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DESIGN OF AN EXPERIMENT TO SUPPRESS HAIL IN ILLINOIS

by

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INTRODUCTION

This project deals with the development of an optimum design of a hail suppression experiment in Illinois. The ultimate goal of the project is to advise the Illinois government and citizens as to the desirability of hail suppression in Illinois, and if desirable, the proper experimental design. Importantly, this project builds upon results from 6 years of prior hail research, some of which was aimed at this goal.

After 10 years of various kinds of specialized hail research projects (1957-1966), the Illinois State Water Survey began a research program in 1967 that was aimed partially at developing a proper design for a hail suppression experiment in Illinois (Fig. 1). Such an experiment in Illinois was considered to have viable prospects within a national framework since the Illinois hail climate is representative of that throughout the Midwest and the crop-hail losses in the Midwest rank second nationally only to those of the Great Plains. More crop-hail insurance is sold in Illinois than any other State, and Illinois ranks 7th nationally in total hail losses per year. In 1973 Illinois led the nation in crop-hail losses with a total of $40 million.

The Design of an Experiment to Suppress Hail (DESH) was not envisioned to be a hurried effort, but one composed of a series of interlocking studies and incorporating a 'building block,' 'stop-go' approach. In the logical sequence of such a program, as shown on Fig. 1, the initial studies were those considered critical to answering prime unknowns about midwestern hail, and thus were essential to proper planning of the later studies of the current design program. The more recent studies and years of study included:

1) ascertaining the potential economic benefits of hail suppression (1969-72);

2) the gathering of basic surface hail data to understand its time-space variability, suitable size and" shape of experimental area, and damage-producing characteristics (1967-72);

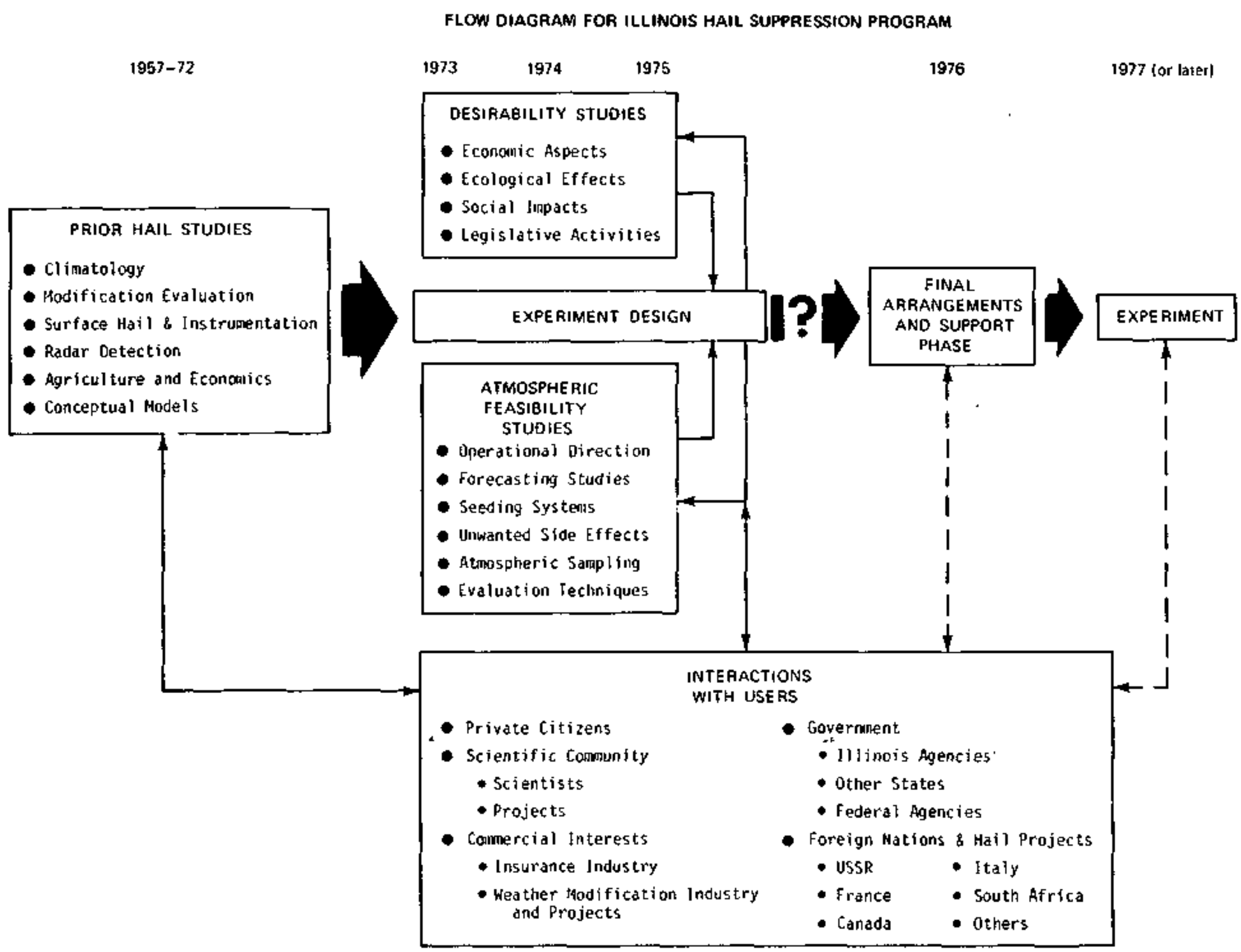
3) developing instruments to provide desired measures of surface hail (1967-72);

4-) investigating the utility of 3-cm wavelength weather radars to detect hailstorms in field operations and for suppression evaluation (1967-69);

5) analyzing historical hail data so as to ascertain the optimum statistical design, best evaluation techniques, and the probable length of a well-designed program (1967-70); and

6) conceptual modeling of hailstorms (1969-72).

Fig. 1


FLOW DIAGRAM FOR ILLINOIS HAIL SUPPRESSION PROGRAM
1957-72
1973
1974
1975
1976
1977 (or later)
DESIRABILITY STUDIES
Economic Aspects
Ecological Effects
Social Impacts
Legislative Activities
PRIOR HAIL STUDIES
Climatology
Modification Evaluation
Surface Hail & Instrumentation
Radar Detection
Agriculture and Economics
Conceptual Models
EXPERIMENT DESIGN
!?
FINAL ARRANGEMENTS AND SUPPORT PHASE
EXPERIMENT
ATMOSPHERIC FEASIBILITY STUDIES
Operational Direction
Forecasting Studies
Seeding Systems
Unwanted Side Effects
Atmospheric Sampling
Evaluation Techniques
INTERACTIONS WITH USERS
Private Citizens
Scientific Community
Scientists
Projects
Commercial Interests
Insurance Industry
Weather Modification Industry and Projects
Government
Illinois Agencies
Other States
Federal Agencies
Foreign Nations & Hail Projects
USSR
France
Canada
Italy
South Africa
Others

All of these initial studies have been performed under a combination of State, private industry, and National Science Foundation sponsorship (NSF GA-482, GA-1520, GA-4618, and GA-16917). These studies have provided a) the information desired, and b) importantly, the information that indicated that a suppression experiment in Illinois was possible within a scientific framework and desirable within an economic framework. Other important study and information areas essential to a properly designed experiment are under study but as yet unaccomplished. These include:

1) investigation of seeding systems and determination of the technology needed for Illinois types of hailstorms;

2) evaluation of potential adverse side-effects from hail modification (increased severe weather, decreased rainfall);

3) study of hail forecasting techniques for operational utility;

4) evaluation of 10-cm radar for monitoring of hail-production in storms for operational seeding decisions;

5) the development of a proper social framework for the experiment;

6) chemical monitoring of background amounts of potential seeding materials in Illinois rainwater and hailstones so that measurements during an experiment can be used in the evaluation of possible effects on the ecosystem, to examine the efficacy of the seeding system, and to discern possible differences in the hailfall characteristics of seeded and nonseeded storms;

7) atmospheric sampling of Illinois hail-producing cloud conditions with respect to their moisture and nuclei flux, updraft characteristics, and relevant cloud nuclei so as to guide decisions on seeding agents and techniques; and

8) numerical modeling of single and multiple convective clouds for prognostic and diagnostic (evaluation) utility.

Fortunately, two other major atmospheric research programs developed in Illinois in the 1971-72 period: one concerned the study of inadvertent modification of rain and hail at St. Louis, and the other concerned the development of a rain enhancement experiment in Illinois. The St. Louis METROMEX program with NSF, AEC, and State support is providing information needed under studies 7) and 8) above. The rain enhancement program with Bureau of Reclamation support has provided some of the information needed in studies 6), 7), and 8). The decrease of support for this project may necessitate future research on this hail project of the large cloud and updraft data sample. The Survey also developed, over a 2-yr period, a model state law concerning the permissive control of weather modification activities in Illinois, and it was enacted in September 1973. These efforts and programs have and will provide information in these subject areas needed for DESH (Design of Experiment to Suppress Hail) in Illinois.

Therefore, DESH concerns studies 1), 2), 3), 4), 5), and 6). Items 1-4 are being handled through a simulation approach since they basically direct themselves to the final and largely operational aspects of the envisioned experiment. Item 5 involves a 1974 survey of public attitudes on potential hail suppression in Illinois plus a variety of communications of results and recommendations to the public and the government. Item 6 involves a rainwater and hailstone sampling effort during 1974 to measure silver content.

USER RELATIONSHIPS

A central thrust of DESH concerns interfaces with users. The strong interactions and efforts with users during the first year of this project have occurred for two basic reasons. First, the project is oriented strongly to providing information to users of all types. Secondly, the project builds upon six years of hail research sponsored by a commercial interest, the State, and the National Science Foundation. This considerable experience and resulting data base make us recognized national and international leaders in hail research and knowledge.

The principal users of our results can be categorized within two groups: 1) private and commerical users, and 2) government users. The major role of user interaction in this project is displayed on Fig. 1.

The private and commercial users of the results of this project and those of prior hail research efforts at the Water Survey fall into six classes. Probably the one group reflecting the greatest interest in our results is the crop-hail insurance industry. We have worked closely with this industry in our project, and they supplied us with a variety of data including crop-hail adjustors' worksheets giving detailed data on losses within the hail network study area. We have in turn worked with them providing results and information about hail in Illinois, plus general information about hail suppression programs. Examples of our interactions with the hail insurance industry are presented in Appendix A.

Within the category of non-governmental users are two other classes, 1) students performing scientific research related to hail; and 2) scientists, largely meteorologists, performing research and operational duties related to hail. Basically their utilization relates to our hail data and related meteorological results. Another user has been the general public. Several newsreleases and TV-radio interviews were conducted to inform the public about hail in general and this project. A fifth user is the hail suppression industry. Analysis and evaluation of commercially performed and public supported hail suppression projects has been performed. Efforts to supply this industry with information from our project of use to them have been extensive. The sixth type of non-governmental user has included authors of books who have sought out our material for their use.

The other major class of users is governmental (Fig. 1), and this includes state, federal, and foreign governments and their scientists. Within the context of state-related users, we include the State of Illinois with its aeronautical interests. Aeronautical interests in the state and University of Illinois have utilized project results and weather data available through our operations for training pilots and for planning aircraft operations. The state of South Dakota has utilized our advice in attempts to evaluate their statewide hail seeding project. Certainly, a prime user of the results.of this research has been the State Water Survey. This use involves results pertaining to the proper design of a hail suppression experiment for Illinois. These elements include a) a means to forecast hail, b) the means to detect hailstorms with radar, c) the means to seed hailstorms, d) the instrumentation to measure the surface hail and rain, and e) techniques to evaluate the results. Results relating to six other basic hail research activities have been completed in this and prior hail studies over the past 6 years, and were the basis for the Survey's decision in 1973 to complete the current project so as to advise the State of Illinois on the need and optimum design of a future hail suppression experiment.

The project results and expertise have been utilized in several federal agencies. One user has been the National Center for Atmospheric Research which has sought information and assistance in their NHRE project. We were involved in the activities of the planning committee for the national NHRE and have been subsequently involved as subcontractors for radar and surface network projects there. Various hail information also have been supplied to representatives of Environmental Data Service and the National Weather Service, parts of NOAA.

A final set of governmental users relate to foreign nations. Considerable effort has been extended to supply extensive information, both in published form and through visits, to scientists and representatives of the governments of the Soviet Union, Canada, Italy, and France. Our latest activities have included providing information to the Republic of South Africa on the design and evaluation of a program being conducted by an American commercial seeding organization for that nation.

In summary, we have provided a vast variety of data and information on hail to a widely ranging audience. To provide some example of this wide audience, a partial list of those who requested information during 1973 appears below. These people were given varying kinds of information in relation to their requests.

