ILLINOIS STATE WATER SURVEY
ATMOSPHERIC SCIENCES SECTION

ILLINOIS PRECIPITATION ENHANCEMENT PROGRAM
PHASE I

October 10, 1973

Interim Report

for

1 July 1972 - 31 July 1973

To

Division of Atmospheric Water Resources Management
Bureau of Reclamation
U. S. Department of Interior

Prepared by

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Stanley A. Changnon

Principal Investigator

Contract 14-06-D-7197

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DEPARTMENT OF
REGISTRATION AND EDUCATION
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WILLIAM C. ACKERMANN. CHIEF

October 10, 1973

Dr. Archie M. Kahan, Chief
Division of Atmospheric Water Resources Management
U. S. Department of the Interior
Bureau of Reclamation
Engineering and Research Center
Building 67, Denver Federal Center
Denver, Colorado 80225

Dear Dr. Kahan:

Enclosed is the Second Interim Report for the Illinois Precipitation Enhancement Program: Phase I. It covers the research activities pursued during the 1 July 1972 - 31 July 1973 period.

This report covers only the Atmospheric Sampling Program as approved in your letter of 10 August. The FY-73 activities and work planned for FY-74 are described. The project personnel are described in Appendix 2.

Sincerely,
ILLINOIS STATE WATER SURVEY

Stanley A. Changnon, Jr.

Stanley A. Changnon, Jr., Head
Atmospheric Sciences Section
217/333-4260

SAC/rr
Enclosure

INTERIM REPORT
1 July 1972 - 31 July 1973

Introduction

The Precipitation Enhancement Program for Illinois was conceived as a 5-year program aimed at establishing whether it would be (a) desirable and (b) scientifically feasible to enhance precipitation in Illinois. It consisted of nine study areas on the time scale shown in Figure 1. As a consequence of the major reduction in support in FY-74, all programs other than the Atmospheric Sampling Project were terminated on 30 June 1973. The work carried out under these other programs has been detailed in separate technical reports (Appendix 1). This report will deal only with the continuing activities under the Atmospheric Sampling Program.

A research plan and associated field program were developed to meet the ultimate objective of the project—namely to determine the physical potential of Illinois cloud systems for modification. Pennsylvania State University was contracted to provide aircraft services. These included a two-engine airplane, basic scientific package, recording system, installation of equipment provided by the State Water Survey, and pilot and technician services. In anticipation of a field effort covering several seasons, work was initiated on activation of a radar facility at Savoy, Illinois and a 10,000 mi^2 raingage network lying primarily south and west of Urbana. Work on these facilities ceased when funding levels cast doubt on continuation of the field effort in FY-74. The base of the field operations was shifted to Pere Marquette State Park so as to utilize the existing radar and operational facilities and the recording raingage network operated by the State Water Survey during the summer season.

Research Plan

The goal of the Atmospheric Sampling Program is two-fold.

1. To determine if, in Central and Southern Illinois, general meteorological and specific cloud conditions present the opportunity for significant modification of precipitation. Chief interest is in enhancement but the alternates of decrease or redistribution are also parts of the overall problem.

2. To generate information which can be used in selecting the most feasible seeding hypotheses for testing in later modification programs, and in the design of the experiment, should the answer to 1 be positive.

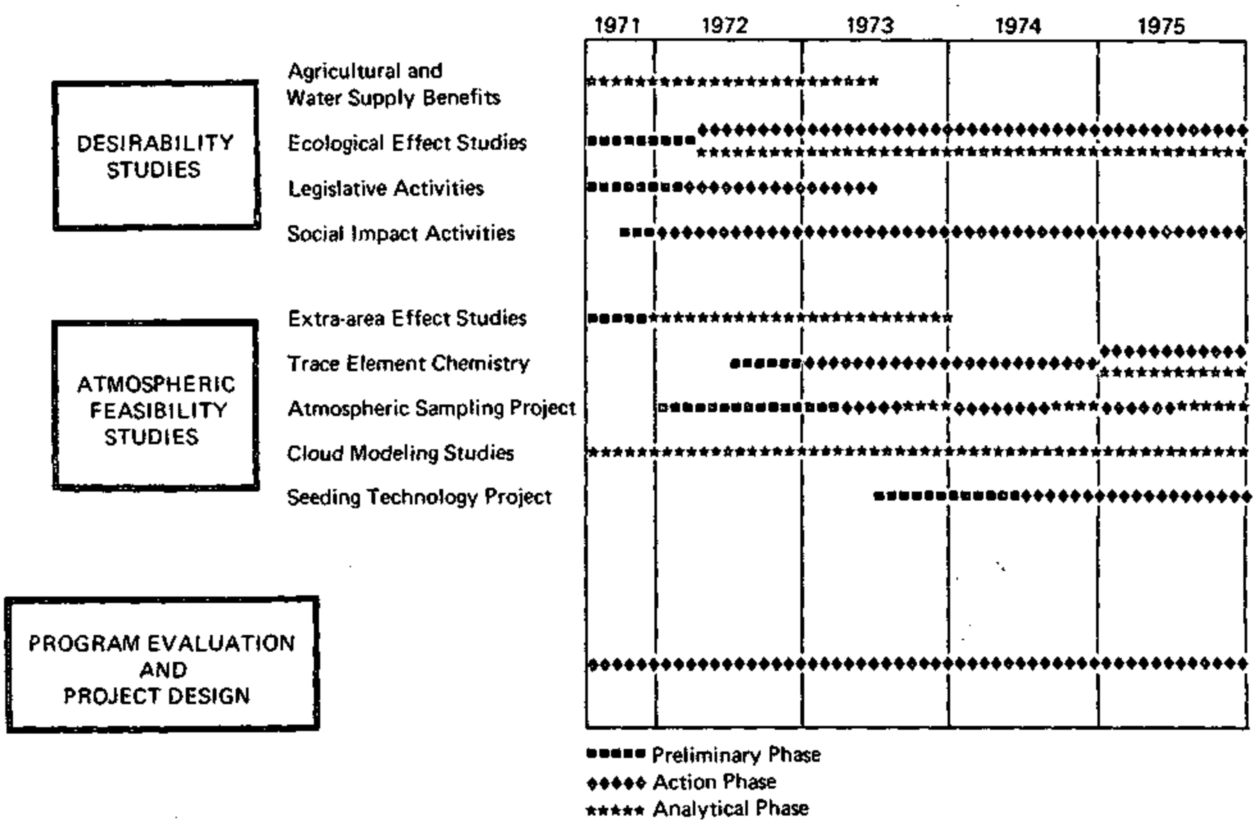

Figure 1. The original program schedule for the Illinois Precipitation Enhancement Program

In view of these objectives the program attempts to establish (a) the population statistics of those variables deemed important in the precipitation process and the relationship between them and observed precipitation and (b) the relationship between the microphysical and dynamical structure of a cloud and the rain that is produced. Thus, the program incorporates a mix of population-statistic studies and case history studies.

