Abstract
A paradox has developed involving one hand sizeable reductions during the last two years in federal support of weather modification, as opposed to major scientific-technical advances in the field plus strong recommendations for increased federal support from the scientific community. The major recent advances include the capability to operationally dissipate cold fogs, to enhance snow from orographic clouds, and to increase rain from tropical clouds, plus the discovery of sizeable urban-related increases in rainfall. Other advances include special weather radars, aircraft with new cloud sensors and the capability to penetrate thunderstorms, new seeding materials and delivery systems, and new techniques for evaluation of projects. These have been coupled with the spread of weather modification around the world and with the initiation of major seeding projects in Colorado (NHRE, HIPLEX, and San Juan Project), Florida, South Dakota, and Illinois-Missouri (METROMEX). Several groups (NACOA, NAS, ICAS, NWC, AMS) all made a series of positive recommendations for advancing the field through more federal support and reorganization. Yet, beginning in FY74, federal support for weather modification dropped 21% when other R&D increased 11%. Many possible causes for the paradox appear, including fear of weather changes, lack of scientific commitment, and a series of public, scientific, political, and military controversies. The three basic issues are that weather modification is still an immature technology; the socio-economic impacts are ill defined; and its management has been uncertain. Proper resolution of the paradox is more apt to occur either because of a dramatic scientific breakthrough or from growing concerns about weather and climate-related environmental changes.

1. Introduction
As a university-type research scientist and administrator of a state research group who has been significantly involved in weather modification research supported by federal agencies, I view a most serious paradox. It concerns the major reductions in federal support of weather modification during 1973 in the face of strong growth recommendations for its research from the scientific community. This paradox is further amplified by the fact that major scientific and technical advances in weather modification have been achieved recently. This is an interesting paradox to analyze, not only for the atmospheric scientists, but for all scientists who 1) must rely on the federal government for major support of their research, and 2) are involved in research requiring stable long-term funding for its successful completion.

It seems valuable to inspect the paradox, not only to examine its causes, but also to make predictions as to how and if weather modification will escape from it. As a prelude, I have first summarized the major advances in the field in the past five years and reviewed the research recommendations by various groups. I then have contrasted these to the reductions in federal support. Federal spending for weather modification doubled between FY67 and FY72, but in FY74 it suddenly dropped to the FY68 level.

2. Major advances
Since 1967 major advances have occurred in certain phases of weather modification, and these plus several technical innovations have interacted to bring the entire field forward at a reasonable, if not rapid, pace (Droessler, 1972; Changnon, 1973; Simpson et al., 1974). These advances included four important scientific findings, and these have been accompanied by long-needed new instrumentation, seeding technologies, evaluation methods, and research into the socio-economic aspects of modification. The recent growth of weather modification is reflected in the global spread of its use and in the initiation of several major new programs in the United States. The signal advances are these:

1) Cold fog can be operationally dissipated—13 airports (including Seattle, Salt Lake City, and Des Moines) were using it on an operational basis in 1973 (American Meteorological Society, 1973; Charak and DiGiulian, 1974).
2) Orographic clouds can be modified to yield 10 to 30% snow increases under certain conditions with 4 operational projects now in the Sierras to increase runoff (Grant et al., 1971; Mielke et al., 1970).
3) 165+% enhancement of rain can be secured from single tropical cumulus clouds under certain conditions (Simpson, 1970; Simpson et al., 1971; Woodley, 1970).
4) 10 to 30% increases in summer rain have been discovered in and near cities in the humid Midwest, resulting from inadvertent urban effects (Changnon, 1968, 1969; Huff and Changnon, 1973; Sanderson et al., 1973; Schickedanz, 1974).

The cold fog findings have led to wide operational use of the dispersion techniques by commercial aviation; the orographic findings from Colorado led to further
testing in other western areas and to operational applications in other mountainous areas of the west, largely by power companies; and the rain enhancement from single tropical cumulus clouds led to a major Florida experiment to learn if more sizeable areal increases in rainfall were possible by merging large tropical clouds (Simpson and Woodley, 1970, 1971; Simpson et al., 1973). Climatic studies discerned sizeable modification (increases) in summer rainfall and severe weather in and near Chicago, St. Louis, Washington, Houston, New Orleans, and other cities, all apparently due to urban releases of aerosols and heat. Results also showed that rain is not decreased nor increased measurably beyond the local urban increases, suggesting the persistent fears of "robbing Peter to pay Paul" about rain-making may not be true.

Although predictable modification of the cloud types critical in rain and severe weather production in the non-mountainous areas of the United States has not been attained, these recent urban discoveries plus the accomplishments for modifying cold fog, mountain snow, and rain from tropical cumulus clouds, provided a reasonable foundation for expectations for eventual modification of other clouds. These expectations, coupled with growing problems that weather modification could address, including our food, fibre, and energy needs, would seem to have provided the rationale for sustained, if not increased, weather modification research efforts (Braham and Squires, 1974).

