

## NATIONAL HAIL RESEARCH EXPERIMENT

### 1. Introduction

Since the authorization of the National Hail Research Experiment in September 1969, the principal effort in the project office has been directed towards the development of equipment and techniques preparatory to the first season of full-scale field operations of the project in the summer of 1972.

### 2. Summer 1971

During a short experimental season (mid-June through July) such facilities as were available were operated. Included in these were the following:

- a. Four radiosonde teams provided and operated by the U.S. Army and the U.S. Air Force.
- b. The hail and precipitation network installed and maintained by NOAA.
- c. The surface weather stations installed and maintained with the assistance of the NCAR Field Observing Facility.
- d. The NCAR Buffalo, Queen Air and Sabreliner.
- e. The NOAA DC-6.
- f. The University of Wyoming C-45 and two mobile ground crews.
- g. The NASA Convair 990.
- h. The University of Nevada Desert Research Institute M33 Radar.
- i. The CP-1 Radar of the NCAR Field Observing Facility.
- j. The Air National Guard Radar Facility at Greeley with aircraft controllers provided by the Federal Aviation Administration.

The trials were conducted from Grover, the project headquarters, where the principal logistic facilities had been established.

Prior to the trials two types of aircraft instrument system comparisons were conducted, the first by a series of tower fly-bys to compare temperature, pressure and relative humidity with an absolute reference. Several discrepancies were found and corrected. The second tests involved a series of inter-comparison flights to provide a comparison, continuous in time and space, of meteorological and aircraft variables. This data is now being analyzed at the University of Oklahoma.

Certain facilities were not available. Neither of the dual-wavelength radar systems (University of Chicago - Illinois State Water Survey and NCAR) was ready due to failure of the manufacturer to deliver the 8.5 meter antenna necessary for each system. Furthermore, the South Dakota School of Mines and Technology armored T-28 aircraft suffered complete mechanical failure just prior to the beginning of the observational program. Cloud penetrations for the purpose of making exploratory measurements of liquid water content and vertical motions, which had been planned as an important component of the program, were therefore not possible.

It has also been planned to use this aircraft for the accurate delivery of nucleant into the hail focus during cloud seeding missions, and this also had to be abandoned. The emergency substitute for this aircraft, a Beech Baron, does not have cloud penetrating ability, and could be used in cloud seeding missions only from below the cloud base. By the time this aircraft was procured and equipped for such work, only two weeks of the season remained. In consequence only three seeding events were possible, with inconclusive results.

A ground-launched seeding rocket system was scheduled for trials in the second part of the season. Unfortunately, the manufacturer was unable to meet the schedule. However, work on this small ground-launched rocket is continuing and a limited number will be available to test during 1972. This rocket falls within the FAA model rocket regulation and consequently a controlled firing area is not required.

In addition, there was only limited participation by Colorado State University. The T-6 which was to have been used for cloud base measurements was not available due to telemetry and data formatting difficulties. The F-101 instrumentation was not completed until mid-July and the aircraft was only available for operations during the final week.

Despite these setbacks, a number of selected storms were studied and, though necessarily deficient in certain respects observationally, will no doubt yield important results when their analysis is completed.

It had been intended that this was to be a season devoted to familiarization with techniques rather than to the acquisition of definitive research

material. There is no doubt that much useful experience was gained, particularly in the areas of aircraft control and coordination, and in communications.

3. Summer 1972

For the summer of 1972, the first season of full-scale operations, the principal objectives remain as previously stated:

a. To gain an increased understanding, by observation and analysis, of all aspects of the cloud dynamics and microphysics governing the severe convective storms that produce damaging hailfall; and

b. Equipped with this knowledge, to develop, if possible, a practicable method for suppressing the occurrence of damaging hail.

Items of particular interest under (a), which will receive high priority next year, are (1) the relationship of the precipitation pattern of the storm to the cloud droplet spectrum at cloud base and to the vertical velocity profile, and (2) the relationship between the vertical velocity profile and the vertical distribution of liquid water content.

The principal unresolved problem in operational procedures concerns the technique of delivering the nucleating agent into the hail focus of the cloud. At present, consideration is being given to methods of delivery by aircraft and by ground-launched rocket. As for aircraft delivery, there are four possibilities: by rocket, by flares from above the cloud, by delivery of nucleant from below cloud base, and by delivery from aircraft penetrating near the hail focus. Each system presents its peculiar difficulty - delivery by flare and at cloud base is more or less inefficient and lacking in accuracy, by rocket from aircraft somewhat inflexible as well as of doubtful accuracy, whilst cloud penetration requires an armored aircraft. As regards the latter requirement, this would involve the use of not less than three such aircraft for the conduct of the statistical randomized experiment proposed.

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4. Budget FY 1972

The funds required to accomplish the 1972 objectives are set forth in the table that follows. The estimate for FY 1972 is \$2,691,000. As indicated in the attached table, the total new funding required to carry out the FY 1972 NHRE program is \$2,441,927 together with the FY 1971 carry over of \$249,073.



NATIONAL HAIL RESEARCH EXPERIMENT (NHRE) FY 1972 BUDGET

	Salaries	Benefits	Materials/ Supplies	Purchased Services	Travel	Equipment	Sub Totals	TOTALS
<b>ADMINISTRATIVE (5110)</b>								
General 5111	81,000	10,500	500	1,500	8,000	0	101,500	101,500
ADMINISTRATIVE SUMMARY								
101,500								
<b>RESEARCH (5120)</b>								
General 5121	60,000	7,500	5,000	2,000	3,000	6,500	84,000	
Liquid Water Meter 5122	29,000	3,500	4,000	5,000	1,000	10,000	52,500	
Data Analysis 5124	45,000	4,500	1,500	25,000	3,500	20,000	99,500	
Seeding 5125	0	0	65,000	105,000	0	5,000	175,000	
Nucleation Studies 5126	28,500	3,500	2,500	0	0	2,000	36,500	
Cloud Physics 5127	20,000	2,500	0	0	0	5,000	27,500	
RESEARCH SUMMARY								
475,000								
<b>EQUIPMENT/DEVELOPMENT (5130)</b>								
DWL Radar NCAR 5131	25,000	3,000	7,000	4,000	8,000	249,000	296,000	
Dropsonde 5132	2,200	300	2,500	5,000	2,500	15,000	27,500	
Data Display and Communications 5134	52,000	6,500	31,500	0	2,500	178,000	270,500	
EQUIPMENT/DEVELOPMENT SUMMARY								
594,000								
<b>EQUIPMENT PROCUREMENT (5140)</b>								
Communications 5143	0	0	0	0	0	10,000	10,000	
Airborne Instrumentation 5144	0	0	0	0	0	50,000	50,000	
EQUIPMENT PROCUREMENT SUMMARY								
60,000								
<b>UNIVERSITY SUPPORT (5150)</b>								
General 5151	0	0	0	1,000,000	0	0	1,000,000	
UNIVERSITY SUPPORT SUMMARY								
1,000,000								
<b>FIELD SUPPORT (5160)</b>								
Logistics/Field Support 5161	45,000	5,000	10,000	100,000	15,000	30,000	205,000	
Upper Air 5162	0	0	5,000	140,000	0	0	145,000	
Surface Networks 5163	12,000	1,300	5,700	0	7,500	50,500	77,000	
Aircraft Control 5164	2,500	500	3,000	25,000	2,500	0	33,500	
FIELD SUPPORT SUMMARY								
460,500								
TOTAL FY1972 \$ 2,691,000								
FY1971 CARRYOVER \$ 249,073								
FY1972 FUNDS \$ 2,441,927								

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Notes on the National Hail Research Experiment FY 1972 Budget

(a) ADMINISTRATIVE (5110). This category covers the basic administrative costs of the program. The salaries are for the Scientific Director, a Project Manager, an Operations Analyst and Statistician, and a Secretary. The travel funds cover all administrative travel including those of the Advisory Panel members. The balance of the funds programmed are for miscellaneous office supplies, equipment and services.

(b) RESEARCH (5120). Six basic categories are included within this budget section.

1. General (5121). The goal of this program is to provide NHRE with the research capability in several areas not specifically covered by outside or NCAR participants. Three main areas will be studied: hailstorm climatology, hailstorm dynamics, and atmospheric electricity. Two additional Ph.D scientists are programmed for FY 1972.

2. Liquid Water Meter (5122). The problems encountered by the South Dakota School of Mines and Technology T-28 aircraft resulted in the liquid water meter not being tested in flight during the past summer. Before next summer, three periods of aircraft testing are planned. The NCAR Queen Air aircraft is being requested for this testing and the tests will be conducted during the next several months.

The original instrument was designed for use in the wing tip of the T-28. The use on another aircraft has required the instrument to be reconstructed. This work is now nearly completed. In the new configuration the instrument, except for some electronics which are in the aircraft cabin, is enclosed in a sealed tube 4 inches in diameter and 19 inches long. This tube can be mounted in nose booms, on pylons, or at wing tips, and thus makes the instrument more adaptable for use in other aircraft.

To supplement the aircraft tests, arrangements have been discussed with the University of Chicago to use their wet wind tunnel for testing the ability of the instrument to function under high liquid water content conditions. In addition to the testing of the ability of the instrument to function

under operational conditions, considerable effort will be devoted to laboratory calibration and testing to discover if any systematic errors are involved in the operation.

A second unit of the instrument will be constructed before next summer. This unit will be used for laboratory testing, as a back up unit, and may possibly be mounted on one of the aircraft that fly at cloud base.

3. Data Analysis (5124). The goal of this program will be to provide a data retrieval, processing, analysis and distribution capability within NHRE. The processed data archive will be maintained at NCAR. Selected data will be obtained from each participant. Support data, such as rawinsonde, surface meteorological data, etc., will be reduced, processed and analyzed in this program. A catalogue of processed data will be published each year.

4. Seeding (5125). The goal of this program is to provide a cloud seeding capability within NHRE. The plan for FY 1972 is to test and evaluate several cloud seeding systems including in situ delivery, cloud base delivery and a small ground-launched rocket system.

5. Nucleation Studies (5126). Modification of the hailstorm will be studied using a temperature spectrum of freezing nuclei derived from measurements made during the field program. The numerical model will be used in further studies to evaluate the effect of the nucleation temperature of ice-forming nuclei, of the concentration and size of particles of different artificial seeding agents on clouds.

In the laboratory formation of micro-clouds around freezing water drops will also be studied. The results of present investigations indicate that the ice phase formation in the vicinity of a freezing drop depends only on the presence of ice forming nuclei in air. Ejection of particles containing ice nucleating agents from drops was not observed unless a drop placed on a substrate was subcooled very rapidly. Different clay minerals, chemical compounds present in soils and different organic chemical compounds will be used in ice nucleation studies.

In addition to the above investigation, a limited number of membrane filters containing aerosol particles sampled around storms will be analyzed

for ice-forming nuclei. Also, the temperature of ice nucleation will be determined for different types of ice in hailstones collected during the 1971 field program.

6. Cloud Physics (5127). The purpose of this research is to investigate the formation and growth of cloud particles (ice forms as well as droplets) by diffusion and accretion in growing cumulus clouds preceding their development into mature hailstorms. A Ph.D scientist is programmed for FY 1972.

(c) EQUIPMENT DEVELOPMENT (5130). This category covers in-house development programs.

1. Dual-Wavelength Radar (5131). In support of NHRE this program will continue to develop and will operate a dual-wavelength radar system for thunderstorm measurements. Procurement of a digital Doppler analyzer will be initiated in FY 1972. When completed, this radar system, consisting of a 1° beamwidth antenna used with a CP-2 coherent 10 cm radar and 3 cm radar, a digital reflectivity and Doppler analyzer will provide:

- a. Reflectivity measurements,
- b. Dual-wavelength measurements to yield liquid water data and hail detection, and
- c. Speed measurements on hydrometeors.

These measurements will yield high resolution information on the in-cloud wind field and on the type and distribution of precipitation, and together with the CHILL (University of Chicago, University of Illinois) Radar System at another site it will form a two-station Doppler system which will provide a truly new dimension in our description of storm dynamics.

2. Dropsonde (5132). The major objective in FY 1972 is to drop 55 dropsondes, in groups of 5 to 10, through the updraft (the weak echo region) of selected storms. This will provide a two-dimensional picture of the vertical motions of both the weak echo region and the overlying high reflectivity areas.

3. Data Display (5134). The program activities planned for FY 1972 are to:



- a. Add color video techniques to the present capability of the data display system for the emphasis of critical weather and cloud features, i.e., hail areas, high radar reflectivity, movement and changes in reflectivities, associated aircraft tracks and telemetered data, etc.
- b. Add an aircraft telemetry system and improve the existing University of Wyoming system.
- c. Improve and write new computer display programs to show a more comprehensive picture of scientific and operational information. For example: improved displays of graphical data coordinated with pictorial data, and three-dimensional displays shown in a two-dimensional simulation.
- d. Develop a remote radar display to be used with the dual-wavelength radar system, located near Fort Morgan. This would allow coordinated use of the radar system at Grover and Fort Morgan and permit scientific studies over a greater area.

(d) EQUIPMENT PROCUREMENT (5140). Funds for the off-the-shelf procurement are included in this category. This category will be phased out in FY 1972.

1. Communications (5143). Improved radio communications to more locations and vehicles are needed. This will require the purchase and installation of at least 10 UHF, two-way radios for use on already existing networks.

2. Airborne Instrumentation (5144). The objective is to provide new instrumentation for aircraft employed in NHRE. The purchase of a scanning radiometer, OMNI and DME navigation equipment, and miscellaneous observing equipment is planned for FY 1972.

(e) UNIVERSITY SUPPORT (5150). This category covers the expenses of all participating universities. In developing the FY 1972 program it was

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assumed that the 1971 participants would continue along with several additions as discussed below. An estimate for each subcontract cost is shown in parentheses.

1. University of Wyoming (\$250,000). The objectives of the research program are twofold:

- a. Contribute to the investigation of hailstorm dynamics through aircraft observations in the subcloud layer and on certain occasions in the lower regions of the organized updraft, and ground observations by two specially equipped mobile ground teams that can be positioned at selected locations relative to the storm.
- b. Contribute to the clarification of the microphysical processes involved in hail formation through ice nuclei measurements in the updraft, through observing the development of possible hail embryos in developing cumulus and through the analysis of precipitation samples.

2. South Dakota School of Mines and Technology (\$100,000). The objectives of the research program are, through aircraft measurements, to determine the composition of the high reflectivity zones in the updraft regions of selected severe convective storms, and to use these and other selected data in refining numerical hailstorm models.

3. Colorado State University (\$200,000). The objectives of the CSU research program are to determine, through airborne and surface measurements, the dynamical-thermodynamical properties of hailstorms, to complete the instrumentation and telemetry systems associated with the T-28 and F-101B aircraft, and to assist in the NHRE hailstorm modification program.

4. University of Chicago (\$100,000). The research objectives are to:

- a. Complete the development and evaluation of a Dual-Wavelength Radar System for hail detection.
- b. Use the above radar system in cooperation with NHRE for studies of hail growth mechanisms.

5. Illinois State Water Survey (\$100,000). The research objectives are:

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- a. Evaluation of the system's capability to detect hail at the ground and aloft.
- b. Evaluation of the system's capability to measure and map the liquid water content of storms.
- c. Interpretation and evaluation of recorded results for application to hailstorm research.

6. University of Oklahoma (\$50,000). The aircraft calibration and intercomparisons will be continued in FY 1972. The intercomparison flights will provide a comparison continuous in time and space of meteorological and aircraft variables. The acquired data will be analysed using modern statistical methods in order to estimate the relative accuracy.

7. University of Nevada, Desert Research Institute (\$50,000). This subcontract would provide engineering and computer programming support for the Data Acquisition and Display System, operation and maintenance of the DRI M33 Radar, and consultant services concerning a multiple aircraft tracking system.

The above subcontracts total \$850,000. In addition, \$150,000 is included to cover costs of other university proposals. Included in this category are additional proposals to be submitted by Dr. Robert Knollenberg, University of Chicago, and Dr. John Hallett, University of Nevada.

(f) FIELD SUPPORT (5160). This category covers general field operating expenses.

1. Logistics and Facilities (5161). The major portion of the funding is for utilities, landline communications, site preparation and construction, vehicles, transportation and lease of heavy equipment. The travel is for NHRE field personnel for whom travel is not programmed in one of the other categories.

2. Upper Air (5162). This program will provide for four (4) rawinsonde stations to be located at Fort Morgan, Grover, and Sterling, Colorado and Kimball, Nebraska. Two each will be furnished by the U.S. Army and the U.S. Air Force at an estimated cost of \$40,000 per station. This includes expendables (less helium), and travel and per diem expenses for the personnel. The cost of helium is estimated at \$5,000.

3. Surface Networks (5163). NHRE related costs for operation of the surface weather and hail measurement networks will be covered under this program.

4. Aircraft Control and Support (5164). This program will provide for the operation of the Air National Guard Facility, Greeley, Colorado. This includes maintenance personnel, FAA controllers (overtime and travel only), travel, spare parts, and utilities. Also included in this category are the funds (\$20,000) for insurance for aircraft and seeding operations.