

DESIGN OF THE 1986 ILLINOIS WEATHER MODIFICATION EXPERIMENT

S. A. Changnon, Jr. and F. A. Huff  
Climate and Meteorological Section  
Illinois State Water Survey  
Champaign, Illinois 61820

Abstract. A summary of the design aspects of the 1986 PACE field project is presented. A review of the experimental background, overall objectives, the 1986 objectives, and an assessment of the 1986 field effort and design is provided. In general, the design proved satisfactory, although a few modest adjustments were needed to overcome certain unforeseen sampling problems.

1. BACKGROUND

Initial field experimentation under the Illinois weather modification program known as PACE (Precipitation Augmentation for Crops Experiment) were carried out during July-August 1986 in central Illinois. The initial design was based on: numerous pre-experimental studies under PACE during 1978-1985; previous research by the Illinois State Water Survey on the physics and dynamics of mid-western clouds; the distribution characteristics of convective precipitation in Illinois; plus, consideration of previous findings by others in weather modification research, such as the NOAA program (FACE) in Florida and the various Great Plains studies sponsored by the Bureau of Reclamation.

Some of the more pertinent pre-experimental studies carried out by Water Survey personnel (Changnon et al., 1983, 1985, 1986) included:

- 1) A review and assessment of midwestern cloud characteristics leading to the hypotheses to be employed in the 1986 experiments;
- 2) Comprehensive studies of radar echo data available in the experimental region to obtain quantitative information and knowledge on the space and time distribution of convective rain entities in non-treated weather systems (see Huff, 1987);
- 3) Evaluation of the cloud contamination problem in cloud seeding experiments;
- 4) Assessment of past cloud seeding projects with respect to problems, failures, and successes;
- 5) Several synoptic climatology studies relating to such important factors as the distribution of synoptic storm types, the frequency distribution of July-August rainy days by storm type and time of day, and the probability of severe weather occurrences (flash floods, hail, tornadoes, damaging winds, etc.);
- 6) Operational requirements including such items as aircraft, radar, weather forecast facilities, computers, and data reduction; and,
- 7) Agricultural modeling and watershed studies, pertinent to eventual evaluation of modification benefits.

1.1 PACE Objective

The conduct of the 1986 field effort represents initiation of Phase 2 under the 1978 PACE planning document which stated the overall objectives and goals of the PACE program, as follows:

- 1) to determine the precipitation alterations attainable in various growing season weather conditions;
- 2) to determine the impact on all facets of

- 3) to discern the ultimate socio-economic and environmental desirability of the weather alterations.

The specific objectives as stated in the 1978 document were:

- 1) to execute carefully designed field experiments involving cloud modification and rain enhancement in the central agricultural region of the United States;
- 2) to document the alteration of cloud dynamics and other physical responses from modification;
- 3) to develop the conceptual and numerical models to guide the experimentation in the ultimate transfer of the technology developed;
- 4) to identify changes in areal precipitation caused by the modification of warm season rainfall entities; and
- 5) to determine any extra area effects of seeding modification.

Phase 1, the pre-experimental phase, was largely completed during 1985 and early 1986. In general, this involved studies (such as those mentioned previously) relating to the assessment of all available background information essential to establishment of reasonable hypotheses for successful modification of clouds in Illinois and the Midwest, development of appropriate design criteria to evaluate the hypotheses, and development of the operational methodology (equipment requirements, data collection and reduction, randomization techniques, etc.).

Phase 2 is to be devoted to exploratory experimentation, and if successful, Phase 3 is to be a confirmatory experiment. Moving from Phase 1 to Phase 2 required that findings in Phase 1 were deemed sufficient to proceed.

1.2 1986 Objectives

The initial field experiments of Phase 2 were designed primarily to:

- 1) Start investigation of in-cloud reaction to silver iodide seeding at  $-10^{\circ}\text{C}$  to test portions of the PACE dynamic seeding hypotheses;
- 2) Collect data to increase understanding of the physics and dynamics of midwestern clouds and to gather data useful in other allied projects of the Water Survey;
- 3) Stimulate staff interest and gain experience in the operation of weather modification experiments;

- 4) Test and further develop field facilities;
- 5) Develop a team that could direct and conduct future PACE field experimentation.

