THE PRESENT STATUS AND FUTURE POTENTIAL OF HAIL SUPPRESSION

Stanley A. Changnon, Jr. and Griffith M. Morgan, Jr.
Illinois State Water Survey

INTRODUCTION

Hail suppression activities in the United States during the mid-1970's are at a critical crossroads. Since 1972 there has been moderately widespread use of hail suppression, covering up to 170,000 km^2 of the Great Plains (Changnon, 1973). After 4 years of a nearby statewide operational suppression program in South Dakota, the effort has ended in 1976 by a political controversy. Major United States experimentation in hail suppression, needed to reveal the in-cloud modification processes and to help verify or refute a suppression hypothesis, has temporarily faltered after four years of activity in northeast Colorado (RANN and UCAR Review Panel, 1974). Efforts to sustain a national hail suppression research effort and to design a new experiment continue, but a second non-experimental year is in the offing and the future is not yet resolved. However, individual and group (state) desires to employ an uncertain technology that could increase agricultural production seem more likely now than in past years because of the world food situation and generally higher prices for crops, recent extremely high hail losses in the Midwest, missions of certain federal agencies, international competition over weather modification, and a general improvement in the scientific understanding of hailstorms.

About 2% of the national crop production each year is lost to hail ($685 million), and in some hail-prone areas of the Great Plains, this average loss represents 15 to 25% of the crop value (Boone, 1974). Although property loss due to hail is less and is estimated to be 10% of the crop loss (Changnon, 1972), cities and towns of the Great Plains area suffer occasional major damages from hail.

Hail insurance has been the major means for the protection of an individual from hail, and 15% of the United States crops are insured at a cost of some $300 million annually. However, the crop production lost to hail cannot be recovered, and crop-hail insurance can be a very expensive individual solution in certain areas, costing 25% of the crop value in parts of the Great Plains.

These factors collectively call for an in-depth assessment of the future of hail suppression in the United States. Do we have a proven technology; can the technology be improved, should and will it be more widely applied and if so can it be done; how will it be paid for; who will decide when and where to apply it; who will do the modification research and operations; and what kinds of social and legal problems will it create? These are but a few of the questions that are being addressed in a new study, a technology assessment of hail suppression in the United States (TASH). This technology assessment will attempt to provide answers regarding hail suppression for those who now or will later contemplate use of hail suppression; for those who will develop the technology; and for those who will decide, on a local, regional, or national basis, the need for hail suppression and how to optimize its use within our evoling social system.

This technology assessment of future hail suppression is a 15-month project being conducted by a group of physical and social scientists from a variety of institutions[1] who are making a systematic integrative investigation of this potential technology of the future. Although a technology assessment often addresses the past, present, and future of the technology itself (in this case the suppressing of hail), a technology assessment really focuses on the wide range of impacts from the use of the technology and on the policy actions needed to optimize any utilization of the technology. Coates (1974), a pioneer in technology assessment methodology, states, "Technology assessment is a class of policy studies which systematically examines the effects on society that may occur when a technology is introduced, extended, or modified with special emphasis on those consequences that are unintended, indirect, or delayed."

The timing of a technology assessment of hail suppression is propitious for other reasons. First, from a policy view, the development and application of hail suppression technologies have not yet proceeded so far that efforts to redirect present efforts would be institutionally impractical. There is still time to decide whether and in what manner future hail suppression efforts should proceed. Secondly, there exists a respectable conceptual and empirical base of information for conducting the assessment. For example, a considerable body of field research, both in the physical and social sciences and on individual facets of this issue have been completed. One important facet of this technology assessment that is relevant to the atmospheric sciences is the focus of this paper.

Meteorologists at the Illinois State Water Survey involved in the technology assessment effort are addressing the issues of the hail suppression technology including the levels it could attain, the research and development requirements, and the operational and evaluation techniques. As background for this effort, a comprehensive climatological study of hail in North America was accomplished (Changnon, 1975a). It helped define the different regions of hail in the United States and the temporal fluctuations of hail over different sized areas, both important factors in understanding the where and when of adoption and utilization of hail suppression.

One of the major meteorological efforts in the assessment concerns delineation of the potential hail suppression capabilities of the next 20 years, 1976-1995. The approach being employed calls for defining a wide range of modification capabilities that bracket any capability that might develop in the next 20 years. Inasmuch as most hail suppression projects have indicated a simultaneous alteration of rainfall, it was necessary that modeling of future capabilities incorporate the potential for rain alterations occurring because of hail suppression efforts.

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[1] These include Dr. Eugene Haas and Dr. Barbara Farhar of the Human Ecology Research Services, Prof. Ray J. Davis of Tucson, Ariz.; Prof. Earl Swanson of the Agricultural Economics Dept. of the University of Illinois; E. Ray Fosse of Crop-Hail Insurance Actuarial Assoc.; Prof. Dean Mann of the University of California at Santa Barbara, and the authors.

It appeared most proper to "base" the future hail suppression estimates, or models, on the amount of knowledge and information available for current, 1975, hail suppression levels and related rain modification capabilities. Thus, the most relevant current information on hail modification and the associated alterations of rainfall was needed as the starting point for conceptualizing the future development of hail suppression.

This paper reports first on our efforts to define the current, 1976 status of hail suppression. The results from a variety of sources reveal an interesting range of outcomes and suggest that an in-depth scientific assessment of the existing projects would be timely and beneficial to the atmospheric sciences community. The second phase of this paper addresses, through use of scenarios, possible future levels of hail suppression capabilities and related effects on rainfall.

Three sources of information on the current status of hail suppression were employed. First, all available "evidence" from various evaluations of existing or recent hail suppression projects was gathered and summarized. The second source of information was the most recent published scientific reviews of weather modification. The third source of information included two recent opinion surveys. One of these was done as part of the TASH project to sample beliefs of hail scientists and practioneers as to current and future suppression levels. A weather modification opinion survey that included hail-related questions done by two Colorado scientists in 1975 provided another set of information as to beliefs about the current status of hail suppression.

From two of these three sources (evidence from project evaluations and published scientific reviews) values representing the present status of hail suppression were determined. These status values were compared with the views reported in the two opinion surveys.

PRESENT STATUS

Project Evaluations

Results from several recent or on-going hail suppression projects, both operational and experimental, were sought. In each instance, we looked for results on projects that had been conducted on essentially one locale for at least 3 years.