The predictable modification of the cumulus cloud and its most awesome off-spring, the thunderstorm, remains unresolved, although the urban results gave new hope that it could be done. Thunderstorm modification is sought because they produce more than 50% of the rain and most of the severe local weather in the eastern 2/3 of the United States. Recent findings from experiments attempting to enhance rain from cumulus clouds and thunderstorms reveal a range from 30% decreases in Arizona and Missouri to 25% increases in South Dakota and North Dakota (Battan and Kassander, 1967; Braham and Flueck, 1970; Dennis and Schock, 1971; Miller and Cain, 1973; Grant et al., 1974). Modification apparently was occurring in these experiments but the causes were not well understood. Growing belief in the possibility of suppressing hail from thunderstorms led to a national experiment dedicated to evaluating that possibility.

Clearly the predictable modification of the cumulus cloud and its occasional product, the thunderstorm, appears to be a central goal of the modification research of the future (Changnon et al., 1974). However, because the cumulus cloud is very complex internally, and highly variable in time and space, its organizational arrays vary widely. Its study and modification obviously require patience and a variety of sophisticated measurement tools and evaluation techniques. To this end, major steps forward were being made in the past few years to develop the models and techniques needed to research the cumulus cloud so as to learn how to modify it on a predictable basis.

Rapid advances in understanding the microphysical and dynamical processes in clouds led to advances in their conceptual and numerical modeling. Such models have been used in ascertaining the seeding potential over an area before a project, and on a daily operational basis they are often used as an important forecast tool in most experiments. Their use in evaluating the results of a project is just emerging.

Long-desired new instrumentation useful in furthering weather modification research was developed. Computers for numerical modeling and also for incorporation with weather radar systems led to important advances for making real-time operational decisions as to when and where to attempt modification. New weather radars capable of measuring rain, hail, and liquid water in clouds and new Doppler radars capable of measuring airflow into clouds have led to new knowledge of cloud processes allowing better evaluation of seeding (National Center for Atmospheric Research, 1973). An armored jet aircraft was developed for penetrating and studying severe hailstorms in the National Hail Research Experiment (NHRE) (Sand and Schleusener, 1974). Advances in aircraft-mounted sensors have allowed better assessment of critical conditions such as cloud droplets, liquid water content, and condensation nuclei, all needed in evaluating the susceptibility of clouds to modification.

Seeding materials and systems to deliver them have both improved markedly. Pyrotechnic flares with higher output rates of more uniform seeding materials, and other seeding devices that could be dropped into storms from high flying aircraft both served to insure more effective seeding rates in critical storm zones. A major finding showed that seeded convective clouds, especially those in a complex multi-storm system, exchanged seeding material with other adjacent major clouds on the scale of up to 65 km in space and 60 min in time (Summers, 1972; Gatz, 1974).

Research in a most critical area, the design and evaluation of cloud modification projects, made great strides due to the more skillful use of statistical techniques, increasing physical knowledge of the clouds, and more knowledge of natural variability (Simpson, 1973; Flueck, 1973; Changnon, 1974). This increased knowledge and improved forecasting have led to reductions in the time needed to detect results of experiments, always a major problem in weather modification experiments. For example, there has been increasing use of the individual and paired cloud approaches which rely heavily on numerical and physical models for evaluation.

The 1969-73 period marked the initiation, largely through National Science Foundation (NSF) support, of serious, comprehensive research into the social, legal, economic, and ecological ramifications of weather modification (Frazier, 1970; Taubenfeld, 1970; Sewell, 1973; Haas, 1973). In particular, in-depth studies were conducted on the agricultural impacts of potential rain
augmentation and hail suppression. This new emphasis heralded the fact that weather modification was at or approaching a believable technological level. The National Oceanic and Atmospheric Administration (NOAA), under the auspices of a new 1972 federal law, began the function of maintaining records of all private (non-federal) weather modification activities in the United States, and in 1973 this was expanded to include federal projects. New, in-depth state laws regarding permissive control of weather modification were passed in Colorado, Illinois, and Texas.

Figure 1 shows where weather modification has occurred in the world during the past 28 years. Most developed nations have employed some weather modification, and during recent years many weather modification projects have been initiated in new areas. In the United States during 1973 more than 375,000 km² experienced weather modification (Charak and DiGiulian, 1974), and more than two-thirds of Utah and South Dakota were being operationally seeded during periods of 1973. Hail suppression projects were initiated in several nations in Africa and Europe and even in Japan. The Soviet Union continued to expand their hail suppression programs so that there are now 11 projects in operation encompassing more than 42,000 km². The Soviet program also has involved extensive research in fog, rain, and snow management (Battan, 1973). American companies have also reported on successful hail suppression in two parts of Africa, and there has been a growth of operational hail suppression projects in the United States supported by local funds in Texas and South Dakota (Henderson, 1970; Williams, 1972; Sierra Res. Corp., 1972; Henderson and Changnon, 1972).