Precipitation modification is directed toward changing or redistributing the rainfall, with or without a change in the precipitation efficiency. For example, "dynamic" seeding attempts to increase the cloud rainfall by increasing the flux of moisture - but the precipitation increase may not be proportional to the enhanced inflow. On the other hand the concept of "leaching" is totally concerned with increasing the efficiency.

The enhancement of both rainfall and precipitation efficiency is to be studied on three scales - for a region, for a cloud area within a region, and for a single cloud. In view of the growing concern about extra-area effects, the program as originally planned was to have considered a region roughly 100 miles by 125 miles. The southern Illinois network is roughly half this size. Because of logistics, airplane sampling is usually confined to two or three cloud areas on any one day.

The preliminary results of the economic study indicated that the field efforts should concentrate on the growing season (mid April-October) but within that season there are periods when decrease, rather than increase, in precipitation may be the desired outcome. At least one winter month should be included in order to gain some knowledge of winter storm structure. The field program in FY-73 was carried out during June and July, the height of the growing season.

The parameters chosen for study are listed below. This list includes only those which can be realistically determined considering the observational state-of-the-art and the available personnel and funding. The thrust of the analysis will be toward determining the natural dependence of precipitation and/or precipitation efficiency on a relevant parameter or group of parameters. A major effort will seek the "missing link" which causes a synoptically favorable day to produce little rain. Key independent parameters are the efficiency and timing of the coalescence mechanism (item 9), the water content just below and just above the freezing level (item 10) and the nucleus concentrations (item 11). These parameters are correlated and in fact the first two are functions of the third.

1. Precipitation, the dependent variable.

   The surface precipitation is the end product of any program in modifying precipitation. Surface measurements of precipitation amount are essential - and information on rate and type is important. Radar observations are an important supplement in estimating precipitation.

2. Precipitation Efficiency, dependent variable.

   Precipitation efficiency is the ratio of precipitation (item 1) and moisture inflow (item 3). Because of the difficulties in measuring the latter, it will be possible to only crudely estimate the value of this parameter.

3. Moisture Inflow.

   This parameter is very important, not only because it enters into the calculation of precipitation efficiency but because it certainly must influence the rain amount. Precipitation efficiency itself may be a function of inflow.

   It is very difficult to accurately measure moisture inflow but estimates can be obtained in several ways: (a) from the vertical flux through cloud base level based on vertical velocity and moisture measurements, (b) from airplane wind and moisture measurements below cloud base, and (c) measurements based on pibal and/or radiosonde measurements from several balloons released around the area.

4. Regional Cloud Cover and Fraction of Cloudy Area Precipitating.

   In some respects these parameters provide a rough estimate of both the inflow and precipitation efficiency. They are also of climatological interest and are important parameters for operational planning of any modification experiment.

   Nephanalysis based on satellite, surface and airplane observations can provide the cloud data. Radar and surface observations provide precipitation data.

5. Visual and Radar Cloud Geometries: dimensions, depth, base and top height, separation, family configurations, etc.

   These provide a "picture of the animal". Precipitation is known to be correlated with some of these dimensional variables. Particular attention will be given to cloud groupings, separation between clouds and line spacings since these are important to the merger and line generation hypotheses for precipitation enhancement.

   Sources of the necessary measurements are the same as those given in item 4.

6. Regional and Local Thermodynamic Structure.

   Obviously the vertical thermodynamic structure, humidity as well as temperature, is important in cloud and precipitation development. It is essential to determine how representative of a cloud area regularly available sounding information may be. The relationships between rainfall and precipitation efficiency and the local and synoptic thermodynamic structure will be sought. In addition, differences between regional and local soundings in the vicinity of the cloud area will be carefully studied. Both regional and local soundings will be used as input into the one dimensional model and the predictions compared to observed cloud and precipitation parameters.

7. Mesoscale and Local Kinematics.

Mesoscale and local convergence profoundly influence the cloud and precipitation development. To estimate the former, careful sectional analyses will be made hourly during the flight periods. Special pibal observations in the cloudy area are most valuable and are occasionally available.

8. Updraft Dimension, Strength and Duration at both Cloud Base and Seeding Level.

These variables are of interest both from physical and operational seeding considerations. The sensitivity of one dimensional models to cloud updraft diameter amply illustrates the former. They determine the amount of vapor "processed" by the cloud and influence the efficiencies of the precipitation processes. In addition, they must be considered in planning for delivery of a seeding agent.

These parameters are best measured by aircraft although radar observations and cloud photographs can provide estimates.

9. Efficiency of the Coalescence Process.

This is a critical factor. It has been well established that precipitation first forms within convective clouds by both the "all water" coalescence mechanism and the Findeisin "ice" mechanism. Sometimes rain forms in the lower part of a deep cloud by the former mechanism first and shortly after in the upper part by the ice mechanism. Sometimes the timing is reversed but most frequently the two rain mechanisms initiate rain within two or three minutes of each other.

One possible approach to modification is to change the timing and/or efficiency of one or both of the mechanisms. The result, in terms of total rainfall, of any hypothesized alteration is difficult to predict. You can argue that (a) if you <u>increase</u> the efficiency of the water process, you "unload" the updraft and therefore increase the total flux of moisture and therefore more water can be processed by the cloud or (b) if you <u>decrease</u> the efficiency of the water process thereby keeping the water in the updraft to the freezing and/or the seeding level, much more latent energy is available through freezing to accelerate the updraft and increase the total flux of moisture.

There may be situations when (a) is to be preferred to (b) and vice versa. Our knowledge is still so rudimentary that the supposed consequences of either approach are not much more than guesses. Experiments using the one dimensional model can be instructive. A basic effort in the sampling program is directed toward determining the variations in precipitation as a function of the efficiences and timing of the two mechanisms.

The problem is to estimate the efficiencies and timings of the water and ice mechanisms. The optimum would be to measure the evolution of the vertical profile of the three forms of condensate, "cloud" water, "precipitation" water and ice. Although this optimum cannot be realized on the current time scale and budget, it may be possible to distill major factors from the in-situ sampling of the condensate and the radar surveillance.

10. Amount of Latent Energy Available and Time Period Available.

Latent energy here refers to the energy which will be realized in freezing. This is basically the amount of liquid water at the seeding level and how long a significant amount of water is retained at this level. This has great significance from a logistic point of view. For instance, if under particular cloud and synoptic conditions liquid water occurs at -5C for only 2 or 3 minutes, delivery of ice nuclei has to be carefully timed. Again in-situ sampling of the condensate and vertical scanning of the cloud by radar provide information about this parameter.

11. Nucleus Sizes and Concentrations: Condensation and Freezing.

Since most current seeding hypotheses depend on the alteration of the nucleus populations, the dependence of the rainfall on the sizes and concentrations of the condensation and freezing nuclei for given thermodynamic and kinematic conditions should be determined. It is once again the still unanswered question - just how important is the microphysics in rain production. From operational considerations it is important to determine how frequently the opportunity to significantly alter the nucleus population presents itself.