One set of information was from a recent evaluation of a commercial hail suppression project in west Texas (Changnon, 1975b). Four years of a project in a two-county area that used cloud-base seeding with AgI was investigated by using historical Weather Bureau hail-day data and crop-hail insurance data. The various results are summarized in Table 1 and show hail reductions ranging from 5% to 94% for various time and space comparisons. The value considered to be the single best estimate of a meaningful reduction was the 48% reduction in the insurance loss cost value, a meaningful value that normalizes annual loss by the annual liability ($ loss ÷ $ liability x 100). Although the statistical significance of these values was not determined, available Illinois and Colorado evaluation statistics (Schickedanz and Changnon, 1970, 1971) suggest these reductions are significant at the 5% level. A study of the rainfall in and around the seeded area revealed there was no detectable alteration in the rainfall (Schickedanz, 1974). Schickedanz (1975) also analyzed the 1970-1973 insurance loss cost data for the seeded counties and the surrounding non-seeded counties in Texas. Predictor equations for the loss cost in each of the two seeded counties were developed on the pre-seed relations of the annual values for the 1926-1969 period. The predicted loss costs of the seeded counties for the 1970-1973 period were much higher than the actual loss costs, and the differences were found to be significant at the 0.05 level. Thus, there is strong evidence of hail suppression in this project.

Another set of information was generated by performing a short study of a commercial hail suppression project that has been conducted for 15 years in southwestern South Dakota (Butchbaker, 1973). Annual hail insurance rates in and around the seeded counties were obtained from the Crop-Hail Insurance Actuarial Association for the 1954-1975 period to derive an estimate of the possible hail suppression in that area. County rates were altered in most years by the Association in response to changing loss and hence should reflect any alterations in crop-hail loss experience in each county. Cloud-base seeding with AgI released from aircraft began in a 2-county area in 1961, and then the seeding effort spread in 1968 to two more adjacent counties to the east. Differences in the annual insurance rates for these two pairs of seeded counties (each with different starting dates) and for two adjacent (control) counties, one to the north and one to the east of the seeded counties, without seeding were determined. These differences (Table 2) were examined for any indications of an alteration of hail rate in the seeded counties.

The before-seeding differences are compared with those after the seeding began for the seeded and no-seed counties. Four values were determined and a relative decrease in hail insurance rates in the seeded counties was shown by each, ranging from 5% to 50%. The median of these four values represents a reduction of 31%. These values were not tested for statistical significance.

An experimental weather modification project run for 4 years in North Dakota (Miller et al.,1975) was chosen as a third source of useful information on the current status of hail suppression in the Mountain-High Plains climatic area. This project involved cloud-base seeding with AgI and attempted to suppress hail and to enhance rainfall. Four sets of hail altered values were presented in the published paper. These values were a 4% reduction in hail depth, a 21% reduction in hailfall energy, a 40% reduction in radar reflectivity, and a 60% reduction in crop-hail losses. Collectively, they indicate an overall reduction of about 30%. This project also reported a 23% increase in rainfall. Simpson (1975a) made a separate evaluation of this project that largely supports the evaluation showing the reductions. Simpson states that "this project provides substantial, but not conclusive, evidence of a cause-effect relationship between seeding and hailfall in the intended direction." Simpson listed certain results considered to be critical. These included:

Table 1. Evaluation of various 1970-73 hail values for a 2-county area of Texas with hail suppression.

Evaluation Basis	Plainview (in seeded area) Hail-Day Data	Seeded Area Liability Values	Seeded Area Losses	Seeded Area Loss Costs (2)
Temporal	41% below average, 3rd lowest on record (1)	81% below average, lowest on record (1)	89% below average, lowest on record (1)	48% below average, lowest on record (1)
Spatial	12% reduction based on comparison with Lubbock values (55 km south); 94% below based on comparison with Levelland values (80 km SW of Plainview)	63% reduction by comparison to 2 adjacent (parallel and east-west oriented) counties with adequate liability (3)	80% below mean of 5 adjacent counties with adequate liability (3)	43% reduction by comparison with adjacent east-west parallel counties; 5% with two counties bracketing (one north and one south) the seeded counties

(1) Record period is 1946-73

(2) Loss cost = [losses ($) ÷ liability ($)] X 100

(3) Liability >$100,000 (≥ 5% of area) in each year

Table 2. Comparison of differences in insurance rates between counties seeded for hail suppression and unseeded adjacent counties in southwestern North Dakota.

	Actual Values, $		Actual rate difference expressed as percent of the control counties mean rate	
	A-C[1]	B-C[1]	A-C[1]	B-C[1]
Average difference before seeding began	6.3	1.6	53	12
Average difference after seeding began	6.0	1.0	40	6
Difference in before-after seeding values	0.3	0.6	13	6
Before-after difference as a percent of before value	5	37	25	50

[1] A = Bowman and Slope counties where seeding began in 1961; before-seed period was 1954-1960

B = Adams and Hettinger counties where seeding began in 1968; before-seed period was 1954-1967

C = Stark and Grant counties are the Control (no seed) adjacent counties

1. Hail/rain ratio (impact energy over mm precipitation) was 0.49 for seed/no-seed. Significance level not given.

2. Insured crop-hail damage ratios suggested 50-75 percent reduction, at confidence level 0.92.

3. Different hailfall versus radar-storm relationships for seeded versus control storms.

   Example: Regressions between maximum hail energy and maximum echo top heights differ significantly for seeded and unseeded storms. Some of the regressions are marginally significant.

Thus, this project provides results that strongly suggest the suppression of hail.

A fourth set of information came from 3 years (1971-74) of results of a hail suppression project being operated by an American firm in South Africa. This project also involves AgI seeding, but the material is injected at cloud-top levels rather than at cloud base. The investigation was based on tobacco crop loss insurance data. The findings (Schickedanz, 1975; Changnon and Morgan, 1976) show a variety of alterations in the hail loss during the seeded period, most of which are not highly significant. Importantly, the results show a diminishment of large daily damage values but with an increase in days with small damage values. This is reflected in the crop severity ratio (area of loss ÷ amount of loss) which shows a reduction of 40% in the seeded period and this is significant at the 5% level (Changnon and Morgan, 1976). Davis and Mielke (1974) also evaluted the South African project and reported comparable results. Simpson (1975a) also investigated the project, and stated, "I believe that the data for the three seasons so far (up to May 1975) would show, if the control cases were randomly selected, a near-conclusive demonstration of hail damage reduction on the order of 50 percent." An analyses of the rainfall during the hail suppression period shows a 4% decrease, but it is not statistically significant (Katsiambrias <u>et al.</u>, 1975).

Table 3. Results of the South Dakota weather modification programs.

	Differences, %, in areas with modification	
	Hail (1)	Rain (2)
1972	-40	+11.5
1973	-20	+ 4.2
1974	-18	+ 9.6
1975	Information not yet available	+ 3.9

(1) Based on comparison of crop-insurance loss cost values with historical, 1924-1971, average.

(2) Based on comparison of May-August rainfall values in seeded and non-seeded areas with adjustment for historical relationships.

A fifth set of information was the results from the South Dakota 'statewide' seeding program. Actually about 50% to 70% of the state, depending on the year, has experienced efforts to simultaneously suppress hail and increase summer rainfall from 1972 through 1975. Cloud-base seeding with AgI was used. The annual results (South Dakota Division of Weather Modification, 1976, and information from discussion with Jack Donnan on 20 November 1975) are summarized in Table 3. The rainfall data used are from the counties in the state, and the hailfall evaluations use the loss cost data obtained from the Crop-Hail Insurance Actuarial Association. Review of the reported values show 1) a consistent increase in rainfall in each year with values from 3.9% to 11.5%, and 2) decreases in hail losses with values from 18% to 40%. The multi-year medians are +7% for rainfall and -20% for hail loss. The 3-year run of low hail losses in the seeded counties have a probability of 6.2% of occurrence (South Dakota Division of Weather Modification, 1976). However, the values do not exhibit any statistical significance.

