However, this review suggests there has been a major policy dilemma since about 1968. As Congressman Rhodes stated in 1982, "the federal (weather modification) efforts have been badly fragmented and dispersed throughout the years with poor coordination and lack of leadership." A series of decisions and circumstances began working to damage the overall weather modification effort.

The organization funding most of the basic research of the nation, NSF, proceeded with what appears to have been an appropriate role for ten years (until 1968). The Congressional decision to terminate the leadership role of NSF was a questionable decision because the "basic research phase" of the field had not been sufficiently resolved by 1968. The decision also gave further impetus to the mission agencies to go their own way and ultimately to focus even more than they were on "development" rather than on "research." Then, the NSF weather modification research program was shifted into RANN. All this effectively blunted interest in, and commitment to, support within NSF, and the federal government generally.

The armed forces were the initial sponsors of R and D in weather modification; key findings occurred early; and their sponsorship set an early policy of R and D for national security. However, they effectively lost their role in the field in the Vietnam backlash, when their decision to do clandestine cloud seeding during the war became known (Science, 1974).

The Bureau of Reclamation, able to develop a strong constituency and thus to gain and maintain relatively sizable funding, remained heavily dependent on western water interests in Congress (Rhodes, 1982). The Bureau's mission (and constituency) limited the scope of its R and D to snow and rain; thus it was unable to assume an

overall, national leadership role although it routinely received more funding than any other agency. It has now branched into international areas of activity.

The USDA, which had much at stake in the development of the technology, essentially decided to limit its work to lightning studies. It deferred to NOAA and other agencies with a "let the other guy do it" policy.

NOAA, the agency whose meteorological mission and capabilities suggested that it could rationally take the long sought lead agency role, never assumed the lead, even when strong external recommendations from "blue-ribbon" outside advisors existed. Why it did not do so relates to internal leadership decisions, and external constituency. These factors led to a certain ambivalence about the field by the agency.

It is within this history of agency limitations, lack of national leadership, questionable decisions, differences in program goals, and agency competition that one finds the major cause of lack of progress in the field of weather modification. It has been clearly understood from the beginning (1940's) that the principal player in weather modification R and D was to be the federal government (Fleagle et al., 1974), not the states nor the private sector, and that capabilities to modify the weather are in the national interest (Advisory Committee on Weather Modification, 1957; Weather Modification Advisory Board, 1978). But the federal government's management approach has failed to move the field forward to realize its promise.

4. MAJOR NEGATIVE RESULTS OF POOR POLICIES: FEEDBACK PROCESS.

The federal management of the national R and D program produced widespread questioning and negative scientific perspectives and public views about weather modification research. These in turn helped lead to the current policy of diminished priority.

From R to D Too Soon. First was the too early shift from a concentration on research (with little developmental emphasis) to a major project orientation with emphasis on development and applications. The theme of the Bureau of Reclamation and its Skywater Program of the 1960's was "atmospheric management." In an agency with a strong water engineering viewpoint, it was apparently important to have a program with the theme: "Enough science is resolved to begin applications." The use by DOD of cloud seeding during the Vietnamese conflict is a major and unfortunate example of premature application of a technology. Whether it was an effective or ineffective weapon, no one knew--but it was condemned on either score.

The continuing use of existing cloud seeding techniques in the U.S. after 1950 also had a major effect on agency policies. Commercial firms, supported by funds from private groups and businesses around the nation who believed they could modify clouds for beneficial purposes,helped create another dimension to the field that influenced policy makers. These activities likely helped move policy decisions toward a too rapid shift from a research to an applications attitude. Operational, as opposed to experimental weather modification also led to public and scientific controversies that grew with time.

By the late 1960's the field had three controversies which still persist: 1) between scientists disagreeing over the outcome of weather modification projects and about the scientific status of the field; 2) between scientists and operators (engineers) over the status of the development of the technology; and 3) relating to differences between public (i.e., user views) with a willingness to use a less than certain technology, and the more conservative views of scientists over the use of weather modification techniques. These controversies ultimately contributed to a sense of uncertainty at policy levels over the management of the R and D and its scientific status (Rhodes, 1982). Furthermore, as the complexities of the socio-economic effects of changed weather (by whatever means) appeared in the 1970's from studies of social scientists, it became clearer that capabilities to modify the weather were not clear cases of all benefits. This situation combined with occasional local controversies probably fueled the fears of bureaucrats who could just as easily chose to fund less controversial science of apparent equal importance.