The growth in weather modification activity around the world was, to a degree, brought about by American weather modification firms. For instance, American firms earned $4.3 million in 1972 through foreign weather modification research and operations (Changnon, 1973). About 50% of their total income from non-federal sources in 1972 came from foreign sources. In addition, the federal agencies, particularly the Navy, exported weather modification to several foreign nations including Panama, the Philippines, and Portugal during the recent years (St. Amand et al., 1971; Gosnell, 1973).

The considerable activity in weather modification during the past five years is further illustrated by the several new large-scale programs planned and initiated. The successful results from the experimental work on orographic clouds in Colorado (Grant et al., 1968) led the Bureau of Reclamation to design and initiate in 1970
the Colorado River Basin Pilot Project to enhance snow in the San Juan Mountains in southwestern Colorado (Bureau of Reclamation, 1971; Kahan, 1972).

The National Science Foundation launched the 5-year National Hail Research Experiment (NHRE) in 1972 (NCAR, 1973). This large-scale program in northeastern Colorado is attempting to establish the feasibility of suppressing hail damage in the High Plains where hail is a major problem (Changnon, 1972).

Another recent major federally supported program in southern Florida has been supported by NOAA. This carefully designed experimental effort has shown clear evidence of rain increases from single tropical clouds and recently became a more complex project dealing with rain enhancement in multi-cloud systems through dynamic processes (Simpson et al., 1973). The success of that project partially led or forced, depending on one's view, federal agencies to attempt rain enhancement during 1971 droughts in Florida, Texas, and Oklahoma.

Another significant new weather modification program was the initiation by the state of South Dakota of a "statewide" program in 1972 (Williams, 1973). This project was unique because of its breadth and dependence on local and state financial support. It was aimed at precipitation enhancement and hail suppression. The METROMEX program, which began in St. Louis in 1971, was another major undertaking, and although oriented to the study of inadvertent precipitation modification, it has had an impact upon planned weather modification programs (Semonin and Changnon, 1974).

NOAA began in 1972 to plan for a large project to study precipitation modification in the High Plains, and after maneuvers by federal agencies and OMB, this program was shifted in 1973 to the Bureau of Reclamation. The preliminary field testing for the High Plains Project will be initiated during 1974. It appears that the final project will concentrate on test areas in Texas, Kansas, and Montana.

The $77 million spent by the federal government on weather modification in the 5-year period ending in FY73 resulted in major scientific and technical advances in weather modification. Whether these advances are commensurate with the amount of support is impossible to evaluate, but it is reasonable to say that the advances of the past 5 years outstrip those of any prior 5 years of activity in weather modification.

3. Weather modification recommendations

A variety of organizations, societies, and governmental entities has in recent years made various recommendations regarding future weather modification efforts. These were usually tied to national goals which were defined as either those interpreted by mission-oriented agency, or those identified by some august scientific group. I believe that the recommendations, which were all generally quite positive toward weather modification, were based largely on the many achievements that have been occurring during the past 5 to 7 years. Certain recommendations of recent vintage are presented to illustrate their content and tone.

A task force, under the auspices of the Department of Agriculture and State Universities, in 1968 made a wide ranging series of recommendations for a national program of weather modification research with specific reference to agriculture and forestry (Joint Task Force, 1968). Specific programs were recommended on 1) the direct modification of certain weather (rain, hail, lightning, and wind); 2) the study of biological and hydrological consequences of weather modification; 3) the economic and social aspects of weather and modification; and 4) decision-making in weather modification. Recommendations called for a $9.8 million effort in FY72, increasing to a $21.2 million effort in FY77.

A 1971 review of precipitation modification was performed by the National Water Commission (1971). Although the report painted a rather realistic and cautious picture of the capability of precipitation enhancement to make any major contributions to the nation’s water supply in the foreseeable future, it did include as a major recommendation that “research on precipitation enhancement and hail suppression. The METROMEX program, which began in St. Louis in 1971, was another major undertaking, and although oriented to the study of inadvertent precipitation modification, it has had an impact upon planned weather modification programs (Semonin and Changnon, 1974).

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A 1971 review of precipitation modification was performed by the National Water Commission (1971). Although the report painted a rather realistic and cautious picture of the capability of precipitation enhancement to make any major contributions to the nation’s water supply in the foreseeable future, it did include as a major recommendation that “research on precipitation modification should continue, and future research should concentrate on establishing increases in runoff through drought periods." Studies of ecological and legal problems relating to precipitation modification were also recommended.

