PROJECT SKYWATER

Bureau of Reclamation
Programs in Precipitation Management

Dr. B. A. Silverman, Chief

Research and Development Branch
Division of Atmospheric Water Resources Management

Research in precipitation management under the Bureau of Reclamation's Project Skywater is in transition, moving from individual field experiments to larger, more comprehensive programs aimed at resolving major scientific uncertainties and melding the many aspects of the technology into an effective, socially acceptable water management tool.

Project Skywater, managed by the Division of Atmospheric Water Resources Management, is immediately concerned with two applications of precipitation management and their impact on the environment: (1) Augmentation of winter snowpack in mountainous regions of the West, and (2) enhancement of growing season precipitation over the High Plains. The fiscal year 1976 appropriation for this research is $4.65 million, with an additional $1.63 million for the transitional quarter. The expected budget for fiscal year 1977 is $4.65 million. Approximately 78 percent of the budget is for contracted research or support to state or local seeding programs. Locations of the current Skywater participants are shown in figure 1.

WINTER OROGRAPHIC PROGRAMS

Skywater's major activities with winter orographic events currently involve analysis of past projects and the planning of a new one. Field activities in the 5-year Colorado River Basin Pilot Project and the 3-year Pyramid Lake Pilot Project were completed in the spring of 1975, and results of both projects are being evaluated. The Bureau, in association with Aerometric Research, Inc., is conducting a comprehensive reanalysis of data from the two pilot projects and five earlier field experiments. Design and environmental planning are well underway for the Sierra Cooperative Pilot Project, a major step in developing an orographic technology effective in the maritime atmosphere of the north-central Sierra Nevada.

Colorado River Basin Pilot Project

The Colorado River Basin Pilot Project has not yet been fully evaluated, but the pattern of results emerging from analysis of the first 4 years' data is unlikely to change significantly with the inclusion of the fifth year's data. Overall statistical comparisons of seed and no-seed precipitation events, based on a priori evaluation criteria, showed no differences that could not be ascribed to chance. However, a posteriori analysis revealed that many of the experimental days forecast to meet the seedability criteria had in fact failed to satisfy the criteria for a significant portion of the storm period. When only those days that truly met the seedability criteria (based on all available data) were considered, seed-day precipitation

exceeded no-seed-day precipitation by a significant amount. The analysis thus far of precipitation data from stations outside the target area suggests that a broad area was positively affected by seeding, though the seasonal increases were small over most of the affected area.

The Colorado River Basin Pilot Project has brought to light several problem areas that must be addressed in future winter orographic programs. Evidence of low-level trapping of seeding material suggests that transport and diffusion in mountainous terrain are even more complex than previously thought. This factor, coupled with the apparent short-term fluctuations in such cloud characteristics as cloud-top height, suggests that observational systems, seedability criteria, and seeding delivery techniques should be reexamined before initiating a new project.

Pyramid Lake Pilot Project

Final analysis of the Pyramid Lake Pilot Project should be available within a few months. Work so far suggests that the findings will be consistent with physical relationships found in other projects.

Reanalysis of Winter Orographic Seeding Projects

The reanalysis of data from the two pilot projects and from five smaller winter orographic seeding projects was undertaken (1) to bring together in one document the results of these separate projects, (2) to perform common analyses on independent data sets, (3) to identify results from analyses of the total data set that might not be evident in the individual project analyses, and (4) to develop more generalized seedability criteria that reflect both topographical and meteorological factors. In addition to the two pilot projects, data sets from the Jemez Project in New Mexico, the Bridger Project in Montana, the Censare and Santa Barbara Projects in California, and the Climax Project in Colorado are included in the analyses.

In phase I of the reanalysis, seed, no-seed comparisons were made for data partitioned by each of the 11 parameters shown in figure 2. These 11 parameters were chosen to describe the time available for precipitation, the water available, the nuclei available, the mixing available, and frontal indices. As anticipated, phase I analyses indicated that one parameter was a good predictor in a few projects, another parameter in other projects, but no single parameter was a good predictor in all seven projects.

Phase II is a multiparameter analysis considering only the most physically reasonable combinations of the 11 parameters. Analyses for individual projects and groups of projects are beginning to show consistent relationships. Cloud-top temperature and condensation rate appear to be the primary meteorological factors in stable clouds; residence time and degree of instability show a strong effect on unstable clouds. Partitioning of unstable cloud cases by stability and wind speed shows large increases associated with moderate instability and low-wind speed. Large decreases occur with high instability and high wind speed. For stable conditions, some parts of the project area receive increases and others decreases - depending on cloud-top temperature, wind speed, and topography. For a given stability condition, the barrier width is critical in determining where, relative to the barrier crest, the effects of seeding are felt.