Inadequate Field Projects. The federal management of the R and D of weather modification, particularly since 1968, led to several major field projects which failed due to a variety of problems described previously (Changnon, 1973, 1980; Congressional Research Service, 1979). The federal management approach contributed to inadequately funded projects; to projects terminated before definitive answers could be achieved; and often to questionable choices of institutions and of leaders to direct projects. The agency push to big field projects often ran afoul of poor physical-statistical designs that produced inconclusive answers (Statistical Task Force, 1978), and use of instrumentation inadequate 1) to make atmospheric measurements essential to knowing where and how to seed clouds, and 2) to assess the results of cloud seeding (Wyckoff, 1970). Thus, in retrospect, major experiments in weather modification had little chance to succeed at the levels scientists expected. Insufficient knowledge of critical atmospheric processes effectively led to inconclusive results in most major field projects and to a consequent widespread perception in the scientific community of "poor science" and an inability of weather modification research "to deliver."

Scientific Gains vs. Expenditures. The prior two outcomes (R and D too soon and poor field projects) largely resulting from the federal policies toward weather modification, helped create another major negative outcome, criticism of weather modification support on a scientific and economic basis (costs vs. gains, or benefits). In the early 1970's leaders in the field claimed that weather modification benefits offered the greatest possible service to mankind by meteorologists (Droessler, 1972). However, the high costs versus benefits became an issue

and likely affected policy (Atlas, 1975). This criticism often focused on what has (or has not) been developed as predictable modification technologies. Unfortunately, many scientific accomplishments from weather modification research in areas such as meteorological instrumentation and increased knowledge of cloud physics and dynamics in wide use (Braham and Squires, 1974) have gone largely unnoticed. The existence of several long-term operational programs in California, with evidence of positive results (increased streamflow) has led some states and private sector interests to question the need for major costly R and D efforts. Some have claimed excessive federal expenditures without sufficient gains in weather modification capabilities (Hosler, 1977); hence, a policy-related question to be assessed is the benefit/cost status of the research field. Although analysis of this question is desirable, an in-depth assessment is beyond the scope of this discussion. However, certain comparisons can be made. First, one can examine federal expenditures for research in atmospheric sciences in recent years. In 1983 about $425 million was expended with $10 million for weather modification, or 2.9% of the total (Committee on Atmosphere and Oceans, 1985). The national climate research funds were about $120 million (35%), and funding for atmospheric pollution research was $68 million (20%). Clearly, weather modification support in the 1980's has been very low relative to other major means for solving atmospheric problems (weather forecasting, design climatology, air pollution, long-range predictions, etc.). However, even in periods of greater funding of weather modification such as the middle 1970's (Table 1), weather modification has not compared well. When it received a peak of $18.7 million in FY77, this figure was only 6% of the total annual atmospheric research expenditure.

More insight into the value of investing in any form of atmospheric research can be gained by comparing recent research expenditures for weather forecasting with those for weather modification. During the 1966-1978 period, the federal government spent $92 million on research in weather prediction (Interdepartmental Committee on Atmospheric Sciences reports, 1966-1978). An available assessment of the skill in precipitation predictions for this same 13-year period (National Academy of Sciences, 1980a) showed that the skill (for probability forecasts) in warm season rainfall predictions, for periods of 3 hours up to 3 days, was 19% in 1966 and increased to 22% in 1978; this is a gain of 3%, or a 15% improvement over the skill level in 1966. Was this gain worth $92 million or a portion thereof?

In this same time period (1966-1978) the federal government spent $178 million on weather modification research. In this time frame, scientists established that both warm and cold fogs could be operationally modified; that snowfalls in the Sierras and Rockies during certain weather situations could be increased; and that individual cumulus clouds in Florida and South Dakota could be seeded to increase rainfall (Weather Modification Advisory Board, 1978). Did these justify $178 million? Would weather predictions be much better if the $178 million had been spent on forecasting research? Would a greater increase in predictive skill produce socio-economic benefits comparable to those from these modification capabilities?