Requestors of Hail Information, Findings, and Data

B. C. Reed, Manager, Safeco Insurance Companies, St. Louis, Missouri
D. G. Yoder, Claims Supervisor, Country Mutual Company, Bloomington, I11.
N. G. Bailey, Prof. Dept. of Aeronautics, Miami University, Ohio
E. P. Lozowski, Asst. Prof., University of Alberta, Canada
D. D. Vento, Central Office of Agronomy and Ecology, Rome, Italy
G. Thiem, Manager, Crop Insurance Research Bureau, Evanston, Illinois
K. M. Hudson, Student, National Law Center, Geo. Washington Univ., Va.
W. A. Mordy, Center for Study of Democratic Institutions, Santa Barbara
M. C. Williams, Director, South Dakota Weather Modification Commission, Pierre
T. J. Henderson, President, Atmospherics Inc., Fresno, California
J. H. Renick, Directing Meteorologist, Alberta Hail Studies, Canada
D. R. Haragon, Chairman Dept. of Geosciences, Texas Tech. Univ., Lubbock
G. C. Simmons, Director, Scott, Foresman and Co., Glencoe, Illinois
S. Nelson, Meteorologist, National Weather Service, Oklahoma
W. Swinbank, Director, National Hail Research Experiment, Boulder, Colorado
L. Rediger, Claims Manager, The Country Insurance Companies, Bloomington, I11.
G. S. Strong, Student, University of Alberta, Canada
P. J. Waite, Climatologist for Iowa, NOAA, Des Moines, Iowa
L. B. Kueck, Underwriter, MFA Insurance Companies, Columbia, Missouri
R. E. Flexman, Director, Inst, of Aviation, University of Illinois, Urbana
P. Admirat, Director, French Hail Research Program, Marseilles

Our relationships with several users have been established and are being judiciously maintained. Those with hail insurance companies, certain State agencies concerned with weather, and on-going hail research and hail suppression projects here and abroad are being sustained.

These relationships have been established 1) through performing research for and with crop-hail insurance companies, 2) exchange of data with insurance companies and other hail projects, and 3) through long-term consistent effort to publish hail results in a variety of scientific journals. These relationships are sustained by telephone, by routine correspondence, sharing of annual data, and by performance of (or assistance in) joint research studies or operational projects. It does involve a recognized, time-consuming effort to sustain such relationships.

Progress of Project

* The progress and plans of the various aspects of DESH can be easily evaluated because the research.has been programmed using a systems engineering approach. The variety of sub-projects involving various physical studies are interrelated using a series of milestones. The timing of these with the social and ecological research activities was carefully planned.

The original project Milestone Chart is included (Fig. 2). Milestones 10 through 15, described below, have just been passed, and the results obtained under each form much of this report. The results of the first year results (Milestone #15) is represented by the compilation of this report. The headings of the following list identify the Milestones that they refer to. Important social and environmental sampling efforts related to Milestone 31 also began in this period.

LIST OF MILESTONES SCHEDULED FOR END OF FIRST YEAR

10. Radar analysis - end of second observation period concluded; preliminary analysis completed on 6 cases (see Appendix B); and needed changes for future data and operations were incorporated into 1974 operations. Results in fall effort were reviewed and compared with first (Spring 1973) period results. Analysis done includes partial reconstruction of the life cycle of storms and hail-producing systems (lines) to determine ability to monitor hail development, and to identify precursors of hail development and fallout. Results are important in a) development of hail prevention operational criteria, b) evaluation of alternative hail prevention techniques, c) evaluation of potential unwanted side effects, and d) examination of radar observations and analysis techniques for adequacy accomplish the above.

11. Analysis of meteorological and surface observations - end of second observational period all data digitized and mapped on a storm case basis. The effort in 1974 was slightly modified as dictated by the 1973 results. The spring and fall 1973 observations consisted of hail, rain, and weather observations over the Central Illinois Network plus regional meteorological observations, radiosonde releases, and surface synoptic and upper air observations received via teletype and facsimile for use in operational forecasting and study. Observations collected in non-radar operational (May-August 1973) period have supported studies on hail damage as a function of hail parameters, of forecasting, and of related meteorological parameters such as wind relationships with hail damage.

12. Hail forecast studies - initial results from study of pre-project (1967-72) #5 hail events were obtained, and decisions made as to the directions for future field operations and analyses. Forecasting techniques are being developed for operational use and for use in hail prevention evaluation schemes. The effort included a) study of radar-hail relationships based on past network data and our large store of past radar films, b) evaluation of an ensemble of stability indices and parameters derived from soundings for forecasting skill, and c) determination of synoptic dependence of hail occurrence based on a digitized synoptic weather data bank and digital techniques.

13. Evaluation of hail prevention techniques - results from the conclusion of literature review completed; list of seeding techniques completed along with identification of weaknesses in theories of individual techniques; evaluation of results from other hail suppression projects (experimental and operational) to gain insight on the effectiveness of their techniques; and consideration of seeding techniques and prediction of effect of each type of intervention on radar parameters was begun.

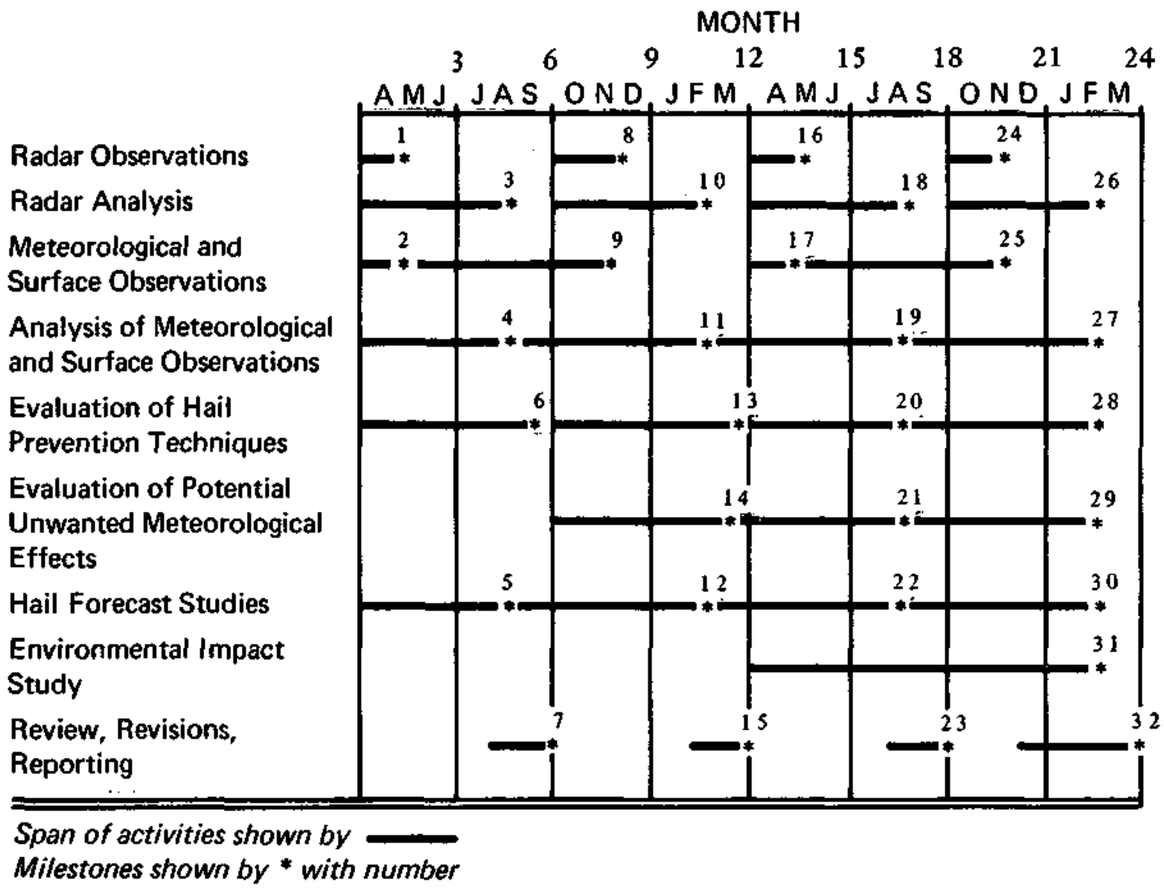


Figure 2. Milestone Chart

14. Evaluation of potential unwanted meteorological effects - first analyses of this initiated, but work is lagging behind plans after Milestone 14.

15. Review of results of the observations from the first and second operational periods, related analyses, and studies was completed. Revisions of procedures, techniques and lists have been completed, and the summary of first year's results (this report) has been completed.

RADAR OPERATIONS AND ANALYSIS

(Milestone 10)

Radar System

The radar system employed in DESH is the dual wavelength radar developed by the Water Survey in cooperation with the Laboratory for Atmospheric Probing of the University of Chicago. The system also has been utilized as part of the National Hail Research Experiment, and was commited to operations during 1 May-31 July in Colorado as part of that project. Its location for DESH is shown on Figure 6.

Radar operations in the fall were conducted mostly with the processer recording mode set to record only the 10-cm and 3-cm powers and summary doppler data. In this mode, tape consumption is low, yet all desired information such as the hail signals and liquid water contents can be computed afterwards. The operations in the fall of 1973 yielded data that filled 19 magnetic tapes (2,400 ft each) during 12 days of operation. Scope cameras were operated at all times, and 5 rolls (100 ft each) of scope photographs were collected. About 100 Polaroid photographs were also taken.

Development of this large, complex system is still underway, and time is divided between its exploitation in pursuit of research goals and in working on it to bring it to an optimum performance level for DESH and NHRE. Problems in system development are obstacles to full data utilization in the analysis phases for both the 1973 Colorado and Illinois data-collection efforts. Some discussion of these problems will be given here, but details of radar system development are more pertinent to the system-oriented Colorado project and will be more fully covered in the 2-yr final report being prepared for that project.

Scope and Photographic Problems. Film from the dual wavelength radar was difficult to analyze because the scope display did not represent details of intense echo cores in a clear and distinct fashion. Noise in the data (see B Scans Section below) also contributed to.the difficulty in analyzing storm structure from the film but this was a secondary concern.

The display used in 1973 was such that when the signal crossed the 18 dbz threshold, the displayed intensity was a maximum. Between this threshold value and 30 dbz the display was left black. The 30 to 41.5 dbz signal range was displayed at a low intensity and four high ranges, at 12 dbz intervals, were displayed at successively higher scope intensities. This echo presentation scheme resulted in two problems. First, the film (RAR 2496) used to photograph the scope usually was not able to reproduce the higher display intensities in a manner that could be distinguished by eye. Occasionally, it was also difficult to distinguish the threshold contour from the intense regions on the display (see Fig. 3). Therefore, a new display of grey shades was developed (Fig. 4) in which only two non-zero brightness levels are employed. The less bright. level corresponds to the 18 to 29.5 dbz signal range, the brighter shade to the 30 to 41.5 dbz range, and the range 42 to 53.5 dbz is allowed to remain black. The two brightness levels are then repeated for signals in the ranges of 54 to 63.5 dbz and 64 to 73.5 dbz, respectively. Figure 4 is an example of how dual wavelength data appear on film when the new display was in use on a severe hailstorm and tornado day on 4 March 1974. The structure of this well-organized storm is readily discernable.

B Scans. Examination of the B scans of the dual wavelength data revealed the presence of occasional erroneously high signal values. The spurious data usually occur in groups along radar radials, such that if the signal in one range bin is noisy, the entire ray at that azimuth and elevation is noisy. This tendency can be noted in Fig. 3. Since the erroneous data include very high dbz values and gradients, these become easily eliminated.

Hail Signal Research. The CHILL radar is being utilized, even as it is being developed and brought up to full operational efficiency, in support of the National Hail Research Experiment in Colorado and in support of DESH in Illinois. Data accumulates from both of these efforts. These data, recorded on magnetic tape, are the material with which the hail-detection potential of the CHILL radar will be studied and evaluated. A very preliminary step in this evaluation has been taken and is reported here.

The following discussion will center on data collected in Colorado with NHRE on 29 June 1973. The main concern here is the radar system and not the particular hail situations. What can be learned about the system with this Colorado data will be an advance for our Illinois work, as well.

Figure 5 shows a composite in "B" scan format (range vs. azimuthal angle) of the pattern of 10 cm Z and the derivative with range of the ratio of Z_{10} to Z3. The theory of dual wavelength hail detection says that, apart from signal fluctuation effects, this derivative, which we call y', can be negative only at the far edge, with respect to the radar, of a hail volume or shaft. In the figures displayed here, y' is plotted in coded form (table) with letters for the positive range of values and numbers for the negative. The incremental interval is 0.5 db/150 m, or 3.3 db/km. The values of Z^{10} are also coded: 0 is the 18 dbz threshold, 1 is 25-29 dbz, 2 is 30-34.5 dbz, and 3 is 35-39.5 dbz.

In a full evaluation of the hail detecting capability we will require very detailed and comprehensive data on when and where it is hailing and not hailing. In the present case we can only focus attention on the hailgauge location (NHRE No. 449), indicated clearly on each map., at which we know positively that hail fell between 2035 and 2105 MDT, and with greatest intensity in the 2040-45 period.

The radar maps for times near the time of most intense hail are of some interest. First, the 10 cm Z values over and around the gauge are not very high (highest value < 39.5 dbz). However, we do see negative values of y' in the neighborhood of the gauge, some of them quite large negative values. In other words, the hail signal suggests the presence of hail while the conventional 10 cm Z criterion is marginal. Of course, by using surface data from one gauge only, we can say nothing about false alarms.

The y' fields in Fig. 5 are seen to be rather erratic or noisy. This can be a real effect due to the distribution of hail and water, but undoubtedly also is a result of signal fluctuations. Considerable work remains to be done to determine the scale of smoothing to be applied to these fields to remove, as much as possible, the effect of these signal fluctuations.

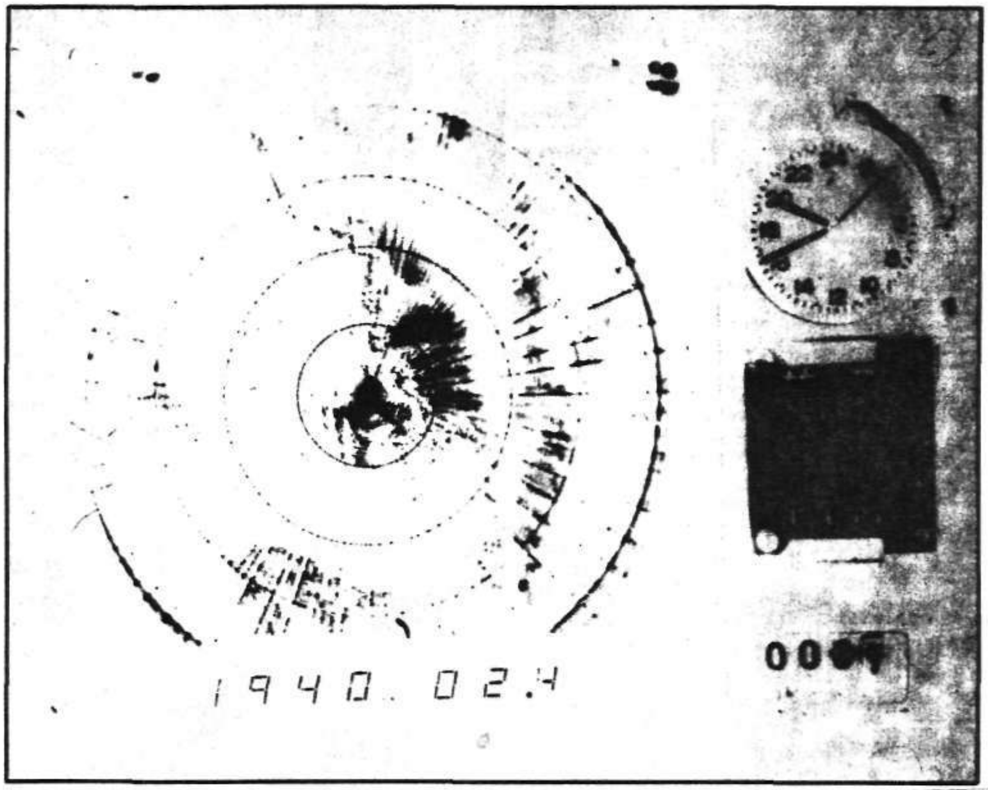


Figure 3. Original radar display used in 1973

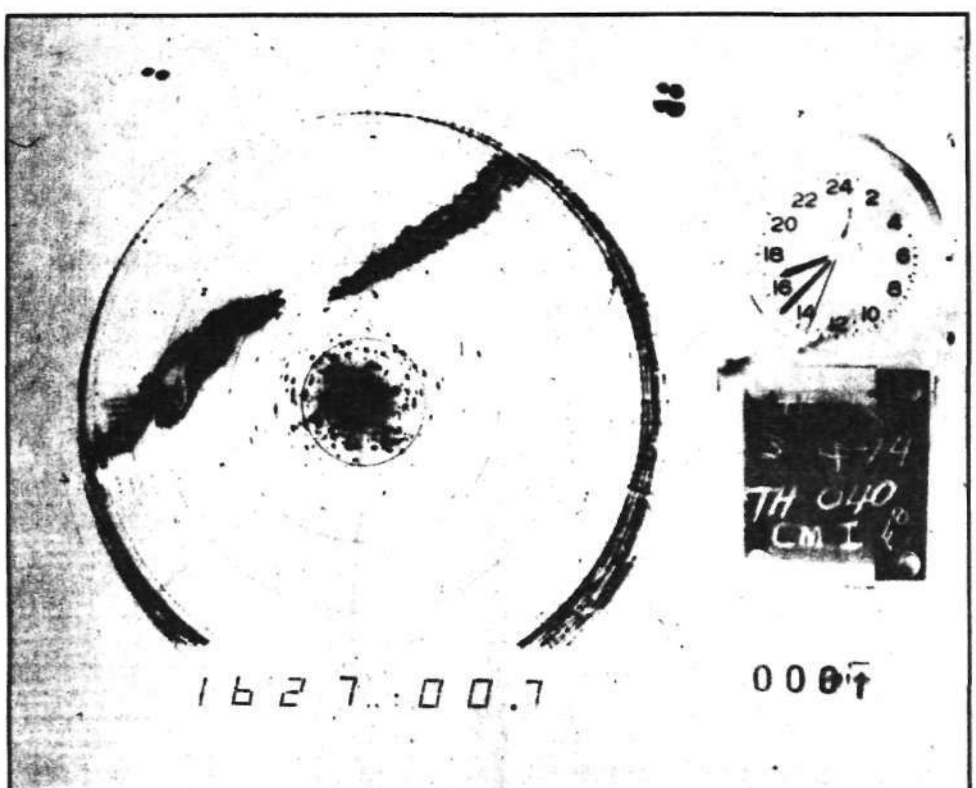


Figure 4. Altered radar display for 1974

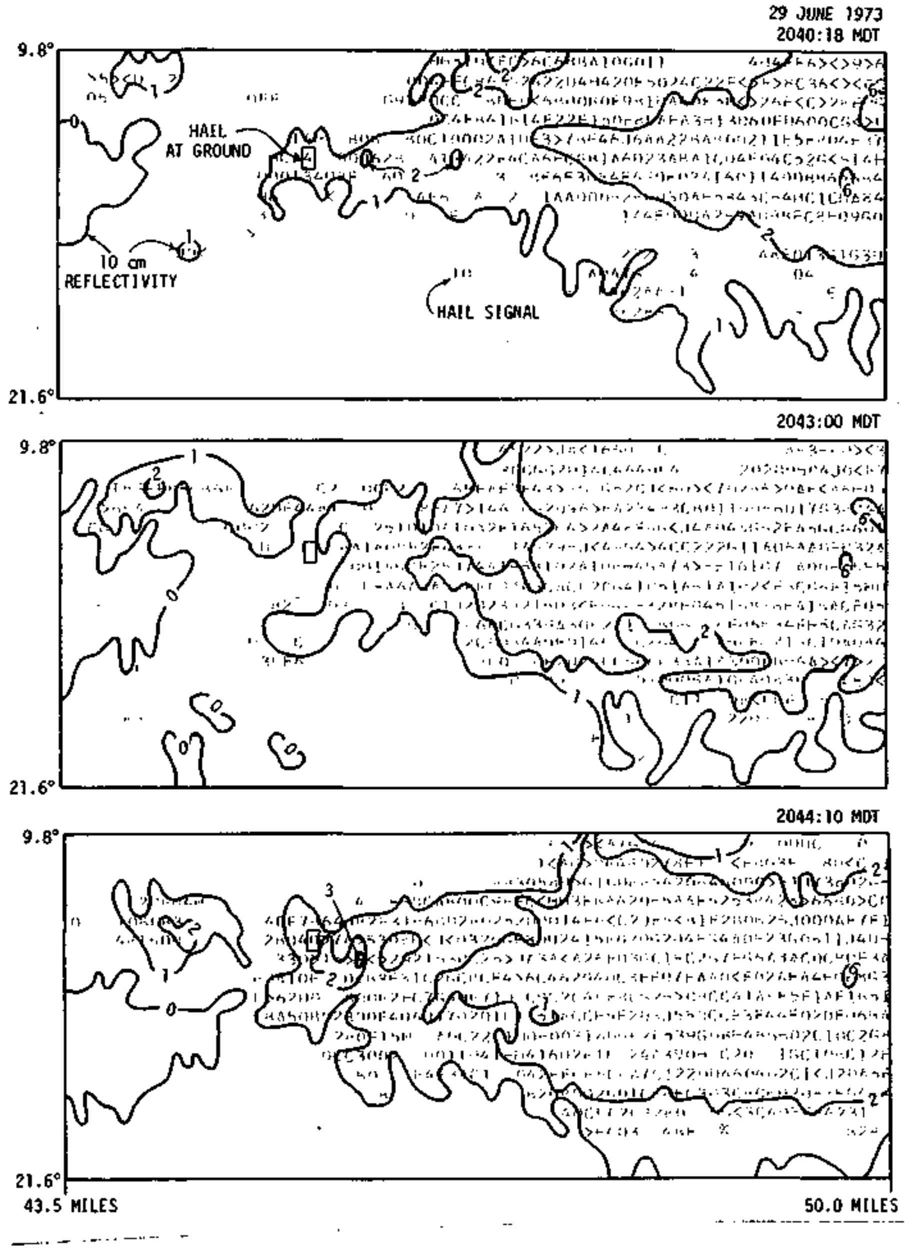


Figure 5. Hail signal (characters) and 10 cm reflectivity (contoured) for the period 2040-2045 MDT June 29, 1973. Numbers correspond to negative values of hail signal. The characters J-A and 0-9 correspond to the range +5 to -4.5 db/150 meters, in 1/2 db/150 meters units. Reflectivity contour labels correspond to signals of 18-24.5 dbz = 0, 25-29.5 dbz = 1, 30-34.5 dbz = 2, 35-39.5 dbz = 3, and 50-54.5 dbz = 6. During this 5-minute period approximately 0.1 inch (water equivalent) of hail was recorded at site 339 (the box in the figure).

METEOROLOGICAL AND HAIL OBSERVATIONS
(Milestones 11 and 14)

Field Operations

Operations in the Spring of 1973 provided good surface hail data but associated radar data were scanty. The radar had undergone considerable modification (the entire 3 cm radar portion had been miniaturized and remounted on the rotating part of the antenna of the 10 cm system) and was not in good operational condition until the second half of March. Signal processer problems then nullified attempts to tape record data, and the radar had to be dismantled for transfer to Ft. Morgan, Colorado, in the first days of April so as to ready for NHRE operations planned to begin on 1 May.

Nevertheless, the operational and forecasting experience gained in this initial period of exercising our weather watch capability was extremely valuable and did produce a very interesting example of a tornado and hail producing situation (see Appendix B, a case study). A remarkably similar situation occurred during the fall 1973 operational period and was successfully forecast.

The fall operational period of 2 September to 6 November was much more successful than the Spring effort with useful radar data collected on four hail days. Radar operations also supported a study supported by the U. S. Air Force Cambridge Research Laboratory to investigate attenuation, rainfall rates, and liquid water content along ray paths through the atmosphere. That study used dual wavelength radar data in conjunction with surface measurements of raindrop sizes made with 6 spectrometers and high speed raingages.

Weather Watch-Forecasting and Analytical Operations

A fall season operational schedule was arranged based on spring experiences. On each day, a team of two researchers was responsible for following the weather situation and forecasting potential operational periods. This scheme allowed the remaining project staff to dedicate themselves to other responsibilities until significant weather began to occur. Once a storm situation began, all available staff were involved. A flexible schedule was developed to cover all possible daytime and nocturnal operational requirements. When a storm period was over, a return was made to the routine daily schedule. This scheme was quite successful; and, no significant convective weather within radar range was missed. All the hailstorm activity on 3 periods (50%) which occurred between 2300 and 0600 CDT was effectively recorded.

Surface Network Operations

The operations of the Eastern Illinois Network (Fig. 6) began in mid-March 1973 and were terminated in early November 1973. The network consisted of 81 recording raingages with hailpads alongside them and an

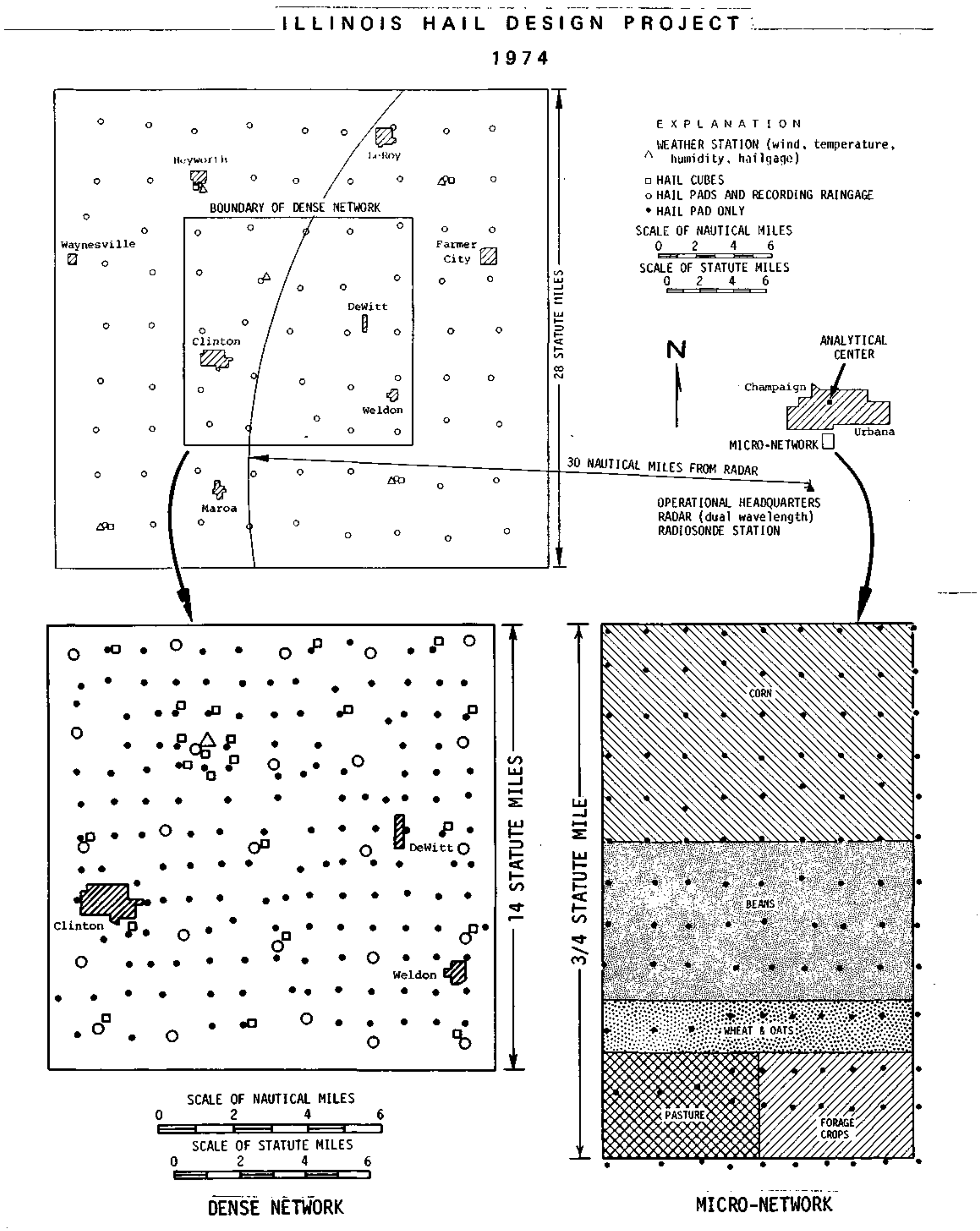


Figure 6. The various hail research networks and weather facilities of the DESH project

additional 151 hailpads in the inner Dense Network (Fig. 6). The Dense Network had a hailpad density of about 1 per square mile. Additional hail information in the network area came 1) from 345 cooperative observers in the 5 counties containing the raingage network, and 2) from crop hail insurance loss data from all companies selling insurance in the area.

The entire network was operated during the periods of dual wavelength radar operations in the spring and fall. When the radar was in Colorado for NHRE operations in May-August 1973, only the Dense Network portion was operated.

Several weather equipment items were purchased, installed, and operated. Five hygrothermographs (and shelters) and five wind sets were obtained and operated during the fall (September-October) period at sites shown in Fig. 6. The portable rawinsonde purchased under this grant was used briefly during the fall operations, and most radiosonde observations were made with a GMD-l/A set temporarily loaned to Project METROMEX and thence to DESH by the Air Force Special Rawinsonde Unit from Tinker AFB, Oklahoma. This was convenient because of the greater capability (automatic tracking) of the GMD and the greater operational experience with this type of equipment. The radiosonde operations occurred at the operational headquarters located east of the network (Fig. 6). Calibration runs were accomplished during good weather in which a single sonde was followed with both the USAF and the new portable equipment. Surface hourly wind, temperature, and humidity data have been reduced for all of the fall hail days.

During the fall operations, the radar, 2 teletype machines, and a facsimile map machine were operated. Radiosondes were also released on potential hail days. The data collected from these sources were used to prepare real-time weather forecasts and are being used in case analyses.

Network Hail Summary

A total of 23 hail days occurred on the network during the March-October period. A total of 558 hailpads were struck with about 45,000 hailstones. The largest stone size was 1 1/4 inches in diameter. There were 93 separate hailstreaks for the year. The average hailstreak size was 6.2 mi^2 with maximum and minimum sizes of 21.7 and 1.3 mi^2, respectively. Figure 7 shows the number of hail occurrences in the Dense Network for the March-October period. Extreme variability is apparent with as many as 6 occurrences and few as none. Cooperative hail observers sent 106 hail reports on 22 hail days. April 20 was the most extensive hail day with 16 observer reports.

Fall Hail Cases

There were three hail periods in September-October 1973 within the Eastern Illinois network. Three sites had hail on 24 September, and 3 sites had hail on 1 October. The most active hail period was 3-4 October when 10

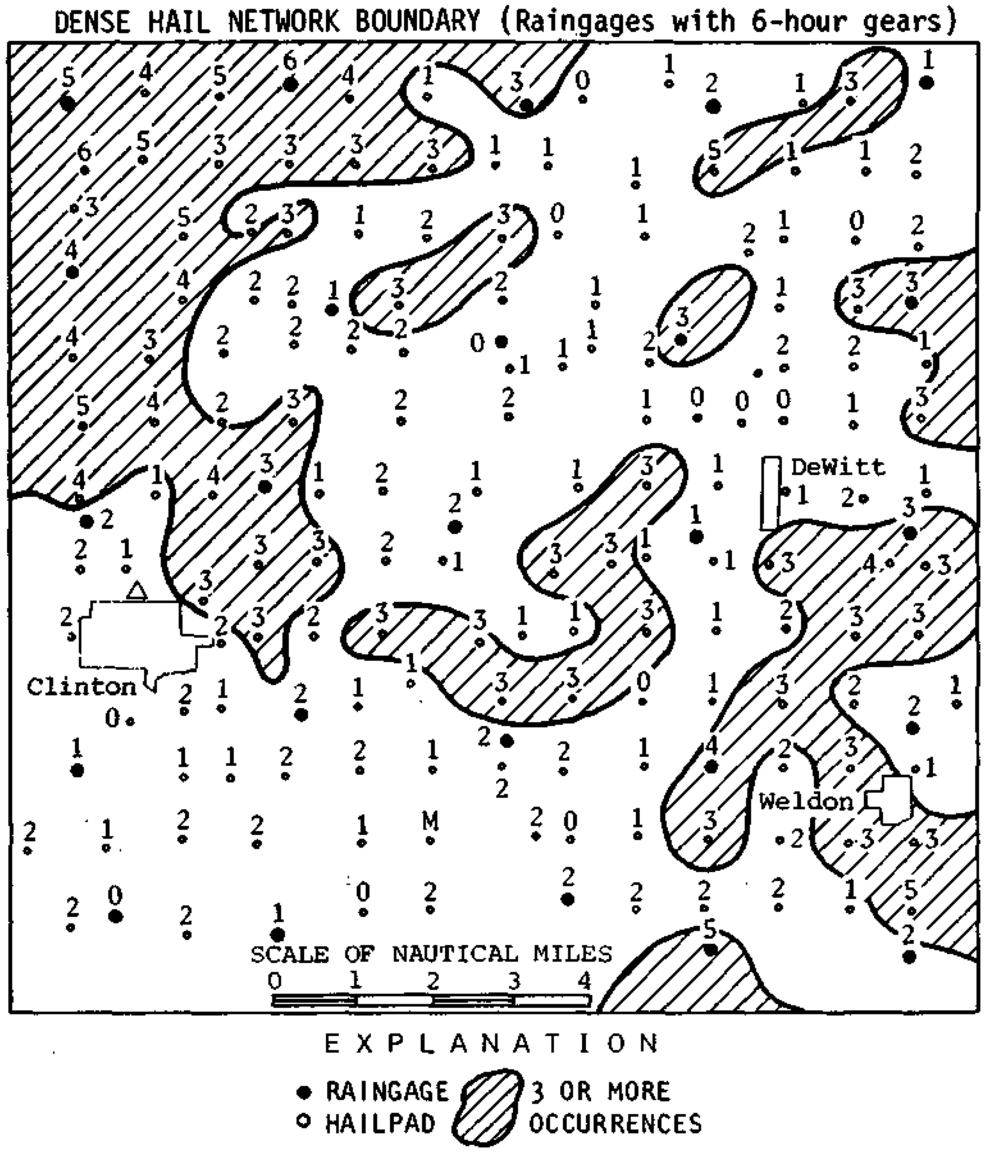


Figure 7. Pattern based on point hail occurrences in 1973

sites had hail. Hail within the network began at 0009 CDT on 4 October. The cooperative hail observer reports indicated hail began around 2330 CDT in neighboring areas to the west. Figure 8 shows the hailstreaks and associated raincell for 4 October. No temporal analyses for rainfall are given in this map, but the raincell did move across the network from the west at approximately 24 mph. Five hailstreaks were defined, and the largest covered about 12 square miles. This hailstreak was quite coherent in time. Most (2/3) of the hailstones were - 1/4 inch in diameter. The remaining third of the stones were generally 1/2 inch in diameter, and the maximum size reported was 3/4 inch (from the hailstreak just south of the 1-inch rain core).

In addition to the standard hailpad analysis (stone number, size, energy), measurements were made of the direction of arrival of the hailstones, based on the orientation of the elongated (wind driven) hail dents on the pads. Study of the 4 October hailfall helped to illustrate an unrecognized and important characteristic of hailfalls. This characteristic was also brought to light during our analysis of the five-sided hailcube in Nebraska (Morgan and Towery, 1974) as part of the NHRE. Although the hailstreaks were oriented east-west and the hailshaft was moving to the east, the stones arrived at the instruments from northerly directions. This is supported by the surface wind data during the hailfalls. This observed difference between the hailstreak motion and orientation and the direction of arrival of the stones is of importance since 1) the direction of arrival helps determine the degree of damage to crops which are planted in rows (for instance, if the stones arrive along the rows there is a useful shielding effect due to the crop itself, Changnon and Hornaday, 1966); and 2) there had been a belief that, in general, windblown hailstones either fell with a random, often circular distribution (Changnon and Barron, 1970), or tended to fall from a direction parallel to the forward motion of the hailstreak (Changnon, 1973). Earlier findings on hailstreak motion (Changnon, 1970) and hailshaft (core) motion (Changnon, 1968) relative to the rain core and its storm entity show the hailshaft generally moves approximately with and slightly to the right of the storm direction. Changnon's (1973) findings show that approximately 70% of all hailstones are windblown (falling at angles $\geq 15°$ from the vertical). Coupling of these two sets of earlier findings with that noted in 1973 for streak and stone arrival directions suggests that the stones often fall into air which is on the right side of a spreading downdraft. Past experience in observing this characteristic of hailfalls suggests a strong tendency for stones to be moving to the right of the streak axis.

Review of Hail in Illinois During 1973

A general review of hail in Illinois during 1973 was done as part of this project. Records from the National Weather Service and from the Water Survey's extensive data base on hail from two special study areas in Illinois were employed. Insurance company records showed $23,751,000 in crop losses in Illinois in 1973, the largest loss in the United States. This is roughly one-half of the State's loss since only 50% of the crops were insured.

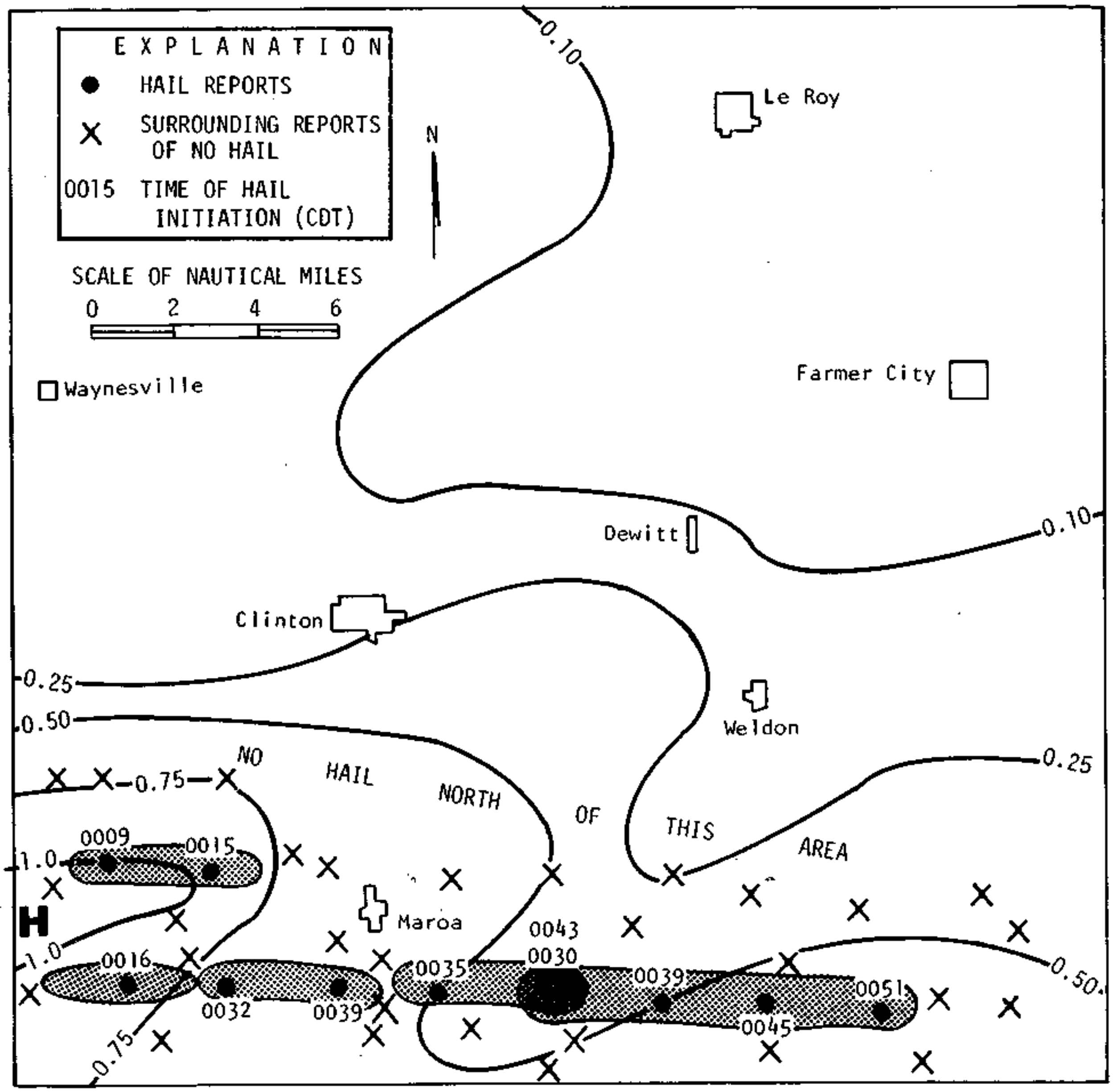


Figure 8. Hailstreaks and associated rain cell on 4 October 1973

First, the daily weather records of some 200 Illinois cooperative substations of the EDS were examined. These data indicate the days with hail (damaging and non-damaging), and these hail days data were selected for the March-October period of 1973.

Analysis of the hail day records showed that hail in Illinois during 1973 was quite unusual. First, hail fell on 57 days, or 23 percent of the total days in the March-October period. This is much less than the normal of 80 hail days (Changnon, 1962). June was the prime hail month in 1973, whereas April normally is the prime month (Huff and Changnon, 1959). Hail fell on 15 days in June 1973, half of the monthly total. Although the frequency of days with hail in the state was less than average, there were some outstanding storm days with widespread, large, and often damaging hail.

Review of hail days in the growing season reveals that the first major hailstorms of 1973 occurred on 20-21 April when hail fell throughout portions of the entire State, extending from Brookport in the extreme south to Elgin in the extreme north. The hail on 21 April was particularly large and damaging to property in central and northern Illinois with 1-inch hailstones reported at Bloomington, Kankakee, and several other locations.

The next major hail day was 10 May when large hail fell in extreme southern Illinois producing 1-inch hailstones in the Sparta and Waterloo areas. Another extensive hail period occurred on 27-28 May when hail fell at scattered locations throughout central Illinois including Effingham, Streator, and Gibson City.

Widespread hail accompanied by strong winds appeared again in Illinois on 4 June. Most of this hail occurred in east central Illinois and was moderately large in a few locations.

The most outstanding hail period in Illinois during 1973 occurred in a 4-day period, 16-19 June. On 16 June, hail fell all across northern Illinois including hailfalls at Aurora, Freeport, Dixon, and Watseka. Hailstones were in the 1/2- to 1-inch diameter range. On 17 June spotty hail fell farther south in the central Illinois area. On 18 June, hail began in western and southern Illinois with hail being reported in a large area extending across 1/4 of Illinois. On the final day of this spectacular period, 19 June, the hailstorms reappeared at many locations in southwestern Illinois.

Some locally damaging hailstorms occurred later in the season. Severe hail fell in the East St. Louis-Edwardsville area on 12 and 13 August, and then very large hail, greater than 2 inches in diameter, fell in northwestern Illinois on 21 September.

Some very outstanding and interesting hail events occurred in the Water Survey's two extensive hail study areas. Under sponsorship of this grant, hail is studied in a 700-square-mile area in central Illinois. The Survey is also studying hail in a 2000-square-mile area centered on St. Louis, also under RANN sponsorship, primarily to investigate how the city and its industries affect thunderstorms and the production of hail. Prior studies

WEATHER ANALYSIS AND FORECASTING STUDIES

(Milestone 12)

Introduction

Much of the field oriented research at the Water Survey bears on convective storms and related phenomena. This applies to DESH and METROMEX (the study of urban effects on summer rain and severe weather) quite specifically. In the area of synoptics and forecasting, this has great importance. These two major weather modification projects, in pursuing their individual goals, are producing a combined body of knowledge which will be of lasting value to the Survey in its future research and experiments, and to the State of Illinois in terms of basic knowledge about thunderstorms a major weather resource and simultaneous problem. For this reason we have created a Synoptics and Forecasting Group composed of 4 staff members to enhance the complementary nature of our projects. The aim is to minimize any duplication of effort in developing analytical techniques, and to share discoveries and insights. Thus, we have chosen the analytical techniques to be developed (fields to be contoured, forecast parameters to be studied, etc.) for use in DESH and METROMEX. The analysis tools developed here will, when perfected, be available to all Survey and weather researchers.

Studies are underway to develop objective techniques for a wide range of synoptic, sub-synoptic and meso-scale problems. These weather forecasting and analysis efforts look toward the combined goal of research based on case studies and future operation of a field hail prevention (or precipitation enhancement) experiment. Thus, where data is presently being punched up by hand for case studies, attention is being given to means of getting weather data to the computer by more rapid means for real-time operations.

The following describes the present problem design, accomplishments and anticipated problems that must be resolved before the system can become fully operational.

Objective Analysis

The use of objective,computer techniques to plot, analyze and display meteorological data amplifies greatly the amount and quality of information the scientist or forecaster-analyst can examine and utilize. It will do a quicker, better and certainly cheaper job of presenting him with the simple fields he is used to analyzing by hand (fields such as temperature, moisture, cloud cover, pressure, wind streamlines, and the like). More importantly, perhaps, it makes possible the routine examination of derived fields (such as derivatives and fluxes) which are not otherwise available to him within a useful period of time. A typical objectively analyzed streamline field is shown in Fig. 9.

have shown that the urban-industrial areas of St. Louis, Chicago, and other major cities apparently have produced sizeable increases in the number of hailstorms per year and in the number of hailstones produced by each storm.

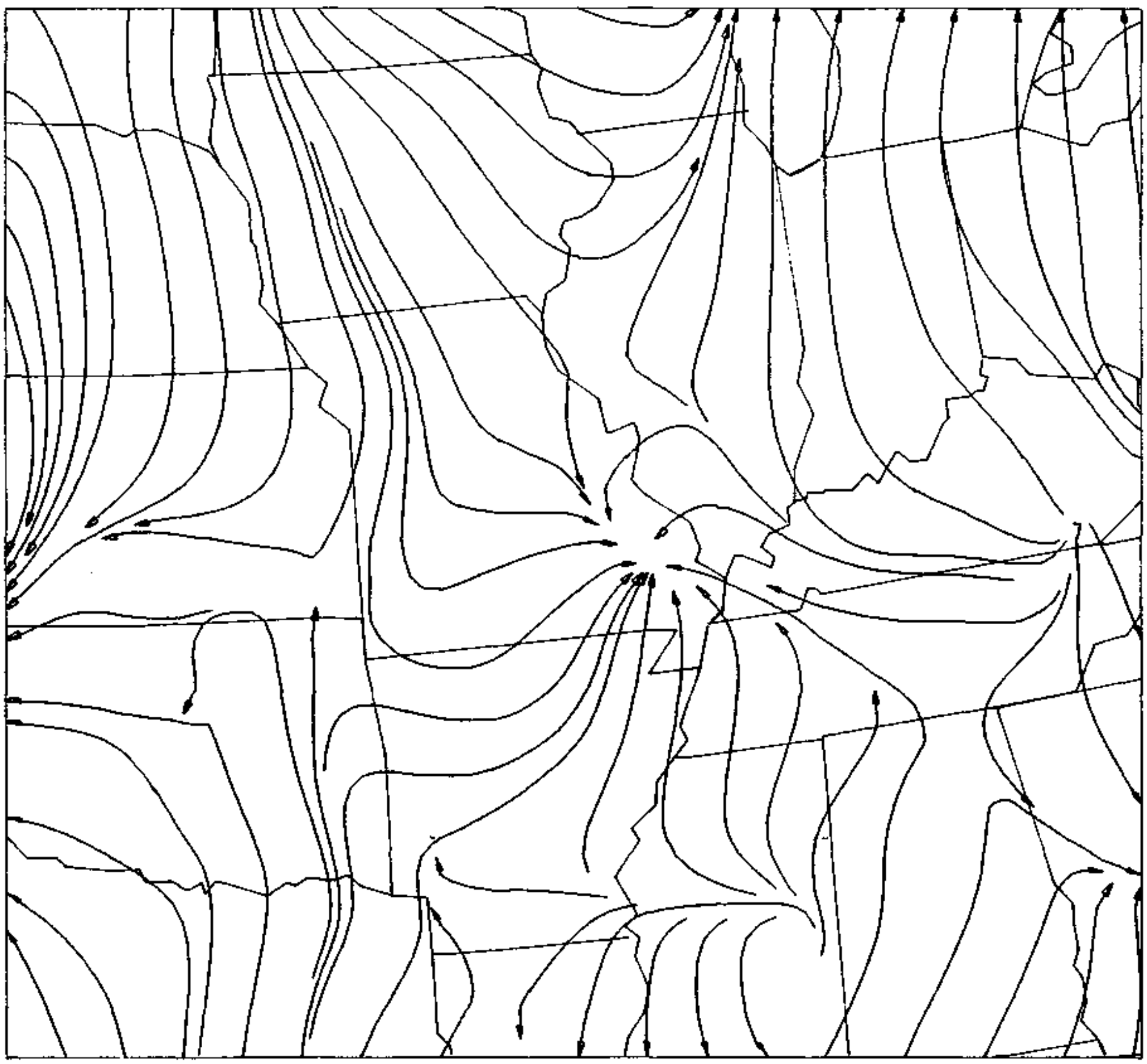
During March-October 1973, some portions of the Survey's dense hail network in central Illinois had as many as 6 hailstorms. Other locations located less than 5 miles away had none. There were 14 hail days in 1973 in this tight gridded network. One-inch or larger hailstones, often thought to be uncommon in Illinois, were found to have occurred on 7 of these 14 days with the largest hailstones being 1.5 inches in diameter. Hail covered at least half of this 700-square-mile area on 4 days in 1973.

The Survey's larger, less dense hail study network centered on St. Louis also provided some quite interesting information about 1973 hail. This network was operated only during the summer months, June through August, when normally there is less than one hailfall at a point in the St. Louis area. However, hailfalls in the St. Louis area reached as many as 4 occurrences at points just east of Granite City and East St. Louis. Many locations in the Missouri portion of the hail network had none. In general, this entire study area had much above normal summer hail.

Hail fell somewhere in this St. Louis network on 19 days during this 92-day period, and spectacular hail fell on at least 4 summer days. Very violent hailstorms occurred on the night of 4-5 June. Hailstorms began in East St. Louis and swept eastward through Collinsville and on through Lebanon producing stones of up to 1.3 inches in diameter.

The next interesting storm event in the St. Louis network occurred on the night of 18-19 June. Hailstorms on this night were notable because of the widespread hailfalls covering 600 square miles of the 2000-square-mile study area. Probably the worst, or most damaging storm of the summer, occurred in Granite City on 12 August when hailfalls lasted up to 25 minutes with some 2-inch hailstones. Another interesting storm event of 1973 occurred on the next day, 13 August. This storm was quite intense just east of St. Louis, producing 1-inch hailstones, but most importantly it yielded many hailstones. For example, one Survey hailgage measured 624 hailstones in a 1-square-foot area in a 5-minute period.

In summary, Illinois had a very unusual hail season. It was marked by lower than normal numbers of days with hail, a shift to June for the month of maximum hail frequency, and many outstanding storm periods, primarily in June. These facts alone indicate that there was a large amount of crop and property damage. Indeed, Illinois led the nation in hail losses. The studies of hail on the networks in central and southwestern Illinois provided a unique look at the true frequency of hailstorms and their intensities over small areas. In general, the dense networks prove that hail in county-size areas is much more frequent and produces damaging hailfalls more often than historical data obtained on a much less dense scale might indicate.



SURFRCE STREAMLINES 1700 CST 30 JULY 1973

Figure 9. A typical objectively analyzed surface streamline field

Because of their versatility, objective techniques will be used for:

a) post analyses studies comparing hail days versus no hail days in efforts to isolate sub-synoptic scale phenomena, thermodynamical and/or kinematical, that tend to produce widespread hailfalls;

b) case studies including squall line formation, frontogenesis, cyclogenesis, nocturnal thunderstorm maintenance and their statistical and climatological interrelationships;

c) extended research and development of objective severe storm indicators along lines pursued by Eadlich and Mancusso (1967) for purposes of better defining objective severe storm indices, and

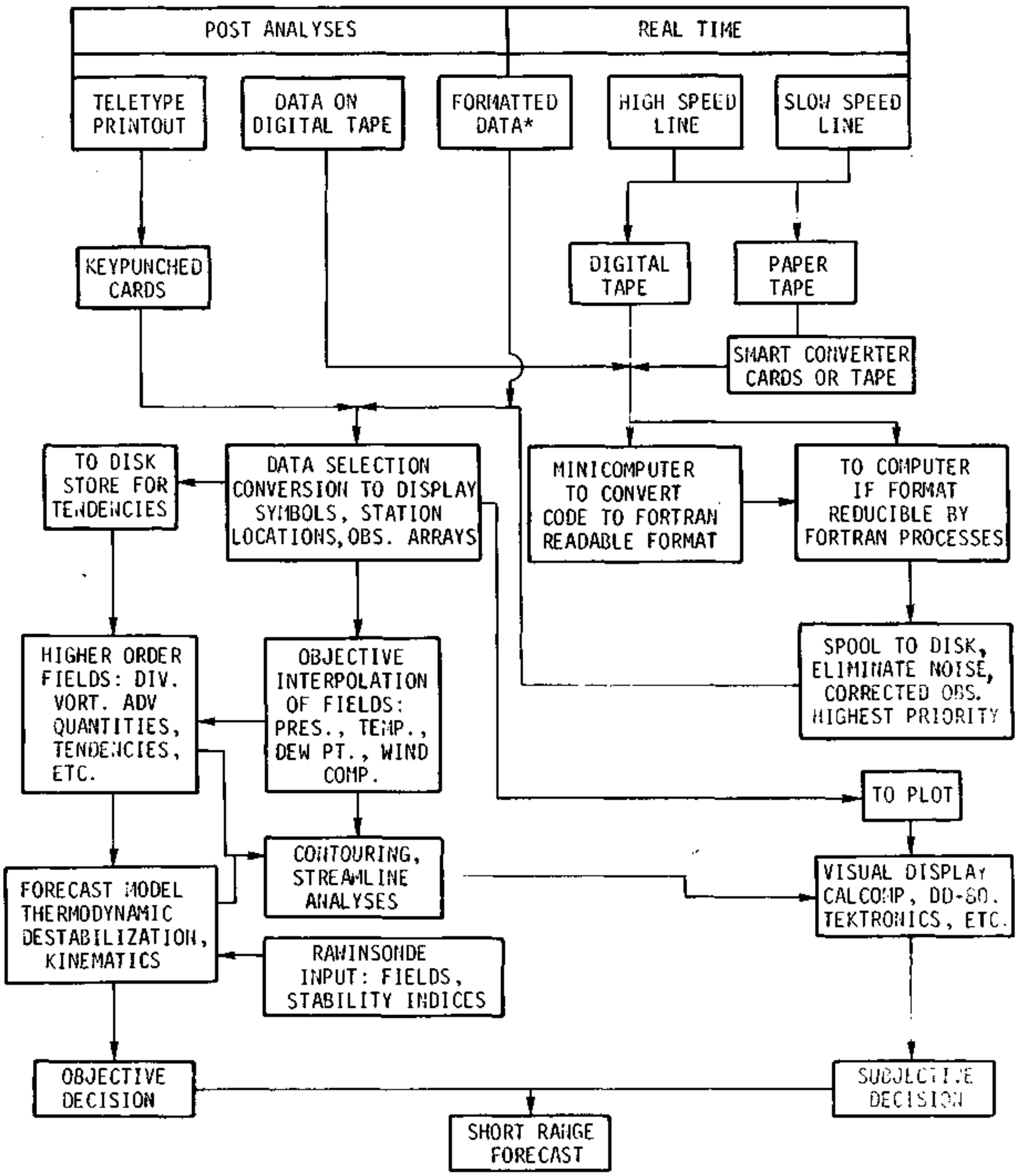
d) developing objective techniques combining observations from diverse sources such as radar, satellites, surface and upper air observations to present a coherent description of the state of the lower troposphere. Variational techniques are available from previous studies and will be considered for application where necessary.

A flow chart for post analysis and real-time data acquisition and objective analysis of hourly surface data is shown in Fig. 10. Most of these programs are readily adaptable to upper-level analyses. The route beginning with tele-type printout is complete, or nearing completion, except for the section which includes the forecast model. Basic equations for the forecast model have been derived.

The objective interpolation algorithms are adapted from Cressman (1959) and Barnes (1964, 1973). Streamline and contouring packages were developed by Achtemeier (1973). The Barnes method has the advantage that the response amplitude of pattern scales supportable by the data distribution can be chosen prior to the analysis. Both techniques suffer from extrapolation into data void regions and from weighting algorithms that are isotropic. Further, large irregularities in the data distribution and poor exposure of instruments limit the analyses. Finally, localized effects such as caused by thunderstorms are smoothed and presented over larger areas. An anisotropic weighting function and analytic and variational methods to reduce and better treat effects of subscale phenomena are under consideration.

Thunderstorm Forecast Model

While our approach to the thunderstorm forecast problem must, to a degree, parallel or overlap work conducted by the National Weather Service, National Severe Storms Forecast Center, and other agencies, output from this project is expected to be sufficiently dissimilar from products of the above agencies as to warrant the few instances of duplication. Though the ultimate goal is to obtain a strong proficiency in hailstorm forecasting, the general thunderstorm problem must be treated first.



* Formatted data may be available or a real time or post analysis basis from other agencies.

Figure 10. Flow chart for objective analysis and forecasting system

In particular, the thunderstorm forecast should say something about the severity and occurrence time of thunderstorm over a potentially small area (≤ 1000 mi^2). Further, for economical operation of a hail suppression project, good proficiency at predicting the occurrence time in advance is necessary for scheduling aircraft and field operations. Though radar echoes can be tracked and their location forecast over short time periods (say 1 to 2 hours) with fair reliability, it is clear that the radar must be supported by techniques based on meteorological observations which can provide information on vitally necessary onset times and intensity trends.

It is well known that upper midwestern thunderstorm activity results largely from complex interactions between motion scales that concentrate potential latent energy and destabilize the atmosphere prior to the onset of convection. Thunderstorm scales have never been adequately described;, however, it is possible to isolate synoptic scale influences and, to a limited extent, mesoscale effects provided the observations are of sufficient accuracy, resolution and frequency.

The basic supposition for the thunderstorm forecast model is that the vertically integrated effects of subsynoptic and mesoscale phenomena are detectable in the surface observations both in space and time. This is not to say that these systems can be accurately described by the surface observations - just that their pressure can be detected. Wind and pressure fields are expected to respond with greatest sensitivity. Temperature and dewpoint carry additional information on energy fluxes especially in the event of substantial vertical mass exchange.

Of particular importance are local stability changes brought about by these smaller scale motion fields (House, 1959, 1963). Since the onset of convection is dependent upon existing stability and rates of destabilization the stability equation (Haltiner and Martin, 1957) provides an initial quantitative statement for the model. Temperature fields necessary to estimate temperature advection in vertically shearing flow must be obtained from the 12 hourly rawinsondes and advected by a scheme yet to be determined. Local serial ascents will help to update the advected fields.

Surface observations provide a good monitor of potential thunderstorm producing systems on an hourly basis. Errors in the observations are expected to smooth out over a period of time. Assuming a vertical distribution of divergence, destabilization resulting from vertical motion can be estimated from the surface divergence field. Further, isallobaric gradients indicate locations of divergence accelerations (Magor, 1959) and are uncontaminated by semi-diurnal pressure oscillations.

Though errors in such a forecast model are expected, it is hoped these will be systematic enough to allow treatment in a statistical sense. It may be necessary to stratify short range predictions according to synoptic type.

Hailstorm Forecast Model

For the operational aspects of hailstorm forecasting, the above described model will provide most of the necessary output information. However, to identify hail prone situations, definite hail criteria must be established. Tornado producing synoptic conditions are described in detail by Miller (1967, 1972), NSSFC (1956) and others. Though hailstorms often occur in conjunction with tornado producing events, they by no means occur only with those events. For this reason, a concerted search for parameters or combinations of parameters on the synoptic and subsynoptic scales is being undertaken to further define hail prone environmental conditions.

Data Sample

Considerable effort has been expended on the assembly of a basic data sample for synoptic weather conditions, hail in Illinois, and radar data. This has taken the form of a 6-yr daily calendar for the months of March through October, 1967 to 1972. This has involved examination of crop-insurance damage reports, Storm Data, the SELS logs, and the original records of first-order stations and cooperative observer substations. The resulting calendar indicates all thunderstorm days, all rain days, all hail days, all days of damaging windstorms, and all tornado days for a large area in Central Illinois and for sub-zones within this area.

The radar summary charts (hourly graphical summaries of NWS radar data) for the 6-yr period have been obtained on microfilm from NSSFC. These have been used first in clearing up uncertainties in utilizing the cooperative weather observer reports for making the weather calendar. Techniques for using these films to make an objective calendar of convective weather days are under study. There would be important advantages to succeeding in this effort: radar indicates quantities, such as storm height and motion, which meteorologists can attempt to predict, whereas the occurrence of thunder (and/or lightning) is not generally understood or dealt with, and its reporting is subject to errors. The use of this form of radar data for climatological purposes is also of interest.

Stability Indices

Another study in progress is determining the utility of each of a long list of stability indices and hail forecast parameters. The parameters are derived from upper air sounding data and surface observations. The study is presently in the stage of choosing a reasonable set of parameters to be examined and preparing the program to compute them for each sounding.

HAIL PREVENTION INVESTIGATIONS

(Milestone 13)

Literature Search and Review

The accumulation of bibliographic materials is proceeding smoothly, though it has been a somewhat larger effort than anticipated. It was our good fortune to be able to employ a graduate student in Library Science as the principal aid in the inventory.

Virtually all titles and abstracts on the subjects of hail and hail suppression, from the 19th Century to the present, are now in hand. This task was greatly eased due to the publication in the Meteorological and Geoastrophysical Abstracts of an annotated bibliography on hail in 1950. An NTIS search on hail and hail prevention was ordered but produced only 50 titles, all subsequent to 1964.

Cards have been prepared for all materials through 1960, and this work proceeds. About half of the titles through 1960 are either on hand or have been ordered. Reprints and other materials on hail which were on hand at the Water Survey have been collected and consolidated with the hail file.

The titles are being entered on punched cards so that they can be reproduced, sorted, and manipulated as desired. This will, among other things, facilitate furnishing the bibliography to other potential users. The punched cards will contain

1. an identifying number
2. author name/s
3. title
4. journal name, if applicable
5. volume
6. number
7. pages
8. year
9. language of article
10. language of summary or abstract (as many as necessary)
11. subject heading (as many as necessary)
12. geographical location when applicable

A number of titles have been punched on cards and are being used to check out the computer program.

When this effort is completed, those items relating to various seeding technologies can and will be sorted and studied. The results will be used to evaluate each technique for use in seeding Illinois hailstorms.

Evaluation of Updraft Seeding

The updraft data collected by aircraft for Project METROMEX in 1971, 1972, and 1973 are the primary source of data being used for the updraft seeding study. The data being used includes that obtained during tracer missions for the Atomic Energy Commission. A second source of data will be updraft data obtained in June-July 1973 by the Penn State aircraft which was being flown for another Water Survey project. These data are feeder cloud inflow and in-cloud updraft data.

The analytical procedure being used is to locate the position of the aircraft at the time of the updraft measurement, determine the updraft location relative to the thunderstorm, and determine if hail occurred from that particular thunderstorm. All of the updraft are being studied with hopes of obtaining hail and no-hail updraft characteristics.

Approximate location plots have been done for all the METROMEX 1972 data and for a few days in 1973. There have been updrafts from a total of 11 days plotted, and hail occurred on 3 of those 11 days. The procedure of precisely locating and correlating the aircraft, radar, and hail data is in progress. It is estimated that a combination of all the 1971-73 aircraft data will yield 25 days with updraft data and will allow a reasonable comparison of hail and no-hail characteristics of updrafts.

A similar procedure will be used on the 1973 Penn State aircraft data for hail days. This data is mainly from growing congestus clouds, as opposed to active thunderstorms. The in-cloud data were also often taken at an altitude (- 12,000 feet MSL) much above cloud base and near the freezing level. These cloud data also could have particular significance because it was taken at a level where the updrafts were found to be more organized than at cloud base levels. Many clouds had numerous updrafts at their bases (3 to 7), and these were often weak (~ 200 FPM) and quite disorganized.

NEW PROJECTS

Weather Attitude Sampling Project

This project (WASP) was planned and initiated in the January-March period as a part of Milestone 31 (see chart) its goal is to sample an adequate number of Central Illinois citizens so as to gain information 1) on the impact of weather on their lives, and 2) on their attitudes towards hail suppression specifically and weather modification in general. Such information is considered an essential part 1) of the design of any future experiment and 2) of the advice given the State on the desirability of such a project. Prior economic studies of hail have provided the basis for adequate economic decisions.

A newly enacted state law on the control of weather modification promoted by the Survey provides for a sound legal framework.

WASP is being conducted under the direction and with HERS, a Colorado group experienced in sampling and interpreting weather modification attitudes. This work is under the direction of Dr. Eugene Haas. The project staff at the Water Survey has helped in many of the logistic aspects of the project including devising sampling questions, getting sampling information, developing lists of residents, and making of arrangements for those who will do the interviewing using Survey telephone facilities.

The WASP sampling effort will be conducted in April 1974, the start of the second year of the project. Under direction of HERS personnel, some 300 citizens chosen at random from the project area will be questioned at length. These answers will be interpreted by HERS and furnished to the Water Survey.

Silver Background Sampling

The collection of rainfall and hailfall samples at Champaign began in March 1974. This effort is being performed to gather background data on levels of silver in precipitation. This is based on the belief that a future experiment will likely use Agl as a seeding agent, and that pre-experiment baseline values will be useful in evaluating any silver values during the experiment. It is also information deemed desirable in achieving Milestone 31 (see Chart).

Micro-Network Study

A primary need for information on surface sampling errors for hail over areas of less than one square mile led to a 1973 Survey project as part of NHRE (Morgan and Towery, 1973). A dense network of hail sensors (114) was installed during May-July 1973 in Nebraska by the Survey under NCAR sponsorship, and data on 3 hailfalls were obtained. This sample is too small to serve the statistical needs, and when NHRE support was diminished in 1974, NCAR terminated this project. However, this project was re-instated in Illinois under State sponsorship. This micro-network (see Fig. 6) was installed in March 1974 on the Agronomy South Farm of the University of Illinois. This installation of 117 hailpads in this locale also allows a unique opportunity to compare various hailfall parameters with degree and type of losses to a variety of crops. The proximity of this network to the DESH analytical center and operational headquarters also allows for rapid and easy servicing, a problem in Nebraska. Furthermore, the point average hail frequency in Illinois for the March-October period equals that in the NHRE network.

PROJECT PUBLICATIONS

Scientific Papers

Towery, N. G., and S. A. Changnon, 1974: A Review of Hail Sensors, J. of Wea. Mod., 14 pp.

Morgan, G. M., 1973: A General Description of Hail Problem on the Po Valley of Northern Italy, J. of Appl. Meteoro. , 338-353.

Changnon, S. A., 1973: Review of Soviet Hail Suppression Program. Report to NSF, 16 pp.

Changnon, S. A., 1973: Hail Sensing and Small-Scale Variability of Windblown Hail, J. of Wea. Mod., 30-42.

Changnon, S. A., 1974: Review of Methods to Evaluate Precipitation Modification Efforts. Proc. Int. Conf. on Weather Mod., W.M.O., Geneva, 32 pp.

Morgan, G. M., 1973: Review of Italian and French Hail Projects, Paper and Report to NSF.

Morgan, G. M., and G. Langer, 1973: Ice Nuclei from Electrical Discharges. Quarterly Journal Royal Meteorological Society, 387-388.

Scientific Reports

Changnon, S. A., 1973: Recommendations for a 5-year Canadian Hail Suppression-Research Project, Urbana, 18 pp.

Changnon, S. A., 1974: Analysis of 1970-73 Hail Data in the Texas Panhandle to Evaluate Suppression Activities, Urbana, 12 pp.

Morgan, G. M., and S. A. Changnon, 1973: Design of a Hail Suppression Experiment for Illinois, Semi Annual Report on Project to NSF,Grant GA-37859, 15 pp.

ORAL PRESENTATIONS AND NEWS RELEASES

"Measurement and Sensing of Hail", N. G. Towery, paper at National AMS Conference on Agricultural Meteorology, Raleigh, North Carolina, 1973.

"Illinois Hail Studies", N. G. Towery, Midwestern Hail Adjustors School, Macomb, Illinois, 1973.

"Weather and Hail Modification", S. A. Changnon, Interview WICD-TV, Urbana, Illinois, 1973.

"Weather Forecasting and Hail", S. A. Changnon, Interview WILL-TV, Urbana, Illinois, 1973.

"Review of Methods to Evaluate Precipitation Modification Efforts", S. A. Changnon, International Conference on Weather Modification, Tashkent, USSR, and Educational Radio Network, 1973.

"Status of Weather Modification", S. A. Changnon, Lecture WILL-Radio, Urbana, Illinois, 1973.

"Review of Hail in Illinois During 1973", S. A. Changnon, News Release a State News Agency, 1973.

"Formation of Hail", S. A. Changnon, News item to Crop Insurance Research Bureau for distribution as a State News feature, 1974.

"Russian Hail Suppression Projects", S. A. Changnon, talk to NHRE Scientists Meeting, 1973.

"The Illinois Hail Project", S. A. Changnon, News release to State news media, 1973.

PROJECT PERSONNEL

	Prime Activities
Stanley A. Changnon, Jr.	Project Manager
Griffith M. Morgan, Jr.	Director of Weather Research
Neil G. Towery	In Charge of Field Operations
Gary L. Achtemeier	Research Meteorologist, Forecasting Task Area
Ronald C. Grosh	Research Meteorologist, Radar Task Area
Ronald Alsup	Research Assistant, Radar and Radiosonde Operator and Analyst
Edna Anderson	Director of Data Processing
Oscar Anderson	Field Technician and Analyst
Catherine Jackson	Data Processor and Analyst
Jennie Coppenbarger	Network Technician

Student Analytical Assistants

	Prime Activities
Susan Roth	Literature Search
Susan Moyer	Hailpad Analyses
Eugenia Payne	Radar Analyses
Vicka Bell	Radar Analyses
Philip Dortch	Radar Analyses

SUMMARY AND ACHIEVEMENTS

There were several scientific accomplishments during the past year. The systems engineering approach for the 2-yr project has successfully involved a carefully interlocked series of data gathering and analysis efforts. These together have focused on hailstorm forecasting, hailstorm identification with radar, classification of different storm-producing conditions, and the implications of these on a seeding system that embraces these findings with those of the past 6 years that addressed evaluation and surface data.

The research efforts to date have largely involved two general thrusts: 1) spring and fall 1973 field operations and related data analyses, and 2) analyses of historical hail, radar and synoptic weather data. Field operations in 1973 resulted in collection of excellent surface and dual wavelength radar data on 4 different types of hail-producing periods on 6 occasions. These data are allowing us to answer many questions about the short-term (3 to 6 hour) storm forecasting problems, as well as those about our hailstorm identification capability with the radar — both key factors in deciding on the optimal delivery system/s for seeding materials. An in-depth investigation of all hail-producing conditions of the past six years in Illinois was initiated to learn a) how to class these events on a weather-type basis, b) how much in advance can hail-producing systems for a specified area be forecast, and c) how all of this scientific information is integrated to form an operational modification and evaluation system. Results to date suggest a need for an airborne seeding delivery system.

Impacts of the project have been greater than could be expected for a 1-yr project because of the extensive background of our hail research. The Illinois hail results are applicable to most areas of the eastern 2/3's of the United States and certain findings on techniques (statistical evaluation and radar detection) are applicable to any hail areas. The major impacts or user-related accomplishments of the project are listed below.

1. A key achievement has concerned the extensive advice given by S. A. Changnon to the Alberta (Canada) government, at their request, concerning the design of a major 5-yr hail suppression project that the government will initiate in 1974. The Alberta government invited us to give them advice on the project and its potential design. After a 2-day visit in Calgary during

July to confer with their government officials, the Alberta Weather Modification Board, and the senior project scientists, an extensive design report was developed based largely on the available results from Illinois. Subsequently, the two Canadian project directors, in response to our invitation, visited the Water Survey for 2 days in September for in-depth discussions on the use and handling of surface hail data and on various statistical evaluation techniques, an area of Survey expertise.

2. G. M. Morgan was invited by the Istituto di Fisica dell' Atmosphera in Italy (a part of the National Research Council) to spend a month at their expense studying and advising its groups engaged in research on hail and fog. He visited and worked with groups in Rome, Bologna, and Verona, and gave several seminars to groups including the full range of researchers, research directors, and politicians describing the lines of major effort to be followed in hail prevention projects. More detailed and specific advice on development of field sites and choice of instrumentation (radar and surface hail measurements) was given to the relevant groups in many working sessions and personal interactions.

Following the Italian stay, an invitation was extended and accepted for a brief visit to the hail prevention group in Grenoble, France, directed by Dr. Pierre Admirat. A seminar on surface hail measurements and radar was presented to this group. Advice was solicited and given regarding a future three-nation (France - Switzerland - Italy) hail prevention experiment. The desire was expressed to involve Morgan directly in this effort.

3. In a similar vein, we responded with hail information and advice to extensive requests from other governmental groups. For example, the South Dakota Weather Modification Commission requested both data and information concerning evaluation of the effectiveness of their 1972 and 1973 statewide hail suppression program. Hail information has been supplied to various individuals with the National Weather Service who wished advice on how to measure hail and information on the climatology of hail.

4. Discussions were held with NHRE leaders and these led to arrangements for joint field interactions in 1974 involving our senior staff with their experiment. This effort and arrangement was pursued to more directly study the transferability of their system components to a potential Illinois experiment.

5. We have sustained a close communication and a minor data collection relationship with all crop-hail insurance companies in central Illinois. They have supplied us with detailed 1973 hail loss data for central Illinois, and we have been able to answer a variety of their requests for specific hail information. In addition, we supplied their national information service (Crop Insurance Research Bureau, Inc.) with information about the Illinois project.

6. An extensive analysis was performed of the hail data (Weather Service and insurance) in and around a 2-county area of Texas where a 4-yr locally-sponsored hail project has been conducted. This evaluation was

done for 2 reasons: a) to review the results for their application to the Illinois Suppression project design, and b) to provide the commercial seeding firms and local (Texas) citizens with information on the results. A report was written and supplied to interested parties (users).

7. Other external accomplishments worthy of note related to supplying hail information to answer requests from a variety of other sources. Authors of two books on weather wanted to employ our results; the Illinois Institute of Aviation wanted briefings and instructions on hailstorm forecasting and detection for their pilot trainees; and those organizing scientific conferences desired our participation. The state news media published four project news releases.

There is no doubt that utilization of our recommendations have led and will lead to more definitive hail suppression experiments and projects, both in Illinois and other places (Texas, Canada, Colorado, Italy, and France). Major benefits involve increased public information and scientific knowledge, items both difficult to assign dollars to, but both items leading to project efficiency and in general enhancement of the public image of science. The most apparent direct economic benefits to be realized concern periods of experimentation. The Canadian 5-yr project is being designed at a level of $1,000,000 per year, and a 1-yr shortening of that experiment, which could be obtained according to our design suggestions, would be a savings of $1,000,000.

Obviously, the major savings to be hopefully realized from this project concern the ultimate reduction in crop and property loss due to hail. Our evaluation of results from Texas and Colorado suggest 40 to 50% reductions due to hail suppression efforts. If our project shows that such reduction can be obtained in Illinois, it would lead to great savings. Illinois insured crop losses in 1973 were $21.7 million (highest in the Nation), and a sizeable (40 to 50%) reduction due to suppression would have yielded enormous benefits, up to $10 million. Savings to property in Illinois also could be as much as $1,000,000 per year.

Such reduction in crop losses also will lead to more efficient and stable agricultural operations. This in turn leads to a more stable economic base both for the individual farmer and to the State.

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APPENDIX A

CROP INSURANCE RESEARCH BUREAU, INC.

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1856 Sherman Avenue
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December 27, 1973

Mr. Stanley A. Changnon, Jr., Head
Atmospheric Sciences Section
Illinois State Water Survey
P. O. Box 232
Urbana, Illinois 61801

Dear Stanley:

Thanks for your letter and compendium of interesting information on the 1973 hail experience in Illinois.

We will work it in and develop a stripped-down chronological summary which proved so appealing to the newspapers in our Indiana story of last March.

Could you send me a concise statement with your observations of what makes a hailstorm - the necessary conditions and ingredients, etc. Most people don't know and haven't thought much about it. Can you help the reader with clues as to the kind of weather that produces hail — what to look for, when to expect it.

We'll have a good story when it all goes together I'm sure. Will send you a copy and let you know of its impact in the press. We are still collecting information. Hopefully it will be ready sometime next month.

Very truly yours,

George Thiem

George Thiem
General Manager

GT:jw

ROBERT R. WILKINSON
PRESIDENT

E. V. SHARP
VICR-PRESIDENT

H. J. CLOUGH
BECRCTARY

CROP-HAIL INSURANCE ACTUARIAL ASSOCIATION

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CHICAGO. ILLINOIS GOODS

E. RAY FOSSE
ASSISTNAT SECRETARY AND MANAGER

TELEPHONE 312 - 922-7722

12 February 74

12 February 74

Memorandum

To: Great Lakes Advisory Committee Members

Re: 1974 hail loss worksheets

Mr. Stanley A. Changnon, Head, Atmospheric Sciences Section of the Illinois State Water Survey, will appreciate your providing hail loss worksheet copies for 1974 losses, in the following target counties:

Champaign
Dewitt
Macon
McLean
Piatt

Stan has asked that we relay to you their sincere appreciation for the cooperation of your offices and adjusters in assisting in their hail studies research program.

Copies should be sent to: Illinois State Water Survey
Atmospheric Sciences Section
P.O. Box 232
Urbana, Illinois 618 01

In a recent press release Stan remarks that Illinois in 1973 had 57 hail days, or 23% of the days in the March - October period. This, he says, is less than the normal 80 days, but as most of you know frequency was more than made up by severity: Illinois had an industry indicated loss ratio ofmore than 90%. For companies reporting to the Association the total dollar losses paid in 1973 set an all-time record, even though in three earlier years the loss ratio was greater than for 1973.

ERF
2.12.74

ERF

1972 Tex sent; 1973 to follow shortly.

The Country Companies

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CLAIMS DIVISION • P.O. BOX 565 • BLOOMINGTON, ILLINOIS 61701 • PHONE (309) 8280021

March 11, 1974

Stanley A. Changnon, Jr.
Atmospheric Sciences
Illinois Water Survey
Urbana, II 61801

Dear Mr. Changnon:

We have received Report #42 and the two slides you sent. They are very much appreciated. Daryl Yoder and John Williams gave glowing reports of their recent visit with you.

We are very interested in the potential use of such techniques and would like to discuss further the possibilities of some sort of venture for 1974 if it is not too late. As I understand it, there are techniques to master as well as the basic fundamentals of photography.

As we now interpret the potential of remote sensing there could be many benefits to improve our adjusting techniques, possibly reducing overpayments, making better estimates of reserves needed, and others too numerous to mention.

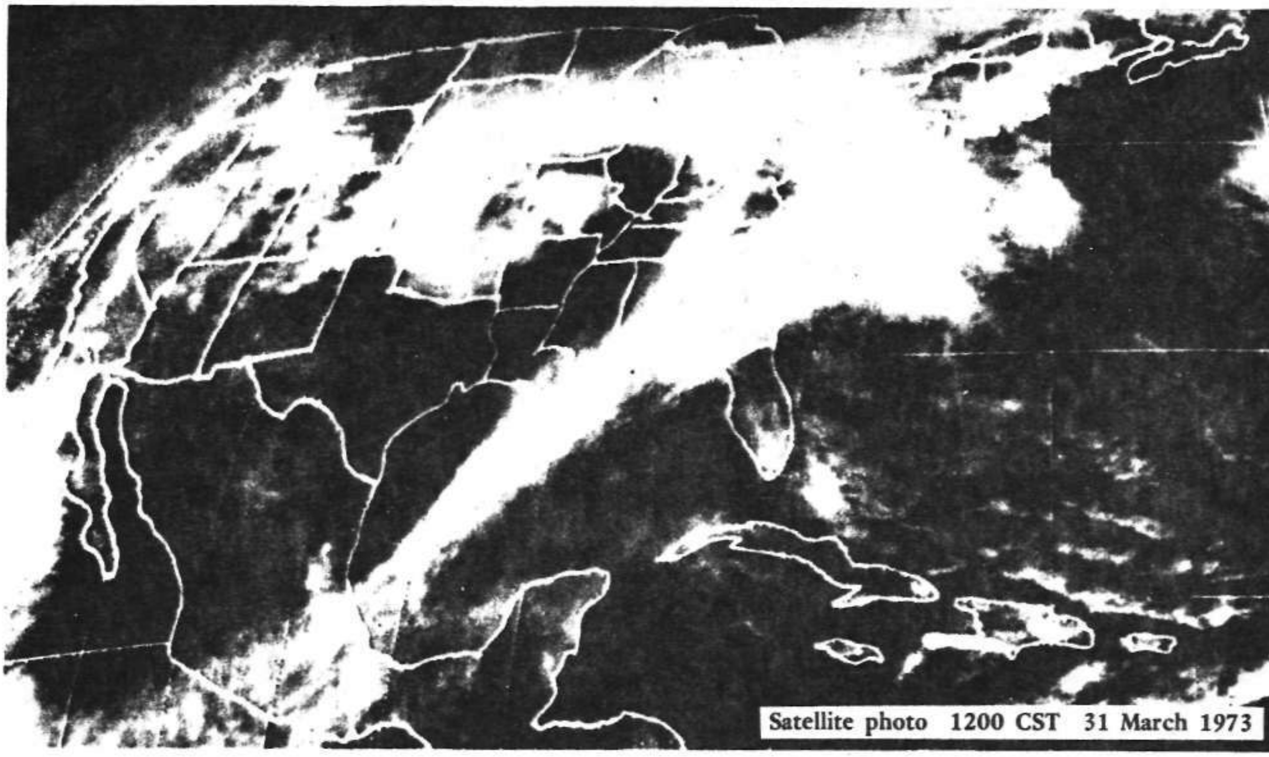
Both Mr. Land and Mr. Whiteman agree we should pursue this subject further with you. Is there some time in the next few weeks we could set up a meeting? I think it would be worthwhile for all of us.

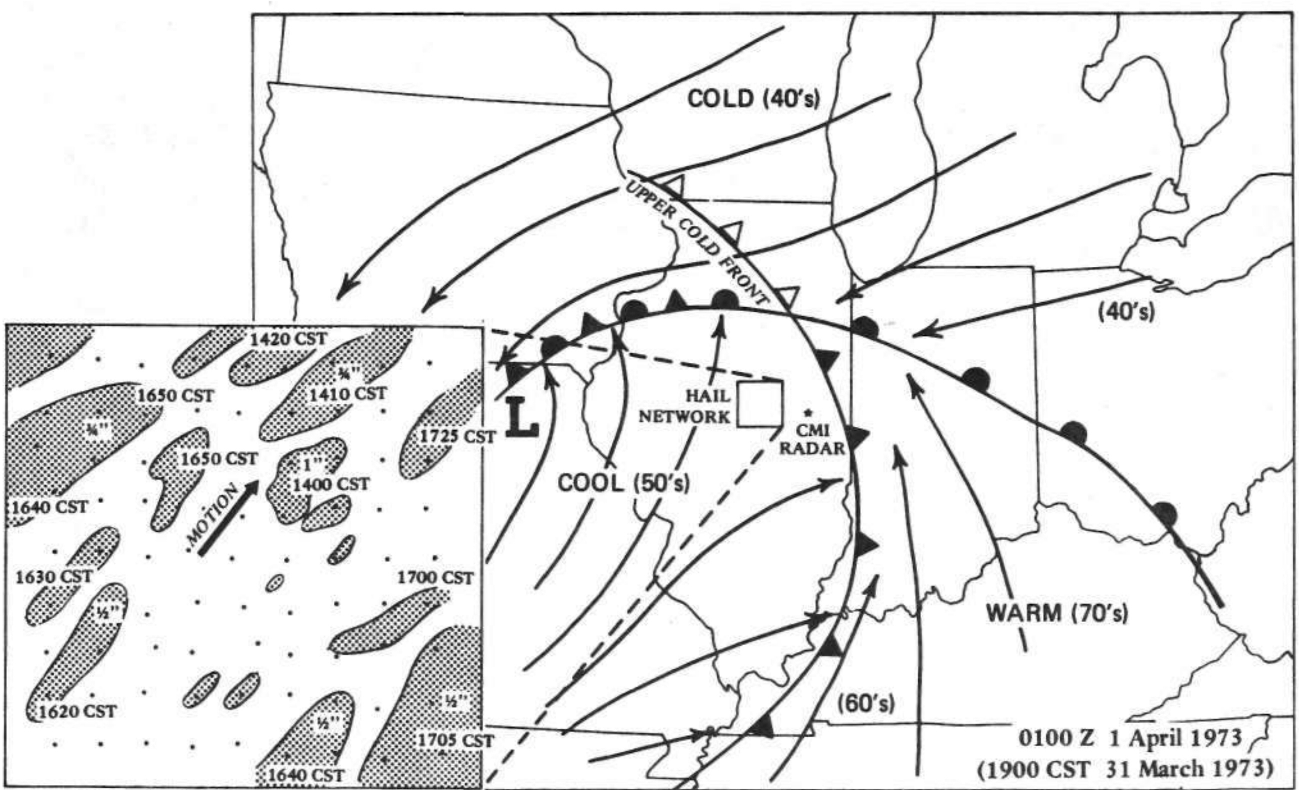
Sincerely,

Louis A. Rediger
Crop Hail Claims Manager
LAR:cd

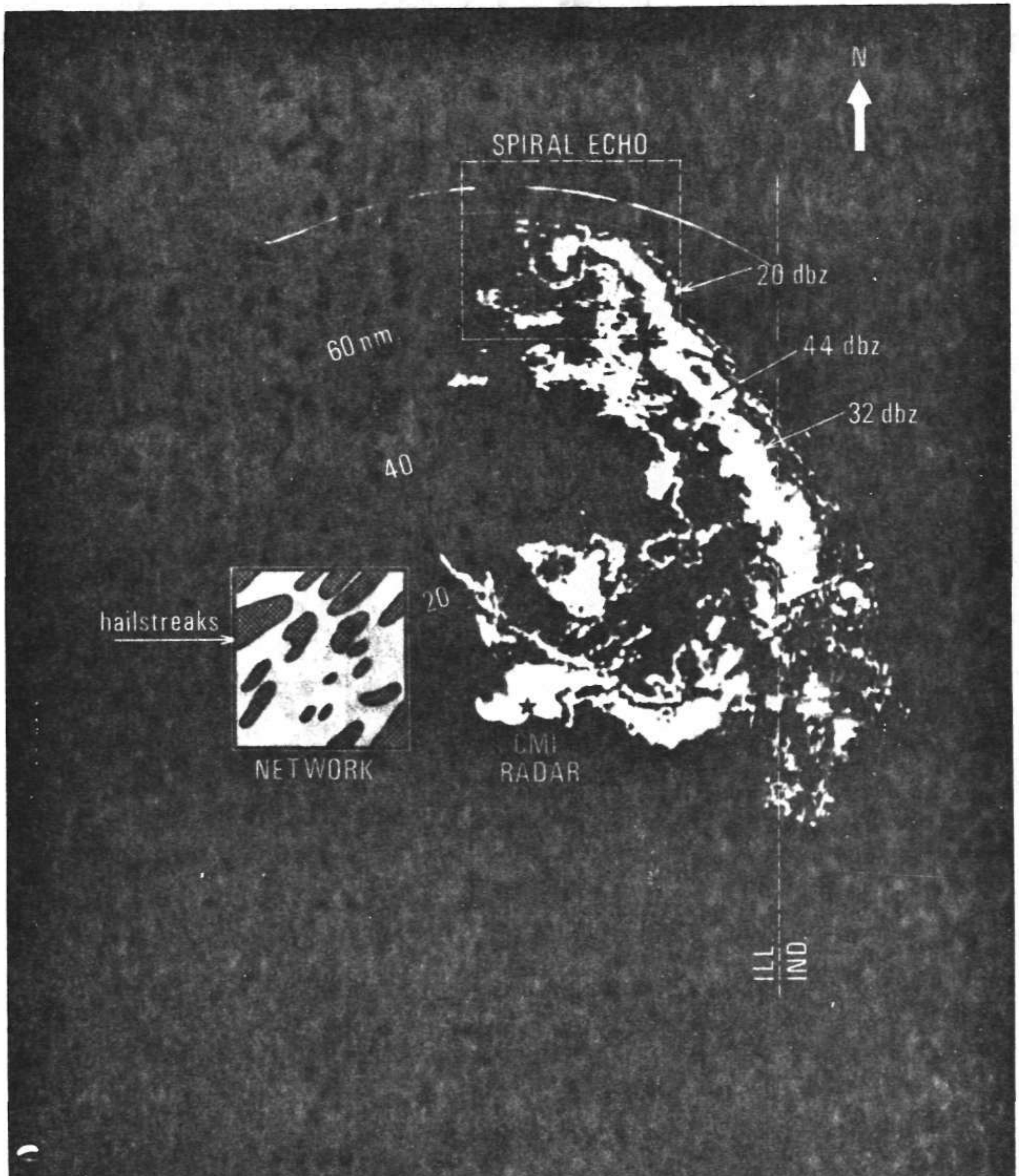
APPENDIX B

Various scales of interest and analyses employed in the project are demonstrated on the attached figures for one major spring 1973 hail system reflecting one significant synoptic class of hailstorms in Illinois. This case features cold frontogenesis within a cold airmass which is being heated in a non-uniform manner due to the macro-scale pattern of cloudiness and clearing (see satellite photograph). Lake Michigan and the Great Lakes played a significant role in the meso-synoptic processes by maintaining cool temperatures to the north of the occlusion (see figure). The newly-formed cold front and the occlusion, which had assumed warm-frontal properties, occluded over Northern Illinois with the air behind the new cold front riding over the colder air. The point of occlusion, a region of extreme lifting and complex advection patterns, was the site of a spiral radar echo which produced very damaging hail in Illinois and Indiana. These processes are clearly visible in the attached weather map and radar photograph. This type of storm system produces widespread and large damaging hail in Illinois, as typified by the 18 hailstreaks found during a 3-hour period in our dense hail-rain network of 720 mi^2 (see map). These findings are significant to those scientists who are attempting to design a hail and severe weather suppression experiments and to better forecast severe weather.





Hailstreaks in 720 sq mi network area



INTEGRATED, RANGE CORRECTED VIDEO DISPLAY
1914 CST, 2° ELEVATION 31 MARCH 1973