A sixth set of potential information was from the 1972-1974 hail suppression experiment in northeast Colorado, the National Hail Research Project (NHRE). Although results for the 1972-1974 experimental period are as yet largely unpublished, all available sources of results were examined. The NHRE Project Plan of 1975-1980 (NCAR, 1974) presents rain and hail results for the 1972-1973 experimental period. These 2-yr results indicate a 30% reduction in hail mass on seeded days, which is reported as not being statistically significant. The results presented on rainfall indicate a 25% increase on the seeded days, a value also not statistically significant. Long (1975) reported that the hail results for 1972-1974 showed a reversal, having been increased on seeded days. The hail mass on seeded days was increased 4% when the 33 "uncontaminated" days were used, but was increased by 41% when all 57 study days were used. Neither value was statistically significant, but a median would be +23%. Great concerns about year-to-year changes in the seeding criteria, the delivery techniques (involving cloud-base seeding with AgI in all 3 years plus rocket-borne seeding added in 1974), and the surface network make the results appear very questionable (RANN and UCAR Review Panel, 1974; and Flueck and Mielke, 1975).

Another important on-going major hail suppression project considered for review was the Alberta (Canada) program. Unfortunately, the 2-year Canadian program has a data sample as yet insufficient to provide useful results (Simpson, 1975b). It involves both cloud-base and cloud-top seeding with AgI.

The various results from the six recent hail suppression projects investigated were examined to select the best estimates of hail and rain alteration and these are shown in Table 4. For projects with more than one measure of a change in hail, the median was used as the 'best estimate'. These could have been obtained in a more sophisticated statistical manner if all the raw data had been available, but for the purposes to be served, the median is considered adequate. The six best-estimate hail modification values, listed in the order presented in Table 4, are -48%, -31%, -30%, -40%, -20%, and +23%. Although most are not statistically significant at the 5% level, an <u>important feature is that all but one are reductions</u>.

Table 4. 1975 status of hail suppression and related rainfall modification.

Best Estimates from Project Evaluations

1. Texas: hail = -48% (crop loss cost value), with no change in rainfall

2. Southwestern North Dakota: hail = 31% (crop-hail insurance rates), with no rain change information available

3. North Dakota Pilot Project: hail = 30% (a composite of hail characteristics, radar, and crop loss data), with +23% change in rainfall

4. South Africa: hail = -40% (crop-loss severity), with -4% change in rainfall

5. South Dakota Statewide Project = -20% in crop loss, +7% increase in rainfall

6. NHRE = +4 to +41% increase in hail mass with median of +23%, rain increase of 25%

7. Canada = Insufficient data sample

Published Assessments

1. AMS = Positive but unsubstantiated claims and growing optimism

2. NAS = 30 to 50% reductions in USSR, and 15% decreases in France, but neither proven by experimentation

3. CSU Workshop = -30% (Nationwide - USA)
   -30% (High Plains), with ±10% rain
   unknown (Midwest, with unknown rain)

Opinion Surveys (median values)

1. Farhar-Grant questionnaire (214 answers) = -25% crop-hail damage (nationwide), although majority (59%) admit they do not know

2. ISWS questionnaire (63 answers) = -30% hail loss with +15% in rain (Great Plains)
   = -20% hail loss with +10% in rain (Midwest)

The only increase is from NHRE and its values are questionable for several reasons. The general level of reduction of 20% to 40% is in agreement with NCAR expectations for successful future NHRE, indicating a 30% reduction is most likely (ESIG, 1975). The best estimates of rain modification, in the order listed in Table 4, are ± 0, no information, +23%, -4%, +7%, and +23%. Again, none of these are statistically significant but they indicate a trend to moderate rain increases (3 out of 5 values available). This is in general agreement with earlier findings from Switzerland which showed 60% to 110% rain increases 0 to 190 kilometers downwind of a 7-yr hail suppression experiment (Neyman et al., 1968). Two of the three positive values came from projects that were aiming to increase rainfall while decreasing hail, whereas the South African (-4%) and Texas (± 0) projects were only trying to suppress hail. This may be fortuitous or it may indicate skill in modifying rainfall during hail suppression.

Published Assessments

A second source of information on the status of hail suppression was that available in recent published assessments. The American Meteorological Society (1973) in its statement on weather modification summarizes the status of hail suppression as "positive but unsubstantiated claims and growing optimism". No details are given.

The National Academy of Sciences (1973) describes claims of 30% to 50% reductions in hail in the Soviet Union and a 15% reduction in France. However, their report stresses that neither of these have been established through scrutinized experimentation. The Academy report also addresses apparently successful hail suppression in Kenya, both with rockets and silver iodide seeding, but no reductions are listed.

The third recent assessment-oriented report is that from a 1975 workshop involving 60 scientists with agricultural and weather modification expertise (Grant and Reid, 1975). Two sets of assessments of the status of hail suppression were made independently by two separate subgroups. One published assessment indicates the current capability is for a 30% reduction in hail with a 70% confidence over areas from 200 to 50,000 km^2. This capability is considered to be applicable nationwide, and is the 30% value shown in Table 4. The other current capability published in the Colorado report indicates hail and associated rain changes on the basis of geographical differences. The values include a reduction of 30% for crop-hail loss in the High Plains with a possible ±10% change in associated rainfall (Table 4). The current status of hail suppression in the Midwest was stated as unknown (Table 4). Hence, the assessments from this workshop, both for the High Plains and the Nation, indicate an existing 30% reduction capability. This is in agreement with many of the best estimate values from the project evaluations shown in Table 4.

Scientific Opinion Surveys

Other estimates of the current status of hail suppression were gathered from two opinion surveys. An extensive questionnaire developed by Dr. Barbara Farhar of the University of Colorado and Professor Lewis O. Grant of Colorado State University was distributed to weather modification scientists and practitioners in 1975. Its questions included this one, "On the average, about how much hail damage to crops (in percentages) can be reliably decreased during a year given current technology?" There were 534 responses to this questionnaire and 318 listed "don't know" to the hail question. Of the 214 who answered the question with a specific value, the percentage changes ranged from a decrease of 2 to a decrease of 82%. The median value of the 214 was a reduction of 25% which is the 'best estimate' value shown in Table 4.

