DESIGN OF AN EXPERIMENT TO SUPPRESS HAIL IN ILLINOIS

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INTRODUCTION

The Illinois State Water Survey, with funding from the National Science Foundation (RANN) and the State of Illinois, has just completed a 30-month program aimed at Designing an Experiment to Suppress Hail in Illinois (DESH). The project had a field phase involving radar and field networks (for rain, hail and weather variables); an analytical phase; a social, legal, economic, and ecological impact phase; and a phase integrating the results with those from past hail projects plus key results from other allied Water Survey field projects. DESH is now completed and a final report has been issued (Changnon and Morgan, 1975) which includes the experimental design for Suppress Hail Experiment (SHE). This paper presents the recommended design for a hail suppression project that might be begun in the 1975-1980 period.

Experimental Goals

The goal of SHE would be to discern the degrees of alteration of various hail characteristics including:

1. hailstone size distribution, and derived parameters (volume of ice, kinetic energy, momentum),
2. amount of crop-hail loss (dollar),
3. hail-day frequency,
4. storm-echo characteristics,
5. area of crop loss,
6. combinations of the above characteristics;

plus, associated rainfall characteristics including:

1. rain-day frequencies,
2. rainfall quantity,
3. rain intensity,
4. amount of seeded material in rainwater.

Proof of concept will be achieved when any three of the surface hail characteristics, including one or more of the three insurance parameters (dollar extent, areal extent, and severity) have been reduced 40% or more (from the non-seeded sample) for either of the seeding methods (cloud base or cloud top) over a period of four years. This ensures a 70% chance of detection at the .05 level of significance if an effect is present. If only one method of seeding is employed (cloud base or cloud top), a 40% reduction is required over a period of three years which ensures a 70% chance of detection at the .05 level of significance. In addition, it is required that at least one of the three hailpads parameters (hailstone size distribution, hailstone frequency, and hailfall energy) exhibits a significant decrease at the .05 level of significance over the four year period (two seeding methods employed) or over the three year period (one seeding method employed). Furthermore, it is considered highly desirable that the direction of the differences for other secondary parameters (e.g., from radar and meteorological data) be consistent with the known physical theory and with the direction of the primary parameter differences. In the above context, the historical data are used in the role of crucial and supplementary data to strengthen the conclusions reached concerning "Proof of Concept".

Key experimental features basic to this goal of SHE are:

1. employment of advanced statistical-physical evaluation techniques using control data obtained through randomization and from historical data (1947-1975);

2. utilization of the best established modification hypothesis and seeding techniques;

3. one area experimentation in a heavily cropped and densely insured region; and

4. involvement of all types of users (local, state, federal) of the potential suppression technology directly or indirectly (information exchange) in the experiment.

Design Philosphy

The design of SHE is founded on a philosphy (and approach) identified in 1967 that before launching of SHE there will be sufficient scientific information and evidence of suppression and its mechanisms presented elsewhere to launch a 'proof of concept experiment' (POCE). The perceived need to establish the potential of hail suppression for the nation (National Science Foundation, 1968) led to this philosphy.

The approach chosen for satisfying this national goal was 1) to initiate an extensive, scientifically-oriented experiment in the High Plains (NE Colorado) to a) perform the necessary fundamental research, and b) to test suppression techniques there; and 2) if successful, to subsequently test the results and modification technologies in other hail climatic zones (National Science Foundation, 1968; NCAR, 1969). NHRE became the first part of this sequential approach, and Illinois with its quite different hail climate prepared to become the site for the second part.

Under this approach, however, the expensive scientific investigations of all facets of hailstorms, particularly those concerning the near-storm dynamics and in-storm microphysical processes, were never to be pursued in the Illinois studies. These results were to be obtained in NHRE and translated to Illinois conditions, a condition reflected in the prime goal of the Survey's radar-related involvement and hail research in NHRE.

Thus, the POCE approach for SHE in Illinois was to be based upon four sets of information, as follows:

1. All results from the extensive, 15-year studies of hail in Illinois.

2. Available data from below-cloud and in-cloud measurements obtained from other Water Survey flight programs in 1970-75.

3. The achieved suppression levels revealed by well-conducted commercial (non-randomized) hail suppression programs (Texas and South Africa).

4. The scientific findings about hailstorm modification processes and the actual suppression results achieved in well-conducted randomized research programs (North Dakota and NHRE).

These four information sources not only affect the design of SHE, but they also directly relate to decisions to implement SHE. A critical summary of the key weaknesses in each of these information sources is relevant for understanding the design of SHE and the ensuing recommendations for its implementation. The 15-year effort in Illinois (source number 1) was hurt most by the various failures of the complex CHILL[1] radar system plus its use on NHRE during the spring and summers of 1972, 1973 and 1974, which together resulted in too little 10-cm and dual wavelength data on Illinois hailstorms. The Water Survey flight programs of METROMEX[2] and PEP[3] furnished some useful data, particularly about below cloud updrafts, but the unexpected cessation of the PEP aircraft program due to federal funding cuts led to only limited in-cloud information and none for nocturnal storms. The evaluation of commercial hail suppression projects was largely completed, but as expected it is limited by the lack of certainty due to no randomization.

Finally, the results from scientific projects have been helpful in identifying alterations, as in North Dakota. However, the many failures of

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1 The CHILL radar is a dual wavelength (3 and 10 cm) system developed by the University of Chicago and the Illinois State Water Survey on a program funded by the National Science Foundation.

2 METROMEX is the METROpolitan Meteorological Experiment, a multi-institutional program to investigate urban influences on weather, funded by NSF-RANN.

3 PEP was the Precipitation Enhancement Program aimed at preparing the design for a rainfall augmentation experiment in Illinois. PEP was funded by the Department of Atmospheric Water Resources Management, Bureau of Reclamation.

NHRE for 1972-74 (NSF-UCAR, NHRE Panel, 1974) have 1) not led to any believable identification of hail alteration, and 2) more tragically led to a lack of research into the scientific aspects about hailstorms that only NHRE was supported to provide. Other hail research projects in Illinois and South Dakota were not supported for in-depth hailstorm studies involving aircraft.

Application of Results

A design of SHE is offered, even with the limitations to desired information, because any pursuit of hail suppression in the Midwest in the near future should be based on the best design concepts and information available at this time. A failure to develop a design at this time because certain information elements are missing is not considered justifiable, particularly if socio-economic pressures lead to a decision to start a suppression project (experimental or otherwise) in the Midwest.

The results of SHE, if it were conducted in Illinois, would be applicable to other parts of the Midwest. A study of the hail climate of the nation reveals the area would roughly include the area from east of the 100th Meridian (eastern Kansas and Nebraska) to the Appalachian Mountains (eastern Ohio) and north from Tennessee to Minnesota and Michigan. This is an area where most hailstorms are produced by macroscale weather disturbances with only minor urban and topographic effects on storm frequency.

Design Components

The design of SHE is based on four components and the following portions of this section describes these.

The first of these concerns the modification hypothesis and the related seeding technologies. It addresses the choice of hypothesis to be tested and the seeding technologies.

The second component is the statistical-physical design and evaluation. It concerns the basic area, randomization, experimental area, data for evaluation, and likely times required for detecting changes in hail.

The third component addressed involves the Operational Aspects. Here, the sub-components of operations including the operational center, the forecast needs, radars and communication system are described.

The four component is the Impact Monitoring and Interactions effort. This entails monitoring of impacts to crops, public attitudes, and ecology. It also involves the interactions with institutions of all types, the public, and with all users of the results.

MODIFICATION HYPOTHESIS AND SEEDING TECHNIQUE

Hypothesis Choice

Some major a priori constraints had to be placed on our freedom of choice of hypothesis and seeding methods in arriving at the design of SHE. First, systems employing artillery, ground-based rockets, or horizontally fired air-to-air rockets are not viable in the Midwest at the present time. Secondly, although we cannot a priori rule out the eventual utility of ground-based emission of seeding material in operational programs, such an approach would introduce unnecessary uncertainties into the most critical element of the experiment. Hence, ground-based seeding was considered as unsuitable for a proof-of-concept experiment at this time. Third, the hypothesis and method chosen could not be "avant garde". It must be readily available without the need for developmental programs. Ideally, there must be experiment companies available, willing, and capable of pursing the operational aspects. Although not necessarily accepted by a majority of the scientific community, the method chosen must have been visible to the scientific community for a time sufficient to be considered a "mature" idea. Although not proven, it also must have found sufficient approval and acceptance through statistical evaluation to represent a "reasonable gamble" to those paying for its application.

Conceptual Models. Synoptic stratification of Illinois hail days has shown that the occurrence of hailstorms under simple air mass conditions is of very small import in Illinois. Hailstorms of consequence tend overwhelmingly to be either associated with synoptic scale systems or organized into mesoscale systems. This is probably not specific just to Illinois and is the result of the nearly constant convectively unstable state of warm summertime air masses over the continent. This suggests that the simple, unsteady bubble model of the air mass hailstorm need not be considered of importance for a hail prevention experiment.

Illinois hailstorm echoes tend to occur largely in lines and organized areas, and from this and results on their associated synoptic weather conditions, it is reasonable to infer that the storms of importance will resemble the multi-cell feeder cloud system or the supercell long-traveling storm. The prevelance of the multi-cell type of storm over the other is clear. As in other areas, the hail damage through the growing season in the Midwest is dominated by just a few days of very severe damage out of many more (on an areal basis) of moderate or light damage. It would be tempting to say that these heavy to severe damage cases are due to steady state supercell storms, but that is not correct. Massive, long-track storms typical of the so-called supercell storm, have occurred only twice (15 May 1968 and 3 April 1974) in the 2000 mi^2 area in the 1967-75 period. In fact, a colossal storm, the worst summer hailstorm in Illinois since 1964 occurred in the St. Louis METROMEX research area on 12 August 1973 and was stationary and not at all typical of the supercell type of storm. Clearly, the storm type of consequence and high frequency is the multi-cellular type.

Statistics on the absolute frequency of supercell hailstorms and other types of storms in the Midwest are needed. This problem is to be confronted as a subtask in a new 15-month Water Survey project aimed at assessing the technology of hail prevention. For the moment this must be considered a serious lacuna in our background knowledge about hailstorms in the Midwest.

Basic Modification Hypothesis. Considerations of feasibility and reasonable economy rapidly rule out the total glaciation approach to hailstorm suppression in the Midwest and probably elsewhere. The augmented embryo concentration (competition) approach appears both feasible and economical at the present moment. It is an approach which is, within our present knowledge of the hail process, logical and scientifically sound. It has an encouragingly high degree of credibility within the scientific community. It is also being applied in a number of regions of the world with some statistical indications of success.

There are two distinct approaches to operational application of the competing embryo technique to Illinois hailstorms: 1) cloud base updraft seeding of feeder cells and, when necessary, of mature parent storms; and 2) mid-level seeding of the tops of the new or feeder cells as they grow through a critical height-temperature level.

Seeding Techniques

Delivery Systems. The above-mentioned distinctly different approaches to essentially the same modification hypothesis differ radically only in the system of delivery of the seeding agent. Each suffers in its own way the uncertainties of ice phase seeding: 1) uncertain diffusion of the particles through the required volume; 2) deactivation by exposure to above-freezing water cloud; 3) adverse scavenging by water; and 4) adverse scavenging by natural and artificial ice crystals. The proponents of these two systems can cite operational advantages of one over the other and the disadvantages of the other. Each system operates within the conceptual framework of the same model of the hailstorm. The choice of system arrived at for SHE utilizes both these techniques, separately, in a three-way randomized design.

The high level system is being applied in hail prevention programs in Alberta, Canada and South Africa. Our analysis of the results of this latter project has indicated that it may be reducing the hail damage. The cloud base approach has been applied in Texas, North Dakota, and Kenya. Our analysis of the Texas data indicate the possibility of a successful reduction of hail damage. The mechanics of both approaches are fully worked out so that no developmental work need be undertaken in order to apply them in Illinois. Lastly, there is a reasonable level of acceptance of the soundness and credibility of both methods within the scientific community. There is no clear basis for choosing one over the other, and our analysis of the requirements for a three-way randomization does not predict an unreasonable lengthening of the experiment over the time required to test a single method. The spirit of a proof-of-concept experiment is to answer questions which are being asked about services which are being used and offered. These two approaches to hail prevention have been applied in highly visible programs with sizeable investment of funds by farmer groups with the prospect that this will continue. There is clearly need for an evaluation of both.

Seeding Material and Rate of Seeding. The hail prevention methods selected for trial in Illinois both make use of silver iodide as the ice nucleant. Both utilize the combustion of pyrotechnic mixtures for the production of AgI particles. The cloud-top technique utilizes dropable pyrotechnic flares containing 50-70 AgI. These are dropped very 1000 feet during top penetrations at the -15 to -20C level. The cloud base approach utilizes end-burning flares containing 100 g AgI which burn from 5 to 7 minutes each, permitting seeding rates from 15-20 g/min and greater.

STATISTICAL-PHYSICAL DESIGN AND EVALUATION

The extensive Survey research into designing and means of evaluating hail suppression projects, coupled with the experimental goals and the design philospsphy chosen for the experiment, plus a review of past project evaluation techniques of past projects lead to a central point: the experiment must be designed around a comprehensive evaluation involving surface hail data. A proof of concept experiment must provide clear proof that crop-damaging hail has been altered. Hence, the evaluation must include 1) crop-hail loss data (as derived from a heavily insured area), and 2) surface hailfall characteristics directly related to crop and property loss. These hailfall data are needed to supplement insurance data for areas where it is lacking and where crop loss occurs more than once in a season.

Proof.

Proof of an effect can only be established satisfactorily with a form of control data collected at random during the experimental period. This requirement does not neglect the use of historical crop loss and hailfall data derived from past 8 years of study in the Illinois experimental area. This historical control data coupled with control data obtained randomly in the experiment will shorten the time to detect an effect in hail, a very desirable goal in an expensive field experiment. The level of significance to be sought for any two of the surface hail characteristics (of those seven recommended for collection) is a probability of 0.05 for Alpha (false assertion of a seeding effect) and 0.3 for the Beta value (a false assertion of a no seeding effect). The recommended hail evaluation data include hail days, hail intensity, hailstone size and frequency, crop-hail losses ($), crop loss area, and various combinations of these.

Evaluation must also entail a careful statistical analysis of the rainfall in the experimental area. This would include the frequency of rain days, the daily amount of rain, rainfall intensity, raincell analyses and areal analyses of the seeding material in rain and hail samples. These rainfall data and seeding material information, coupled with the six hailfall data units (see Introduction), must be interpreted jointly with a) 3-dimensional echo (reflectivity) data, and b) synoptic weather conditions to get interpretative information as to any physical processes being altered by the seeding.

Detection of Effect

Detection of the effect of modification is a critical design issue. Past studies clearly point to hail experimentation in one area since area-to-area correlations of hail are weak and the various target-control approaches for getting control data for evaluating are just not acceptable.

Detection of possible hail changes with single-area experimentation, involving randomized seeding of some experimental unit (hour, day, etc.), is partially a function of area size. The larger the area, the less the time required to detect an effect.

Detection is also a function of sampling which rests on dimension of the verification elements. Prior Survey studies show that area-mean hail values (and hailstreaks) necessitate one sampling instrument per square mile to insure a representative measurement of all hailfall parameters over an area of 100 mi^2 of larger. Similar hail-rain studies since 1967 reveal that all desired rainfall expressions require one raingage per 9 mi^2. Each raingage is to be adapted to also record the time of hail. Optimization of costs of these two factors (area size and instrument density) with a realistic expectation of project support funds indicates choice of an experimental area of 2000 mi^2 with hail samplers every square mile and recording raingages every 9 square miles.

Experimental Unit

A key part of the experimental design and evaluation for hail is the choice of the experimental unit. Various evaluation data and a variety of operational considerations affect the unit chosen and failure to define realistically the criteria to declare an experimental unit can produce serious evaluation complications. The large size of the experimental area derived plus the large number of measurement sites together point toward use of daily units for realistic servicing of instrumentation. Proper management of the extensive airborne seeding system required in any highly time-limiting design (such as seed for x hours, no seed for y hours, then seed for z hours, etc.) is unrealistic. Another critical consideration is the use of crop-hail loss data (necessary for evaluation) which is acquired only on a daily basis. Study of past hailfall periods in the 2000 mi^2 experimental area shows them to have durations of 1 to 12 hours (often the hailstorms are intermittent in this period but produced by one major weather condition), and about 30 percent of the time these periods extend into the nocturnal hours or begin at night. Clearly, the minimum of hail activity is in the 0600-0900 CDT period, but it hails at all times. Thus, the experimental unit chosen is a 24-hour period. It will typically embrace all the hail produced in the area by one major synoptic weather system (a feature desired on the evaluation process).

The 24-hour unit choice, coupled with the logistical problems of servicing a large network plus the fact that hail days have a weak tendency (0.3 probability) to occur in pairs in the area, means that the 2000 passive hail samplers (hailpads) must be changed after each period. A simple device for alternatively and remotely exposing dual hailpads at each site is easily available.

The definition of a 24-hour experimental period will be on an objective forecast basis. The specific criteria are explained in the following section on operations. Essentially, analysis shows the use of a certain area thunderstorm forecast techique will result in forecasts that include all area hail days, and it will "over forecast" hail days by about 30%. That is, using this forecast criteria, all potential hail days will be included in the experimental units, but they will be 70% of the total forecast 24-hour experimental units (or 30% of the units will not be hail days due to natural processes). The forecasting will be updated every hour using objective techniques, and when the criteria are met at any time, an experimental unit will be declared.

At this stage in the decision process, the 3-way randomization (1/3 seeded with cloud base release systems, 1/3 seeded with releases at mid-cloud levels, and 1/3 of the units not seeded) choice would be employed. The randomization process would be designed to ensure a similar number of hail-producing weather conditions in each class. For example, 44% of all area hail days are with squall lines, 13% with warm-stationary fronts, and only 3% are due to local instability with no major frontal features. Such distributions (44, 13, 3) would be sought in the samples of each category to ensure against a "bad draw".

Once a given alternative (seed or no-seed) is made for a given day, that alternative is eliminated from the choices for the next forecast experimental unit. This will ensure against runs of similar treatment, particularly in pairs of hail days.

A third contingency in the experiment, the forecast, and choice of days for experimentation concerns elimination of days with atmospheric conditions capable of extremely severe weather events, major tornadoes (tracks > 15 miles) and short duration flood-producing (>3 inches in 2 hours or 6 inches in 12 hours) rainstorms. Although most of these also are hail days, discussions with state officials about experimentation on such days, the lack of specific knowledge of seeding effects on such events, and the attitudes from public sampling effort collectively indicate truly extreme events should be excluded from experimentation. Where possible, atmospheric conditions conducive to such events which, on the average, occur in the area on one day in any 3-year period (1 day of 48), will be used to forecast and to separate out such days from the experiment. Furthermore, if a 24-hour period has been put in the experimental unit and, because of a forecasting error, starts to become such a potential severe event (as evidenced from atmospheric conditions and/or radar data), it will immediately be dropped as a unit and no seeding will be pursued until a new unit is declared.

After a unit has been declared for seeding, another decision process will be used to initiate the actual seeding operations during the 24-hour period. Costs prohibit the 24-hour surveillance flying of seeding aircraft, so they will be activated by monitoring echo and cloud activity. The development of any detectable (> 20 dBZ) echoes and/or cumulus congestus clouds (satellite) in the area will be the criteria used to launch seeding aircraft. Seeding is to be performed on any cloud (cell) entities which have 1) a reflectivity anywhere that reaches 35 dBZ, and 2) tops growing at ≥ 1000 ft/min. Seeding in 24-hour unit randomly chosen for a seeding experiment will continue on all such candidate clouds (echoes) in and approaching the experimental area. Clouds (echoes) chosen for seeding beyond the area will be those whose track and life stage (based on near real-time calculations of echo average characteristics for that period) indicate they will persist into the area. <u>The goal is to seed all possible hail-producing clouds</u>.

Summary

This section has defined the experimental area (2000 mi^2), its instrument density (1 per mi^2 for hail, 1 per 9 mi^2 for rain), and the experimental unit (24-hour) chosen and the reasons for these choices. Proof of hail suppression must come from surface hail data directly related to crop losses. However, it must be accompanied by a meaningful interpretation of the processes altered by using a comprehensive simultaneous analysis of all data. All the hail data, rain data, information deposition of seeding material, and radar echo results will be interpreted according to synoptic weather conditions.

Statistical proof will utilize these data types analyzed on the basis of a combination of single area randomization and use of area historical data to yield two sets of control data. Rigorous significance levels must be reached by at least two of the hailfall characteristics.

Declaration of 24-hour experimental units will occur when weather conditions reach a pre-set area thunderstorm forecast criteria. Three-way randomization (seed aloft, seed at cloud base, and no seed categories) will then be used with built-in sampling regulations to ensure representative samples of weather conditions in each category. Extreme tornadic and flash flood-producing events will be excluded from the experiment for a variety of scientific and socio-political reasons. Once a seed unit has been declared, seeding activity will be launched on the basis of certain cloud activity (satellite detected) and achievement of radar echo criteria (reflectivity and growth).

These decisions as to area size, sampling density, 24-hour unit, 3-way randomization, level of statistical significance, and forecast declaration system all integrate to affect the time required to detect a change in hail. Since such an experiment is an expensive undertaking, all design choices have been made within a cost-scientific optimization framework with a goal of minimizing the length of the experiment.

Given all these factors, the length of the experiment depends on the level of reduction sought. Use of the two most powerful surface hail factors found (amount of loss, or intensity, coupled with area of loss) reveals the following detection times for either seeding technique. Detection of a 20% reduction (at an alpha = 0.05 and a beta = 0.3) would require 24 years; a 30% reduction, 10 years; a 40% reduction, 5 years; and a 50% reduction, 4 years. A year is defined by the crop loss season (mid-May through September) which averages 16 hail loss days in the proposed 2000 mi^2 area. As noted in the evaluation section of the DESH portion of this report, it appears that 30% to 50% reductions have been found in other hail climates using the seeding technologies advocated for this experiment. Hence, a 40% reduction in two or more hail variables seems to be a reasonable goal of the experiment. This would require a 5-year or shorter experiment for each seeding system. At this time no predictable shift in rainfall quantity or rate can be stated.

OPERATIONAL ASPECTS

The operational aspects of the hail experiment must function to fulfill the project goal, the design, the modification hypothesis, and evaluation needs set forth in the prior three sections. Operations must resemble a well-organized, military-type, 24-hour effort with a staff and facilities adequate to eliminate major failures during the experimental period (mid-May through September). For this reason, the personnel selected to perform the operations should be chosen on the basis of experience with past successful field operations. The operational phase of the experiment has five components: 1) an operational headquarters, 2) a forecast system, 3) a seeding system, 4) an evaluation system and 5) a data processing preliminary analysis and an interpretation effort.

Headquarters

A structure must be established in a locale readily accessible to the field operations and located where 1) the project radars can scan adequately the experimental area, and 2) the project aircraft are based. The space should include offices for the project director, a radar operational-communication center for aircraft, two forecast rooms, electronic shops, a ready-room for briefings, a network operational room, analyses space, data and equipment storage, radar antenna sites, and a radio transmission facility. The aircraft will be at an airport where facilities are adequate for their storage and maintenance, and for the storage of the seeding devices and material.

The experiment will be supervised by a Project Director housed at the Headquarters. He must have an assistant. Their major duties are to oversee the field project effort from May-September, to oversee at all times the on-going analyses, to conduct daily briefings, to supervise the choice of experimental units, and to prepare all reports for the project. Choice of experimental units will be based on the randomized scheme initiated at the project start with forecast input to insure representative sampling. This scheme of randomization is described in the Design and Evaluation section.

Forecast System

The basic functions of the forecast system were defined in the previous section on Design and Evalution. Basically, the forecast system is comprised of the staff and facilities functioning within the Headquarters to 1) develop "alerts" on time scales of 3 to 48 hours before experimental units; 2) declare the 24-hour experimental units on any given clock hour; and 3) utilize radar data, satellite data, and all other forms of weather data to monitor and forecast the onset of storm activity inside the experimental area during an experimental unit. Standard area thunderstorm objective forecast criteria developed on DESH should be used to declare an experimental unit. They will result in a forecast of 22 days (units) per season (mid-May to September) on the average. They will over-forecast the hail events (16 days on the average), but will include all hail events.

As part of declaring the 24-hour unit, this system must perform two other key tasks. It must interact with the random choice of treatment (seed - no-seed) process of the Project Director to furnish the basic synoptic weather condition that is about to produce the hail. This is then combined with past seed - no-seed day information and random tables to ensure a comparable distribution of conditions sampled in each experimental category (seeding at cloud base, seeding at upper cloud levels, and no-seed days).

Secondly, the forecast system, in declaring the 24-hour units, must investigate whether the conditions are those capable of excessively severe weather (defined as tornadoes $\geq$ 15 miles in length or rainstorms capable of $\geq$ 3 inches in 2 hours or $\geq$ 6 inches in 12 hours). For the reasons offered in the Design and Evaluation section, days with conditions capable of such exceptional severe weather are not to be included in the experimental sample. This potential is also to be monitored during a 24-hour unit, and if it develops, the unit is to be discarded from the sample and any on-going seeding is to stop.

To perform these functions, certain key facilities must exist. One is a continuous (24-hour) operating radar facility capable of showing, at the desire of the duty forecaster, the position, maximum reflectivity and height of any or all storms within and 50 miles W, SW and NW of the experimental area. Also required will be a synchronous satellite data terminal capable of displaying the 30-minute satellite photographs. Other weather equipment will include facsimile and teletype circuits. The incoming hourly weather data will be fed into a mini-computer, located at the operational headquarters or at a nearby locale, Here, the objective analysis and forecast techniques developed as part of DESH will be used to make each hour the forecast of all critical conditions.

The DESH objective forecast analysis study also revealed that the forecast system to be effective, would require a weather observation station to be established in the Vandalia area. A rawinsonde site needs to be operated in east-central Illinois to form a triad of stations (Salem, Peoria, and Champaign). Releases every 6 hours at all three stations would be needed, requiring additional on-call releases at the Salem and Peoria NWS stations. A Pibal facility would also be operated for the forecast system at Headquarters.

Personnel must be adequate to perform the 24-hour forecast effort from May through September. This includes a forecast system director, 4 duty meteorologists, and 4 assistants to plot data, feed input to the computer, and operate the rawinsonde.

Seeding System

The seeding system will consist of the aircraft and their equipment (racks and pods) for transporting and releasing the seeding material. The system also includes the seeding materials, a radar for aircraft guidance and tracking, a radar-to-aircraft communication system and all personnel.

The aircraft requirements, as based on discussions with operational weather modifiers and after careful consideration of the storm frequency and storm period durations in the experimental area indicate there must be 10 aircraft available for cloud-base seeding activities and 2 jet aircraft (3 crews) available for the high-level seeding. The cloud-base seeding aircraft should be capable of measuring updraft velocities in storms, and the high-level aircraft should have on-board radar and scope photography. All aircraft should have position recording devices. The often multicellular and multi-line nature of hail-producing periods will frequently necessitate pre-storm distribution of these aircraft at 2 or 3 airports around the area after the experimental unit has been declared. Such a distribution will be based on project forecasts. The forecast group will also alert (3 to 48 hours ahead) and advise the seeding system group as to the operational times and locales in the area during a unit. It will also declare the initiation of seeding (if it is a seed unit).

An aircraft related effort initiated well before the experiment will concern planning with the Federal Aviation Agency. The operation of a project aircraft with ability to go to thunderstorms must be understood and cleared by the FAA. A system of routine communication with FAA on operational periods must be established so that aircraft operations are not restricted.

Seeding Materials. The silver iodide seeding will be conducted using pyrotechnic devices. These will be wing-mounted on the 10 cloud-base aircraft. Dropable pyrotechnics will be carried on the 2 high-level jet aircraft in pods. The racks, pods, and pyrotechnics have already been developed and tested. Adjustments to the burn time (vertical distance) of the dropable flares will be made according to predicted storm heights and likely flight levels. Since the presence of the seeding materials (silver) will be studied using rain and hail samples, care must be used in the storage and handling of the pyrotechnics. This must be in a facility well separated from the locale where rain and hail samples are kept.

Radar. Once operations involving actual seeding have been declared by the forecast group, a radar will be used for directing the seeding aircraft. A radar must be devoted to this task and it must be capable of 3-dimensional scans to search for high reflectivity areas and echo configurations indicative of updraft areas. Every effort must be made on any operational period to rapidly discern a general placement of updraft areas (front, back, etc.) and to identify new echo formation zones. If possible, the positions of at least 3 project aircraft should be monitored on this radar system.

The personnel for the Seeding System will include 2 skilled radar operators, the necessary aircraft crews (12 pilots and 3 crewmen), and a radar technician. Major consideration must be given to the employment of a group skilled in aircraft operations and weather modification to handle the entire Seeding System.

Evaluation System

The goals set forth require an elaborate, smoothly functioning system to evaluate the experiment. The basic evaluation tools include 1) a series of surface networks (hailpads, raingages, observers, rainwater samplers), and 2) crop-loss data, 3) atmospheric data that describe the mesoscale environment, 4) a weather radar system, and 5) satellite (SMS) cloud data.

Networks. Four basic networks devoted to sampling the hail and rain in the experimental area are needed. First, the hailpad network comprising 2000 pads (1/mi^2). These will be a "dual sensor" type, either center pivoted (with a pivot timed to occur at 0600 each day), or a dual pad site with a simple movable shield that covers one of the two pads for a 24-hour period and also shifts at 0600 each day. Simple spring-wound timers will suffice to allow the remotely controlled sampling of two 24-hour hail units in sequence before servicing (changing of pads). studies show no cases in 9 years of 3 hail days in sequence. Servicing of these 2000 hailpads will be handled by 20 local residents with each assigned 100 pads, a number easily serviced in a day. Servicing can be on an "on-call" basis, but will be done at least once a week.

The rainfall will be measured in 220 recording raingages. These will be modified to record hailfall times using a new inexpensive timing device which records hail time on the raingage chart with a second pen. Each raingage will be at a hailpad site and they will be located 3 miles apart. These raingages will be servied by 4 trained technicians on a weekly basis.

Rainwater samplers (plastic bottles on fence posts) will be installed at every other raingage (110 total). These will be serviced in an 8-hour period by 3 local field residents on an "on-call" basis with routine sample bottle changes weekly. In addition, one sampler will be located in each of the six downwind regions (2000 mi^2 each). These will be serviced by a paid observer.

A fourth network will be composed of volunteer hail observers sought in and around the experimental area. About 300 to 400 such observers should be organized and furnished with reporting cards. These will give standard hailfall information and any crop or property damage data. These observers will also be furnished with plastic bags and asked to collect hailstones. These will be used in analyses for seeding material.

Crop Loss Data. The experimental area is to be located where hail insurance coverage is extensive ($>$70% insured). All hail insurance companies and associations will be contacted and asked to furnish detailed information on all hail loss claims in and around the area and also to furnish copies of the detailed work sheets of the adjusters.

Further crop-loss data will be collected by use of an aerial (color and IR) photographic technique developed by the Survey. Flights over the loss areas will be made 5 to 15 days after each storm period at an optimum height, 5000 ft. AGL. These photographs will be analyzed by the Survey's technique to develop loss patterns and area mean loss values for each crop and field. Hence, these mapped values will aid in the detailed estimates of loss in the adjusted fields and will furnish desired data in the uninsured areas. An adjuster will be needed to get ground-truth point data to calibrate the loss values obtained from the photographs.

Atmospheric Data. Certain field operations are required to obtain surface weather and upper air data to aid in the evaluation involving classification of the hail periods by a variety of atmospheric conditions. This will necessitate the installation and operation of 15 surface weather stations located in a grid pattern in the experimental area. Each will record temperature, dew point, and winds. These will be serviced by the raingage network technicians.

In addition, the previously described data produced for the forecast system will be used in the evaluation. This includes the hourly surface weather data from the stations to be established to the south and north of the experimental area, and the pibal and radiosonde data from the Peoria, Salem and Champaign sites. These data coupled with all that routinely available from the weather service will comprise the atmospheric data.

Radar. A weather radar (10-cm) wavelength must be available and dedicated to use in the evaluation process. If possible, the radar should have a capability to detect hail in the storms. The dual wavelength CHILL system has such a capability. Operations must be conducted on all experimental units (days) and in a fixed, 3-dimensional scan pattern over the experimental units (days) and in a fixed, 3-dimensional scal pattern over the experimental area. The scans must sample all levels (based on beam width) from the surface to the -25°C level and enough additional levels to encompass the echo tops. Every effort must be made to develop a complete scan series in 5-minutes or less. Personnel needed will include 3 radar operators, an operational director, and an electronic engineer.

Satellite. The evaluation effort will also utilize the 30-minute cloud data furnished by the synchronous satellites and used in the forecast effort. These data will be routinely collected and retained for all convective cloud days. They will be used in the experimental area and six downwind areas to monitor cloud behavior on the mesoscale. Personnel in the Forecast System will store these data.

Data Processing and Preliminary Analysis

A key aspect for a successful operation and evaluation effort is rapid data processing. Quality of all data (raingage, radar, radiosonde, etc.) must be determined as quickly as possible to detect problems. Hence, facilities (computers and film readers) and staff must be sufficient to allow for routine processing of the data. It is extremely important that the data of all types be digitized. The digitization should be on magnetic tapes so that all data from an individual day can be easily studied, and so that all data of a single device (such as radar) can be examined for a whole season. The personnel needs (editing, checking, reviewing, and digitization) include 3 people for raingage data, 3 for hailpad, hail loss and observer data, and 3 for the radar data. Other more complex data can be evaluated by off-duty forecasters.

Project leaders and subsection directors should spend all available time in the operational period (May to September) performing preliminary analysês of the initial processed data. In the off-season (October to April), the 4 field technicians and 7 radar operators can assist in routine analyses as well as repair/calibration of equipment. The project forecast staff will be used to perform a variety of analyses in the off-season. A key effort of the off-season analyses will be 1) to stay current in the evaluation, and 2) to discover any errors or problems that require revisions in the operations of the next season.

IMPACT MONITORING AND PUBLIC INTERACTIONS

This fourth and equally essential part of a midwestern hail suppression experiment concerns how the meteorological efforts (the first three parts: hypothesis, design, and operations) interface with user and the public. It also addresses actual and potential impacts on the social attitudes, on the economy, on ecology, and with any institutional-legal arrangements.

Interactions

Before the experiment can be launched, a carefully presented program to inform the public must be initiated. A social attitudes study pointed to a favorable public attitude towards weather modification experimentation in Illinois. However, it also revealed a great lack of knowledge about hail suppression and that for a complicated, difficult to understand science like weather modification, the majority of the public tends to depend on key local (township, city and county) decision makers for opinion development. Who these decision makers are can vary, and they may include key farmers, bankers, clergy, mayors, elected county officials, extension agents, and conservation district directors. Thus, one major interaction effort concerns local (in and around the experimental area) users and interests.

In Phase 1 of this local interacting effort, the key people must be identified in and around the 2000 mi^2 area, and then systematically informed about all aspects of the experiment. Presentations to these small groups have to be honest and internally consistent. A short concise project information document should be developed for wide distribution. If reasonable, a "citizen's committee" could be developed as a focal point for a continuing interface throughout the project. A project information person is needed at all times to give talks and to answer questions.

The second phase of this local public interactive effort involves working with these local decision makers to develop a series of public presentations to key groups (service clubs, 4-H groups, farmer unions, etc.). The experiment should not be launched until Phases 1 and 2 are well initiated and a favorable and understanding local response is obtained. Among other things, this will aid in the local arrangements for instrument siting, a major effort.

The public in and around the area should be routinely and continuously informed through the news media about the progress of the project (Phase 3). The project forecast regarding experimental days could be aired over local radio stations, and summaries of annual results must be delivered to the public and to the local and state officials. All possible existing means for distributing information, such as the University of Illinois Extension

Service, should be used to distribute project information, both on a regular basis and about specific items of lay interest.

The other major interactive effort concerns related groups or the non-local users of the project results. First, is the crop-hail and property insurance interests (companies and their associations). Successful hail suppression could have a major impact on this industry, and they will wish to be closely informed of the progress and performance of the experiment. Further, their involvement is sought in the form of furnishing detailed daily loss claims and adjustments for the project area. Their endorsement of the experiment is also sought so that local insurance agents will understand the project and its potential value to them.

Another group of users includes various agriculturalists at universities in and around Illinois, agricultural associations (such as the IAA) and the Farm Bureau, and major agri-business related to the region's agriculture. Hail suppression, if successful, would affect them in various ways. The strong influential reputation of the agriculture experiment station and agricultural groups like IAA also means they must be informed about the project so as to secure their understanding to utilize their communication systems. Key officials in these agricultural groups must be contacted and the experiment explained before it is launched. State experiment stations commonly serve as key information sources for most farmers in the state. Being able to give an honest appraisal of hail suppression is in the interest of the experiment stations.

A third group of users to be informed before, during and after the experiment is the governmental officials. At the state level, this begins with the Governor's Office. It would also include key staff in all departments affected by the experiment (Registration and Education, Agriculture, Conservation and Insurance). As part of this, the State Weather Modification Control Board is to be informed about the project according to State regulations. Also, local area legislators should be informed about the project.

At the federal level, all agencies providing support must be informed of all stages, generally more often than grants or contracts require. The project activities will be routinely reported to NOAA (Dept. of Commerce) according to federal laws on weather modification. Presentations about the project should also be scheduled for the Interdepartmental Committee on Atmospheric Sciences so that all federal agencies involved in weather modification will be aware of the project and its progress. An Environmental Impact Statement may be necessary, depending on the funding source/s and those conducting the experiment.

Another user group includes all atmospheric and agricultural scientists and engineers. The results of the project must be distributed to these two user groups. Specific attention should be given to the exchange of information with the weather modification industry. This group will be the main users of the proven technologies, and the project performance and results are of considerable importance to this industry.

Impact Monitoring

The second portion of this part of the experiment relates to the monitoring of social, legal, economic and ecological impacts. Recommended monitoring efforts are described below.

Public Attitudes. The 1974 sampling in central Illinois of public attitudes towards weather modification provides a unique 'baseline' of information prior to any experimentation. Similar sampling of public attitudes, both in and near the project area, should be conducted annually during the hail suppression experiment. This will be a valuable sociological experiment, and will serve as a means for detecting any trends in attitudes towards the project. Effectiveness of the public information activities can also be judged from the monitoring of public attitudes. The results will also be valuable in any future application of a successful technology in Illinois and elsewhere. This questioning should cover perceived attitudes towards economic and other impacts.

Economic Impacts. The crop-loss data collected from insurance companies will be analyzed in detail as part of the evaluation. The dollar losses and areas of loss will be used to monitor the economic aspects. In particular, the loss data should be compared with historical loss values from the project area. Loss in surrounding similar sized areas and for the entire state should be monitored for qualitative assessments of the effects in the experimental area.

Impacts Beyond the Project Area. The potential for altering the precipitation (rain or hail) beyond the project area is of concern to the public and to the atmospheric scientists. The lack of mesoscale numerical models adequate to predict and understand such large-scale effects means that "Extra Area Effects" (EAE) must be monitored on a descriptive, not causal, basis. Five sets of data available on a daily basis should be collected from the surrounding area (50 miles north and south of the experimental area of 100 miles east of it). These extra-area data sets include a) the daily and hourly rainfall data from the Environmental Data Service, b) hail data from cooperative hail observers established by the project, c) the daily crop-hail insurance loss data, d) hourly radar data of project radar systems and those of the NWS, and e) the cloud data of the SMS satellite. Each of these would be separated according to the seeding criteria for each experimental unit (day), and compared by daily means and totals for six 2000 mi^2 areas including one adjacent to the north of the experimental area, one to the south, one to the northeast, two to the east, and one to the southeast. The cloud, radar, and hourly rainfall data will also allow sequential quantitative analyses of the behavior (areal extent and intensity) of mesoscale systems that pass through the experimental area. A rainwater sampler must be installed in each of the six extra areas to collect water for analysis of the seeding material (AgI).

Ecological Impacts. The alteration of hail is considered to have little or no detectable long-term effects on the Illinois ecosystem. Water from melted hail is an insignificant part of the growing season rainfall, and normal damage of hail to the non-crop flora and to the fauna is largely insignificant. Studies of weather (temperature and precipitation) impacts on rabbits in Illinois shows that the warm season weather factors, which are obviously more critical conditions than hail, explain less than 10% of the variation in rabbit populations.

The only environmental consequence that can be imaged from the hail suppression experiment is that from the seeding material, silver. Silver can be toxic to certain species if ingested in sufficient quantities. The amount of silver iodide to be released into clouds is relatively low but should be apparent at levels of 100 to 200 nanograms per liter in rainwater. These levels are 3 orders of magnitude below toxic levels. Nevertheless rainwater samples will be collected throughout the experimental area (one site per 9 mi^2) and used 1) to evaluate the seeding effectiveness, and 2) to monitor silver deposition. Soil samples should be collected from 6 locations at the end of each season and analyzed for silver content. Research into silver effects on ecosystem is on-going at Colorado State University, and will provide indications of levels at which silver might become a problem in the ecosystem. Results to date do not suggest any possible ecological effect from the quantities of silver found in soils in Colorado where weather modification has been performed.

ADDITIONAL RESEARCH

If possible, three areas of research need to be pursued further before a hail suppression experiment is launched in Illinois. Two of these needs related to inadequate information from other Survey projects involving cloud studies using aircraft. The flight programs of METROMEX and PEP were expected to gather sufficient cloud data (on updraft characteristics and in-cloud parameters such as super-cooled water and nuclei) to negate a cloud sampling effort in DESH.

First, the PEP effort involving mid-cloud sampling was suddenly restricted to 2 months of summer data because of funding reductions. Too few hail-producing storms (prior to their development) were sampled. Hence, available background cloud data critical to seeding rate decisions is more limited than desired. More such flights and data are needed.

Secondly, the cloud base updraft measurements and tracer experiments for METROMEX were totally restricted to daytime efforts. Hence, little useful information is available on the 1) updraft characteristics of nocturnal storms, and 2) aircraft operational problems associated with night-time cloud base seeding. This lack of nocturnal storm data and the obvious operational difficulty is a critical issue since 30% of the hailstorms in the experimental area occur at night. The operational problem can only be solved by sophisticated use of radar data (an understanding of likely updraft positions based on real-time interpretation of radar echo data) and excellent aircraft-radar operator communications. Data on nocturnal clouds and storms should be collected to ascertain cloud base characteristics and their relation to radar echo behavior.

The third need derives from inadequate information on the various possible relationships between hail (surface and aloft) and 10-cm radar data. The limited CHILL radar operations for DESH coupled with the loss of the radar to support NHRE in Colorado in the spring and summer seasons of 1973 and 1974 yielded too small a sample of hailstorm data over the Illinois hail network. Hence, a variety of radar-hail relationships (echo reflectivity, growth, volume, and rates of change) cannot be established with certainty.

Recommended efforts, if possible, prior to launching a hail suppression experiment in Illinois would concern research of data collected in a full hail season (April-September). Efforts would include 1) a surface hail network, 2) a good 10-cm digital radar, 3) a good cloud physics penetration aircraft to collect in-cloud data on all possible hailstorms, 4) a second aircraft to measure cloud base conditions (in concern with radar operations), and 5) a high-level capability jet aircraft (suitable for mid-cloud 15,000 to 25,000 ft seeding) to test its operational limitations (in concert with the 10-cm radar) in summer season storms at night and in the daylight. Data analyzed from these five sources would remove uncertainties relating to evaluation (with radar), seeding rates, and nocturnal operations.

REFERENCES

Changnon, S.A., and G.M. Morgan, 1975: Design of a Hail Experiment for Illinois. Final Report AEN 73-07770, Illinois State Water Survey, Urbana, 189 pp.

National Center for Atmospheric Research, 1969: Plan for the Northeast Colorado Hail Experiment. Boulder, Colorado, 44 pp.

National Science Foundation, 1968: Proposed Plan for a National Hail Suppression Research Program. Washington, D.C., 201 pp.

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