## 2. DESIGN OF THE 1986 EXPERIMENT

As indicated earlier, the 1986 experimental design was based primarily on the results of numerous pre-experimental (Phase 1) studies. These plus funding limitations dictated the approach and limitations for the initial experiments. Various aspects of the design are briefly summarized in the following paragraphs.

Since the ultimate goal of PACE is to establish whether, how, and when clouds and summer precipitation can be modified, it was concluded that part of the 1986 experiment, in addition to the cloud physics studies, should involve actual cloud seeding under typical midwestern weather conditions. However, it was recognized that it is highly unlikely that a definitive answer would result from any single year of experimentation, regardless of the sample size. Rather, there would need to be an orderly progression of developing further concepts, hypotheses, definitions, and classifications which could be applied for more closely focused later experimentation under Part A of Phase 2. The first year was also considered to largely provide a learning experience.

### 2.1 Description of Experiment

The overall 1986 field effort was labeled the "Weather Type Experiment" (WTE). Based on synoptic climatology studies, the 1986 experiment was grouped into treatment of four weather types (Changnon et al., 1986). Two basic blocking methods were considered. These included grouping by synoptic weather conditions or by classifications of weak, moderate, and strong convection. Although grouping by convection was considered best, the necessary information did not exist to specify the degrees of convection with a high degree of reliability for the 1986 operational forecasts. As a result of this uncertainty, the following four synoptic weather classifications were used for blocking since these could be predicted with a high degree of accuracy and would provide a logical stratification of warm season precipitation-producing systems in the Midwest (an important scientific objective). The systems were:

- 1) Cold front cloud systems -- those conditions (clouds) occurring within 150 statute miles of a cold front at the surface.
- 2) Stationary front systems -- those conditions within 150 statute miles of the surface frontal position.
- 3) Warm front systems -- those clouds occurring within 75 statute miles to the south (warm sector) and 150 miles north of the surface front.
- 4) Air mass cloud systems -- primarily cloud systems in the warm sector (warm air mass systems), plus those located over 150 statute miles to the rear of the front (cold air mass clouds). The cold air mass clouds are not likely to be utilized.

WTE was designed to be conducted during July and August, when the agricultural needs for rain augmentation occur most frequently in the Midwest. Experiments were to be done during the period from 1200 to 2100 CDT when the frequency of convective clouds maximizes. Two sets of subexperiments were included in WTE. These were called the "echo

subexperiment" (ESX) and the "cloud physics sub-experiment" (CPS). ESX involved operational-type seeding tests. Experiments were to be made within a 100-mile radius of the radar and field headquarters at the Champaign airport (Fig. 1) using droppable silver iodide flares (mounted on a seeding aircraft) released at the -10°C level in growing cumulus clouds.

The design included provisions for aborting seeding operations under severe weather conditions, as required by Illinois law governing weather modification operations in the state. The following restrictions were adopted to meet legal requirements and our concern to avoid any possible risk to the safety of the public and project personnel. The restrictions were as follows:

- No seeding was to be performed within 100 nautical miles of a Severe Weather Warning Area (issued by the National Weather Service) or within the same convective system involved in the warning even if the seeding target was located at a greater distance.
- No seeding was to be performed within 50 nautical miles of clouds with radar echo tops that exceed 50,000 feet or those that penetrate the tropopause level.
- No seeding was to occur within 50 nautical miles of clouds with echo speeds that exceed 35 knots and 45 dbz maximum reflectivity.
- No seeding was to occur in areas where the radar meteorologist assessed the potential of violent convection, as defined by extremely rapid echo growth, hail signals, and/or evidence of severe winds and tornadic features.

Seeding was allowed in areas covered by Severe Weather Watches; however, all personnel were advised of these situations when they occurred and asked to pay special attention to the developing potential for severe weather.

