On the Need to Evaluate Operational Weather Modification Projects

S. A. Changnon, F. A. Huff, and C. F. Hsu
Illinois State Water Survey
Urbana, Ill. 61801

Abstract
Use of weather modification by farm groups, state agencies, and power companies to perform operational projects continues to expand. Seven percent of the United States experienced cloud seeding during 1977. The major stakeholders—those paying, those performing the seeding, and the scientific community—have all converged on the need to evaluate operational projects. Major assessments of the national situation have recommended that carefully conducted operational projects can be a source of useful scientific information if designed, operated, and evaluated properly. A project has been launched to develop statistical-physical evaluation techniques for operational projects.

1. Introduction
A feature of weather modification in the United States is the existence and growth of operational, or commercial, weather modification projects. Operational projects are generally based on a premise that weather modification works and no proof is needed. Whether these projects can or should be evaluated to gain proof of their efficacy, or to gather scientific knowledge, has been debated for more than 25 years. Certainly, their evaluation has not always been addressed properly or believably. Evaluation of operational weather modification efforts is sufficiently difficult to require a sizeable scientific effort. Not only is atmospheric research needed, but statistical expertise must be involved in the statistical-physical aspects of the evaluation issue.

Why tackle this issue? The key stakeholders in weather modification—the scientists, the weather modification industry, and the user public—have all finally come to realize that this issue must be faced. A major assessment of the national program in weather modification completed in 1978 recommended that considerable attention be given to the evaluation of selected future operational projects (Weather Modification Advisory Board, 1978 and Statistical Task Force, 1978). Such evaluations face a variety of challenges, including: 1) the development of statistical-physical techniques for evaluation; 2) the evaluation of operational projects to test the techniques; and 3) the planning and control of future operational projects to make them easier to evaluate.

2. Importance of an evaluation capability
Since the late 1950s, weather modification in the United States can best be characterized as having two parallel thrusts (Changnon, 1978a). One thrust has been federally-sponsored research, generally characterized by a series of site-specific, moderately large experiments (many of which have been inconclusive due to inadequate planning, or inadequate funding). Experimental results have been mixed, with success in some cases, nothing modified in others, and reversals in others (rain decreased instead of increased). The major findings after 20 years have been that: 1) weather (clouds) is extremely complex and modification is difficult to accomplish and prove; 2) under certain conditions rainfall or snow can be altered over small areas within certain geographical regions; and 3) much broader, more extensive research efforts are needed to bring it to fruition.

The other thrust of the weather modification field has been in the private use of weather modification. Use of private (and corporate) funds to hire commercial firms to perform "operational modification projects" (nonexperimental) has brought forth hundreds of projects, largely performed in the western (drier) half of the United States. Many of these operational projects have lasted only one or two years, but a few in California have been conducted continuously for more than 20 years. Although difficult to evaluate, the evaluation of certain operational projects has helped establish that rainfall was being purposefully modified to obtain 10–15% increases (National Academy of Sciences, 1973).

The most important point of this two-pronged (research versus usage) approach to weather modification is that it has involved usage before the scientific basis for its usage (a true technology) was established. Add to this lack of know-how the well-recognized vagaries (day-to-day, year-to-year) of weather, and the result is that proof of even a moderate change, say a 25% increase in rainfall, is very difficult. Thus, one can readily see the difficulty of proving what operational cloud seeding has done.

Ever-growing private usage of weather modification in the face of this lack of scientific proof can be understood only in light of intensive industrial and public desires to relieve losses due to weather extremes, and to the low cost of cloud seeding. Typically, commercial cloud seeding projects are inexpensive to the individual, costing between 3 and 50 cents per acre depending on the size of area, type of seeding used, and quality of commercial operator hired. A general philosophy has been one of investing in a low-cost gamble.

This two-pronged approach involving usage without much scientific proof also led to local controversies over the effects of operational cloud seeding projects. Projects to suppress hail have been stopped by organized minorities who perceived that the effects of suppressing hail would be to suppress rainfall. Projects to increase snowfall in the mountains have brought forth
controversy over increased avalanches and other perceived environmental damages. After four years of summer operations, a near-statewide modification project in South Dakota (with combined local and state funding) was ended in 1976, basically because tangible evidence of a meaningful change in rainfall and hail was not forthcoming (Farhar and Mewes, 1976). Sociologists who have studied the controversies related to weather modification find that the prime reason for controversy is the lack of scientific consensus (from a lack of knowledge) about weather modification (Changnon et al., 1978).

a. Scientific community

The evaluation of operational weather modification efforts is now strongly urged by the scientific community. The National Academy of Sciences (1973), in a major review of the field of weather modification, made strong recommendations for the involvement and development of statistical skills in all facets of evaluation, considered to be a major need and weakness within the field of weather modification. Subsequently, in a review of the entire field of weather modification, the Domestic Council (1975) made major recommendations relating to the need to perform evaluations of commercial weather modification projects.

An important concept relating to evaluation of operational weather modification projects that has developed in recent years has been the potential for gaining scientific knowledge from such evaluations. Changnon (1974), in a review of weather modification evaluation methods used in North America, pointed to the vast amount of useful information that had been provided by the evaluation of operational projects, including the use of geophysical data to provide physical and economic proof of modification. Changnon (1977) showed the value of evaluating ongoing hail suppression programs to gather information on the potential status of hail suppression capabilities. Most of what is known about North American hail suppression efforts comes from limited evaluations of operational projects, rather than from often poorly conducted experiments (Weather Modification Advisory Board, 1978).

The concept of gaining scientific knowledge from the evaluation of operational projects was further elaborated in recent major assessments of weather modification. The National Weather Modification Advisory Board (WMAB), in conducting the national assessment of the program in weather modification (WMAB, 1978), acknowledged this value by stating, “that among the most informative projects are some non-randomized seeding programs on the mountain slopes in California that used objective measure of seasonal streamflow for verification. Long-term operational projects have emerged after several decades as respected efforts and provide strong evidence of a modification capability.” The Board further noted that certain well-designed seeding projects offer unique opportunities for learning in a systematic way about the effects of cloud seeding, for testing concepts developed in exploratory research, for transferring technology to user groups, and for encouraging sound weather modification practices. It was recognized that certain carefully controlled and randomized projects could help serve as “confirmatory type” experiments. This is particularly applicable to hail suppression projects, where scientific knowledge lags behind that of rainfall and snowfall modification. Federal support for some of the costs is recommended as a cost-effective way of conducting part of the new national research and development program. Indeed, a major recommendation of the WMAB is to support carefully selected commercial operational cloud seeding programs that would be carefully designed and controlled, would have adequate environmental monitoring, and would employ a variety of means, including randomization, for evaluation. Annual funding of $1 000 000 was recommended for such efforts.

Another recent major study of weather modification, a technology assessment of hail suppression (Changnon et al., 1978), also addressed the issue of scientific benefits that can come from evaluation of operational projects. Seven major scientific and technical research recommendations were offered in this assessment, and one states “methods for understanding and evaluating seeding effectiveness must be developed—involving at least radar echo studies, cloud data, and cloud models.”

Clearly, the evaluation of operational seeding programs is considered a high priority task by the scientific community.

b. Operational community

Another call urging evaluation of operational weather modification projects comes from the operational community—those scientists and operators directly involved in the weather modification industry and the performance of projects. The Weather Modification Association (1978) has issued standards for project operations. These represent a strong call for the development and use of operational criteria and instrument systems needed to allow acceptable evaluations of weather modification programs.

The WMAB (1978) pointed to the fact that operational practices used by cloud seeders vary considerably, and that some operators used outdated designs, no on-site monitoring, no real-time observations, and questionable suspension criteria in severe weather. The Board, in an effort to encourage “sound management practices” for future operational weather modification, called for a continuing definition (changing with the improvement of science and technology) of sound standards for operations. The WMAB states “most operational project evaluations, as currently done, are limited because quality standards have not been adhered to.”

The Board report recommends that desirable operational standards should include: 1) projects designed by skilled meteorologists; 2) the development of an evaluation plan for projects of two or more years in length;
3) the delineation of "selective seeding criteria" (forecasts, models, etc.); 4) definition of the seeding method and how it will be used; 5) the on-site, real-time monitoring of meteorological phenomena to recognize seedable opportunities and severe weather events (radars, raingage network, etc.); and 6) data compilation and archiving with assessment of the outcome by independent experts.

The hail suppression technology assessment (Changnon et al., 1977a) also addressed the need for evaluation systems in future operational modification programs. Figure 1 from that report shows the extensive 3-phase monitoring and evaluation system envisioned for a well-conducted operational hail suppression program covering a 13,000 km$^2$ area. The function of this recommended effort includes performing both physical and statistical evaluations, which would be based on the collection and archiving of a wide variety of atmospheric and impact (such as crop loss) data. The variety of data collected for monitoring the target, the downwind area, and the environment are described, followed by an analysis effort (see Fig. 1), which would have input into a research and development component. The technology assessment indicated that the results of the envisioned evaluation research effort would feed into the project's operational-forecasting elements (seen as the "operational system" in Fig. 1) and the "public information and education" element. The technology assessment report calls these efforts in the design and evaluation of operational programs absolute necessities, to be funded as part of the program cost. The report states that "large-area adoption and sustained acceptance of hail suppression will not occur without these design-evaluation-information functions performed by unbiased groups."

Thus, a second reason for the evaluation of operational projects, including the derivation of operational and instrument criteria, are the recommendations from the operational-scientific groups calling for standardization, development, and adoption of operational criteria and instrumentation needed to provide unbiased evaluations for scientists and the public.

c. User community

The third major reason for developing a capability to evaluate operational efforts is the call from the user community, the public. A quote from the WMAB report (1978) states, "in many cases, the views of advocates and opponents [to weather modification] both seem to be based more on intuition than on solid evidence. Yet, both told us [the Board] repeatedly in our public hearings, that they wanted more and better scientific evaluations of cloud seeding outcomes. There is a clear need for better evidence on which users can base decisions about cloud seeding." During the initial adoption of weather modification projects, the user public almost always rejects evaluation-related efforts as too expensive and unnecessary, but sooner or later project sponsors want to know how effective the seeding has been.

The societal aspects of project evaluation are noted in the WMAB study (1978). For example, "Operational seeding projects frequently lose local credibility after a few years. The lack of consumer satisfaction—because of poor or no evaluation—often leads to local or state controversy as to whether the project is doing the job intended and should be allowed to continue. Many projects have been stalled by protests based on perceived ill effects that could not be proven or disproven because of inadequate data. Therefore, we believe operational projects should be on a sounder footing with an effective evaluation component."

The technology assessment of hail suppression (Changnon et al., 1977a) also points to the public demands for evaluation of operational weather modification. This study illustrates that a major factor in the

![Fig. 1. Elements of potential large-scale hail suppression-rain enhancement projects (from Changnon et al., 1977a).](image-url)
sustained use of a new technology such as weather modification is “observability.” This is the degree to which results of the innovation are visible to people. Since evidence of weather modification on the scale of changes of 10–30% in rain or hail are impossible for the general public to detect, scientific evaluation by credible scientists is seen as a major need. In the summary on policy issues of this technology, one of the nine major questions addressed and answered related to “monitoring, record keeping, and evaluation.” The technology assessment report states, “if an effective hail suppression technology is to be utilized, there will have to be some level of monitoring and evaluation, plus record keeping, of the cloud seeding operations and the physical changes flowing therefrom.” As far as the public is concerned, results from evaluation are critically needed for the handling of claims. Compensation is recognized as a necessary facet of large-scale operational weather modification because some will lose while many gain. Recommendations also point to the fact that evaluation will be a costly effort and that those who perform evaluations must be credible and have an impeccable reputation for objectivity, expertise, and integrity. As the report concludes, “a great deal will ride on their (the evaluators’) findings and conclusions.”

Changnon (1978b), in the study of the socio-economic aspects of weather modification, also addresses the issues of public concern and conflicts relating to weather modification and its evaluation. Changnon concludes, “if weather modification is to be continuously utilized on a community or larger area basis, it must be able to demonstrate that modification is based on a good degree of scientific consensus about its capabilities; and it must also have an on-going comprehensive evaluation to furnish clear evidence of its attainment and economic impacts.”

Another factor involved in the user-related need for evaluation of operational weather modification concerns the growth of its usage. Figure 2 reveals the extent and number of operational projects in recent years (WMAB, 1978). Changnon (1975) presented statistics on the status of operational weather modification in 1972. At that time there were 47 projects in the United States covering 221,000 km². The public expenditure for weather modification was $4.2 million. Growth in the usage of weather modification, as revealed in the WMAB report (1978), had more than doubled by 1977. There were 88 commercial projects in the United States in 1977, with weather modification being applied over 676,000 km². This represents 7% of the total area of the United States. The expenditure was $6.5 million. Thus, the growth and usage of operational weather modification, in the face of great public uncertainties, reflects an ever growing need for evaluation. Techniques to do this must be developed.

3. Addressing the need for evaluation
The first major assessment of possible precipitation modification in operational projects was made by an advisory committee to President Eisenhower (Thom, 1957). Another major assessment was done as part of a National Academy of Sciences (1966) study of weather modification. Some believe that the scientific disagreements over these two efforts and others helped develop a general concept that evaluation of operational projects was a fruitless exercise—unless its seeding events were to be randomized. The Statistical Task Force (1978), in its report to the WMAB, indicated that randomization of future operational projects was an essential feature to a believable evaluation. However, others now believe that meaningful physical and statistical evaluations can be achieved, particularly if projects are operated in an objective fashion, if quality control data (precipitation and atmospheric variables) are collected, and if cloud physics and dynamics studies are made of the seeded units (clouds) using remote sensors (radar and satellite data) and cloud-probing aircraft. Indeed, the extensive assessment of inadvertent precipitation modification induced by St. Louis (Changnon et al., 1977b) has helped illustrate how evaluations of nonrandomized influences, such as those generated intermittently by cities, can be achieved.

A multi-year project aimed at the difficult problem of evaluating operational weather modification projects is in progress. Its primary objective is to develop statistical-physical evaluation techniques for operational projects, including both the usual nonrandomized operations and those of the future, and employing some degree of randomization (“piggyback type,” as recommended by the Weather Modification Advisory Board, 1978). Weather data have been collected for areas where studies of projects are likely (either simulations or actual operational projects), and potentially useful statistical techniques have been determined. The statistical techniques are being applied to simulated precipitation changes in several areas (Kansas—warm season rainfall; Montana—seasonal hail; and Illinois—summer rainfall). The study of predictor variables (covariates) for simulated project areas is also being pursued.

The simulation of a rain modification project in a two-county area in west-central Kansas has been
completed. Data from the surrounding areas were used as controls. Five out of 35 years were randomly selected as seeded years, and increases of 10%, 20%, 30%, and 40% superimposed on them. One hundred replications were run. In addition, 500 replications of no increase were also generated to build up a null distribution. Statistical techniques applied to these replications included the double ratio, three forms of multiple regression, six forms of principal components, eight forms of two regression lines, and sum of rank power (nine classes). Power curves and power indexes were calculated for each technique and combination. Findings indicate that overall, the principal component regression (PCR) is the best or near best among the statistical techniques investigated. The PCR was the best technique for individual months (May through September), while the PCR, the multiple regression, and two regression lines worked equally well for the seasonal averages.

After the simulation tests in other areas are complete, the final task will be the application of the better techniques to several carefully selected local scale operational projects dealing with rain and hail. Evaluation of these projects will demonstrate the quality and quantity of information obtainable from such efforts. The computer programs are written in ways to allow for easy use on data sets for other areas. These application tests will also aid in delineating operational criteria for future commercial operations.

This project and others will ultimately develop a variety of ways to evaluate operational projects that are nonrandomized but carefully performed. This capability must exist before widespread adoption and use of weather modification will occur in the United States (Changnon et al., 1977a).

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References