Two other reports in 1971 made major recommendations regarding weather modification. The National Academy of Sciences, after reviewing the atmospheric sciences, assigned priorities for concern and study (Committee on Atmospheric Sciences, 1971). The field of weather modification was given the third highest priority following weather prediction and air pollution. The weather modification recommendations focused on the establishment of a national program of weather modification. There were six recommendations, three addressed to federal government responsibilities and three addressed to science and technology aspects. The recommendations regarding the government included 1) the public issues should be lodged with the Executive Office of the President, 2) an unspecified single agency should be responsible for a national program in weather modification, and 3) the government should present to the United Nations a resolution concerning peaceful utilization and management of weather modification on an international basis. The scientific recommendations included 1) establishing a global climate monitoring network, 2) assigning, to a national laboratory, the responsibility and resources for developing broad levels of capabilities for weather modification, and 3) enhanced research efforts in cloud physics.

The Interdepartmental Committee for Atmospheric Sciences (1971), which has representatives from all federal agencies with atmospheric programs, also reported on weather modification. The major recommendation concerned the approach to attaining well-defined national objectives in weather modification; each objec-
tive was identified as a national project with lead federal agencies identified with each program. The national projects and agencies recommended included a snow enhancement project (Bureau of Reclamation), hurricane project (NOAA), a lightning suppression project (Forest Service), cumulus (rain enhancement) modification project (NOAA), hail-suppression experiment (NSF), Great Lakes snow redistribution project (NOAA), and a national fog modification project (FAA).

In 1972, in its first annual report to the President and Congress, the National Advisory Committee on Oceans and Atmospheres (1972), or NACOA, made five major recommendations for action. First, NACOA pointed to the various needs for legislation to protect our citizens and to regulate weather modification within a framework of beneficial use of modification. Second, they called for hastening of development of precipitation management techniques (by basic research in cloud physics, computer modeling, project design efforts, and remote sensing), and third, they called for efforts to mitigate hurricanes. Their last two recommendations concerned assessing large-scale consequences in terms of public policy and international aspects including study of inadvertent weather modification.

The American Meteorological Society (1973) recently issued a set of recommendations, largely based on the many achievements of recent years. The Society identified three major goals for the "national program" in weather modification, and to achieve these they made six specific recommendations regarding weather modification activities in the 1970s. These included: 1) increased development of numerical models of clouds and storm systems, 2) performance of extensive field experiments on precipitation in the major climatic zones of the United States, 3) research and field experiments concerning mitigation of severe storms, 4) expanded research on warm fog dispersion, 5) extension and expansion of facilities and expertise devoted to weather modification, and 6) increased programs to study inadvertent weather modification.

The most comprehensive recent set of recommendations relating to weather modification efforts were those issued by the National Academy of Sciences (Committee on Atmospheric Sciences, 1973). Their recommendations were centered around a choice of three national goals, all slated for completion in 1980. These goals were 1) to identify conditions for precipitation modification, 2) to develop a technology for suppression of severe storms, and 3) to establish a national and international system for study of inadvertent weather modification. Five recommendations in support of the goals included 1) more laboratory and field programs, 2) greater use of numerical modeling, 3) standardization of seeding instrumentation and agents, 4) establishment of statistical research groups, and 5) creation of a data repository for weather modification. To achieve these goals and recommendations, the Academy Panel made specific recommendations to the federal government. They recommended 1) continued support of universities for basic research, 2) continuation of active programs by mission-oriented federal agencies, and 3) the grouping of several agency functions on weather modification planning and coordination under one agency.

An important recommendation was that NOAA be assigned the principal administrative responsibility for a national program in weather modification. They did not call for a centralization of the conduct of activities, but rather a centralization in planning and responsibility for a strong national program. The future roles of other major federal agencies with past involvement in weather modification were also considered. Their recommendation for sizeable support included a "doubling" of current efforts to reach an estimated $50 million annually for weather modification in FY75.

Review of these many recommendations since 1968 reveals certain similarities. First, all groups recommended that weather modification deserved major federal support because weather modification is high in the national interest. A well-defined national program is needed. Recommendations as to how the federal role should be shaped varied from keeping it much the same, that is, in the hands of several federal agencies, to considerable centralization under one agency.

The scientific research recommendations more nearly agreed, and all focused on the need for precipitation management, the mitigation of severe storms, and study of inadvertent weather modification. Most also recommended research of socio-economic-legal-ecological aspects. Within the context of the scientific thrust was a repeated call for centralization of the research into major laboratories to develop a "critical mass" of scientists for key research areas such as evaluation, numerical modeling, and cloud physics.