The findings of these analysis efforts will be valuable in planning the Sierra Cooperative Pilot Project and other orographic precipitation management endeavors.

Sierra Cooperative Pilot Project

The objective of the Sierra Cooperative Pilot Project is to continue development of precipitation management technology applicable to orographic clouds that form in the maritime air masses that flow over the Sierra Nevada. The Santa Barbara and Censare projects have shown that embedded convective cells are rather common features of storms affecting the Sierras, and these storms will probably require a somewhat different technology than that applicable to continental air masses.

The concept of a Sierra Cooperative Pilot Project was developed in 1972, and planning began early the next year with the initiation of public involvement activities and acquisition of an environmental assessment. Twenty-one public meetings were held in and around the proposed project area during the summer of 1974. Citizens and community officers were encouraged to voice their opinons for consideration in future planning activities. These opinions were included in the studies of both the social and the environmental implications of the proposed project. Federal, state, and private organizations have been involved in providing information for use in an environmental statement.

A contract to draft an experimental design was awarded in May 1975. The design study is being carried out in two phases. During the first phase, the synoptic and mesoscale climatology of the Sierra Nevada and the current state of knowledge of the physics of winter storms of the region were reviewed and a physical model of the precipitation mechanisms of the Sierra Nevada was developed. Two river basins were included in this study, the Feather and the American (see Figure 3). The second phase of the design phase was to identify areas of further investigation and develop the details of an operations plan for a possible pilot project.

Results of the first phase activities indicate that the American River Basin has both a greater seeding potential and a sufficient data base for preparation of an experimental design. It also has a higher frequency of convective cells, which, according to the Santa Barbara Project, contribute a major portion of total storm precipitation.

Several field studies are scheduled for the 1976-77 winter season, including a more detailed climatological study, a transport and diffusion study, and a study to determine the value of the Bureau's 5-cm radar in winter orographic experiments.

There is no firm starting date for seeding activities to begin. Decisions about proceeding are made at each step in the planning process, and analysis of the design studies and consideration of the environmental and social impact will precede the final decision to begin a seeding program.

If there are no major delays in preparing the design and an environmental statement, the earliest project seeding would begin is during the 1977-78 winter season. Up to five winter seasons of seeding would be required to collect sufficient data for sound conclusions about the effectiveness of the technology.

SUMMER CONVECTIVE PROGRAM

Research to develop a technology to enhance rainfall has advanced from the stage of individual field experiments into the High Plains Cooperative Program (HIPLEX), a fully integrated, multisite project involving cooperation among Federal, state and local governments.

Some 29 different organizations from 13 states, including virtually every section of the United States (see Figure 1), are contributing their expertise toward the accomplishment of HIPLEX's goals. The over-all goals of HIPLEX are to resolve the scientific uncertainties in summertime precipitation management technology and to demonstrate that application of the developed technology is both effective and socially acceptable. Its aims are to:

1. Resolve the critical cloud dynamics and precipitation physics uncertainties about seeding effects

2. Develop and test more productive seeding methods and evaluate the results

3. Help prepare public weather modification backgrounds and local expertise, and establish working relations among concerned non-Federal entities

4. Assess the actual economic value of cloud seeding and the possible social and environmental impacts

Technical accomplishments to date in HIPLEX can be grouped under the following categories:

1. Field testing of radar, aircraft systems and other equipment and instrumentation (see figures 4, 5, and 6)

2. Development of cloud climatologies

3. Development of techniques for collecting, processing, storing, and retrieving project data

4. Advances in numerical models (see table 1)

A recommended design for HIPLEX is being developed by the staff of the Illinois State Water Survey.

HIPLEX will concentrate initially on the simple, isolated convective cells and systems. As understanding grows, HIPLEX will move toward larger and more complex mesoscale cloud systems, which provide a large portion of the seasonal precipitation. By the early 1980's, HIPLEX or successor programs may be directed towards a broad scale synoptic rain-producing system.

HIPLEX is carried out at three sites, one each in the Miles City area of Montana, the Goodland-Colby area of Kansas, and the Big Spring-Snyder area of Texas (see figure 7). Miles City has been chosen as the main site

for the 1976 field activities. Operations at all three sites began on May 1 and will end on July 31 in Montana and Texas, and on August 31 in Kansas. The cloud physics aircraft will operate in Montana through July, moving to Kansas for the month of August.

The primary objectives for the 1976 summer season and the sites where the efforts are being pursued are summarized below. Most of these efforts were initiated in earlier years and are likely to continue into the future. However, it is believed that a substantially improved state of knowledge will result from this year's work, which will guide future research efforts.