CPS was given highest priority because of the great need to obtain more cloud physics data to test and adjust (if necessary) the initial hypotheses. These experiments were carried out primarily during July when instrumented aircraft for both cloud physics measurements and cloud seeding were available. Efforts on ESX were then pursued largely during August, although ESX flights were carried out during July whenever they did not interfere with CPS experiments. ESX involved cloud seeding experiments aimed toward rain augmentation, utilizing the best information available with respect to cloud seeding concepts for the Midwest. Verification is entirely dependent on radar echo analyses, since raingage network data were not available for the 1986 experiments. It is again emphasized that no statistically significant results were expected to evolve from the 2-month experiment, but the initial accumulation of usable data occurred and information valuable to the refinement of both ESX and CPS in future field experiments was gathered.

### 2.2 Randomization Procedures

Separate randomizations were made within weather types, with one unit to be seeded with AgI and the other with a placebo. A weather unit was defined as an afternoon or part of an afternoon (as declared by the project meteorologist) when the weather is one of the four types listed earlier. The weather unit was to end at 2100 CDT unless terminated earlier by the project meteorologist.

Thus, if the weather type occurring in the first 1986 experiment was a cold front, the first randomized pair would determine the treatment for the first and second cold fronts of the 2-month experimental period. If the second experiment involved a warm front, then the second randomized pair would determine the treatment in that and the following warm front.

Randomization was done by weather units (days or parts of days) rather than by clouds or other convective entities to satisfy certain criteria considered essential for proper experimentation. That is, these units:

- 1) were physically meaningful and allowed stratification by weather types;
- 2) were defined in real time and could be randomized a priori (before start of seeding); and,
- 3) were clearly separated so that seeding of any one unit could not reasonably be suspected of affecting the observation on another unit.

The decision not to use individual clouds or other convective entities as ESX experimental units was based on doubts about satisfying criteria 2 and 3 above. Insufficient information was available about the possible chemical contamination of seeding from cloud to cloud and the possible synergism of dynamic development of adjacent clouds. Thus, it was concluded that clouds could not provide experimental units in a definition that unequivocally satisfied criterion 3.

Of course, a problem with the above definition of a weather unit (day or part of a day) is that it greatly reduces the sample size compared with that obtained when the weather units (treatment units) are defined as separate cloud or convective entities, and randomization is by such cloud pairs. Late in the summer program, the definition was changed slightly to allow more than one weather unit per day, if they were separated sufficiently in time and/or space to minimize the contamination probability, based on judgement of the project director and duty meteorologist.

Individual cloud units within weather units formed the experimental units for the CPS experiments. Operational considerations indicated that no more than six cloud units would be treatable under CPS in a given weather unit (cold front, warm front, etc.). Therefore, we randomized in pairs for a total of six possible cloud treatments in each weather unit. This was done for sufficient weather units to cover all potential occurrences within a CPS experimental period.

The randomization by pairs in both ESX and CPS was done in the interest of balancing the number of AgI and placebo treatments for each weather type and for the total sample in the 2-month experiment. All randomizing was done prior to the start of the experimental period. The randomization schedule was known only to the randomization officer (Huff) and the statistical consultant (Gabriel). On a day-to-day basis, the aircraft flare arrangement was known to a temporary student assistant who helped with loading the flare boxes and mounting them on the seeding aircraft. The randomization is to be made public only after the final statistical analysis of the experimental data.

### 2.3 Forecasting System

Essential to this effort and any other modification experiment is a well-organized, adequately-staffed forecasting unit with access to all useful weather data and information pertinent for providing short-range forecasts for periods up to 12 hours in advance of scheduled operations, for updating of forecasts as aircraft launch time approaches, and for monitoring weather conditions during operations.

Therefore in designing PACE 1986, a large variety of weather products were specified and secured to meet the needs outlined above. These included: 1) selected sets of meteorological charts received on an Alden 18 facsimile recorder from the National Meteorological Center (NMC); 2) substantial digital and worded data available over the FAS604 line and from monitoring of the NOAA/NWS Public Products line; 3) real-time GOES satellite images received and displayed on a graphics display system; 4) an advanced automatic atmospheric sounding capability (CLASS) supplied by NCAR; and, 5) the Water Survey's radar and associated computer system. These, along with special RAOB observations obtained for nearby stations of NWS, provided the data and information employed for the forecasting, nowcasting (updating), and monitoring of weather conditions for the 1986 field project.