Measurements of nucleus concentrations at cloud base level and at the freezing level, or better yet vertical profiles from surface to seeding level are desirable. But nuclei concentrations are very difficult to measure. The state-of-the-art is such that it is unlikely that truly reliable numbers can be determined. The best that can be hoped for is day-to-day reproducibility.

12. Airflow Around Clouds and Cloud Groups.

This parameter is important to those hypotheses dealing with cloud merging, generation of new lines, etc. These may, in fact, be the only aircraft measurements feasible on thunderstorm-line days. Pibal swarms and/or radar chaff dispersal around storms or aircraft wind measurements taken along a circuit of the cloud system all present possibilities for mapping the airflow.

Field Facilities

In addition to the aircraft provided by Bureau of Reclamation fund, the extensive field facilities operated by State Water Survey in the METROMEX program* were available to the field effort.

Aircraft Facility

The basic aircraft system had been developed over many years of cloud physics research at Pennsylvania State University. The airplane, an Aero Commander, is shown in Figure 2 and the characteristics of the platform are given in Table 1.

Table 1. Airplane Characteristics

Type: Aero Commander 680E
Nominal Cruising Speed: 200 mph @ 10,000 ft.
Normal Research Flight Speed: 70-80 m/s
Operational Ceiling: ≈25,000 ft.
Normal Ceiling (with full instrument package): ≈21,000 ft.
Range: ≈750 stat. mi @ normal cruise, 600 with full instrument load
Normal flight time: 3 hours with full research load

The scientific instrumentation and some pertinent specifications are listed in Table 2 and some of the sensors are shown in Figures 3a to d. The recording systems aboard the airplane are listed in Table 3.

Most of the commercially-available equipment listed in Table 2 have been used rather extensively in research aircraft. Those that need clarification and the custom built equipment are briefly discussed below.

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* Supported jointly by the State of Illinois, National Science Foundation, and Atomic Energy Commission.

Figure 2. The Pennsylvania State University instrumented Aero-commander

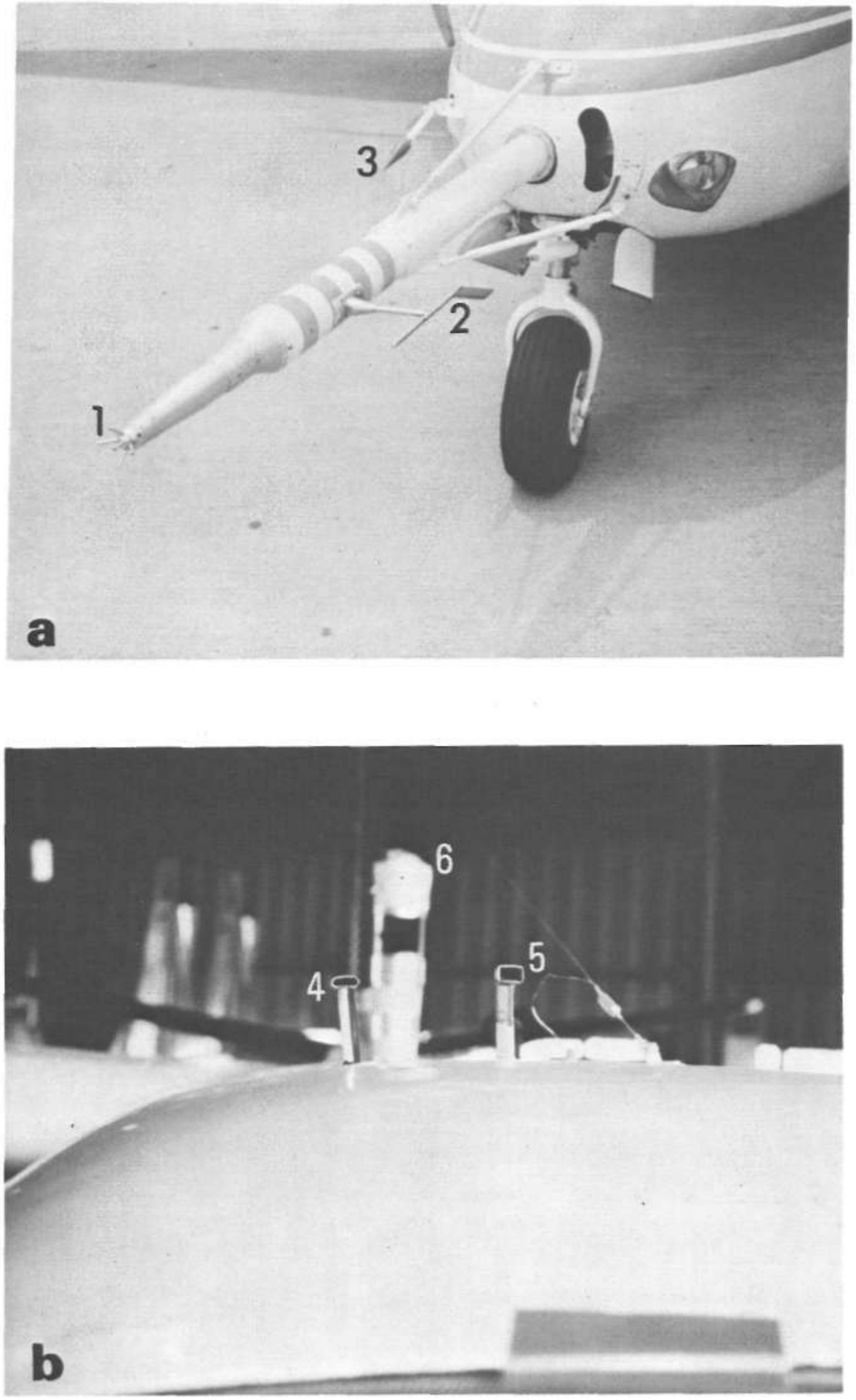

Figure 3. Research probes

(a) Boom instrumentation (1) gust probe (2) angle of attack vane (3) CCN probe

(b) Probes protruding through top of fuselage (view from front of airplane), (4) Rosemount thermometer, non-deiced (5) Rosemount thermometer, deiced (6) Hydrometer sampling port