These kinds of policy questions generally have not been adequately addressed and hence badly needed answers have not been available in most cases. However, in-depth answers were sought in 1975 by NSF about the R and D policies for hail suppression (Changnon et al., 1977), and this 2-year study recommended one of two policy courses. Either the federal government should increase annual expenditures to $3 million or more for up to 20 years, or it should stop all funding. The then current policy provided funding considered inadequate to ever achieve meaningful answers and essentially was considered a waste of resources. However, in most cases, policy development, as it relates to the directions of support in the atmospheric sciences, has often been left to those in federal agencies who try to react to new themes within the mission/s of their agencies and/or to their constituency. This constituency is generally the scientific community with its own beliefs as to what should be investigated for the common good.

5. RECENT EVENTS NEGATIVELY AFFECTING POLICY

Three other relatively recent events were part of the cause of the loss of federal interest in the R and D of weather modification.

A Failure to Act. In the 1976-1977 period, a major assessment of all aspects of weather modification was performed by a national board, and its recommendations called for a major new national program of R and D housed within NOAA (Weather Modification Advisory Board, 1978). This could have launched a new national effort but failed to do so. This was largely because the NOAA Administrator and the Secretary of Commerce, who had publicly indicated their support for making NOAA the lead agency and for moving the recommended national program forward, were unable to act in such a way as to get results. Congressional interest and efforts to obtain Board-recommended legislation failed as terms of interested members ended before enactment could be achieved. Thus, by 1980 the impact of the Board assessment and its policy recommendations had ended. Interest in a new national policy within the executive branch effectively died, an important fact since U.S. science has long been dominated by the executive branch, not by Congress (Dupree, 1964). Complex scientific issues requiring long-term stable support are better addressed by policies of the administration, not by Congress, with its typically shorter temporal views.

Failure to Obtain Success in Florida. The most recent major weather modification experiment was the well publicized Florida Area Cumulus Experiment (FACE). Its "confirmatory phase," FACE-2, was terminated in 1980 by NOAA after collecting what a number of scientists regarded as an inadequate 3-year sample affected by a few unusually heavy rain events. Thus, its findings did not confirm the earlier FACE-1 exploratory results showing sizable rain increases (Woodley et al., 1982, 1983), although sizable rain

increases were indicated for individual clouds (Gagin et al., 1986). Some scientific controversy developed (Kerr, 1982; Changnon and Semonin, 1982), and in the net, the FACE-2 outcome further eroded the field's credibility within the scientific community.

Failure to be Recognized as a Top Priority Research Topic. A third factor that affected recent federal bureaucratic attitudes related to the National Academy of Sciences assessment of the research themes of the 1980's (NAS, 1980b). This report did not identify weather modification as one of the three major research directions to be followed in the 1980's, but rather chose climate, atmospheric chemistry, and mesoscale weather research. This outcome is relatively critical since those in NSF and NOAA who decide on research directions lean heavily for advice on their constituency, the atmospheric sciences community. Programs of both agencies dwindled in the 1980's (Table 1), whereas funding of the Bureau of Reclamation program, which is more congressionally inspired and oriented to the western water constituency, stayed relatively stable.

6. SUMMARY AND RECOMMENDATIONS

The unstated yet basic policy of the federal government from 1945 to about 1980 was, in effect: "We want weather modification technologies for national security, to enhance our water supplies and national economic welfare, and to protect our lives and property, and toward these ends we will apply resources to develop this field." Atmospheric scientists, instead of adopting a position of "it cannot be done," decided to grapple with the difficult problems of weather modification. When major technologies to modify rain and suppress severe weather did not emerge from this R and D effort, for many reasons, the questioning began. The Statistical Task Force (1978) stated a fundamental question: "Why is the field in this seeming void, somewhere between the heaven of resolved technologies of great importance, and the hell of few advances of limited value after the expenditure of about $300 million over 30 years?"

Others have examined the reasons for the supposed "failure" of weather modification research to develop more reliable technologies after "large" expenditures of federal funds over many years. In one sense, the atmospheric scientific community, under the auspices of federal leadership and funding, was attempting to resolve complex atmospheric issues, often using "black box" type experiments. The hope was to find dependable capabilities using the best, albeit limited, available knowledge of crucial atmospheric processes. At the same time, cloud seeding firms were selling this "invisible technology" to the general public and private sector across the U.S., with generally positive statistical results (Panels on Weather and Climate Modification, 1966 and 1973; Weather Modification Advisory Board, 1978). There is evidence that on the research side, there was often questionable project design, operations, and leadership, as well as lack of instrumentation adequate to make the critical measurements such as those of in-cloud processes (Changnon, 1976). Yet progress was made in developing some workable technologies (Hess, 1974; Dennis, 1980, American Meteorological Society, 1985).