A questionnaire about hail suppression capabilities was distributed to 108 scientists during September 1975. These scientists were attending either the annual meeting of the Weather Modification Association in Calgary, Canada, a meeting that focused on hail suppression (Journal of Weather Modification, 1975), or the NHRE Symposium on "Hail and Its Suppression", held at Estes Park, Colorado. About half (63 of 108) responded by completing the questionnaires. The questionnaire requested an estimate of the average achievable modification level (in percent) in 1975 and estimates of the variations (high and low) around this 'best estimate' average due to varying competency and uncertainties. These averages and ranges were requested for both hail and associated rainfall, and for values in 1) the mountain-generated storm areas of the United States and 2) in the Midwest and other areas[1]. Research has shown the regional differences in storms between these two areas (Changnon, 1975a). The results of the questionnaires are shown in Table 5. The median values of 63 best estimates are presented along with medians and extremes, the range of confidence (high and low values) around the best estimate of the current capability.

TABLE 5. Results of questionnaire as to the status of hail suppression in 1975[1].

		Range Around Best Estimate			
	Best Estimate	Lowest Expectation		Highest Expectation	
Rocky Mountains-Great Plains	(median)	Median	Extreme	Median	Extreme
Hail	-30%	0	+40%	-75%	-100%
Rain with hail	+15%	-10%	-35%	+30%	+70%
Midwest and Elsewhere in U.S.					
Hail	-20%	0	+40%	-60%	-100%
Rain	+10%	-5%	-30%	+25%	+70%

[1] Based on 63 responses to 108 questionnaires distributed at Calgary Weather Modification Association Conference (3-4 September) on Hail Suppression, and at Estes Park at NHRE Symposium on Hail and Its Suppression (21-26 September)

The medians of the best estimate values indicate a capability for 30% hail reductions (with +15% rain increases) in the Great Plains, and 20% reductions in the Midwest and elsewhere. Both values appear in Table 4. The range around the best estimates is large. For example, the medians of the highest and lowest expectations for hail in the Rocky Mountains are 0 (no capability) and -75%, respectively. Of considerable interest is the fact that the median values from the two opinion surveys shown in Table 4 are in reasonably good agreement with the other values in the table which were obtained from a variety of projects.

The current consensus about the status of hail suppression is revealed in the two samplings of opinions of weather modification experts in the United States. This consensus reveals a wide variation in capabilities with basically a bi-polar distribution in beliefs regarding the status. The TASH Delphi experiment revealed a very wide range of views on current capabilities. Note in Table 5 how the answers for the 1975 status on hail suppression range from -100% (believe in a capability of total suppression) to +40% which indicates a belief that efforts to suppress hail will actually increase hail by 40%. The Farhar and Grant opinion results show that 59% of those sampled said, "Don't know". However, 26% said obtainable suppression is greater than 20%, and 14% of those sampled said it was 50% or more. The evaluations of current projects with results which indicate a 20% to 50% suppression capability do not agree with the scientific consensus about hail suppression (no knowledge about suppression capability).

Summary

Three different types of information regarding the current status of hail suppression have been collected and evaluated. Three different positions appear in describing the current status. One view is that based upon the results of the evaluations of six hail suppression projects (Table 4). Results for 5 projects indicate the existence of a hail suppression capability ranging from 20% to 48%, although most results are not statistically significant at the 5% level. In general, these results would be classed by most scientists as optimistic.

Another view of hail suppression is that afforded by the various recent scientific reviews of weather modification. These basically reveal a position that suggests "guarded optimism", but with no indication of definitive proof of hail suppression.

The third view that appears might best be labeled as the existing "scientific consensus". The results of two opinion surveys show wide ranging but basically bi-polar attitudes. The majority of weather modification experts indicate no knowledge of a hail suppression capability, but a sizeable minority indicate a moderate (greater than 20%) capability for

[1] Copies of this questionnaire can be obtained from the Illinois State Water Survey, Box 232, Urbana, Illinois.

suppressing hail exists now. At best, the consensus position must be labeled as "don't know", clearly a pessimistic view of hail suppression.

FUTURE MODELS

The second phase of the suppression assessment involved development of hail suppression and associated rain alteration models (values) for 1985 and 1995. The rationale for estimating the future levels of hail suppression included 1) use of the current suppression levels, and 2) the premise that change in capability would occur in the future. Consideration of the wide range of values and beliefs about the current status called for the use of three levels, or 'starting points'; optimistic, neutral, and pessimistic. The actual calculation of the future capabilities was performed using a scenario approach. These scenarios were anchored to the current levels and were bounded by two considerations, the potential future 1) experimentation and resulting scientific developments relevant to hail suppression, and b) operational use of hail suppression. The amount of future activity in these two limiting areas will depend on the future nature of society (need to increase food production, interstate compacts, legal conflicts, etc.). With three different levels of suppression as starting points, and these limiting influences, three scenario routes were developed according to three premises about the future.

1. Moderate to heavy usage of operational hail suppression will occur with only meager experimental attention and support.

2. Moderate to heavy attention (and governmental support) will be given to field experimentation with only meager operational activities occurring.

3. Moderate usage of operational projects will be coupled with moderate attention to experimentation.

The individual scenarios were then framed around the question, "Given current status X and circumstances #1 above, how will the hail suppression capability change? Each scenario is an evolving temporal description of the development of a technical capability to suppress hail. Three scenarios were developed for each of the two basically different hail climates of the United States, the western Mountains-High Plains area (western half of the United States), and the Midwest and all other areas (eastern half). Hence, 3 models, or sets of values, were developed for the west and 3 for the east. The current values were chosen from the range of values reported as the current status (Table 4).

General Remarks on Modification Scenarios

Each scenario is supposed to reflect reasonable and likely scientific and technical developments and not just fanciful imagination. In preparing these models, we temporarily suspended our critical interest in the various past and present hail prevention projects; and for the purposes at hand, we accept as good those current results which cannot be underwritten as certain. We wish at the outset to explicitly identify the six scenario-developed models as "educated scientific estimates", and not as the results of in-depth completed scientific research.

Scientific factors affecting technology development. There are some intangibles which are difficult to deal with in a scientific scenario approach. Improvements or discoveries in certain areas would greatly affect the speed and level of modification technology.

It is unthinkable to expect that a single aspect of a storm, such as production of hail, can be altered without some effect on all other aspects. A cloud system is a complex array of interdependent processes; changing one will change all. The problem of the degree to which hail prevention by chosen techniques will change the rest of the cloud and the surrounding atmosphere is complex to a nearly intractible degree. Obvious negative impacts, if there are any, must be avoided. All other effects must be determined empirically, and only the barest beginnings have been made to date. Advances will occur to remove this uncertainty.

One intangible situation is the effect of the development of a truly satisfactory theory of ice nucleation on the future development of weather modification. Such a development does not seem imminent, but cannot be ruled out for the next 20 years (Young, 1974). Should it occur, it would have a profound effect on many important aspects of weather modification.

It is easier to foresee marked improvement in the understanding of measurements of concentrations of natural and artificial ice nuclei than in nucleation theory. Such an improvement can be expected relatively soon; say within five years. The development in the last few years of the concept of the contact mode (Corrin, 1975) of nucleation (bringing to 3 the number of nucleation modes) has at least focused attention on the complexities in both measurement of nuclei and their action in clouds under various conditions, and this should produce further results. The greatest result from the arrival of acceptable measurements techniques will be more meaningful estimates of seeding rate requirements.