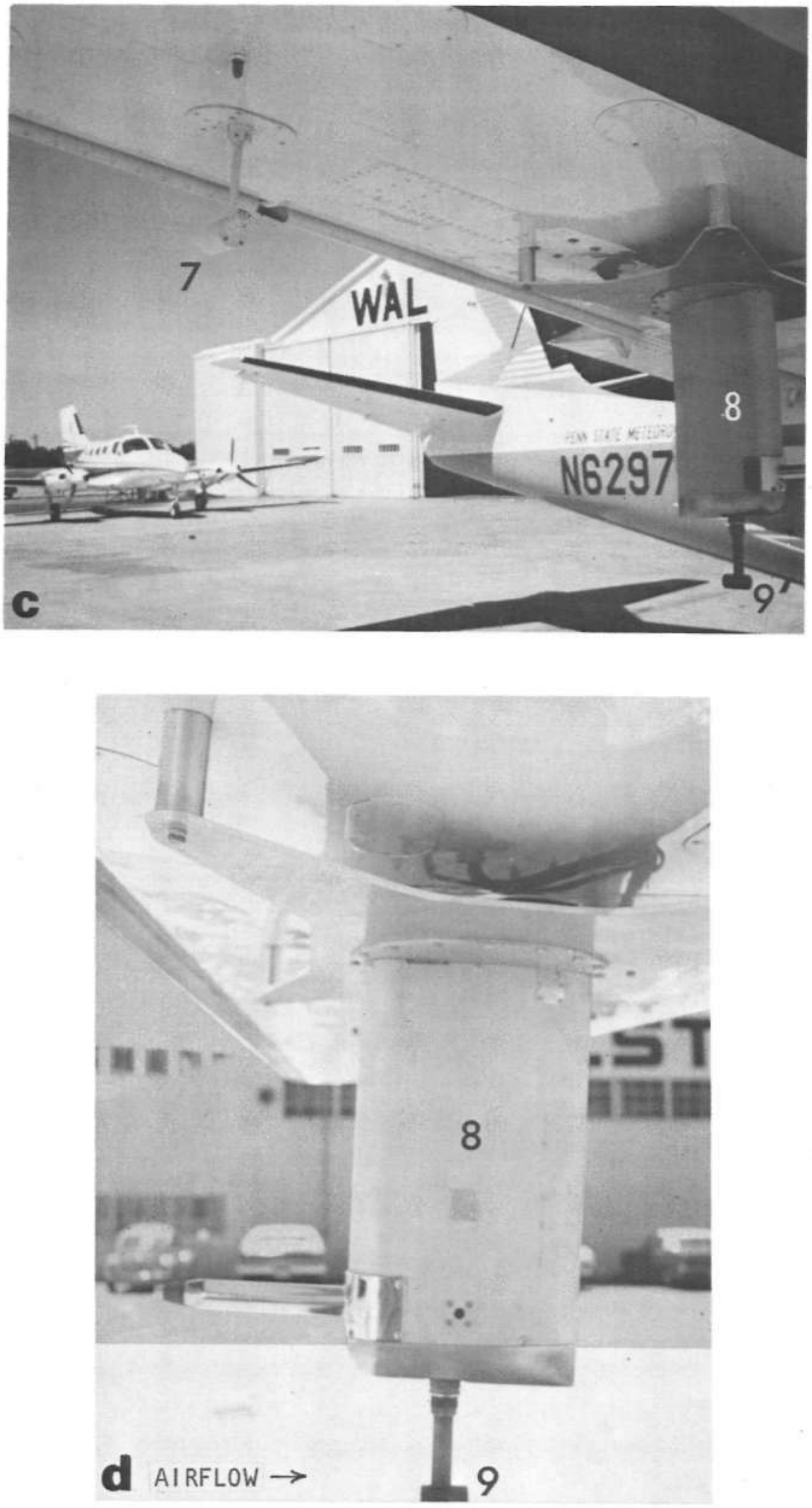

Figure 3. (Continued)
(c) Wing mounted probes (7) Reverse flow housing for temperature element and wet-bulb depression sensor (8) NRL total water meter (9) Johnson-Williams cloud water meter
(d) Enlargement of total water meter

Table 2. Aircraft Instrumentation

Parameter	Range	Accuracy	Time Constant	Manufacturer/Model
State Parameters				
Static Pressure	1034-300 mb	± 1 mb	20 msec	Rosemount, 830 BA
Temperature				
Total, non-deiced	-50 - +50°C	± 0.1°C	.25 sec	Rosemount, 102E2AL
Total, deiced	-40 - +40°C	± 0.1°C	5 sec	Rosemount, 102DL2U
Reverse Flow	-40 - +40°C	± 0.5°C	= 0.2 sec	PSU In-House
Humidity				
Dewpoint	-50 - +50°C	± 0.5°C (T>0°C) ± 1.0°C (T<0°C)	3°C/sec	Cambridge Systems, 137-C3-S3-P
Wet Bulb Depression	0 - 20°C	= 0.05°C	0.1 sec	PSU In-House
Aircraft Parameters				
Indicated Air Speed	0 - 237 mph	± 0.35 mph	25 msec	Rosemount Engr. Co., 831A4
Heading	0 - 360°	± 2°	= 1 sec	Sperry Gyroscope, C-4
Radio Altitude	0 - 2000 ft	± 2 ft (to 500 ft) 5% (500-2000 ft)		Collins Radio Co., ALT-50
VOR Heading	0 - 360°	± 3°		Collins Radio Co.
VOR DME	0 - 100 nm	± 3%		Collins Radio Co.
Air Motion Related Parameters				
Ground Speed	0 - 200 kts	0. 75 kts	= 1 sec	Singer General Precision (Doppler Radar) GPK 1000
Drift Angle	± 40°	0 .17° (10 n mi aver)		Singer General Precision (Doppler Radar)
Vertical Gust Velocity	= ± 10 m/s	± 15 cm/sec	0.053 Hz to 26.4 Hz	Giannini Controls Corporation
Angle of Attack*		± 0.2 deg.		Rosemount Pencil Vane, 861E, Potenteniometric Output
Rate of Climb*				Teledyne IVSI
Cloud Condensate				
Cloud Water Content	0 - 6 gm/m^3		0.65 sec	Johnson-Williams
Total Water Content*	0 - 22 gm/m^3		<0.1 sec	Naval Research Lab.
Hydrometer Spectrum	300 u dia. (min)	<± 10% (D>0.7 mm) <± 5% (D>1.2 mm)	0.8 u sec	PSU In-House
Nuclei				
Cloud Condensation Nucleus Concentration	1/2 - 20 µ dia.			Unico, 1600-10, 4 Stage Impactor
Ice Nucleus Concentration*	1 - 10,000/liter			Mee Inc. Ice Nucleus Counter 140

* Provided by SWS

Table 3. Aircraft Recording Systems

A. Quantitative Recording

Data Logger: Control Equipment Corp.

- Inputs:
  - Analog: 30 differential channels, variable gain, up to ± 10 V
  - Digital: 5 channels, 3 BCD + Sign, TTL, DTL compatible
  - Fixed Data: 3 Thumbwheel + 2 event button markers
- Internal Clock: Accuracy - 1 part/10^7
- Output: 7 track 200 BPI IBM compatible magnetic tape
- Sampling Rate: 0.5 sec

Oscillograph Recorder*: Bell and Howell Type 5-130

- Input: 6 analog channels, galvonometer sensitivity .434 in/volt
- Output: Light sensitive photographic paper, 7 in wide. Paper speed selectable
- Sampling Rate: Continuous recording

B. Qualitative Recording

Time Lapse Photography: MRI modified Keystone 16 mm movie camera, permanently mounted at about 25° to airplane axis. Film rate selectable

Still-Photography*: Hand-held 35 mm camera, wide-angle lens.

Observers Commentary[5]'': Cassette Tape Recorder

* Provided by State Water Survey

Reverse Flow Thermometer: This instrument was built at Penn State University for use in-cloud where the other sensors may experience wetting. The sensing element, a thermocouple, is located in a cylindrical housing, which has an obstruction to the flow on the forward end, but is open at the rear. Thus the air must enter the housing at the rear resulting in reversal in flow at the sensor. The time constant given in Table 2 (provided by Penn State) is applicable to the sensing element only, rather than to the instrument as a whole. Results of recent wind tunnel tests at the University of Chicago (Rodi and Spyers - Duran, 1972) indicate that the response time is probably 20 to 30 seconds. Moreover, the ventilation within the housing is probably very low.

Wet Bulb Depression: The sensing element is composed of a thermopile, with half of the elements wicked. This is mounted in the same reverse flow housing as is the temperature element and therefore probably suffers from the same problems. Moreover there were occasions when water flow to the wicks was intermittent.

Vertical Gust Velocity: The Giannini probe consists of three elements mounted in the boom ahead of the fuselage: transducer which measures the pressure difference across two vertically-aligned ports on the leading edge of the boom, a gyroscope to measure pitch angle, and an accelerometer to measure the vertical acceleration. In the present configuration, all three measurements are recorded on magnetic tape. The software for computing vertical gust velocities is being developed at Penn State.

Total Water Content Meter: This instrument was kindly loaned to us by the developer, Dr. Robert Ruskin of the Naval Research Laboratory. Condensate is evaporated as the incoming air passes through a heated chamber and the vapor density is then measured by an ultra-violet (Lyman Alpha) spectral absorption sensor (Ruskin, 1967). The response of this system is very fast. In order to minimize the possibility of bias arising from the sensing of the water in single large drops, a linearizing and integrating circuit was added before recording on the data logger. The integration was over 0.5 sec, the same as the recording interval. Since the oscillograph recorder is continuous, this circuitry was bypassed in the connection to the Bell and Howell.

Concentration of condensate is given by the difference in vapor density as measured by the dewpoint hygrometer and the total water meter. Partition of the condensate into cloud and precipitation particles can then be determined by comparing simultaneous measurements of the Johnson-Williams and total water meters.

Hydrometeor Spectrum: This PSU in-house development is a drop camera where the field of view is a free stream opening in a vertical tube extending above the airplane, (Lavoie, et al., 1970, p. 53). Film speed is about 160 frames/sec. Strobe lightning is used. The camera is remotely started and stopped by the flight observer.

Ice Nucleus Concentrations: In the Mee ice nucleus counter humidified air flows through a refrigerated chamber. Ice crystals formed in the air stream are sensed optically and electronically counted.

The measurement of ice nucleus concentrations has been plagued with inconsistencies. Two instruments operated side by side seldom give the same results and very often individual instruments do not give reproducible counts (Grant, 1971). An informal 10-day workshop was hosted by Professor Lewis Grant at Colorado State University in March, before installation of the instrument on the airplane. The primary objective was to determine performance characteristics for the Mee counter. Eight ice nucleus counters were operated side by side; three Mee counters (Bu Rec, CSU, and Battelle NW Labs.), the NCAR acoustical counter, two millipore systems (NCAR and CSU), the Ohtake sedimentation chamber and the isothermal chamber. Basic operating parameters were determined for the Mee counters. The agreement between the three Mee counters was very good, considering the sensitivity of the activation of ice nuclei to a number of equipment parameters such as chamber temperature and humidity of the air. The analysis of the data collected during the Workshop has not been completed, but it should eventually provide important insight into the data collected during the flight program. In addition, to these ground tests, two flight intercomparisons were made with the University of Chicago Cloud Physics Lab, which employs a millipore collector and Bigg-Warner chamber for determining ice nucleus concentrations.

Ground Facilities

Operations Base. The airplane was housed at Alton Civic Memorial Airport near Bethalto, Illinois, but main operations base was located at the Water Survey's METROMEX Field Headquarters at Pere Marquette State Park. This extensive facility (Fig. 4) included the radar facility, a complete weather station, communications base and shop, storage and office facilities.

The weather station had both circuit A and circuit C teletypes and a facsimile map recorder. Three hourly charts were plotted routinely, and hourly sectional charts as the weather required. Weather advisories were prepared and continually updated by a professional meteorologist.

The central operations building contained, in addition to the weather station, the radar controls and several scopes, including a SPA-8 off center scope, and the base radio station for ground-to-ground and ground-to-air communications.

Radar. Two radars were operated from Pere Marquette during the flight period, one a 10-cm PPI and the other a 3-cm RHI. The PPI is a FPS-18 with one megawatt peak power. The antenna, a 12-foot diameter dish, produces a pencil beam. It is operated at fixed elevation angle with scanning rate of 5 revolutions per minute. The RHI, the TPS-10 which has had long use in cloud physics research, has regular banana-peel antenna operating at a scan rate of 1° azimuth per second. During flight periods it was usually operated in sector scan mode, covering the area in which the airplane was penetrating clouds. As operated in June and July, the range of the TPS-10 was 60 n mi and of the FPS-18 was about 70 n mi.

Both the FPS-18 and TPS-10 scopes were photographed. In addition the radar signals were processed through an analog signal integrator on a time share basis. The integrated signal from the TPS-10 was recorded continuously, interrupted every 5-min for recording of the FPS-18 integrated signal.

Both radars scanned the area where the airplane was penetrating clouds , during the flight and continuing on until the cloud areas that had been penetrated had dissipated or moved out of range. A SPA-8 radar indicator with off-center display permitted continuous monitoring of echoes in the vicinity of the aircraft. Real-time radar intelligence was transmitted to

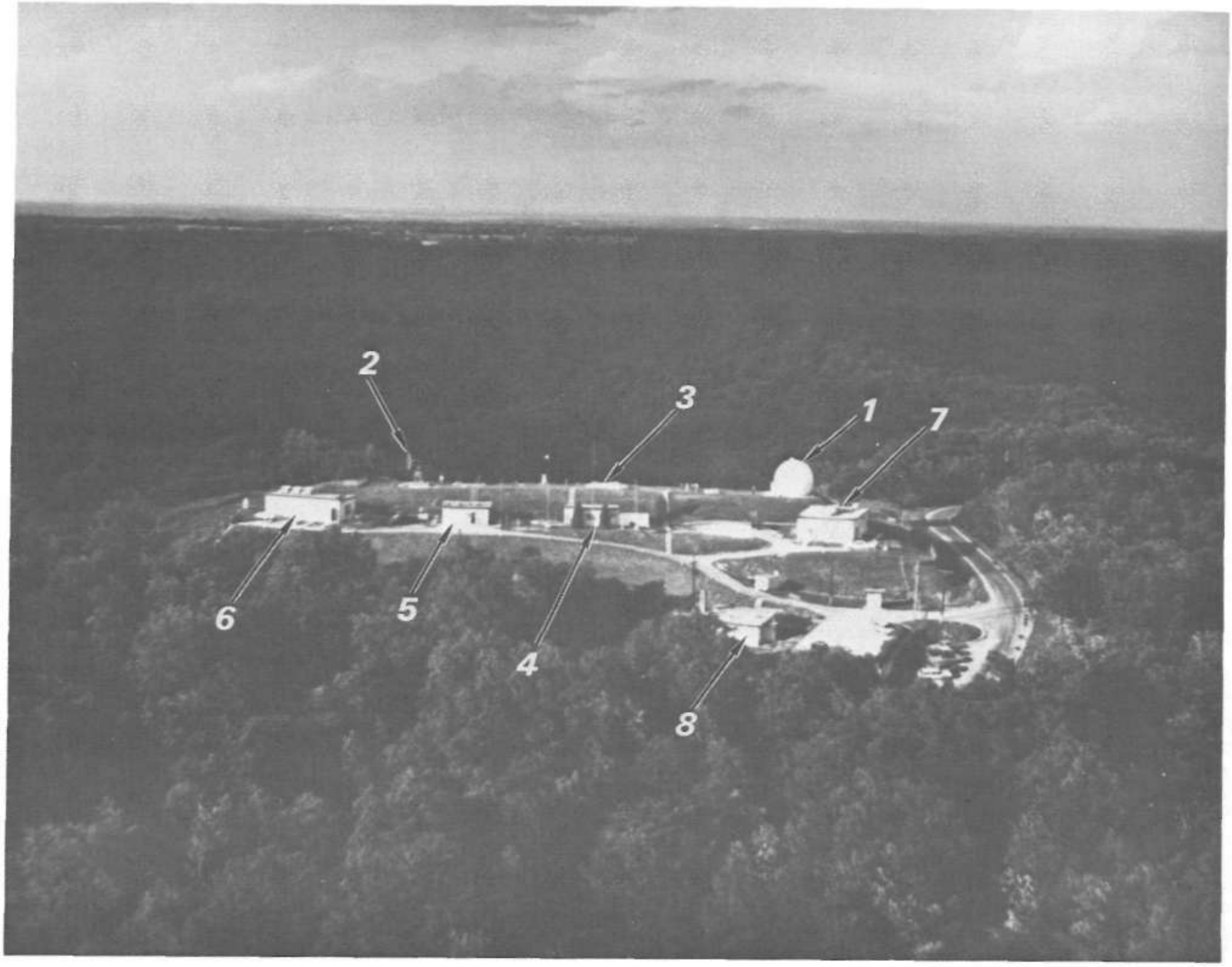

Figure 4. An aerial photograph of the headquarters base at Pere Marquette State Park, Illinois: (1) TPS-10 Radome, (2) FPS-18 Antenna, (3) GMD-1 Antenna, (4) Weather station, radar control room and radio communication center, (5) FPS-18 electronics (6) Electronics and mechanics shop and storage, (7) Office space and housing for staff, (8) Caretaker's home

flight meteorologist by ground-to-air radio communication. The radar meteorologist also provided invaluable guidance in locating favorable cloud areas.

Additional radar data may be available on some occasions from the University of Chicago Cloud Physics TPS-10 which was operated at Greenville, Illinois, on the eastern edge of the raingage network. Dr. R. R. Braham has kindly offered us access to his radar records.

Raingage Network. There are 243 stations in the 3900 mi^2 raingage network (Fig. 5). At each station is located a standard weighing bucket recording raingage. All of the gages, with but few exceptions, operate with 24-hr gears and the charts are changed weekly. Since the 24-hr charts may revolve several times prior to the onset of precipitation, a few gages with weekly gears are placed judiciously throughout the network in order to establish the day of each storm.

Upper Wind and Temperature Soundings. The routine National Weather Service rawinsonde data are available from Peoria, Illinois, to the northeast, Salem, Illinois, to the southeast, Monet, Missouri, to the southwest and Omaha, Nebraska, to the northwest. In addition, special rawinsondes releases were made from Salem and Pere Marquette and aircraft soundings were made during flight. After 10 July, the METROMEX pibal and radiosonde network provides, routinely, radiosonde data at 0700 and 1330 from three locations and pilot balloon data to 3 km at six times during the afternoon from 11 locations. The radiosonde and pibal stations are also shown in Figure 5.

Supplementary Network Instrumentation. Hailpads were located at all but a few of the raingage stations. Other recording instruments of various types were located less densely in the network. These included 26 hygrothermographs, 7 wind sets, an all sky camera, 8 raindrop spectrometers and 6 thunder and lightning detectors. The locations of these instruments are shown in Figure 5.

Flight Operations

The field program was carried out from 5 June thru 31 July. A summary of the daily flight operations and availability, regardless of quality, of the radiosonde data from State Water Survey sources are given in Table 4.

A total of 89 flight hours were expended in 36 flights over the seven weeks. Whenever the opportunity presented itself the flight was devoted to cloud penetrations. If no favorable rain clouds were within reasonable range, flights were made to establish non-precipitation characteristics of cloud parameters and/or stability conditions and nuclei concentrations.

Penetrations were made through cloud areas over the raingage network when they existed. There were many times when nature did not cooperate and

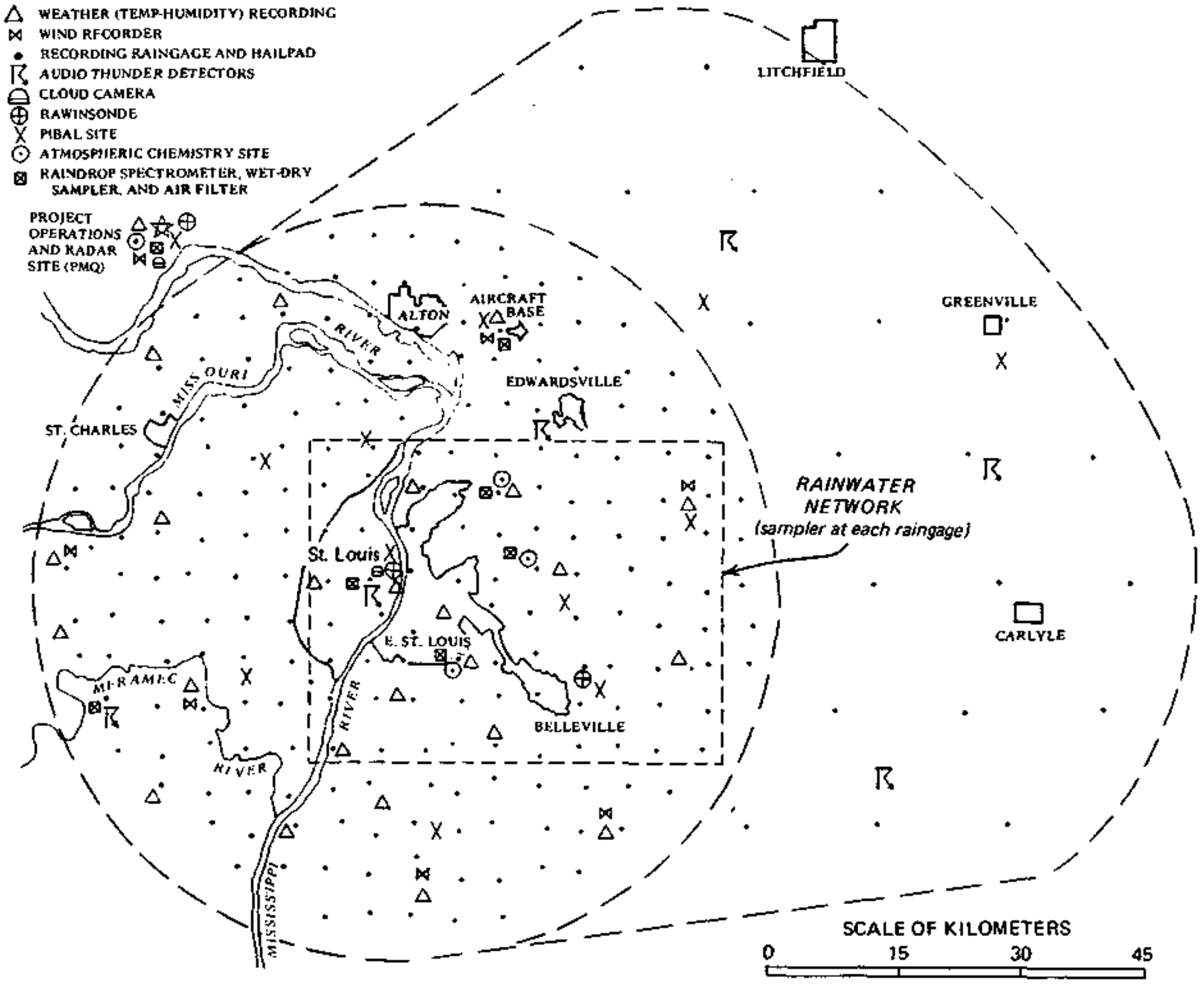

Figure 5. Map showing the network of surface instruments operated by the State Water Survey during the summer of 1973. The aircraft base was located at Bethalto, just east of Alton, and the radar and main operations base at Pere Marquette (PMQ.), north and west of the network.

Table 4. Summary of 1973 Flight Operations

Flt. No.	Date	Times (CDT)	Special Radiosondes STN/Time	Flight Mission
1	6/ 6	1548-1749		Familiarization; Inst, check Cld. Penet: Sc, Twrg Cu
2	6/ 8	1605-1712		Familiarization, Inst. check
3	6/11	1435-1645		Cld. Penet: Cu Cong, Isol and in vcty of Tstm
4	6/13	1711-1943	PMQ/1220	Cld Penet: Cu Cong, Cb Calvus
5	6/14	1510-1808	SLO/1500 PMQ/1233	Cld Penet: Cu Cong, Cb Calvus
6	6/15	1545-1718	PMQ/1606	Nuclei Measurements
7	6/18	1700-1937	SLO/1300 PMQ/1056,1711	Cld. Penet: Ac lyrs ahead of Sev St; Cloud Base Mapping
8	6/24	1153-1416		Equipment test, checks
9	6/26	1058-1315	PMQ/1139,1709	Proximity Sdgs. (Severe Storm)
10	6/28	1406-1722		Nuclei Measurements
11	6/30	1525-1740	SLO/1500	Cld Penet: Cu Cong, Cb Calvus
12	7/ 1	1307-1524	SLO/1500 PMQ/1513	Cld Penet: Twrg Cu, Cb feeder clds
13	7/ 1	1626-1854	SLO/1500	Cld. Penet: Cu Cong, Isol and group in vcty Tstm; Tstm feeder clds
14	7/ 2	1204-1405	SLO/1400 PMQ/1409	Nuclei Measurements
15	7/ 4	1620-1840	SLO/1445 PMQ/1322	Equip. check and tests
16	7/ 8	1520-1725	PMQ/1618	Cld. Penet: Cu Cong, in family and ind. in vcty small Tstm
17	7/ 9	1345-1617	SLO/1430 PMQ/1115,1500	Cld. Penet: Cu Cong family developing into Cb, Tstm feeder clds
18	7/ 9	1725-1957	SLO/1430 PMQ/1115,1500	Cld Penet: Young Tstm cell, isol Cu Cong, Tstm feeder Cu
19	7/10	1453-1741	PMQ/1130	Nuclei Msrmnts (Formation flight with U of C)
20	7/14	1600-1800	PMQ/1013.,1430 BLV/1330 Arch/1330	Cld. Penet: Tstm cell; Twrs in Ac deck

Table 4 - Continued

Flt. No.	Date	Times (CDT)	Special Radiosondes STN/Time	Flight Mission
21	7/16	1403-1657	PMQ/1330 BLV/1330 Arch/1330	Nuclei Measurements
22	7/18	1553-1851	SLO/1430 PMQ/1330,1632 BLV/1330 Arch/1330	Cld. Penet: Cb calvus imbedded in Ac deck; Ac towers
23	7/19	1601-1845	PMQ/1330 BLV/1330 Arch/1330	Cld Penet: Tstm feeder clouds, inflow mapping
24	7/20	1328-1541	SLO/1430 PMQ/1338,1625 Arch/1330,1613 BLV/1330	Cld Penet: Cu Cong vcty Tstm
25	7/20	1641-1858	Same as ft 24	Cld Penet: Cu Cong, Twrg Cu, Ac feeders to Tstm
26	7/23	1326-1541	PMQ/1355,1611 BLV/1330 Arch/1330,1612	Cld Penet: Twrg Cu family, Cu Cong in adv of Cb line
27a	7/24	1330-1509	SLO/1430 PMQ/1411 BLV/1330 Arch/1330	Cld Penet: Ac towers, Cu Cong and Cb Calvus in adv of Cb line
27b	7/24	1609-1830	Same as ft 27a	Area of Twrg Cu and Cu Cong merging into Cb Calvus
28	7/25	1340-1607	PMQ/1345 Arch/1330	Cld Penet: Merging Cu Cong; Ind Cu Cong vcty Tstm
29	7/26	1543-1821	Arch/1420,1600	Nuclei Measurements
30	7/27	1510-1731	BLV/1330 Arch/1330	Nuclei Measurements
31	7/28	1454-1654		Equipment Check
32	7/29	1400-1605	PMQ/0720	Cld Penet: Thick Ac, Cu Cong. (Warm frontal over-running)
33	7/29	1635-1807		Cld Base, Rain Shaft
34	7/30	1355-1615	SLO/1430 PMQ/1330,1500, 1700 BLV/1330,1500, 1630 Arch/1330,1530, 1645	Cld Penet: Cu Cong merging into Cb Calvus ahead of Tstm line
35	7/31	1504-1750	PMQ/1330 BLV/1330 Arch/1330	Nucleus Measurements (Formation with U of C)

the suitable clouds were beyond the network. In these instances the clouds studied were within range of either the State Water Survey or the University of Chicago radars.

A variety of cloud types were studied, ranging from families of towering cumuli to thunderstorm feeder cells. When severe storms dominated the weather the only other clouds in the area were often stratocumulus or altocumulus. In these instances, proximity soundings were made. Most of the cloud penetrations were made near the freezing level.

An airplane sounding was made on every flight. Ice nucleus concentrations were measured throughout the flight. Cloud condensation nucleus concentration measurements could be made reliably only in the clear air, and required five minute or longer slide exposure for detection of giant nuclei. Typically these measurements were made only below and near cloud base.

Coordinated 2-plane cloud missions planned with the University of Chicago Lodestar were not successful because of poor air-to-air communications. Informal 2-plane missions did occur when the two airplanes penetrated the same cloud area in the same time frame. In addition, two formation flights were carried out for intercomparison measurements of ice nucleus and cloud condensation nucleus concentrations and of state parameters.

Considering the intensity of the program, there were few malfunctions in either the airplane or the instrument package. Periodic airplane checks and repair of airplane systems were in most cases accomplished during fair weather. There were occasional failures in the research instrumentation but most of these were repaired before the following flight. The one exception was the malfunction of the evaporator for the total water meter. This could not be repaired in the field and for all flights after 2 3 July the total water meter was capable of measuring up to 1.5 gm/m^3 of liquid water only.

Output from the data logger was available within two days. The data were monitored for unusual behavior as well as for malfunctions not detectable in standard pre-, in-, and post-flight checks of the equipment. These checks prompted some special flights to establish performance on some of the instruments and also some special post-program calibrations and performance tests to be carried out by Penn State.

In general the data appear to be very good. These special tests will permit us to draw conclusions free of concern about instrument characteristics.

Work Plans, FY-74

Well over a hundred clouds were penetrated during the flight program. In accordance with the research plan, some traverses were made for a census of pertinent cloud parameters and others were made to develop cloud histories. Millions of bits of data were generated, but not in forms that are directly usable. Thus, the first task at hand is basic data reduction, with a nearly simultaneous start of the initial analysis.

Data Processing

The quantitative measurements will be processed in two steps. The first will cover scaling of basic measurements and computation of primary parameters and produce a condensed tape to be used in all further computations. The second will massage the data as necessary and calculate derived quantities. The software supplied by Penn State has been modified for use on the University of Illinois Computers and routines have been added for scaling the measurements from the new instruments. Certain sections covering procedures deemed undesirable at this stage were removed. Adjustments and corrections, if any, that are indicated by the post-program equipment checks will be added to the program as necessary.

Techniques for processing the hydrometeor and condensation nuclei measurements will be developed and the data will be routinely processed. The hydrometeor film presents a massive (12,000 ft of 16 mm film) but relatively uncomplicated data reduction task. The collections on the impactor slides are often ambiguous and objective criteria for identification of condensation nuclei have to be developed before the data can be routinely evaluated.

The rain analyses carried out by the State Water Survey in other research programs will probably be adequate for most studies carried out in 1974. Evaluation of radar records will be done as necessary in the individual studies.

Analytical Studies

The initial studies will concentrate on two efforts:

A. Predictions of the one dimensional Hirsch cloud model for routine Weather Service soundings will be compared to those for the special soundings taken during the flight operations. Observations will be used to estimate the validity of the various model predictions.

B. Statistical and cloud history analyses will be carried out for two or three days. These days will be selected on the basis of availability and quality of data and variety of cloud operations.

Unusual, in some instances unique, data were collected during the 1973 flight program. They provide an excellent opportunity to shed light on the precipitation mechanisms and there inter-relationships. Additional cloud studies deserve to be pursued if funds become available.

References

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APPENDIX: 1

Technical Reports

Illinois Precipitation Enhancement Program

1. Evaluation of Potential Benefits of Weather Modification on Water Supply. F. A. Huff, April 1, 1973.
2. Potential of Precipitation Modification in Moderate to Severe Droughts. F. A. Huff, May 1, 1973.
3. Legislative Activities Relating to Weather Modification in Illinois. Stanley A. Changnon, Jr., September 15, 1973.
4. The Relationship of Illinois Weather and Agriculture to the Eastern Cottontail Rabbit. Stephen P. Havera, June 30, 1973.
5. Climatic Studies of Extra-Area Effects from Seeding. Paul T. Schickedanz, June 30, 1973.
6. Modeling Studies for Evaluation and Planning of Precipitation Enhancement in Illinois. Harry T. Ochs and Ben F. Ceselski, June 30, 1973.
7. Trace Element Chemistry Studies. Donald F. Gatz, June 30, 1973.

APPENDIX 2

An analysis of the personnel that were involved in this program in FY-73 and the amount of their involvement appears below.

Salary Support from State of Illinois or Other Sources

	Percent Time	Areas of Effort[1]	Begin	End
W. C. Ackermann	2	3, 4	July	June
S. A. Changnon	17	2, 3, 9, 10	July	June
R. G. Semonin	27	6, 7, 8, 9, 10	July	June
F. A. Huff	37	1, 5, 10	July	June
G. M. Morgan	10	5, 6	July	June
A. L. Sims	40	1	July	Sept
J. W. Wilson	100	2, 3, 4	July	Sept
A. Rattonetti	5	8	Oct	June
M. T. Busch	80	5	Oct	June
D. Gatz	10	8	Sept	June
J. Vogel	10	6	May	June

Salary Support from Bureau of Reclamation

B. Ackerman	50	6	July	June
H. T. Ochs	100	7	July	June
T. Flach	100	6	July	June
T. Thornburn	80	7	July	June
P. T. Schickedanz	25	5	July	June
M. T. Busch	80	5	July	Sept
E. Schlessman	100	1, 5	July	June
S. Havere	50	2	July	June
R. Alsup	25	6, 8	Jan	June
O. Anderson	100	6, 8	Dec	June
B. Ceselski	100	7	July	June

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[1] 1 = Water Supply Benefits, 2 = Ecology, 3 = Legislative, 4 = Social Impact, 5 = Extra-Area Effects, 6 = Atmospheric Sampling, 7 = Modeling, 8 = Trace Chemistry, 9 = Seeding Concepts, and 10 = Project Design.