These recommendations might be judged by some to be self-serving. However, in this context, two sets of recommendations are important. One is the positive recommendation for socio-economic research and more precipitation modification research from the National Water Commission (1971). Its investigators were not members of the meteorological community nor did they have a stake in the outcome of their investigation. The second set of recommendations without bias is that from the American Meteorological Society (1973). The professionals of the meteorological community represent a wide a spectrum of attitudes, both for and against weather modification, as exists in the nation. Thus, the Society's recommendations importantly reflect the consensus of meteorological attitudes regarding what has been accomplished and what should be done.

4. Reductions in federal support

The recent achievements in weather modification and significant recommendations for major and increased federal support of weather modification have been presented. Now, an analysis of the actual fiscal-year support of weather modification by the various federal agencies is
Table 1. Federal support of weather modification research and operations, millions of dollars.¹

<table>
<thead>
<tr>
<th>Fiscal Year</th>
<th>Commerce</th>
<th>Interior</th>
<th>NSF</th>
<th>DOD</th>
<th>Others²</th>
<th>Total</th>
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<tr>
<td>1963</td>
<td>0.19</td>
<td>0.10</td>
<td>1.32</td>
<td>0.96</td>
<td>0.18</td>
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<td>1.57</td>
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</tr>
<tr>
<td>1965</td>
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<td>2.01</td>
<td>1.45</td>
<td>0.14</td>
<td>4.97</td>
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</tr>
<tr>
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<td>1.33</td>
<td>0.33</td>
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<td>1968</td>
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<tr>
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<td>4.70</td>
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<td>4.70</td>
<td>1.30</td>
<td>1.65</td>
<td>15.48</td>
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¹ Excludes DOD spending for weather modification operations in Southeast Asia.
² Includes Transportation, Agriculture, EPA, and NASA.

shown in Table 1. These totals include support for research into inadvertent as well as planned weather modification, and in the last four fiscal years support for inadvertent modification research has been rather constant at about $2.5 million. The support grew from $3 million in FY63 to $19.4 million in FY72 (Committee on Atmospheric Sciences, 1973; ICAS, 1973; Lavoie, 1974). These totals do not include the DOD expenditures of $21.6 million for weather modification operations in Southeast Asia during 1966–1972 (Shapley, 1974). Support doubled during the 5-year “recent” period of rapid findings and achievements. Inspection of the budgets for the major agencies shows that “stay level” spending has existed for DOD which, along with NSF, had made relatively sizeable commitments to weather modification more than 10 years ago. Most agencies, other than DOD and Agriculture, made major funding increases in the 5 to 6 years prior to FY74.

The fluctuations in the total federal spending are also depicted in Fig. 2. The notable decrease in support in FY74 included a 30% decrease at NSF, and a near 40% decrease for Interior. Furthermore, the lack of growth to reach levels recommended by the NAS in 1966 and 1973 is quite apparent. The sizeable $8.5 million non-federal support of weather modification in FY72 is also shown. Soviet expenditures for weather modification were estimated to be in excess of $100 million in 1973, compared with $24 million (federal and private) in the United States.

It is also interesting to compare these weather modification figures with those of the entire federal budget. For instance, the FY73 federal budget for R & D ($16.8 billion) increased by 6.5% (to $17.9 billion) in FY74. Federally-sponsored civilian research (non space and non military) was $5.2 billion in FY73 and rose to $5.8 billion in FY74, an 11.8% increase at the time weather modification dropped by 21%. Even in its rapid growth period of FY69 to FY72, weather modification was not keeping up. Civilian research and development support in 1969 was $8.2 billion and reached $6.8 billion in FY73, a 120% increase. Conversely, weather modification increased from $10.6 to $19.3 million, or 87%.

The situation at NSF is an interesting example. The weather modification program of NSF is within the Research Applied to National Needs (RANN) program. The three major divisions of RANN, other than the Energy Division, all took cuts in their FY74 budgets to help support a $14 million increase in the Energy Division budget. The RANN Environmental Division, which includes the Weather Modification Program, took an average 24% cut, but weather modification budget went from $5.7 million in FY73 to $4.0 million, a 31% cut. In contrast, the Atmospheric Sciences Section of NSF had a budget for FY74 that represented a 6% increase over FY73. A proposed increase in NOAA’s budget from $4.4 million in FY73 to $12.8 million in FY74 never occurred (NOAA Week, 1973). Clearly, the support for weather modification in most federal agencies was severely reduced in FY74. The support cannot approach the magnitude of growth that some agencies and most of the recommendations have called for during the 1970s unless some drastic rejuvenation occurs. The factors that led to the less than recommended growth after FY72, then to a serious reduction in FY74, and to the lack of recovery in FY75 are explored next.