1. A major effort has been undertaken at the Miles City site to determine the most practical and reliable method for the quantitative estimation of convective cell rainfall. The study is addressing such issues as the best mix of radar and rain gages and the determination of Z-R relationships.

2. The Miles City site is also the scene of a study to determine the most effective method or methods of delivery of silver iodide cloud-seeding agents. An attempt is being made to determine what concentration of ice crystals in the desired part of the cloud actually results from the introduction of a given amount of silver iodide delivered at cloud base and at the -5^{o} to -10^{o}C level with silver iodide/acetone generators and flares, and from on top of the cloud with droppable pyrotechnics.

3. A field investigation of mesoscale cloud systems was initiated at the Big Spring site. Measurements are being taken to reveal how the various scales of motion in the atmosphere interact with each other to cause the accelerated growth of some convective systems at the expense of others.

4. Climatological studies are being conducted at all sites to obtain frequency distributions of clouds by type, size, origin, cloud-base temperature, updraft characteristics, rainfall characteristics, etc.

5. Intensive case studies are being pursued at the Miles City site through July and at the Goodland-Colby site during August. These studies will attempt to improve our physical understanding of the precipitation mechanisms in convective clouds and determine the relative role of the ice-phase and coalescence processes in precipitation development. Another related purpose of these studies is to obtain a comprehensive data set for verifying and improving numerical cloud models employed in HIPLEX.

6. Background studies relating to the evaluation of downwind effects are being carried out at all three sites. Satellite, radar, and rainfall data in the target and downwind areas will be analyzed to establish, if possible, a relationship between satellite visual cell, radar echo cell, and rain cell characteristics, and a relationship between visual cloud, radar echo, and rain cell population characteristics in the target and downwind areas. A special study

of Kansas weather will be made to compare the radar-echo populations in the target and downwind areas of the Goodland HIPLEX site, where no seeding will be carried out, and several counties in southwest Kansas where a locally sponsored seeding program will be conducted.

7. State-supported studies to evaluate the consequences of precipitation management to each area are continuing. These studies consider the influence of precipitation timing, intensity, duration, amount and distribution on agricultural production and hydrologic management.

ENVIRONMENTAL IMPACT STATEMENT

A draft programmatic Environmental Statement for Project Skywater was recently filed with the Council on Environmental Quality and is available for public review. Copies can be obtained from Bureau offices in Denver and Washington. Public hearings were held in Miles City on April 19, Denver on April 21, and Sacramento on April 23.

Table 1. - Models used in the HIPLEX program

Name and application1/	Characteristics	Purpose
GPCM (A)	1 Dim'l, Steady-State, Lagrangian, Parameterized Microphysics	Diagnose convective potential for natural and ice-phase seeded conditions
MESOCU (A)	1 Dim'l, Quasi-Time-Dependent, Lagrangian, Parameterized Microphysics	Diagnose convective potential for natural and ice-phase seeded conditions and its change with time due to cloud-environment interactions
SNOMOD2/ (A, B, C)	1 Dim'l, Time-Dependent, Eulerian, Parameterized Microphysics	Predict evolution of a natural and seeded cloud and its precipitation history
HAMOD (B, C)	1 Dim'l, Time-Dependent, Eulerian, Detailed Microphysics	Predict evolution of a natural and seeded cloud and its precipitation history
SLABMOD3/ (B, C)	2 Dim'l, Time-Dependent, Eulerian, Parameterized Microphysics	Predict evolution of natural and seeded cloud fields and their precipitation history
MESOMOD4/ (B, C)	3 Dim'l, Time-Dependent, Eulerian, Parameterized Convection	Predict the evolution of natural and seeded mesoscale convective cloud systems

1/ A Routine estimation of predictor variables for identifying opportunities and for partitioning data in evaluation
B Develop seeding hypotheses
C Physical understanding of natural and seeded clouds and determination of suitable predictor variables and covariates.

2/ Under development at the Bureau of Reclamation

3/ Under development by Dr. H. Orville, SDSMT

4/ Under development by Mr. M. Fritsch, NOAA

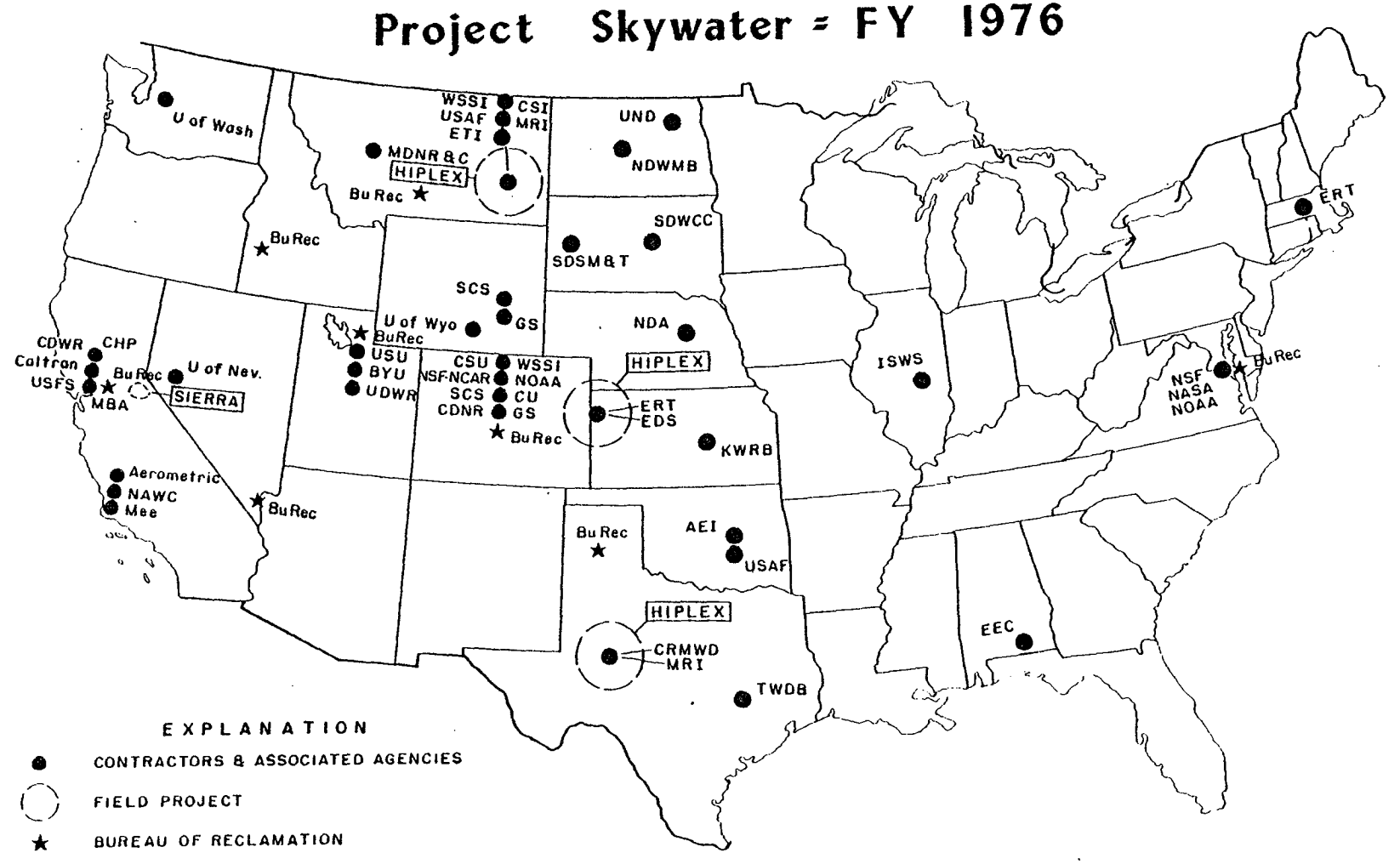

Figure 1. Many state and federal agencies, academic institutions and private companies are involved in Project Skywater.

ANALYSIS PARAMETERS

Time Available	HTI	BTI	
Water Available	TE_{700}	CBWS	WCI
Nuclei Available	LCTTW	LCTTI	T_{500}
Mixing Available	Richardson Number	ENEG	EPOS

Figure 2

ANALYSIS PARAMETERS

HTI (Horizontal Trajectory Index) is an estimate of the residence time of seeding material and/or ice crystals between the average generator location and ridgecrest.

BTI (Barrier Trajectory Index) is an estimate of the location on the barrier where ice crystals will fall when nucleated at cloud top and over the average generator location.

TE_{700} is the equivalent potential temperature at 700 millibars.

CBWS is the saturation mixing ratio at cloud base.

WCI (Water Condensation Index) is the difference between the saturation mixing ratio at cloud base and 2,000 feet above ridgecrest.

LCTTW and **LCTTI** are the Lifted Cloud Top Temperatures with respect to Water and Ice, respectively.

T_{500} is the 500-millibar temperature.

Richardson Number is the average Richardson number over 10-millibar layers between the surface and 500 millibars.

ENEG is the negative energy on a log P-skew T diagram between the cloud base and the level of free convection (LFC) or between cloud base and 500 millibars, if no LFC exists.

EPOS is the positive energy on a log P-skew T diagram between the LFC and the equilibrium level (EL).

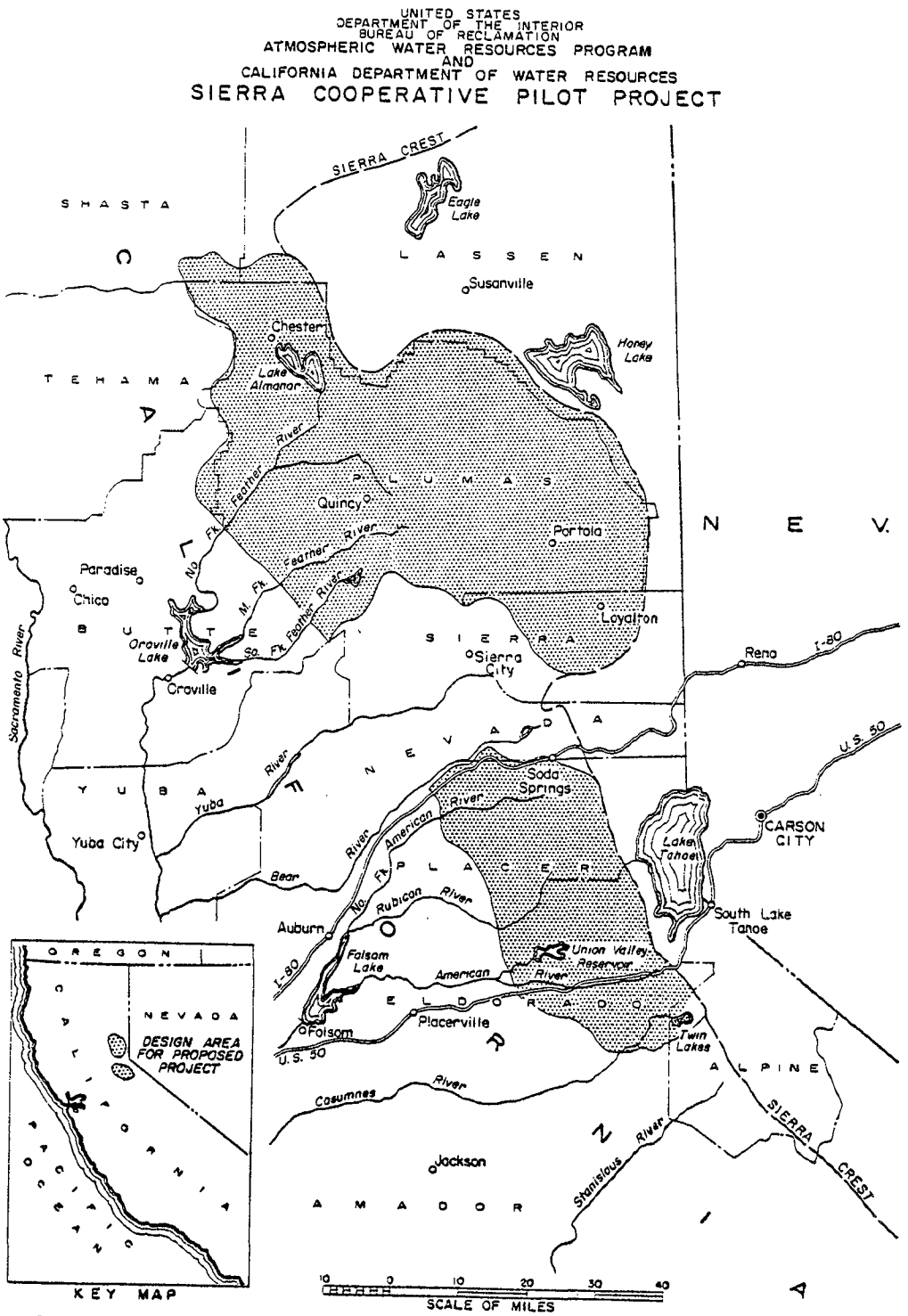

Figure 3. The Feather River and American River basins were considered for sites of the Sierra Cooperative Pilot Project. Primary interest is in the American River headwaters, east of Folsom Lake.

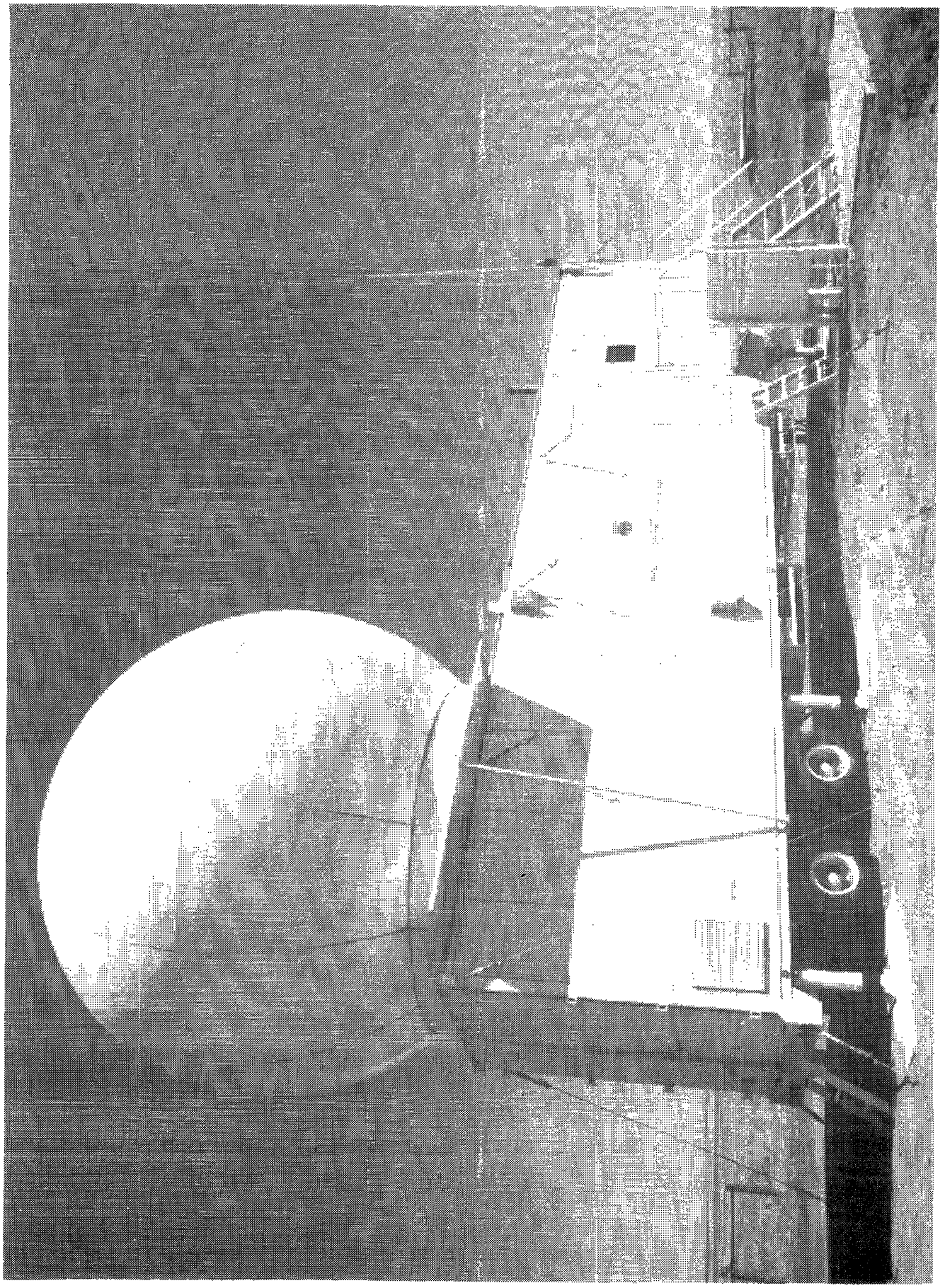

Figure 4. Skywater's 5-centimeter radar system was developed specifically to meet the demands of the research program.

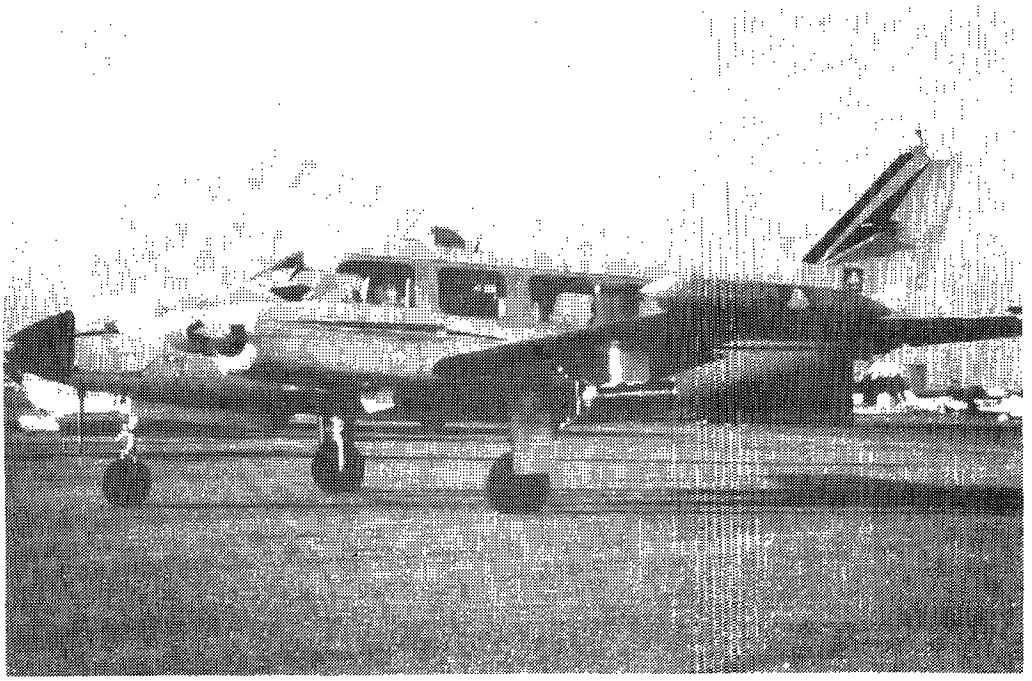

Figure 5. The Bureau of Reclamation has contracted with Meteorology Research, Inc., for use of its cloud-physics aircraft in the High Plains Cooperative Program.

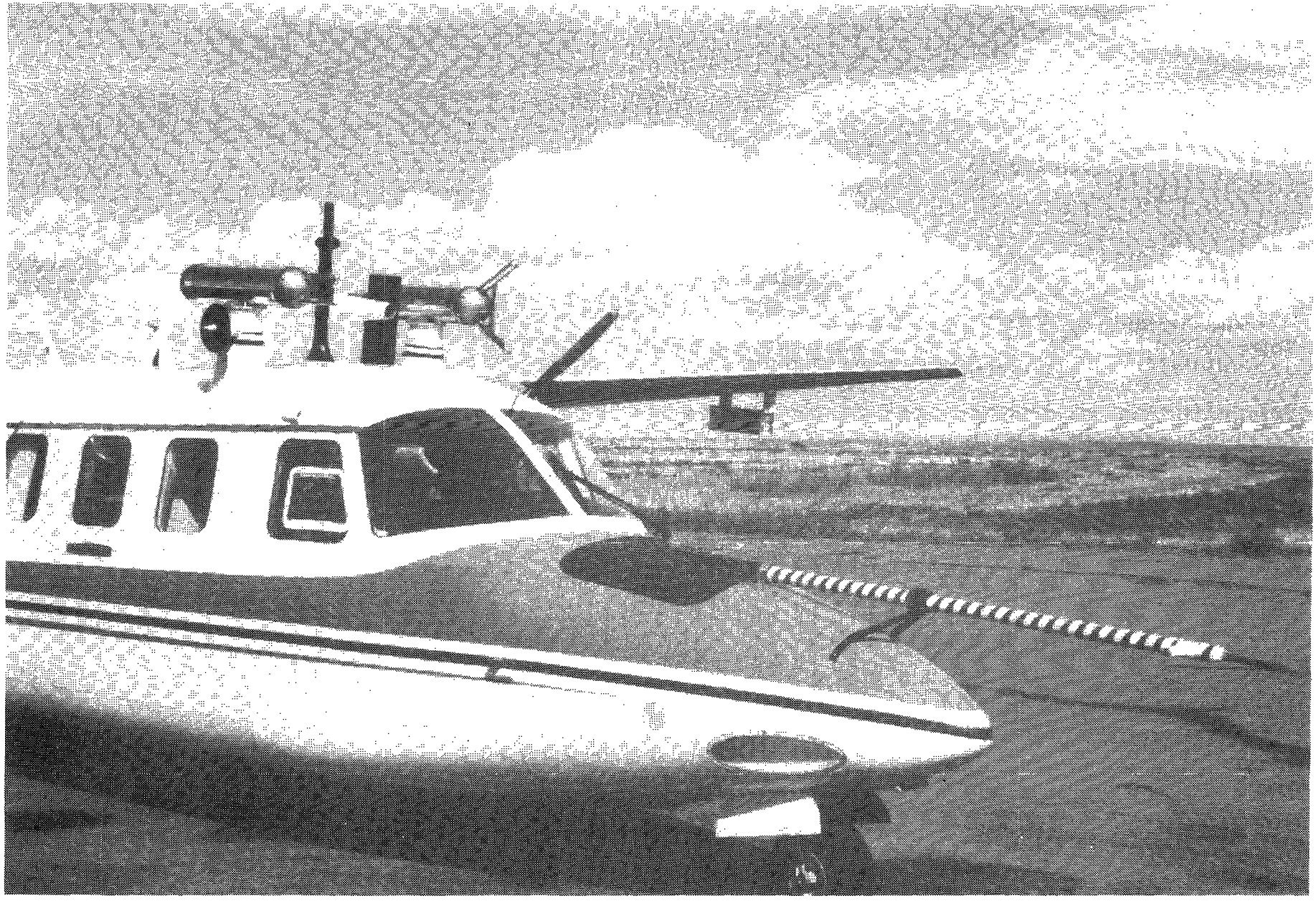

Figure 6. Convergence Systems, Inc., instrumented a Grand Commander as a cloud-physics laboratory for HIPLEX.

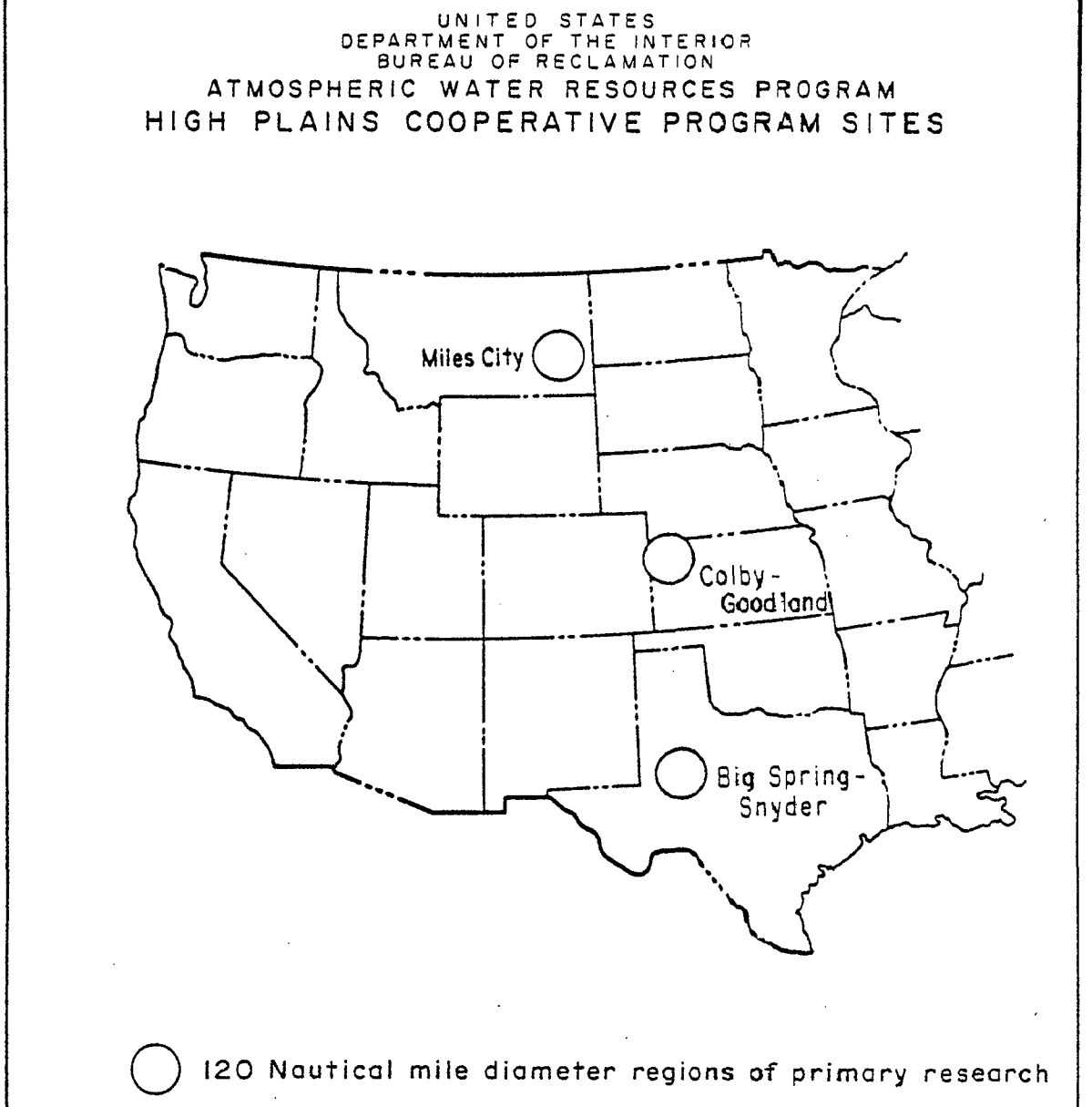

Figure 7. The HIPLEX research sites are at Miles City, Montana; the Colby-Goodland region of northwestern Kansas, and the Big Spring-Snyder area of west-central Texas.