### 2.4 CPS Sampling Procedures

CPS was designed to involve two aircraft, an observational aircraft instrumented to make various types of meteorological measurements, and a seeding aircraft which would treat selected clouds or convective entities as instructed by the project meteorologist aboard the observational aircraft. After treatment in the vicinity of the  $-10^{\circ}\text{C}$  level, sampling of each treated cloud unit would follow basic sampling procedures established by the cloud physics group associated with the PACE research. Supplementary observations, including cloud photographs, were to be made by the seeding aircraft. Continuous observations were to be made by the Survey's radar system throughout each CPS to assist in the aircraft operations and to collect data for later evaluation of the experimental results.

The 1986 design provided no precise definition of the cloud units to be sampled in CPS, since no operational definition of such clouds had been established previously. An initial definition was provided by Survey cloud physicists. This definition of seedable clouds based on visual appearance stated that they should have: 1) a hard white outline with apparent ascending summit on one or more of the cells or turrets; 2) significant horizontal dimensions to the cloud area in which the cell or turret is developing; 3) a limited, if any, vertical slope; and 4) no evidence of dissipation below the developing summit. It was understood that definitions were to be improvised and amended during the experiment, and it is anticipated that one outcome of the 1986 experiment will be a more precise and operationally feasible definition. Clearly, the adopted definition must minimize the effects of seeding any one unit on other seedable units in the target area. More detailed discussion of the CPS sampling and observational procedures is provided by Changnon *et al.*, 1986.

## 2.5 ESX Sampling Procedures

The 1986 design proved for the use of only one aircraft, the seeding aircraft, during operational seeding of weather units. Selection of the convective entities to be treated were made by the project meteorologist (William Woodley) aboard the seeding aircraft, utilizing all available knowledge on the seedability of Midwest clouds. Three-dimensional radar observations of the cloud systems in the experimental area were made continuously prior to, during, and following the cloud treatment. Each treated unit was tracked until it dissipated or passed out of the operating range of the radar system. As in CPS, supplementary observations were made with the seeding aircraft to help in evaluation of experimental results. Radar data were to be the primary evaluation tool, since no recording rain gauge network could be provided within the financial limits of the 1986 PACE research funds. Again, a more complete description of cloud seedability and sampling procedures is provided by Changnon et al., 1986.

## 3. POST-EXPERIMENTAL ASSESSMENT OF 1986 DESIGN

The limited experience gained in the below-normal rainfall conditions occurring in the July-August experimental period (daytime rainfall was 22% of normal) did not reveal any major mistakes or errors in the 1986 design. Certain problems surfaced, but these were largely recognized as potential weaknesses in developing the 1986 design, and were set aside in the interest of carrying out relatively simple, conservative experiments in our initial field effort of PACE. Some of the design aspects which we believe should be considered for adjustment in future field experiments are summarized below.

The definition of a weather unit as the entire period during which a convective system is within the experimental area needs alteration. This greatly reduces sample size, compared with that obtained when the weather units (treatment units) are defined as separate cloud or convective entities within a storm system, and seeding assessment is made by comparing seeded and unseeded pairs of cloud units. Our initial conclusion is that we should probably compare seeded and unseeded pairs within storm systems in future experiments, with sufficient temporal and spatial separation of the cloud units chosen to minimize, although not completely overcome, the possibility of occasional contamination of one unit by another.

Another problem recognized in the initial design which became more apparent during the 1986 operations, is that the stratifying (balancing) by synoptic storm type is not optimal. Realistically, seedable clouds are better defined on the basis of cloud system properties rather than storm type. That is, such factors as degree of build-up, temperature and moisture parameters, existence of a vigorous convection system (such as commonly associated with squall lines and squall areas), and imbedding of convection in middle or high level cloud decks are factors which determine the seedability of existing cloud systems. The last two conditions are not considered seedable at present because of aircraft safety and/or conditions that prevent satisfactory sampling of the treated cloud units. The foregoing are factors that need to be highlighted (if feasible) in establishing future forecasting systems and in the stratification of data for analyses. It is intended to investigate this problem further in the near future, and hopefully,

devise a more logical method of blocking the data.