5. Apparent causes for reduction in federal support

The immediate reasons for decreased federal interest and support of weather modification could be ascribed to several issues or pressures, some of which are external to the specific weather modification field. These “external...
pressures” included 1) the general lowering of the national image of science and the resulting reduction of growth funding for all of science; 2) the diversion of funds elsewhere to support research related to major crises (energy) or to support growth in long-term commitments for other less controversial atmospheric research programs such as the Global Atmospheric Research Programs; 3) desire in the Executive Office and OMB to involve local and state support, rather than federal support, and to have commercial enterprises, rather than federal agencies, performing research and applying technologies as much as possible; and 4) general federal cautionness to uncertain sciences and controversies.

Some agencies chose to reduce support for weather modification so as to sustain that for certain other research programs that either were considered more central to the agency mission or represented responses to international agreements. Certainly the 1973–74 pressure of the energy crisis led to a diversion of NSF/RANN funds away from support of all other science areas. Aside from these, most of these external pressures appeared related to the recent slow growth positions in federal support of all atmospheric research.

Of particular interest then are those “internal factors” unique to the weather modification field. Sustained support in this field is an overriding necessity for proper progress because so much field and laboratory experimentation requires long, multi-year sustainment to achieve meaningful, statistically significant answers within the context of the enormous natural variability of weather. Why then—given the recent progress and the strong recommendations for research—did most federal agencies fail to totally protect or to support growth of their weather modification programs?

A lack of deep commitment by some “involved scientists,” both by those in managerial roles in federal agencies and those performing weather modification research, has to be one of the factors detrimental to the field. The societal payoffs and glamour of weather modification programs were not sufficiently attractive to federal agencies in terms of stress to sustain their growth or even to protect the programs well. The word “glamour” is used because I have been intrigued at the way state and federal governments have sometimes “used” weather modification. Certain agency leaders have criticized, in scientific circles, weather modification, particularly the operational efforts. Yet, they have also embraced it when they desired weather-related attention at public and political interfaces. This tendency to use the field also has been embraced by some research scientists. Many have sought and received basic atmospheric research support by disguising the research as a weather modification project. These approaches have hurt the field because they often led to an oversell and expectations seldom achieved. Consequent uncertainty about its potential has been produced at all levels including the scientific community, the public, and within government agencies. A part of this problem has been the lack of clarity among non-specialists about the large differences between operational efforts and experimental research efforts.

These commitment-related issues are only a part of the paradox. Other factors loom much larger as the causes for various governmental agencies and OMB to retreat from weather modification at a time when progress and recommendations were so positive.

Certainly a series of controversies surface in 1971 and 1972 at public and political levels had an effect on those making federal decisions regarding weather modification. The 1971–72 droughts brought forth requests to the White House from the Governors of Florida, Texas, and Oklahoma for weather modification assistance. This resulted in hurried operations of emergency seeding projects by the Air Force, NOAA, and Bureau of Reclamation. It also brought strong protests to the White House from the private weather modification sector who claimed they had the technology and facilities and were being unfairly excluded from consideration.

This scenario helped bring weather modification to the attention of the Executive Offices where major questions must have arisen about the status of weather modification, particularly when one remembers that the Administration was oriented to use of private enterprise in all possible endeavors. On one hand, a sector of private business was claiming that a technology was available and federal agencies were able to mount an apparent technological effort that they later claimed was successful in making rain (Simpson et al., 1972; U.S. News and World Report, 1972 2; Sax and Cress, 1971; Lorang and Ball, 1972). On the other hand, these and other federal agencies were still clamoring for sizeable support for more basic research to learn how to modify the weather. The basic inconsistency of this situation is likely to have fostered the negative attitude of OMB toward sizeable federal support of weather modification research. There were other political overtones because at least one of the major agency programs apparently had been sustained largely through Congressional, rather than Executive Office, interest.

Other controversies certainly brought political attention to weather modification. One was the news media claim that the Rapid City Flood in 1972 was caused by a weather modification experiment. This is still being debated scientifically (Reed, 1973; St. Amand et al., 1973; Schleusener and Dennis, 1973; Murphy and Borland, Schleusener and Dennis, 1973; Murphy and Borland, 1973), and although it has generally been shown to be an unlikely relationship the debate likely impressed uncertain and fraught with dangers that could bring forth undesirable public pressures.

National concern over use of weather modification by the military in Southeast Asia emerged in 1972 and still

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2 31 May 1971: As rainmakers try to end drought. 63–64.
have, most likely, acted negatively on decision-makers in weather modification because of its uncertainties and the need to outlaw its use on an international basis. Such a high-level political and ecological debate could make agency decision makers hesitant about pursuing hard for weather modification budgets, particularly when the political and ecological concerns were not as yet clearly defined.