Other more mundane apparing developments expected relate to the logistical and cost aspects of weather modification. For instance, more refined techniques in aircraft traffic control and greater confidence in medium-weight rockets would allow introduction of heretofore forbidden techniques of reagent delivery with a great reduction in cost and greater flexibility and certainty in the delivery.

Improvements in the prediction of hailstorms will reduce the number of occasions when it will be necessary to intervene. Without excellent forecasting and identification of potential (future) hailstorms as separate entities among other, non-hail storms, the hail prevention technology must be applied to a large cloud population. This includes seeding an undesirably high number of cells which would never have produced damaging hail in the natural course of events. Research has shown that seeding for hail suppression in a 5000 km^2 area in Illinois would require 13 aircraft to treat all cells in a given hail period, but that only 40% of these will produce surface hail (Changnon and Morgan, 1976). Such an inefficient application of the treatment agent has several impacts on the effectiveness of the method.

One must assume that present projects which show overall success (Table 4) have done so by producing negative (more hail) effects in some cases and positive (less hail) results in others, but with the effect of the reduction (positive) being predominant. Without accurate isolation of that part of the overall storm population which naturally produces hail, it is virtually impossible to determine the failure and success components and derive methods for improvement.

This problem of the lack of scientific skill in knowing which clouds to seed and when to seed leads not only to much higher costs but to undesirable alterations (more hail, less rain) which mask final results. This can be demonstrated in three cases. First, the North Dakota results (Miller et al., 1975) show that in 27% of the storms in a 4-year period, hail was either not altered or was actually increased. The final result would have been more impressive if these cases had not been seeded. The METROMEX results show that rain in some storms over St. Louis is increased by as much as 100% to 300% (Changnon, 1974a) whereas Auer and Dirks (1974) show that in certain conditions the city acts to decrease storm intensity and lifetime and hence rain production. These counteracting effects do not cancel each other, but the net result is only a 20-30% summer rain increase (Semonin and Changnon, 1974). Thirdly, results from NHRE suggest that seeding of super cells might produce increases in hail (Browning and Foote, 1975). Since these account for about 50% of the hail in the Great Plains and 20% of the hail in the eastern half of the United States (Changnon, 1975a), a project that accidently increases these while decreasing all other storms, particularly in the Great Plains, could produce a net result of slight increase in hail, no change, or a slight decrease.

In a similar view, seeding of nocturnal storms remains a critical problem because 1) many current seeding technologies depend on visual identification of updraft areas which is very difficult at night, and 2) less is known about updraft areas and storm dynamics of many nocturnal thunderstorms. Changnon (1975a) has shown that 32% of the midwestern hail falls at night, and Crow (1969) indicates that 25% of the Great Plains damaging hail is nocturnal. The likely lack of success in effective seeding of nocturnal storms is another factor that has tended to mask the degree of change. For example, let us assume that the 20% average reduction in hail loss in South Dakota (Table 4) was due solely to success with daytime storms which are 75% of the total. The average reduction that must be achieved in the daytime is about 28% to reach a total seasonal reduction of 20%. Here again, continuing scientific study of severe nocturnal (hail) storms, projected to occur in the next 10 years in SESAME, plus continued nocturnal seeding operations and experimentation, should upgrade the knowledge and skills for modification of nocturnal storms.

An analogous problem at the present time is the prohibition placed on cloud seeding during periods when severe weather (particularly tornadoes) is either forecast or underway. This has been considered by NHRE with a potential decision to forego experimentation in such conditions. The same problem has been faced in the design of midwestern hail suppression project (Changnon and Morgan, 1976). In Illinois about 10% of experimental units (hail days) are associated with tornadoes, and state leaders indicated there should be no seeding on these potential tornado days, many of which are serious hail loss days. With a better understanding of hail and severe weather, and as confidence in hail suppression builds, it will be possible to perform modification without undue risk.

In summary, the important point here is that there are several opportunities for scientific and technical discoveries and/or improvements, any of which will affect and improve the technology of hail prevention and favorably affect (reduce) its cost.

Features of the Modification Models

The six scenarios (three for the West and three for the East) outline the future levels that hail suppression can achieve. Each scenario covers a 20-year period (1976-1995) of activities, and each addresses changes in hail and in rainfall related to purposeful modification of hailstorms.

For widespread regional adoption of hail suppression, possible downwind effects on hail and rain were considered. A realistic specifiction of this effect would contain the range (distance) and the quantitative effect (increase or decrease in hail, rain, severe weather or cloudiness). However, the lack of specific information or evidence on downwind effects from hail suppression leads to the conclusion that for the sake of this study, no large scale alterations in downwind precipitation could be defined.

Since most of the hail reductions evident in the 1975 (Table 4) are measured in crop-hail loss values, the future values (models) of hail change are considered to be expressions of changes achieved in property and crop-hail damages. Thus, they imply a change in all the hailstorm factors (hailstone size, hailstone frequency, and wind associated with hail) that collectively interact to produce crop and property damage attributed to hail. The rainfall changes listed are in the amount of the total rainfall during the hail suppression season, whether it be April to July, or May through November. However, the changes in rainfall shown are only those produced as a result of changes in rain on days when hail occurs.

It is possible to rationally develop arguments which predict quite opposite effects on rainfall due to hail prevention cloud seeding. Under the competing embryo hypothesis, the simplest reasoning leads to a prediction of an increase in rainfall; so many hail embryos are created by the seeding that they take up all, or nearly all, of the cloud water. This amounts to a very efficient conversion of cloud water to precipitation in a system which is not naturally so efficient. Under the hypotheses based on more massive applications of seeding material, the effect on precipitation is much more difficult to predict due to opposite and competing effects. On the one hand the dynamic (heating) effect of freezing water becomes significant, potentially resulting in intensification of the inflow of water vapor. If the precipitation efficiency remains the same, this should produce more rainfall. However, after heavy glaciation of the cloud, many of the small ice crystals which are created may be swept away by strong horizontal winds at the top of the cloud. Importantly, at temperatures below -5°C, ice crystals do not aggregate (stick together) very efficiently so that few large particles can form.

Future hail and rainfall values in the models are also season-long averages over a seeded area, whether it is 1000 or 100,000 km^2. However, alterations on most hail days or with individual hailstorms will not equal this modeled average value. A variety of factors including failures in the seeding system, forecasting errors, and storm complexity will lead to different outcomes on a day-to-day and storm-to-storm basis. For instance, Simpson (1973) has shown a capability to increase rainfall in a few individual storms by 300%, but the overall area average increase is much less, about 10%. Similar results were obtained in METROMEX where urban-industrial effects produce 100 to 200% increases of rainfall in a few storms, (Huff, 1975), but the area-seasonal average increase is only 25% (Changnon, 1974a).