A third problem that was anticipated and surfaced in the 1986 experiments was missed treatment opportunities, because favorable seeding conditions sometimes occurred in early morning to mid-forenoon. The optimal method of overcoming this problem is to have a 24-hour forecasting operation. This was not feasible within 1986 project funding. However, we did partly overcome this problem late in the summer operations through adjustment in our forecasting and weather monitoring activities with no increase in personnel. Similar procedures, with some further adjustments likely, will be utilized in future field efforts.

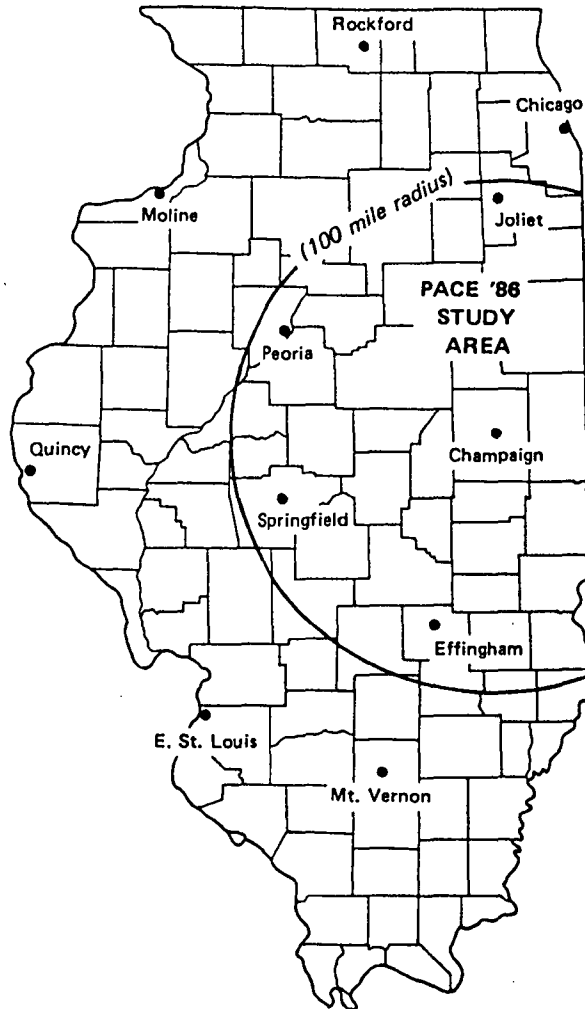
The 1986 experience also indicates an adjustment may be desirable in the restriction on seeding within 50 nautical miles of clouds having echo speeds exceeding 35 knots and maximum reflectivity exceeding 45 dbz. These conditions are not uncommon in midwestern convective systems, and the present limits may cause unnecessary loss of treatment opportunities. An upward adjustment in these values will be made if further investigation of the frequency distribution of these two factors indicates it would be appropriate.

Several suggestions for additions to future experiments have been proposed by various PACE scientists, consultants, and contract personnel. Their feasibility and desirability will be assessed prior to future field experiments. These include consideration of adding dry ice as an alternative seeding agent, starting the field sampling earlier in the summer, and conducting CPS independently of ESX.

Acknowledgments. The research leading to the development of the 1986 design was supported by a research contract with NOAA, NA86RAH065051 during 1980-1985. Many survey scientists, too numerous to acknowledge appropriately here, were involved in various research studies which led to accumulation of the information and knowledge required in the design of the 1986 field project. Significant assistance was also received from various consultants involved in PACE, including Dr. K. R. Gabriel, Dr. William Woodley and Tom Henderson.

## 4. REFERENCES

- Changnon, S. A., Jr., D. B. Johnson, and R. G. Semonin (Principal Investigators), 1983. Pre-Experimental Studies During 1980-1982 for Precipitation Augmentation for Crops Experiment. Final Report on NOAA Contract NA80RAC00072, SWS Contract Report 315, Illinois State Water Survey, Champaign, 479 pp.
- Changnon, S. A., Jr. and R. G. Semonin (Principal Investigators), 1985. Precipitation Augmentation for Crops Experiment, Annual Report for May 1984-April 1985. SWS Contract Report 365, Illinois State Water Survey, Champaign, 171 pp. + appendices.
- