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# ERL Program Plan FY 73-1

**U.S. DEPARTMENT OF COMMERCE**
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
Environmental Research Laboratories

## High Plains Precipitation Enhancement Research Project

Office of Weather Modification

BOULDER, COLORADO

August 1972

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
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ERL Program Plan FY 73-1

# HIGH PLAINS PRECIPITATION ENHANCEMENT RESEARCH PROJECT

Preliminary Planning Document

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CONTENTS

# HIGH PLAINS PRECIPITATION ENHANCEMENT RESEARCH PROJECT

NOAA/ERL
Office of Weather Modification

## INTRODUCTION

Few examples in the atmospheric sciences have benefits to mankind greater than those produced by weather modification. This is why so many attempts have been made over the last 20 years to develop a weather modification technology.

Evidence is accumulating that weather modification is now indeed a reality. We can definitely state that under certain conditions we can change the structure and microphysics of clouds. We can also state categorically that these same changes affect precipitation. The technical difficulty occurs when an attempt is made to evaluate the results in terms of increased or decreased precipitation. The best evidence presently suggests that seasonal increases in precipitation of 15 to 20 percent have been produced over 10 to 20 years by certain projects in mountainous regions of the West. Other experimental results suggest that increases of 100 percent have been produced from isolated cumulus clouds. In a general sense, it must be pointed out that these results have been attained usually under favorable meteorological circumstances. On the other hand, a number of carefully conducted field experiments have been carried out using statistical techniques for the evaluation, and the results have indicated decreases in precipitation produced by the weather modification efforts.

Although the effects of seeding clouds can be predicted in some instances, the scientists are less knowledgeable about the effect such seeding may have on clouds outside of the target area. There have been suggestions that these effects can occur at considerable distances.

Because of these uncertainties and our limited cloud physics knowledge, the "Committee on Atmospheric Sciences" of the National Academy of Sciences in their most recent report (1972) established these three goals:

> "(1) Identification by the year 1980 of the conditions under which precipitation can be increased, decreased, and redistributed in representative climatological areas through the addition of artificial ice and condensation nuclei.
>
> "(2) Development by the year 1980 of the technology to mitigate the effect of the following weather hazards: hailstorms, tornadoes, flood-producing rainstorms, fogs and lightning. The efficacy of the addition of ice nuclei to reduce hurricane wind intensities needs further testing in the immediate future.
>
> "(3) Establishment of a coordinated national and international system for investigating the inadvertent effects of man-made pollutants, with a target date of 1980 for the determination of the extent, trend and magnitude of the effect of various crucial pollutants on local weather conditions and on the climate of the world.
>
> "We believe that the three[1] goals listed above are of such national and international importance that they should form the principal objective of the nation's weather modification program."

In support of these recommendations and with encouragement from OMB to concentrate on precipitation enhancement, a

[1] Only the first two goals are addressed here. The third is addressed in NOAA Program Plan 71-1, *Geophysical Monitoring for Climatic Change,* dated February 1971.

program is being developed to start in FY 74 and continue for the next 5 years; it will provide the data needed to establish weather modification as a technology.

NOAA conducted two planning conferences in April and May 1972 to discuss needed programs and facilities with experts in cloud physics and weather modification from the Bureau of Reclamation, the universities, and private industry. The recommendations coming from these meetings have been incorporated in NOAA's program plans for FY 1974.

## GOALS AND OBJECTIVES

Goals:

- *To develop a way to evaluate the effectiveness of precipitation enhancement technologies.*
- *To develop the full potential for the enhancement, redistribution, and suppression of precipitation.*

Objectives:

- *To execute carefully designed and controlled precipitation enhancement experiments making maximum use of the experimental site.*
- *To increase our knowledge of the microphysical and dynamical characteristics of clouds.*
- *To determine any extra-area effects of cloud seeding.*
- *To develop a major new industry within the U.S. and for export.*

Rather than fragment the efforts needed to solve the research problems in weather modification, it is proposed to establish an experimental site or sites in the High Plains where year-round precipitation enhancement studies can be carried out over a well instrumented area.

In such an area we can determine the (1) precipitation efficiency of cumulus modification and precipitation enhancement, (2) development of large-scale precipitation enhancement from shallow winter-type cloud systems during upslope flow conditions, and (3) enhancement of precipitation from the cyclonic storm systems moving through this area.

Of great importance to weather modification as a whole, the High Plains Program will measure, using remote sensors and instrumented aircraft, cloud physics parameters generally describing the microphysical and dynamical characteristics of clouds. These critical parameters are needed in sophisticated cloud models for predicting cloud behavior and precipitation growth and fallout. To a large degree they have at best only been approximated in past experiments. The real promise of success lies in the use of real-time physical measurements, multi-dimensional mathematical simulation models, computer support, and advanced evaluation designs.

Peripheral, but of equal importance to enhancing precipitation, is a study of extra-area effects, that is, unintended effects of seeding that occur outside the target area. The extra-area effects have come to light only recently, and some recent results suggest that these effects may be of major importance.

The sociological, legal, ecological, and economic problems associated with changing the precipitation regime are recognized as important problems, and studies in these areas will be pursued concurrently with the cloud physics research.

## SITE SELECTION CRITERIA

In considering the High Plains for an experimental area, we must take into account several factors. We must establish (1) where the frequencies of the regimes to be modified are the greatest, (2) where contamination from other experiments or actual operations can be avoided, (3) where the social, economic, and legal climate is conducive to experimentation, and (4) where the precipitation needs are greatest.

*Precipitation need.* The natural distribution of annual precipitation in the High Plains is shown in figure 1. Annual precipitation varies from about 12 inches in the "rain