Other local controversies about weather modification projects in Colorado and Oklahoma made regional if not national headlines, and as a minimum, they reflected public concern over when, where, how, and if weather modification should be conducted. Thus, during 1971–72 this once glamour-related field became one fraught with public involvement and political concerns (Haas, 1973; Changnon, 1973; Lansford, 1973). Basically, these controversies had to lead to a net deleterious effect within the federal agencies, if for no other reason than the fact that the public and politicians were now into the decision-making process for weather modification, and not just the agency program managers and the scientists.

A recent RANN-sponsored meeting of two groups, 1) the principal investigators of their 11 projects studying the social, political, legal, and economic aspects of weather modification, and 2) the Fellows of the Center for Study of Democratic Institutions, provided interesting insight into image-related problems of weather modification (Mordy, 1974). One image problem included the fact that the recent, post 1970 achievements in weather modification and growing public belief that modification could be achieved both occurred at an inopportune time. For example, we were not at that time experiencing weather crises or even a major weather stress, and we were in a period of great environmental concern and unrest which was occurring at a time of low public esteem of science. Another image problem noted related to the basic fear among many about the wisdom of altering weather. The field also still includes quackery and has been noted for over-stated claims. The sustained scientific debate over weather modification among leading atmospheric scientists produces an image of uncertainty among the public and bureaucrats. Improper management of large projects has also hurt weather modification (NSF–RANN and UCAR Review Panel, 1974). Other scientists and bureaucrats also imagine that much of the federal support has been wasted on poor research or has been inadequate to produce facilities and meaningful experiments. Particularly relevant to this “critical mass” issue is the fact that establishing absolute proof of modification within the natural vagaries of weather has necessitated long and expensive experiments.

Much of what I have discussed deals with factors that have, most likely, acted negatively on decision-makers in federal agencies. It is also apparent that weather modification has been hurt by certain federal management policies (Fleagle et al., 1974). Program competition and jealousy between the prime agencies involved in weather modification have occurred, and politics have too often been involved in decisions that should have been left entirely to science and systems analysis. The glamour of weather modification has not gone unnoticed by politicians. Probably central to these management problems has been the lack of centralized planning and control by one agency of the scientific research and technological aspects.

Another reason that weather modification has not grown faster and in a more logical way has been the lack of support for it by the Department of Agriculture, the agency which represents the single activity area most apt to be affected significantly by weather modification. This failure is illuminated by their own report on weather modification prepared by a Joint Task Force (1968) composed of scientists from the Department and State Universities. They made strong recommendations for USDA-supported research amounting to $7 million in FY72. The actual USDA support in FY72 was only $35,000, or 0.5% of the recommended figure. The inability of that Department to assume its rightful major supportive role for weather modification appears to be another significant factor in its lack of proper growth.

Out of all these possible reasons for declining weather modification support, which might be interactive or just random occurrences, I believe there are three key underlying factors. First, weather modification is an immature, uncertain technology unable yet to display a clear potential for producing sizeable alterations and benefits in most areas of the United States. This point is particularly critical because of the recent federal thrusts toward applied science and use of readily available technologies. Second, and closely coupled to this immaturity, is a serious lack of information about the socio-economic aspects of weather, a lack that bears a void in relation to weather modification. Thus, there is as yet no solid basis for making decisions as to the level of support it deserves (Fleagle et al., 1974). Fear of unknown problems and a lack of the knowledge of disbenefits produce uncertainty, but ongoing RANN projects concerning the socio-economic aspects should eventually help correct this. After all, the many recent recommendations for major support were not based on hard numbers but rather on generalities (and implied fears) about weather’s importance to the nation. This is coupled to the third factor, which is less-than-optimum management at all levels. Factors 1 and 2 coupled with uncertain management are seen as the key reasons for the paradox.

6. Summary and predictions

I have concluded that the basic, central reason for the “advances/funding” paradox is that weather modification is an uncertain technology that as yet is without clearly definable socio-economic promise and with un-
certain federal management. Some involved with weather modification will strongly feel that my listing of its ills or problems is a mistake. I disagree and believe that proper use of weather modification can only come from a description of all aspects, good or bad, so as to achieve an unbiased scientific enlightenment that is so lacking today.

After all the explanation about the weather modification paradox and its causes, it is probably realistic to say that none of the causes can or will be resolved soon. Thus, it is fair to speculate that those conditions in the next few years which would have a drastic impact on and cause a sizeable growth in federal support of weather modification.

It appears reasonable to predict that a major weather-related problem, such as a national drought, would bring forth sizeable federal (and private) support for weather modification. It is clear that American agriculture has taken on a new national image of importance (Wade, 1973; Science News, 1973). Future crises relating to agricultural production and weather will occur, and as in 1971, weather modification will likely be rushed to the scene of the disaster. Unfortunately, weather modification may not be in a position to address correctly such crises with crash programs and thus may fail and further retard its progress. The federal support may also wither as the crises end, bringing more damaging fluctuations to the field. In this instance, added spending for crisis efforts would only end the current paradox and probably begin another one.