One can postulate that today's situation--without capabilities to sizably change the weather over large areas, the recent severe decrease in federal funding, and a lack of scientific credibility in the field--is due to the mishandling of the field by the scientific community. One could also postulate that the public's poor image of weather modification is a result of scientific uncertainty and the fact that many operational cloud seeding projects also have often been unable to physically establish useful outcomes.

It probably goes too far to cast blame on the scientists. They influence, but do not make policy. Nor is the public to blame. The poor public image of weather modification is a cause for the lack of progress and funding. But one cannot postulate that federal policy in weather modification is due to public views. In fact, most federal policies in weather modification R and D are largely a result of bureaucratic decisions based not so much on broad public attitudes or socio-economic perspectives, as on agency views of their mission, budget constraints, and their reading of the existing scientific opportunity and public attitudes.

The lack of progress in the field since the late sixties and the reduction of support in the 1980's are partly due to a series of policy choices by the federal government. The initial interest and federal approach to the research during the late 1950's and early 1960's appear to have been appropriate for that time. However, a series of decisions in the late 1960's and 1970's led to a generally unhealthy environment for a scientific endeavor needing stable, long-term funding for basic and applied research to unravel complex atmospheric unknowns.

The federal management of weather modification R and D helped lead to uncertainties over its operational usage and various controversies and beliefs that there was too little science payoff for the expenditures. By the late 1970's these and other factors had led to decreased federal attention and support, and thus conditions persisted into the 1980's. A policy opportunity missed was the lack of response to the recommendations of the Weather Modification Advisory Board calling for a coordinated research and development program under a lead agency, NOAA. Thereafter, funding declined and the theme of many scientists still interested in the field became "back to basic research." Public interest in use of weather modification had also dwindled from the support of 79 U.S. operational projects in 1977 to only 37 in 1985. This could be attributed to generally drought-free conditions over most of the U.S.; to the decrease in national interest in weather modification often fueled by on-going federal projects; and to difficult economic times for agriculture, and/or to greater public uncertainty over the status of the field. Federal support which averaged $16 million annually in the 1970's dwindled to $8 million in FY84.

In this historical assessment, it must be realized that a general lack of national interest in weather modification (research or operational usage) may be rooted in external physical and socio-economic factors. For example, the nation has a relative abundance of water (no major recent droughts, high streamflows and record high levels of the Great Lakes and the Great Lakes). We face situations where more water will require costly structural additions/modifications, where government subsidized water costs lead to wasted water in irrigation, and a sagging agricultural economy related to ever increasing crop yields. These conditions will make it difficult to create new interest and funding for weather modification R and D.

In conclusion, the policies of the last 20 years are seen as one of the central factors in the slow advance of weather modification and its current low priority. If one accepts the premise that a capability to modify the weather is in the national interest, then it appears a new national policy as a basis for re-establishing a more logical long-term R and D program will be required. Congressman Rhodes (1982) stated, "The potential societal benefits of weather modification are too great for us to ignore or to pursue it in piecemeal fashion. We need a better sense of national strategy." The achievements of the weather modification field over the last 10 years, particularly in areas of instrument development, seeding techniques, and in knowledge of how to design and evaluate experimental and operational projects, are encouraging. The reasons for an ambitious national program in weather modification research are enumerated (WMAB, 1978; Changnon, 1980; Silverman, 1986). What is needed is action at the policy level with new national legislation recognizing the need for a coordinated federal program. There is a need for a lead agency for the generic technology development mission. Whether that should be NOAA or some other agency should be debated. There is also need for an interagency mechanism similar to the old ICAS, which fell into disuse.

Saying something is needed does not make it so. Efforts by the entire scientific community as well as those who are associated with weather modification will be needed.

Acknowledgements. The reviews and comments of Fred White, Peter Lamb, Thomas Henderson, William Woodley and Loreena Ivens are deeply appreciated. The support of the National Science Foundation, Grant No. ATM-8611278, is gratefully acknowledged, as this grant made it possible for the authors to collaborate on the paper. The views expressed are not those of the National Science Foundation.

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