Eastern Scenario #1: Application with Major Scientific Breakthroughs

We assumed first that the sense of the rain and hail changes noted in the studies of inadvertent weather modification at St. Louis and La Porte (Changnon, 1968; Changnon, 1972; Semonin and Changnon, 1974) will be reversed initially under planned hail prevention in the eastern United States (Semonin and Changnon, 1975). These results have indicated a direct relationship whereby increases in warm season rainfall are associated with increases in hail (in terms of frequency and energy), lightning frequencies, thunderstorm duration and lightning frequencies, strong wind frequencies, and radar echo sizes, etc. (Changnon, 1974a). These would suggest that by decreasing hail we will also decrease the rainfall and these other phenomena, and Silverman and Nelson (1975) substantiate this possibility in their model calculations. NHRE has considered potential seeding-produced changes in lightning, but no data are available and alterations are considered negligible (ESIG, 1975). Changnon (1974b) has shown the urban-rural differences for hail, rain and thunderstorms for 9 cities in the eastern half of the United States. Seven were found to have average changes in warm season precipitation ranging for rainfall from 9% to 27% increases, for thunderstorms from 10% to 42% increases, and for hailstorm days from 67% to 276% increases. None had decreases.

These results suggest that for a given reduction produced in hail in the eastern United States, a relatively smaller reduction in rainfall should take place. Inverting these figures very roughly to infer percent decrease would suggest that the percentage decrease in rain would be 1/4 to 1/3 the percentage decrease in hail (i.e., a 60% decrease in hail would have a 20% decrease in rain). The inverted percentage reductions in high surface wind speeds and lightning would have a comparable ratio, 1/3 of the hail decrease.

The factor to be determined in order to shed further light on this aspect of the problem is the percent of rainfall falling on "operational seeded" days, or on hail days. The unidentified urban inadvertent weather modification mechamism conceivably operates on all days. In Illinois, 47% of the warm season rainfall falls on days with hail (Changnon, 1975a). The areal variations of rain explain 50% of the hail pattern in Illinois (Huff, 1960).

As part of the scanario we also propose that the technology will be the cloud-base approach to seeding since tracer experiments prove it will function (Semonin, 1972).

In this scenario, the 1975 capability for modifying hail and associated rain, winds and lightning is defined as zero (no skill). However, since a portion of the urban alteration of rain and clouds is related to microphysical processes (Braham, 1974), it is not unreasonable to expect that the degree of inadvertent weather (rain and hail) modification shown will help lead to the future utilization of hail suppression in the eastern United States. This is likely to be sought because of period of high hail losses such as those currently existing in the Midwest. Illinois led the nation in hail losses in 1973 and 1975 and Iowa led in 1974 (Changnon and Morgan, 1976). If one couples this situation with the reduction values for the Dakotas (Table 4), considering them to be largely representative of the storms of the Midwest, a reasonable expectation would be a capability for a 30% reduction in hail in 1985. The inadvertent (urban) results suggest that this also would be accompanied by 10% (1/3 of hail value) relations in summer rainfall, but since only half the rain occurs with hailstorm situations, the net rain change due to hail suppression would be 5%. The associated reductions in the frequencies of strong summer winds and lightning would be 10% (1/3 of the hail value). A 5-percent rain decrease would be minor in light of the reductions in damaging hail, winds and lightning.

Demonstration of this capability by 1985 would likely lead to considerable field experimentation and additional research so that by 1995 a major scientific breakthrough, such as in the theory of nucleation, could occur along with major advances in all other operational phases (nocturnal storm seeding, storm forecasting, and delivery systems) of modification. Such major developments are hypothesized to result by 1995 in a doubling of the 1985 hail suppression capability resulting in a 60% hail reduction. These major scientific advances would likely lead to a capability to moderately increase rainfall (+10%), and to a doubling in the wind and lightning suppression capabilities. The resulting values for this model of events appear in Table 6.

Eastern Scenario #2: Applications with Moderate Advances

This scenario assumes no hail suppression capability in 1975. However, successful experimentation in the Great Plains during the 1976-1980 period would lead to a -30% hail suppression capability with a +6% rain capability (see Western Scenario #1). The increased adoption of hail suppression during 1981-1985 in the Great Plains would lead to a -45% hail suppression capability by 1985 because of general improvement in storm knowledge and seeding techniques. This capability is partially translatable to the East since about 40% of the Great Plains storm types are similar to those in the

Table 6. Models of Modification to Hail Loss and to Rain Quantity, High Wind Speeds and Lightning Frequencies in the Hail Season.

	Scenario model type		1975	1985	1995
	Eastern U.S. Capabilities, Percentage Change				
#1	Applications based on existing findings coupled with major scientific breakthroughs	a. hail	0	-30	-60
		b. rain	0	- 5	+10
		c. high wind	0	-10	-20
		d. lightning	0	-10	-20
#2	Applications based on immediate use of existing findings but without major scientific breakthroughs	a. hail	-12	-22	-32
		b. rain	+ 5	+15	+25
#3	Experimental approach	a. hail	0	-11	-21
		b. rain	0	+ 5	+ 9
	Western U.S. Capabilities, Percentage Change				
#1	Applications based on existing findings coupled with major scientific breakthroughs	a. hail	-30	-40	-80
		b. rain	+ 6	+16	+32
#2	Applications based on existing findings in another area without any major scientific breakthroughs	a. hail	-48	-58	-68
		b. rain	0	+ 6	+16
#3	Experimental approach	a. hail	0	-15	-30
		b. rain	0	+10	+15
		c. high wind	0	+10	+10
		d. lightning	0	0	0

eastern United States (Changnon, 1975a). The resulting seasonal average decrease in hail from suppression in the East would be 18% (40% x 45%), and the rain alteration, based on the urban results, would also be a decrease, -6% (1/3 of the hail decrease). Experimentation would ensue in the East during 1985-1990, but success with the major storm systems would likely not be achieved due to their complexity. Thus, the 1995 capability would remain as in 1985. No wind or lightning alterations are considered likely in this model.

Eastern Scenario #3: The Experimental Approach

This scenario is to a great degree the experimental scenario originally envisioned as a goal for the Midwest by the Illinois State Water Survey in its project to design an experiment in Illinois (Changnon and Morgan, 1976). It is keyed to the National Hail Research Experiment for its initiation. No hail prevention experimentation would begin until 1981 after moderately successful results of NHRE were announced in 1980. There would then be an experiment in the eastern United States of some 3 to 5 years duration to assess the transferability of the NHRE technology to the eastern half of the United States. By 1985 the eastern technology would be in the application stage. At that time, its progress is expected to show successful results only for conventional daytime hailstorms (not for the very severe organized storm systems: the tornado cases = 10%, the nocturnal storms = 33%, or the super cells = 20%) which produce only 37% of the hail. The expected hail reduction, as based on the current best overall values in Table 4, would be 30%. When this is multiplied by the modifiable storms (37%), an overall reduction capability of 11% results. Similarly, the associated rainfall could be increased by 23%, the best estimate based on the five rain-change values in Table 4. However, the resulting increase in warm season rain due to hail suppression efforts would be 5% (37% x 23% x 53%, the rain with the hail events).