**NORMAL ANNUAL PRECIPITATION (INCHES)**

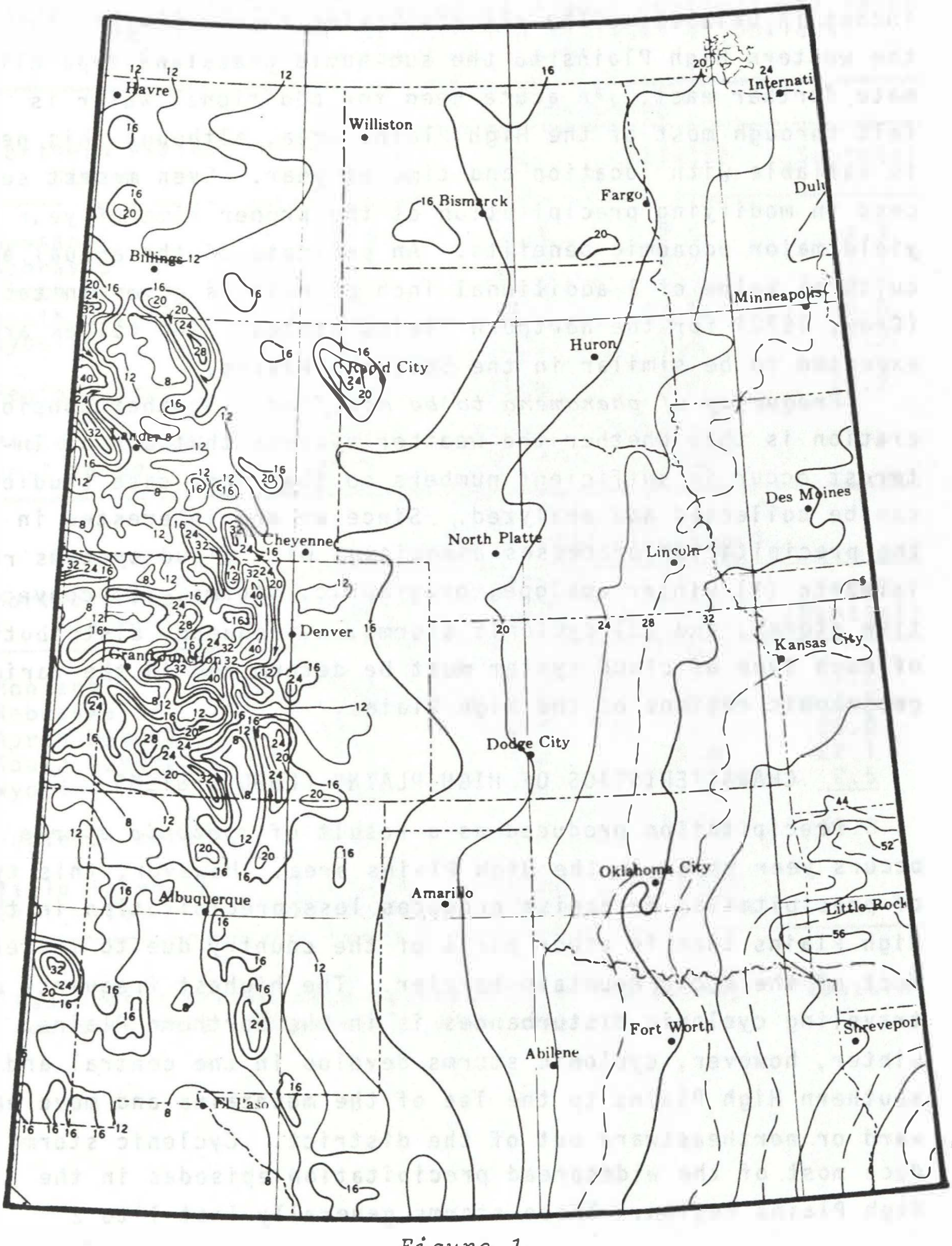


*Figure 1.*

shadow" of the Rocky Mountains to a maximum of around 35 inches in Oklahoma. The climate varies from semi-arid in the western High Plains to the sub-humid grassland-type climate further east. An acute need for additional water is felt through most of the High Plains area, although this need is variable with location and time of year. Even modest success in modifying precipitation at the proper time of year could yield major economic benefits. An estimate of the annual agricultural value of 1 additional inch of rain is given in table 1 (Crow, 1972) for the Northern Plains States. The values are expected to be similar in the Southern Plains.

*Frequency of phenomena to be modified.* Another consideration is that whether the weather systems that are of interest occur in sufficient numbers so that many case studies can be collected and analyzed. Since we are interested in the precipitation processes associated with cloud systems related to (1) winter upslope, orographic, storms, (2) convective storms, and (3) cyclonic storms, a frequency distribution of each type of cloud system must be determined in the various geographic regions of the High Plains.

## .CHARACTERISTICS OF HIGH PLAINS CLOUD SYSTEMS

Precipitation produced as a result of *cyclonic storms* occurs year round in the High Plains area. However, this type of precipitation mechanism produces less precipitation in the High Plains than in other parts of the country due to the effect of the Rocky Mountain barrier. The highest frequency of traveling cyclonic disturbances is in the Northern Plains. In winter, however, cyclonic storms develop in the central and southern High Plains to the lee of the mountains and move eastward or northeastward out of the district. Cyclonic storms produce most of the widespread precipitation episodes in the High Plains region. These storms generally last 1 to 2

Table 1. Preliminary Estimates of Annual Agricultural Value of 1 Additional Inch of Rain (in Millions of Dollars)[1] (from Crow, 1972)

| Northern Plains States | Ranching: Grazing Forage | Hay | Alfalfa | Subtotal |
|---|---|---|---|---|
| Montana[2] | 2.4 | 1.3 | 0.6 | 4.3 |
| Nebraska[3] | 0.5 | 0.4 | 0.2 | 1.1 |
| North Dakota | 0.6 | 2.3 | 1.3 | 4.2 |
| South Dakota | 1.2 | 4.0 | 1.4 | 6.6 |
| Wyoming | 0.8 | - | 0.2 | 1.0 |
| Regional total | 5.5 | 8.0 | 3.7 | 17.2 |
| Yield increase | 20#/a | 150#/a | 300#/a | |
| Unit value | $5/T | $10/T | $12/T | |

| Northern Plains States | Farming (only some key crops): Wheat | Barley-oats | Corn | Total (Partial) |
|---|---|---|---|---|
| Montana[2] | 5.4 | 1.5 | - | 11.2 |
| Nebraska[3] | 2.6 | 0.2 | 0.6 | 4.5 |
| North Dakota | 13.7 | 4.1 | - | 22.0 |
| South Dakota | 4.3 | 0.2 | 11.0 | 22.1 |
| Wyoming | 1.5 | - | - | 2.5 |
| Regional total | 27.5 | 6.0 | 11.6 | 62.3 |
| Yield increase | 2-3 bu/a | 2 bu/a | 4 bu/a | |
| Unit value | $1.20/bu | $.70/bu | $1.20/bu | |

[1]Based on a preliminary estimate by P. A. Hurley. [2]Eastern counties only. [3]Panhandle area only.



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days and can produce rain or snow over a large area. The potential for augmenting the natural precipitation by artificial seeding is not well established, since these storms may have a high efficiency in the conversion of atmospheric water vapor to precipitation. A seeding technology has not yet been developed for large-scale cyclonic storms. It is highly desirable to explore the applicability of various seeding technologies by means of theoretical models.

Normally, around 70 to 75 percent of the annual precipitation falls during the crop-growing months, April through September. Much of this precipitation is produced by *convective storms*. The rains of this period are usually of short duration, predominantly of the thundershower type having a diurnal periodicity. In the western High Plains, scattered local thundershowers occur mainly during the afternoon and evening. Farther to the east, thundershowers occur most frequently during the nighttime and in the early morning. The potential for modifying convective storms appears to be quite good, although a large number of these individual convective cloud systems must be modified to produce an effect on the water balance of the whole region. Various seeding technologies have been developed for convective clouds. The NOAA Experimental Meteorology Laboratory in Miami, Florida, has been conducting dynamic seeding of cumulus clouds; cloud base seeding has been studied in Australia; Dry Ice seeding has been conducted by Soviet scientists; and airborne upwind seeding has been done in Israel and in the U.S. Project Whitetop experiment. A major effort must be made to determine which of the technologies already developed will best apply to convective storms in the High Plains. New technologies, such as ion seeding from aircraft to affect droplet coalescence, will be investigated as well as hygroscopic condensation nuclei seeding.

Polar air from Canada and the far northwest periodically invades the middle and southern High Plains in the winter and produces widespread regions of upslope flow and cloudiness immediately east of the Rocky Mountains. The precipitation produced by these systems is fairly light during most of the winter, but in the fall and spring the outbreaks of polar air are met by breaks of polar air are beginning or waning, they are met by moist, warm air currents from the Gulf of Mexico. The juxtaposition of these two currents produces the rainy season in the western High Plains, which reaches its peak in May. *Upslope, or orographic, clouds* have both a long duration (typically 1 or 2 days) and a large areal coverage (approximately 100,000 to 200,000 square miles). Deep upslope conditions merge into the cyclonic cloud category and are thought to be naturally efficient cloud systems from which little additional rainfall could be artificially produced. Shallow upslope cloud systems, however, in which the cloud top temperatures are between -5°C and -15°C, are eminently suitable for artificial seeding over a large area, because of the small number of natural ice nuclei active at these temperatures. These storms typically occur 12 times a year in the central plains or nine times a year in the northern plains. Figure 2 shows the monthly distribution of upslope conditions at Denver, Colorado, throughout the cold season (September to April). Similar statistics are being developed for the whole High Plains region. A seeding technology has been developed for shallow storms of this type in the Great Lakes area by NOAA's Atmospheric Physics and Chemistry Laboratory.

## CONCEPTUAL DESIGN

The conceptual design for the High Plains experiment is shown schematically in figure 3. Three separate designs will be required in this experiment — one for each of the major cloud systems to be modified (i.e., cyclonic, convective, and upslope). The field experiment will be based on basic

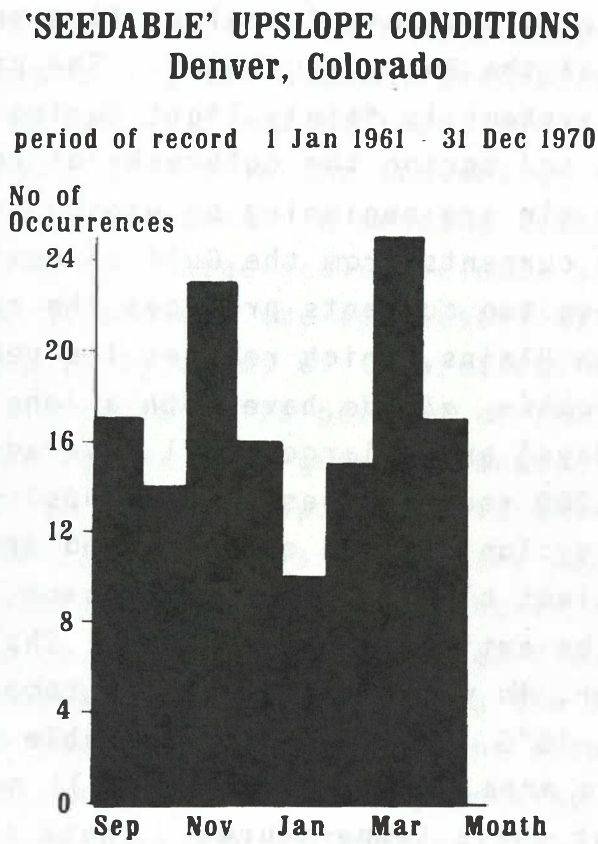



*Figure 2.*

physical and statistical design criteria. Any experiment has three fundamental phases: design, execution, and analysis. Physical and statistical design concepts will be incorporated into all phases of the experiment. Usually, the better the physical concept the sharper the statistical tests of hypotheses become through incorporating statistical principles into the experimental design.

The conceptual design of a *cyclonic cloud system experiment* must be based on climatological information. These storms are relatively long lasting and often give fairly large amounts of precipitation over large areas. The frequency of occurrence of these storms must be determined. A design concept will be built on this information as well as on physical information of the micro- and mesoscale characteristics of

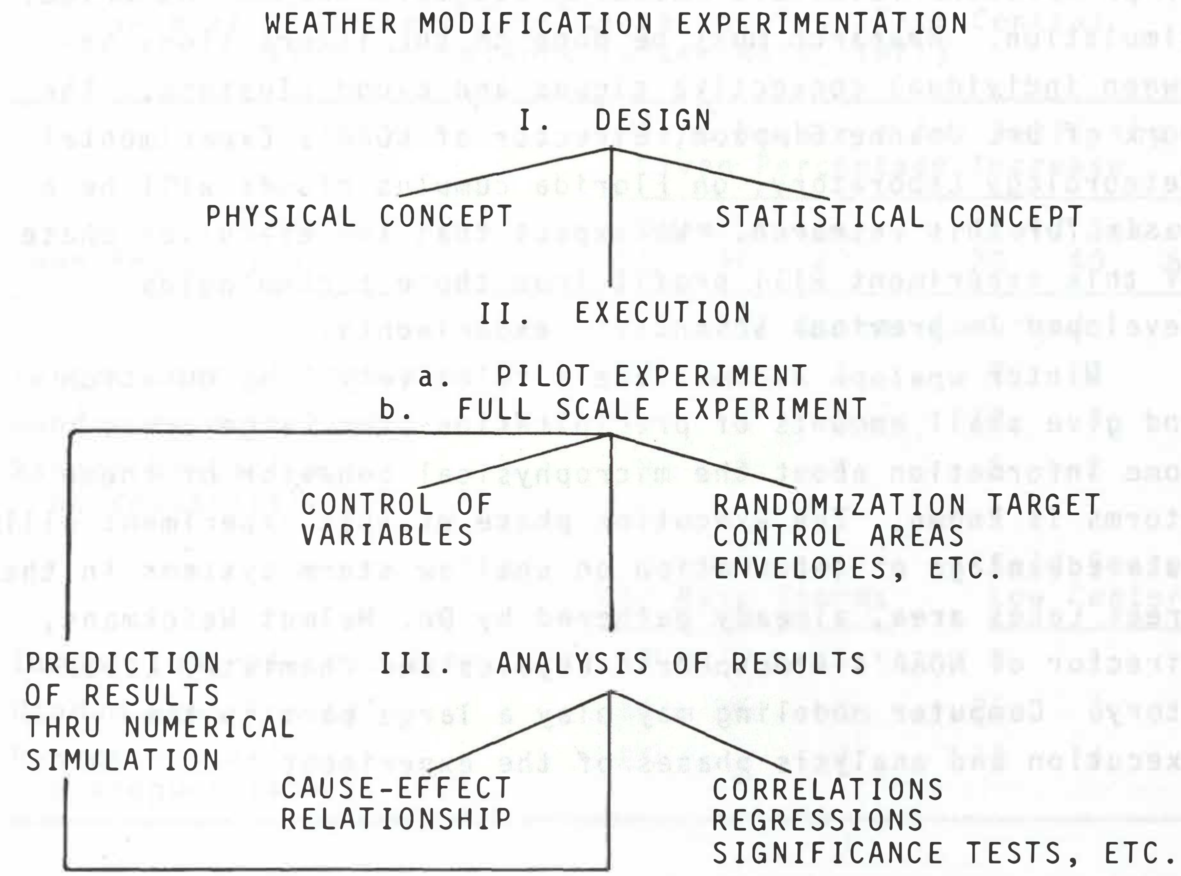



*Figure 3.*

these storms. A statistical concept will be structured to take full advantage of physical principles. The design of the execution phase of the experiment will involve a prediction of results through numerical simulation. Variables such as nuclei concentration can be controlled and a cause-effect relationship may be determined through statistical and physical analysis of the results.

The conceptual design of a *convective cloud system experiment* will be based on the short duration of these storms and the large amounts of precipitation falling over small, scattered areas. Much is known about the meso- and micro-physical principles involved in convective storm episodes, and numerical models that are now available could be modified to predict the results of seeding attempts through numerical simulation. Research must be done on the interactions between individual convective clouds and cloud clusters. The work of Dr. Joanne Simpson, Director of NOAA's Experimental Meteorology Laboratory, on Florida cumulus clouds will be a basis for this research. We expect that the execution phase of this experiment will profit from these technologies developed in previous scientific experiments.

Winter *upslope storms* have a relatively long duration and give small amounts of precipitation over large areas. Some information about the microphysical behavior of these storms is known. The execution phase of this experiment will take advantage of information on shallow storm systems in the Great Lakes area, already gathered by Dr. Helmut Weickmann, Director of NOAA's Atmospheric Physics and Chemistry Laboratory. Computer modeling may play a large part in the execution and analysis phases of the experiment.

## LENGTH OF EXPERIMENT

The time required to obtain statistical significance for different percentage increases of precipitation for the various cloud systems depends on the experiment design utilized. F. A. Huff (1971) analyzed storms occurring over a dense rain gage network in Illinois and determined the number of years it would take to verify a given percentage increase in precipitation for different storm types and experimental designs (see table 2). The High Plains site selected must allow for the completion of the experiment in the shortest time possible. Table 2 shows that the target control crossover design allows for the earliest completion.

Table 2. Length of Experiment Required to Obtain Significance at 95 percent Confidence Level on East Central Illinois Network (after Huff, 1971)

| Sampling design | Years Required for Verifying Given Percentage Increase | | | | | |
|---|---|---|---|---|---|---|
| | Warm Season | | | Cold Season | | |
| | 20 | 40 | 60 | 20 | 40 | 60 |
| | All Storms Combined | | | | | |
| Target control crossover | 2 | 1 | 1 | 2 | 1 | 1 |
| Random experimental | 16 | 5 | 2 | 13 | 4 | 2 |
| Random historical nonsequential | 8 | 2 | 1 | 6 | 2 | 1 |
| | Warm Season Air Mass Storms | | | Cold Season Low Centers | | |
| Target control crossover | 7 | 2 | 1 | 3 | 1 | 1 |
| Random experimental | 54 | 16 | 8 | 26 | 8 | 4 |
| Random historical nonsequential | 27 | 8 | 4 | 13 | 4 | 2 |

## SURFACE NETWORK AND EXPERIMENT DESIGN

The final judgment of the success of a rain augmentation project is always the amount of rain on the ground. This amount must be measured carefully during the research phase of the project. Therefore, the need for the installation of a sophisticated network of rain and snow gages is foreseen. We plan to have an area of 150 x 150 miles designated as the research network. This area will be subdivided into nine 50 x 50 mile squares (figure 4). The center square will be equipped with weather radars of various sophistication. The network will provide maximum flexibility for the design of the experiment. For the statistical design, it will permit a crossover design of target and control areas for a variety of storm motions.

PROPOSED STATION NETWORK

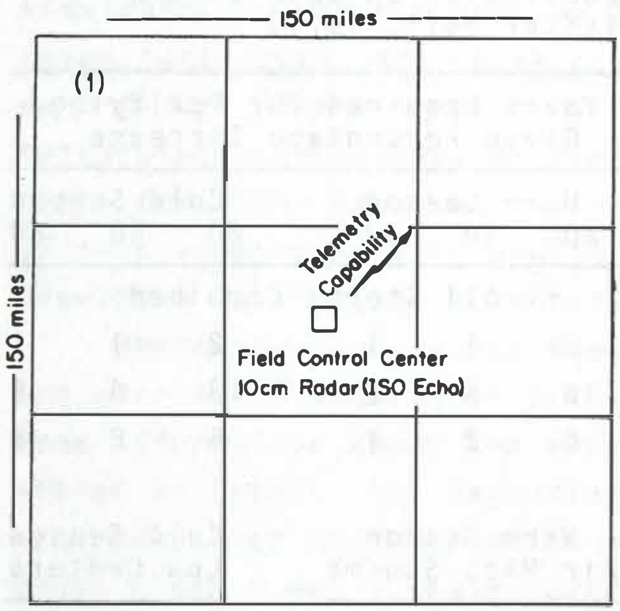



*Figure 4.*

[1]250 rain and snow gages per square, plus other stations reporting weather parameters.

For specific physical experimentation, the network will be large enough to permit studies of extra-area effects.

Station density must be a compromise between a high density network for convective precipitation measurement and a lower density network for large-scale storm types. For these reasons, a compromise figure of one station per 10 square miles, or 250 stations per square (50 x 50 miles), is foreseen. Station types of various sophistication — recording, nonrecording, telemetering capability, etc. — will be employed. The network will include stations that collect other weather data such as temperature, wind, pressure, and humidity.

The center of the network will be equipped with a conventional weather radar to define and measure precipitation characteristics and Doppler radar systems to analyze cloud dynamics. This center station will receive information telemetered from key stations in the network and will have a limited capability to analyze these data by mini-computer programs.

For proper three-dimensional atmospheric analysis, installation of one rawinsonde station will be required at each corner and in the center of the 150 x 150 mile network. In addition, measurements of the number of condensation and ice-forming nuclei present in the area will be needed, and subsequently information describing the electrical state of the atmosphere. The cloud top temperatures, as well as the presence of supercooled water or ice within the clouds, will be determined by remote sensing.

The center station will be the operational control facility for both surface and airborne seeding and analysis operations.

WEATHER MODIFICATION FORECASTING AND MODELING CENTER

If maximum use is to be made of the available resources, early recognition of cloud seeding opportunities is imperative. Studies of climatological data indicate that the number of seedable weather events during a year is limited. The statistical design and planned duration of a seeding experiment are based on these climatological considerations as well as on the successful short-range prediction of the storm episodes. Forecasts must be issued far enough in advance to make it possible for research operations to be scheduled and carried out.

The Weather Modification Forecasting and Modeling Center would (a) predict the horizontal and vertical extent of expected cloud formations, and (b) using cloud models, analyze and assess the growth of clouds, formation of rain, and rain amounts anticipated under both natural and seeded conditions.

The Weather Modification Forecasting and Modeling Center presents a unique opportunity, because of the availability of the remote sensing and cloud physics facilities, as well as the mathematical modeling capability, to advance the quality of "short-range" forecasting (under 6 hours), while simultaneously providing essential research inputs to the High Plains Precipitation Enhancement Research Project.

In addition to the conventional meteorological data provided to this center, we would also need real-time satellite data and a comprehensive climatology reference section.

## EXTRA-AREA EFFECTS

Integrated into the overall design will be a research program to determine the extra-area effects of the seeding experiment. This important aspect of the High Plains Program has not been adequately explored by previous experiments. A contract has been let and work is underway to establish a methodology for determining the extra-area effects of a seeding operation. In the present study, only precipitation effects are considered. Ultimately, we must consider other effects, such as ecological, economic, social and legal consequences.

The methodology to be developed will be adaptable to investigating the extended area effects of on-going nonrandomized projects, as well as effects in the area surrounding the High Plains tests. From the legislative viewpoint of assessing the circumstances under which weather modification needs regulating, studies as now underway and applicable to the High Plains Precipitation Enhancement Research Project are absolutely essential.

## CLOUD MODELS FOR HIGH PLAINS APPLICATION

When a mathematical model can be established which describes in quantitative terms the development and growth of a cumulus cloud, it strongly implies that we understand the underlying cloud physics and dynamics. Such models will be developed more rapidly as a result of the High Plains Project.

Present cloud models are in various stages of development. Some are highly parameterized models that simulate the development of cumulus clouds in a one- or two-dimensional space framework and in steady state or time dependent situations. These models are useful in making operational decisions and in conducting preliminary research on the interaction of cloud microphysics and dynamics on a broad scale. Other cloud models are being developed to treat in great detail the cloud and rain processes, such as condensation-coalescence growth of cloud particles and their evolution to rain and hail or graupel particles. These models simulate the interactions between cloud microphysics and dynamics on a cloud scale and are used to increase our understanding of precipitation processes.

The models require extensive measurements in and around the clouds to verify or update the theoretical work, so that, in turn, the models can give better support to research operations and evaluations. We would like to measure updraft profiles in clouds as well as the flux of moisture and sources of air feeding the clouds. In addition, we need to know their liquid water content, as well as the mass of ice and supercooled water. The budgets of natural condensation nuclei and ice-forming nuclei are essential information — particularly in weather modification programs. These and many other observations are needed for a comprehensive project in precipitation enhancement.

Models for the larger cloud systems are not yet available, due partly to the absence of measurements of the microphysical and cloud dynamic characteristics. Measurements on a cloud scale and larger are needed here. The High Plains Program is designed to provide these essential measurements leading to advanced models that can be useful in physical evaluation as well as in operations of weather modification programs.

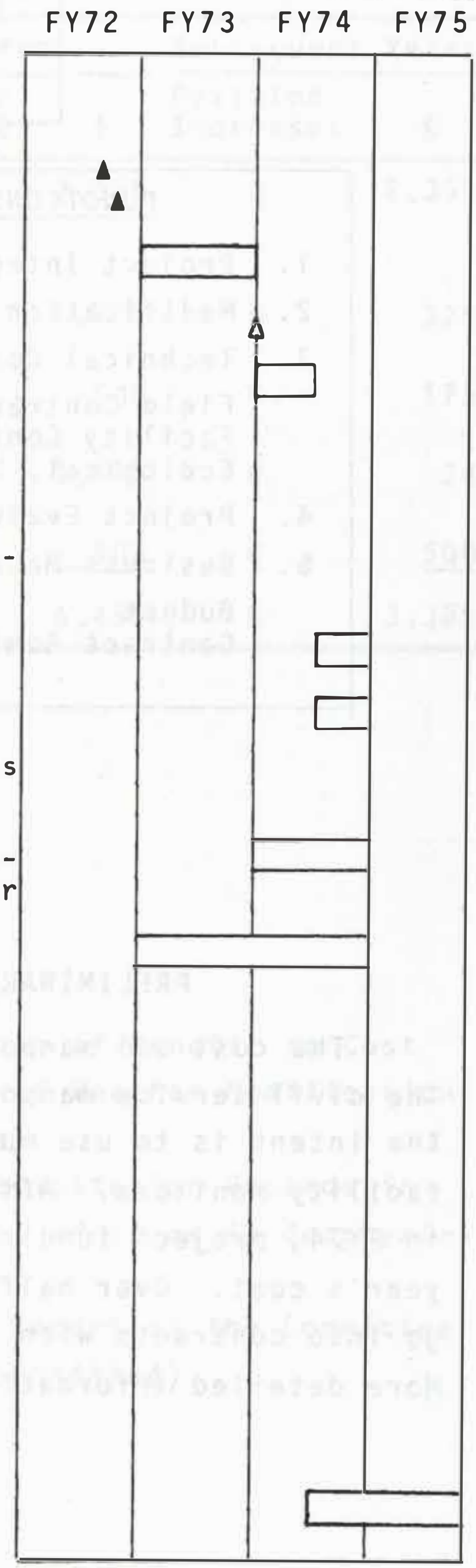
## PROJECT PHASING

NOAA's goal is to start a full operational season on convective, winter-upslope, and cyclonic cloud systems during FY 1975. Efforts during FY 1973 will concentrate on site selection surveys, background research on High Plains cloud systems, computer models appropriate to the High Plains cloud systems, detailed operation and evaluation plans, and other supporting planning research. FY 1974 will be primarily devoted to facilities procurement, installation and checkout, and the evaluation and selection of support contractors. Planning and supporting research studies begun in FY 1973 will continue through FY 1974. Limited field operations may begin in late FY 1974. Table 3 shows a graphic description of the project phasing.

## PROJECT MANAGEMENT

NOAA envisions this program as one making maximum use of contractors. Civil Service manpower increases will be held to an absolute minimum. Wherever in-house capabilities exist, they will be used, e.g., see appendices B and C. For support that does not exist in-house, NOAA will be looking to the universities and the private weather modification sector. With this approach, NOAA hopes to achieve a pooling of expertise and a quick transfer of technology to the private sector. In essence, NOAA hopes to create a strong government-university-private industry team that will operate under the direction of a NOAA/ERL High Plains Project Office as outlined in figure 5.

Table 3. Project Phasing for High Plains Precipitation Enhancement Project




1. NOAA/ERL - Weather Modification Community Planning Conferences on
   - a. Precipitation Enhancement
   - b. Facilities
2. Site Selection Surveys and Experimental Design
3. Site Selection Decision
4. Procurement of Equipment
   - a. Surface Network and Upper Air Stations
   - b. Radar and Remote Sensing
   - c. Field Station
   - d. Weather Modification Forecasting and Modeling Center
5. Establishment of Facilities
6. Contractor Selection
   - a. High Plains Program Operations
   - b. Facilities Support
7. Establishment of Weather Modification Forecasting & Modeling Center
8. Supporting Studies
   - a. Airborne Surveys of the Characteristics of High Plains Clouds and Storm Systems
   - b. Selection of Cloud Models to Fit the High Plains Situation
   - c. Operational Plans for the Three Weather Systems
   - d. Evaluation Plans for Real-Time Basis (Physical and Statistical)
   - e. Nucleation Material and Trace Analysis
   - f. Initiation of Contracts to Evaluate Legal, Economic and Social Problems
9. Start of Year Round Operations (Includes A/C Support)

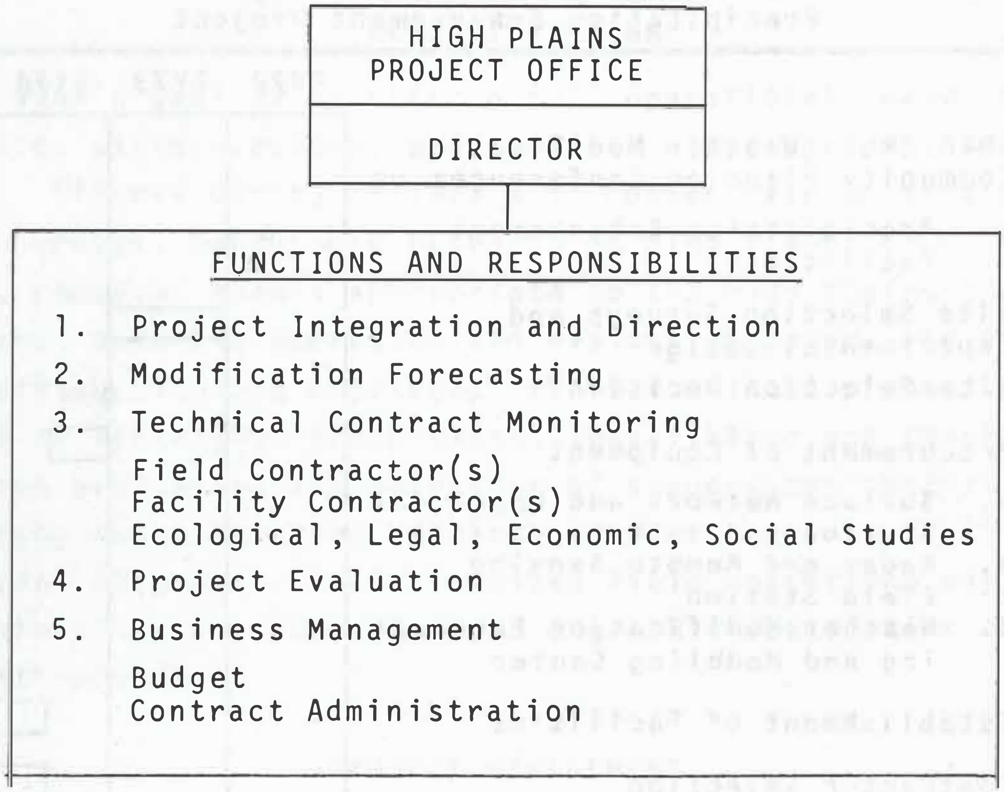



*Figure 5.*

## PRELIMINARY COST AND MANPOWER DATA

The cost and manpower data are summarized in table 4. The civil service manpower increases are very modest, because the intent is to use much of this manpower as contract and facility monitors. After the initial outlay for facilities in FY74, project funding drops to one-half of the initial year's cost. Over half of the funding in any given year will go into contracts with private industry and universities. More detailed information is presented in appendix A.

Table 4. Preliminary Cost and Manpower Estimates
($ in Thousands)

| | FY74 | | Subsequent Years | |
|---|---|---|---|---|
| | Position Increases | $ | Position Increases | $ |
| Program Development & Operation | 8 | 2,335 | 0 | 2,335 |
| Facilities | | | | |
| Surface Network/ Field Station | 1 | 1,575 | 0 | 325 |
| Modification Forecasting and Modeling Center | 1 | 500 | 0 | 175 |
| Radar and Remote Sensing | 1 | 1,545 | 0 | 50 |
| Legal, Economic, and Ecological | 0 | 500 | 0 | 500 |
| Totals | 11 | 6,455 | 0 | 3,385 |

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Crow, L. W. (1972), Some Considerations of Benefit to Cost Relationships Regarding the Use of Weather Modification (LWC No. 99), 7 April 1972, 28 pp.

Huff, F. A. (1971), Evaluation of Precipitation Records in Weather Modification Experiments, *Advances in Geophysics* 15 (Academic Press).

National Academy of Sciences (1972), Report of the Committee on Atmospheric Sciences (to be published).

## APPENDIX A

### Additional High Plains Precipitation Enhancement Research Project Cost Information

#### PROGRAM DEVELOPMENT

| | FY 74 | | | |
|---|---|---|---|---|
| | Positions | R&D Operations | Capital Outlay | Total |
| Planning Staff | 8 | 335 | - | 335 |
| Data Reduction and Analysis (CDC 6600, 800 hours) | - | 400 | - | 400 |
| Forecasting Services | - | 100 | - | 100 |
| Contracts for | | | | |
| Convective Precipitation Research and Operations | - | 750 | - | 750 |
| Upslope Effect Precipitation Research and Operations | - | 500 | - | 500 |
| Cyclonic Storm Precipitation Research and Operations | - | 250 | - | 250 |
| | 8 | 2,335 | - | 2,335 |

FACILITIES

| Surface Network/ Field Station | Positions | FY 74 R&D Operations | Capital Outlay | Total |
|---|---|---|---|---|
| Contract Monitor | 1 | 50 | --- | 50 |
| Operations Support Contract | - | 275 | --- | 275 |
| Telemetry, Recording, & Display Capability Including Communications with A/C, Ground Network and Forecasting Center | - | --- | 300 | 300 |
| 5 Rawinsonde Stations | - | --- | 200 | 200 |
| Surface Sensing Network System | - | --- | 500 | 500 |
| 1 Acoustic Sounder | - | --- | 150 | 150 |
| 1 Lidar | - | --- | 100 | 100 |
| | 1 | 325 | 1,250 | 1,575 |

| Modification Forecasting and Modeling Center | Positions | R&D Operations | Capital Outlay | Total |
|---|---|---|---|---|
| Contract Monitor | 1 | 50 | --- | 50 |
| Operations Support Contract | - | 125 | --- | 125 |
| Laser Facsimile Recording Equipment | - | --- | 25 | 25 |
| Radar Remote Read-Out | - | --- | 25 | 25 |
| Standard Meteorological Read-Out Instrumentation | - | --- | 25 | 25 |
| Teletype and Facsimile | - | --- | 25 | 25 |
| Video Recording Equipment | - | --- | 25 | 25 |
| Communication Equipment | - | --- | 25 | 25 |
| Satellite Read-Out | - | --- | 175 | 175 |
| | 1 | 175 | 325 | 500 |

| Radar and Remote Sensing | FY 74 | | | |
|---|---|---|---|---|
| | Positions | R&D Operations | Capital Outlay | Total |
| Operational Integration | 1 | 50 | --- | 50 |
| 3 Doppler Radar Systems for Cloud Dynamics Analysis | - | --- | 500 | 500 |
| 1 Precipitation Radar | - | --- | 400 | 400 |
| 1 Downward Looking Doppler for A/C | - | --- | 200 | 200 |
| Radiometer Sounding System for A/C | - | --- | 40 | 40 |
| Thermal Imager for A/C | - | --- | 40 | 40 |
| Solar Pyranometer for A/C | - | --- | 40 | 40 |
| IR Interferometer for A/C | - | --- | 50 | 50 |
| Multi-Frequency Microwave Radiometer | - | --- | 175 | 175 |
| Raman Spectrometer | - | --- | 50 | 50 |
| | 1 | 50 | 1,495 | 1,545 |

LEGAL, ECONOMIC, ECOLOGICAL

| | FY 74 | | | |
|---|---|---|---|---|
| | Positions | R&D Operations | Capital Outlay | Total |
| Legal | - | 150 | - | 150 |
| Economic | - | 150 | - | 150 |
| Ecological | - | 200 | - | 200 |
| | - | 500 | - | 500 |
| Grand Totals | 11 | 3,385 | 3,070 | 6,455 |

# APPENDIX B

## APCL Contributions to the High Plains Precipitation Enhancement Project

APCL plans to be involved in formulation, design, execution, and analysis of the High Plains Project with respect to its scientific approach and execution. APCL's competence lies in working out the scientific concepts, selecting of contractors and their scientific supervision, and finally in contributing to the research phase of the field operations. Specifically the following areas of immediate importance to the High Plains Project fall within APCL's competence:

<u>Meso and Micro Cloud Physics</u>

1. Study of dynamics and life history of mesoscale cloud systems
2. Development of numerical models of cloud and precipitation systems
3. Development of cloud systems models for experimental area

<u>Inadvertent Modification Aspects</u>

1. Monitoring of cloud condensation and ice nuclei in experimental area and environment
2. Development of a lidar system that determines the areal aerosol distribution in a PPI model

<u>Nucleation Chemistry</u>

1. Silver Iodide
   a. Mechanisms of its nucleation activities
   b. Duration of activity (persistence)
   c. Toxicity
   d. Substitutes
2. General
   a. Efficiency of delivery systems

b. Cloud stabilization materials

c. Trace analysis for temporal and spatial distribution

Atmospheric Electricity

Electric rain augmentation through enhancement of coagulation coefficient

Advanced Instrumentation

1. Airborne measurements of air and moisture flow into and within clouds
2. Airborne liquid water content measurements
3. Airborne snow particle sampling
4. Airborne ice and supercooled water detection
5. Ground network instrumentation
6. Data evaluation and presentation

Infrared Remote Observations

1. Analysis of thermal budget of clouds and cloud systems
2. Measure cloud physics parameters and dynamical characteristics of clouds
3. Areal extent of precipitation
4. Seeding effectiveness
5. Downwind effects

It is expected that the High Plains Program will stimulate related and supporting studies in other areas. We think particularly of the problem of control of albedo and the surface radiation budget through large-scale dissipation of winter stratocumulus clouds. Such cloud layers occur over oceanic and continental regions as well, and as previously observed their dissipation over land in spring may cause convection in the cleared area through increased insolation. Effects of large-scale dissipation of cloud layers on weather are hitherto unexplored.

APPENDIX C

# WPL Contributions to the High Plains Precipitation Enhancement Project

The combination of acoustic, microwave, and optical techniques provides a very wide range of remote sensing opportunities applicable to weather modification studies. While a single instrument may be limited to measurements in clear air, or in cloud, or in precipitation, the combination offers major capabilities for the remote measurement of wind, temperature, humidity, precipitation, and cloud particles, both in the cloud *and* in its environment. The different potential roles of acoustic, microwave, and optical remote sensing in weather modification studies are summarized below.

## 1. Acoustic Echo Sounding and Weather Modification

The Wave Propagation Laboratory proposes to use acoustic echo sounding equipment already available to study temperature structure, convection patterns, and winds in the planetary boundary layer to heights of 1 to 2 km to supplement weather modification efforts, where knowledge of such boundary layer parameters is required. In addition, we propose to construct a new low frequency, larger antenna system to enable probing to heights of 3 to 5 km to study horizontal and vertical winds in the sub-cloud layer, within clouds, and at the vertical boundaries of convective clouds. This new acoustic sounder system may also be able to monitor cloud top heights to 5 km, and to study how cloud structure changes during seeding. The following paragraphs provide background information on this proposed effort.

Studies underway in WPL are proving the feasibility of quantitative evaluation of acoustic echoes in terms of the atmospheric temperature structure and total wind vector. A significant contribution to this capability will be available after tests are completed at the Haswell, Colorado, site during August 1973. In addition, the fabrication of more advanced data processing circuits and antennas promises to extend the range and to improve real-time assessment of atmospheric structure during the FY 1973 time frame.

Acoustic echo sounding has already proved to be of value in understanding atmospheric temperature structure, the morphology of convective plumes, and as a sensor of winds in the planetary boundary layer. Present equipment, operating at acoustic frequencies of from 1 to 2 kHz, is limited in range to 1 to 2 km because of absorption of acoustic energy in the atmosphere. However, by building a sounder for operation on lower frequencies, it will be entirely feasible to monitor clear air temperature structure and winds from the boundary layer to the cloud base altitudes experienced over the High Plains. It may even be possible to investigate airflow in the clear air surrounding isolated clouds, so that much better understanding of entrainment and mixing through cloud vertical boundaries could be obtained.

During the occurrence of stratiform clouds, produced by upslope flow along the front range of the Rockies, acoustic sounding has demonstrated the capability of monitoring the height of cloud tops. Temperature structure is evidently produced by evaporation and radiative cooling at cloud tops. Thus, we have already shown the feasibility of the acoustic echo sounder for monitoring cloud top heights, when the clouds are within range of the present equipment. This information would be of value in determining cloud top temperature in making decisions on whether to seed. In addition, after seeding is accomplished, the additional temperature structure introduced into the cloud by the release of latent heat of condensation and fusion might provide tracers of the sequence of physical events within the cloud. Thus, the sounder may provide a new tool for monitoring changes in cloud structure, even before precipitation is initiated.

We conclude that active acoustic sounding holds great promise of providing an important new tool in weather modification studies.

## 2. Microwave Remote Sensing and Weather Modification

Doppler radar methods have been applied to the study of meteorological systems during the past decade, and the potential power of the Doppler radar for measuring wind fields associated with convective cells has been demonstrated. Radars operating at wavelengths of 3 cm and 10 cm, using hydrometeor and artificial (chaff) targets, are capable of measuring the detailed wind field of cloud systems including the subcloud region and the inflow and outflow regions. It is anticipated that the effects of cloud seeding on hydrometeor size distributions and their trajectories can be determined by Doppler radar.

Ground-based Doppler radar systems, currently in use in research problems, provide velocity measurements of hydrometeor targets to ranges of 120 km. Rapid progress in the development of on-line Doppler data processing methods indicates that velocity measurements can be made in 0.25 seconds for multiple ranges for volumes defined by the 0.01 radian angular resolution and a 75 meter range resolution. Thus, the wind field associated with a cloud system that extended 20° in azimuth, 10° in elevation, and 10 km in depth can be characterized by $10^5$ independent Doppler velocity measurements acquired in 3 minutes. Artificial tracers must be injected into the regions where no hydrometeor scatterers are detectable. Doppler radars operating at shorter wavelengths can be used to probe clouds that do not contain precipitating particles. Two ground-based Doppler radars can measure the two-dimensional wind field over about $10^4$ square kilometers. A Doppler radar triad, available within the present technology, would be an important tool for studying cloud dynamics in a preselected area by providing three-dimensional wind fields in almost real time. Highly mobile truck-mounted radars could enable the preselected area of radar coverage to range over a substantial area of the plains on a daily basis.

Aircraft seeding of clouds for weather modification can take place over a much wider area than that covered by a single ground-based Doppler system. It is clear that the airborne Doppler systems will need to be developed to enable cloud systems to be studied over extended regions of the High Plains. In addition to providing the necessary range coverage, the airborne Doppler radar will be particularly effective for mapping the vertical motions inside a storm by using a vertical looking radar in an aircraft flying above the storm. The radar beam cross sectional area will be small because of the short range from the radar to the cloud, leading to excellent spatial resolution in the updraft and downdraft regions. Side-looking Doppler radars mounted in aircraft flying around the storm can give the horizontal wind field, and the side-looking radars can scan in a vertical plane perpendicular to the aircraft motion to give a rapid scan of the entire cloud system. The airborne Doppler radar would use the data processing techniques already developed for ground-based systems and would use short wavelength radars to minimize the antenna size. A feasibility study and test should be performed in FY 73 if airborne Doppler systems are to be available for the High Plains project.

Other information can be derived from the Doppler radar measurements and can provide valuable data for weather modification. In particular, the size distribution of the scattering particles can be determined with a vertical looking radar, and depolarization measurements may provide information about the types of scattering particles.

It is clear that Doppler radar provides the unique capability of measuring the detailed three-dimensional wind field over large volumes in a short time, and it will be an essential tool for weather modification studies. Ground-based radars can provide this data in a limited area, but the airborne Doppler must be developed to cover the extended regions in which cloud seeding might be used.

Ground-based and airborne microwave radiometers are a potential source of information on line integrals of liquid water content and ice-water fraction through cloud systems. Because of the dependence of the dielectric constant of water on frequency, and because of the large variation in water content of clouds, multi-frequency observations (three or more) are required. Ground-based observations of convective thunderstorms in Colorado at 10.7 GHz have indicated the potential of the technique, but much work is needed on the multi-frequency technique.

Airborne observations with a 60 GHz radiometer in the clear air around cloud systems can yield significant information on vertical temperature structure. Similar observations at 22 GHz can yield integrated water vapor content above an aircraft. Both of these techniques have been field tested.

3. Optical Remote Sensing and Weather Modification

The Wave Propagation Laboratory of ERL is engaged in optical atmospheric remote sensing studies that are highly applicable to weather modification research. Single-ended (monostatic) laser scattering (lidar) techniques show promise of probing the clear air atmosphere, regions of precipitation, and the cloud surface from either ground or airborne platforms. Profiles of atmospheric temperature, humidity, aerosols, precipitation, and wind field are potentially measurable by lidar. Cloud surface range and motion, and probably composition (ice or water) are also accessible to laser scattering methods. A two-ended (long path) laser scintillation technique has demonstrated the capability of measuring the mean transverse wind (and hence inflow) at low levels.

Remote measurement of water vapor mixing ratio and nitrogen density fluctuations (and thereby temperature fluctuations) by means of remote Raman (inelastic) scattering spectroscopy have been demonstrated. Ranges up to kilometers have been achieved with limited signal to noise, and greater ranges could be obtained through procurement of better transmitters. Research is being extended into scattered spectral line shape and rotational Raman spectrum envelope techniques to allow remote, active measurement of temperature profiles directly rather than via density measurements.

On-frequency scattering of laser radiation gives an indication of aerosol distribution. The ability to characterize aerosols (composition and size distribution) will be improved by current research on multicolor scattering behavior and by planned studies of inelastic scattering (Raman flourescence).

Eddy correlation techniques by means of spatially separated laser beams have given an indication of wind field for sufficiently inhomogeneous atmospheric conditions. Research on optimum beam separation and development of improved hardware is needed. Wind sensing by Doppler lidar, which uses the small frequency shift of scattering from a moving particle for measuring longitudinal velocity, has been successful at short ranges of several hundred meters. Techniques for extending the range to several kilometers are under study. Research on transverse wind measurement by means of particle traversal of projected laser interference fringes will begin in FY 73. This technique has been used successfully by other laboratories at short ranges.

Cloud range and motion (change in range) are conveniently measured by simple on-frequency scanning lidar. Since the Raman scattering for solid ice differs from that for liquid water, we expect that water droplet and ice crystal aerosols will be sharply distinguishable by inelastic laser scattering. Laboratory research on this question is now starting. If successful, inelastic scattering differentiation of ice and water aerosols will remove the ambiguity caused by multiple scattering effects in depolarization-based measurements of cloud composition.

Scintillation of a laser beam caused by atmospheric turbulence allows a measurement of the mean transverse wind across a two-ended optical path. A system using the time-delayed correlation of scintillation signals at two separated apertures is now operational. This technique is limited to configurations where both ends of the path are accessible. By measuring mean winds across a closed path, we can determine net inflow. Inflow measurements associated with thermal plumes are scheduled for early in FY 73.

Further research is needed to extend these techniques to weather modification needs for characterizing the storm environment and assessing modification results. Part of this research is planned within present funds of the Wave Propagation Laboratory, but a major increase in funds would be required to effectively pursue studies in the areas specifically needed for weather modification remote sensing, and then to provide the hardware and operating costs for the field units for weather modification research and operations.



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