Other factors may also lead to increased weather modification support. Major claims of foreign nations regarding successful breakthroughs in weather modification have brought forth in the past, and are likely able to bring forth in the future, extensive new support. The Soviets' claims on hail suppression certainly brought forth a decision for a national hail suppression program.

A dramatic breakthrough in weather modification, one that would have sizeable scientific acceptance and public attention, would probably drive the support up greatly, particularly when coupled to emerging findings allowing assessment of the socio-economic impacts. Fears of weather-related environmental change, as shown by inadvertent weather modification by cities, also may be a catalyst. These two situations could lead to the wisest solution of the paradox involving more stable long-term support.

The feedback loop of federal uncertainties about weather modification and its research support is seen to stem from a variety of factors that are often a part of a potential or emerging technology. Use of this uncertain technology in "fire-fighting" efforts is not the proper approach. It is essential to identify the reasons why weather modification should be investigated. How it fits into our national goals must be established in clear economic, social, and legal terms. The potential gains and losses must be made sufficiently clear to choose and justify a national priority for it, and until this is done weather modification support will likely be less than adequate and certainly will be unstable.

In general, it is reasonable to say that weather and climate modification represents a national need because weather interacts with all national activities—the energy we use, the food and fibre we produce, and thus the quality of our life. Weather modification can be seen as having four general values. First, it offers a better life through partial alterations of nature's variations and weather-related stresses. Second, weather modification can produce economic benefits, both here and abroad as an exportable technology. Third, weather modification is a factor concerning our national security, both as a potential weapon and/or as a means to combat or understand the weather modification of other nations. Finally, these factors all tie together to help form the final reason—that it is relevant to our national need to be able to understand, predict, and if necessary, to control (improve) climate or to alter undesirable climatic changes.

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References


Safety Board report stresses meteorological instruction

The National Transportation Safety Board has issued a special study of fatal, weather-involved general aviation (nonairline) accident rates in 1964 through 1972. The study showed that since 1967 the trend of such accidents has been steadily upward while the trend of the rate of all fatal accidents has been generally downward.

A total of 4714 persons died in 1972 weather-involved general aviation accidents in the period 1964–72. No other cause was as frequently cited as weather; these accidents represented 36.6% of all fatal general aviation crashes, and came “with disturbing regularity despite improvements in aircraft, instrumentation, training, training facilities, the air traffic control system, weather facilities, weather services and navigational aids,” the Safety Board said.

In the cases studied, 74% of National Weather Service forecasts were substantially correct or overstated the weather problem expected. In 11%, the weather was worse than forecast. More than 28% of the pilots received no preflight weather briefings, and the accident rate for pilots who studied weather information by themselves was nearly 10 times the rate for pilots briefed by trained weather briefers.

The Safety Board had concluded in 1967 that too many pilots were utilizing weather information; 4) require that a student demonstrate “competence to procure and utilize weather information”; 5) require a commercial certificate applicant to give evidence of meteorological knowledge; 6) increase the emphasis on weather, and pilot limitations in it, in the FAA General Aviation Accident Prevention Program; 7) take priority action to meet the 1976 goal for nationwide implementation of its “Flight Watch” service—updating for en route pilots by radio the preflight weather information they received; and 8) experiment, at least, with audio recording of preflight weather briefings.

The Board urged that the Federal Aviation Administration 1) increase the 35 h minimum of student pilot classroom instruction and specify meteorology curriculum hours; 2) examine such students for practical application as well as technical knowledge of meteorology; 3) require that a student demonstrate “competence to procure and utilize weather information”; 4) require a commercial certificate applicant to give evidence of meteorological knowledge; 5) increase the emphasis on weather, and pilot limitations in it, in the FAA General Aviation Accident Prevention Program; 6) take priority action to meet the 1976 goal for nationwide implementation of its “Flight Watch” service—upgrading for en route pilots by radio the preflight weather information they received; and 7) experiment, at least, with audio recording of preflight weather briefings.

The Board urged the National Weather Service to 1) accelerate efforts to update its manual, Aviation Weather for Pilots and Operations Personnel; 2) speed expansion of its nationwide evaluation staff toward its proposed one-per-State complement, and include the quality control of aviation weather observations in this evaluation meteorologist’s responsibilities; and 3) accelerate efforts to “improve the presentation of aviation weather products.”

Single copies of the report are available without charge from the Publications Branch, National Transportation Safety Board, Washington, D.C. 20591. Multiple copies may be ordered by mail from the National Technical Information Service, U.S. Department of Commerce, Springfield, Va. 22151.

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