Since neither of these values would be economically impressive, efforts to improve the technology would be slow and would continue to be based largely on experimentation. Continued NHRE and SESAME research on super cells from 1981 through 1985 would begin to suggest ways to successfully modify these storms. Follow-on experimental efforts in the Midwest with organized line storms and nocturnal storms could be expected in the 1985-1995 period, and this coupled with findings from likely operational projects in parts of the East with loss would yield results showing a capability of 30% reductions of hail damage with 70% of the storms (21% of total loss). The basic rain increase capability also would not be improved (+25%) but it could also be successfully applied to 70% of the storms yielding a seasonal average increase of 9% (25% x 70% x 53%) by 1995.

Western Scenario #1: Applications with Moderate Advances

The 1975 status of hail suppression in the West in this scenario was based on the results presented in Table 4 for the three projects in the Dakotas. This represents an average reduction of hail loss of 30% plus an associated rain increaseof 23%. Since the rain with hail is about 25%

of the seasonal total (Crow, 1969), the net increase in seasonal rainfall resulting from hail suppression efforts alone is 6%. These values agree well with the capabilities expressed for the High Plains (Grant and Reid), 1975).

The findings from ongoing projects in the Great Plains, plus those from the second phase of NHRE during 1976-1980 would provide clear proof of the 1975 capability (-30% hail, +6% rain), and widespread adoption would occur in the Great Plains. This would include adoption of jet aircraft seeding at cloud-top levels, as in South Africa and Alberta, and the resulting modification capability would become -45% for hail loss in 1985 (Table 6). In particular, the capability to modify equally well nocturnal storms (20% of the total) could be expected and this alone would account for an overall 9% improvement in hail reduction (45% skill x 20% of storms), plus a comparable 3% improvement in enhancement of rain with hail by 1995.

Western Scenario #2: Applications with Major Advances

This scenario also assumes the hail suppression capability shown for the Dakotas in Table 4 exists in 1975. This means a 30% reduction in hail loss with a +6% alteration in association rainfall (Table 6). Such a capability would result in widespread application of suppression efforts in 1975-1985 and a general but slow improvement in the seeding skills. The continuation of NHRE during 1976-1980 would provide useful additions to suppression knowledge but with no major scientific breakthroughs to enhance rapidly the capability. Hence, a slow rate of improvement (approximately 33% of the 1975 value) in modification occurs as a reasonable expectation, leading to a 40% hail reduction capability and a 8% rain increase in 1985 (Table 6). This scenario includes the occurrence of a major scientific-technological breakthrough, as with the Eastern Scenario #1, in the 1985-1995 period. This potential breakthrough (in nucleation theory, forecasting, and suitable storm detection) would lead to a doubling of the 1985 hail modification capabilities. Hence, the 1995 hail suppression skill would be -80% and associated rain increases would lead to a 16% increase in seasonal rain with hail (Table 6).

Western Scenario #3: Experimental Approach

This model scenario is founded largely on NHRE. The 1975 NHRE results on hail and rain are not statistically significant and are further considered to be questionable for a variety of reasons (between year radar calibration differences, seeding technique variations, network shifts, etc.). Hence, the 1975 hail and rain values are zero (Table 6) reflecting no existing capability in the west.

The future experimentation and analysis of NHRE in the 1976-1985 period would likely exclude super cells and/or show no capability for their suppression (Browning and Foote, 1975). A reasonable capability (-30%) for hail suppression from ordinary storms can be expected to be established by 1985 (ESIG, 1975), but since these storms produce only 50% of the total loss, the overall reduction capability will be -15% (Table 6). No rain modification skill appears reasonable and conceptually, a 10% rain decrease with hail suppression is predicted by 1985. Studies to define seeding effects on surface winds and lightning will be pursued in NHRE, but nothing would be established by 1985. Conceptually, seeding could produce increases in winds with no change in lightning (ESIG, 1975).

Efforts beyond 1985 would likely involve a second experiment focusing on super cells and nocturnal storms. Resolution of the proper seeding approach to these storms could be expected along with improved forecasts and detection of incipient hailstorms for treatment. The well-established, level of a 30% reduction in hailstorms would apply to all storms yielding a seasonal capability of -30% (Table 6). Skill in treatment and a storm selection would remove the 1985 problem of rain reductions with hail decreases. However, a 10% increase in a strength of high winds associated with hail suppression activities is considered an outome for 1995 with a 5% increase in lightning (Table 6).

Summary

There are three views of the current status of hail suppression. These can be labeled as 1) optimistic, 2) slightly optimistic, and 3) pessimistic, and they reflect a wide range of opinion and results. Clearly, the current status of hail suppression is in a state of uncertainty. Results of recent projects do not agree with scientific consensus. Review of the existing results from 6 recent operational and experimental hail suppression projects suggests a hail suppression capability in the range of 20% to 50%. The Environmental Impact Statement prepared by NCAR for future NHRE suppression efforts (Environmental-Societal Impacts Group, 1975) indicates that the best estimate of a hail suppression capability to be achieved is a reduction of 30% in hail values that affect crops. One of the necessary steps in the wise experimentation and use of hail suppression in the United States is to cast the current status in its proper light. This can only be accomplished by a more vigorous in-depth study and evaluation of the results of the recent projects than could be accomplished within the time and financial constraints of the technology assessment project.

Six future weather modification models were developed on the basis of the possible differences in current status. However, these six models are not considered to have an equal likelihood of occurrence. First of all, although the suppression capabilities achieved in the 3 western and 3 eastern models differ, they are "pairs" in their basic philosophy. There is a scenario in both the East and West that is based on the potential future occurrence of a major scientific breakthrough which will result in a large improvement in suppression capabilities by 1995. There are also scenarios for both the East and West involving intermittent applications and experimentation but based on only moderate scientific advances during the next 20 years. Finally, in both areas there is the "experimental approach" scenario which is rooted largely on considerable continuous experimental activities with minor adoption activities. We believe that the scenarios of moderate scientific advance and intermittent applications are most likely; the experimental-oriented scenario is the next most likely; and the scenario of application plus major advances is least likely.

The values from these six models were compared with the values from the Water Survey opinion survey and a recent report. Table 7 presents the median values for hail suppression and rain modification from the opinion survey along with the prediction for the year 2000 from the CSU workshop (Grant and Reid, 1975). These values show that the scientific belief is 1) for improvement in the capability to decrease hail with time, and 2) that the hail suppression capability in the Great Plains will be greater than that in the Midwest and elsewhere in the nation. Of interest also is the fact that the 1995 medians from the opinion survey are in agreement with the published values of the CSU workshop, both indicating hail reductions with simultaneous rain increases of a similar magnitude 20 to 25 years from now. The future seeding models from the scenarios (Table 7) have values comparable to those expected by knowledgeable scientists.

Table 7. Estimates of Future Status of Hail Suppression.

	Great Plains (West)		Midwest (East)	
	Hail	Rain	Hail	Rain
1985 ISWS opinion survey medians	-60%	+20%	-45%	+15%
1995 ISWS opinion survey medians	-70%	+20%	-60%	+20%
2000 CSU workshop values	-75%	+15%	-50%	+10%

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REFERENCES

American Meteorological Society, 1973: Policy Statement of the AMS on Purposeful and Inadvertent Modification of Weather and Climate. Bull. Amer. Meteor. Soc., 54, 694-695.

Atlas, D. 1975: Selling atmospheric Science. Bull. Amer. Meteor. Soc., 56, 688-689.

Auer, A. H., and R. A. Dirks, 1974: Contributions to an urban meteorological study: METROMEX. Bull. Amer. Meteor. Soc., 55, 106-110.

Boone, L. M., 1974: Estimating crop losses due to hail. Agr. Econ. Report 267, U.S. Dept. Agriculture, Washington, D.C., 40 pp.

Braham, R. R. 1974: Cloud physics of urban weather modification - a preliminary report. Bull. Amer. Meteor. Soc., 55, 100-106.

Browning, K. A., and G. B. Foote, 1975: Airflow and hail growth in supercell storms and some implications for hail suppression. NHRE Tech. Report 75/1, NCAR, Boulder, 75 p.

Butchbaker, A. F., 1973: Results of Bowman-Slope Hail Suppression Program. J. Wea. Mod., 5, 133-145.

Changnon, S. A., 1968: The LaPorte Anamoly - fact or fiction? Bull. Amer. Meteor. Soc., 49, 4-1.

_____, 1973: Weather Modification in 1972: Up or Down? Bull. Amer. Meteor. Soc., 54, 642-646.

_____, 1974a: Interim report of METROMEX studies: 1971-1973: Illinois State Water Survey Report, NSF G1-38317, Urbana, IL. 181 p.

_____, 1974b: A review of inadvertent mesoscale weather and climate modification and assessment of research needs. Preprints, 4th Conf. on Wea. Mod., AMS, Boston, 347-352.

_____, 1975a: Scales of Hail. Preprints, NHRE Symp/Workshop on Hail, NCAR, Boulder, 48 pp.

_____, 1975b: Evaluation of an operational hail suppression project in Texas. J. Wea. Mod., 7, 88-100.

_____, and G. M. Morgan, 1976: Design of a Hail Suppression Experiment for Illinois. Rept. of Investigation 82, Ill. Water Survey, Urbana, IL, 201 pp.

Crow, L., 1969: Relationships between hail and rain in Kansas, Nebraska, and Eastern Colorado. Final Report NSF G-522, Denver, 34 p.

Davis, L. G. and P. W. Mielke, 1974: Statistical Analysis of Crop Damage and Hail Day Rainfall - Weather Modification Season, 1973-74, Annual Report, Volume 11, Submitted to Laeveldse Tabakkooperasie Beperk, Colorado International Corporation, Boulder, Colorado.

Environmental Societal Impacts Group, 1975: Environmental Impact Statement, National Hail Research Experiment. NCAR, Boulder, Draft of 3 November, 65 pp.

Flueck, J. A. and P. W. Mielke, 1975: Evaluation of hail suppression experiments. Preprints NHRE Symposium/Workshop on hail suppression, NCAR, Boulder, Colorado, 26 pp.

Grant, L. O., and J. D. Reid, 1975: Workshop for an Assessment of the Present and Potential Role of Weather Modification in Agricultural Production, Atmospheric Science Paper 236, Colorado State University, Ft. Collins, 236 pp.

Huff, F. A. 1960: Relations between summer hailstorms in Illinois and associated synoptic weather, CHIAA Research Report 5, Chicago, 35 pp.

_____, 1975: Urban effects on the distribution of heavy convective rainfall. Water Resources Research, 11 (6), 889-896.

Journal of Weather Modification, 1975: Hail Suppression, 7 (2), 179 pp.

Katsiambrias, E. Barnett, J., and W. Beaver, 1975: Comments on the Rainfall Analysis for Hail Days in Nelspruit Area. South African Weather Bureau Report, Pretoria, 12 pp.

Long, A. 1975: Hail Suppression Analyses in NHRE. Weather Modification Program Presented to NSF Advisory Panel for Weather Modification Meeting, NSF, Washington, D.C 1 pp.

Miller, J. R., E. I. Boyd, R. A. Schleusener, and A. S. Dennis, 1975: Hail Suppression Data from Western North Dakota 1969-1972. J. Appl. Meteor. 14, 755-762.

National Academy of Sciences, 1973: Weather and Climate Modification, Problem and Progress. Committee on Atmospheric Sciences, Washington, D.C., 100-106.

NCAR, 1974: National Hail Research Experiment Project Plan 1975-1980. Boulder, Colorado, 286 pp.

Neyman, J., E. L. Scott, and M. A. Wells, 1968: Influence of atmospheric stability layers on the effect of ground-based cloud seeding, I. Empirical Results. Proc. Nat. Acad. of Sci., Vol. 60, 416-423.

RANN and UCAR NHRE Review Panel, 1974: Report of the National Hail Research Experiment Review Panel. National Science Foundation, Washington, D.C., 31 pp.

Schickedanz, P. T., 1974: Evaluation of the rainfall data in the vicinity of the Texas Hail Suppression Program. Atmospherics Inc., Fresno, California, 27 pp.

_____, 1975: Evaluation of hail suppression. Preprints NHRE Symposium/ Workshop on Hail, NCAR, Boulder, Colorado. 1-24.

_____, and S. A. Changnon, 1970: The design and evaluation of hail suppression experiments. Mo. Wea. Rev., 98, 242-252.

_____, and _____, 1971: The design and evaluation of the national hail research experiment in Northeast Colorado. J. Wea. Mod., 3, 160-176.

Semonin, R. G., 1972: Tracer chemical experiments on Midwest convective clouds. Proc. 3rd Conf. on Wea. Mod., AMS, Boston, 83-87.

_____, and S. A. Changnon, 1975: METROMEX: Lessons for precipitation enhancement in the Midwest. J. Wea. Mod., 7, 77-87.

Silverman, B., and L. Nelson, 1975: Some model results for natural and seeded hail-bearing clouds. Preprints NHRE Symp/Workshop on Hail, NCAR, Boulder, 15 pp.

Simpson, J., 1973: Bayesian statistics applied to Florida cumulus modification experiments. Preprints, 3rd Conf. Probability and Statistics, AMS, Boston, 73-80.

_____, 1975a: Assessment of results of hail suppression experiments around the world. Preprints, NHRE Symp/Workshop on Hail, NCAR, Boulder, Colorado, 8 pp.

_____, 1975b: Report on the Alberta Hail Project. Dept. of Environ. Sci., University of Virginia, Charlottesville, 39 pp.

South Dakota Division of Weather Modification, 1976: Recent Rain and Hail Analyses of the South Dakota Weather Modification Program. Pierre, South Dakota, 10 pp.

Young, K. E., 1974: The role of contact nucleation in ice phase initiation in clouds. J. Atmos. Sci., 31, 768-776.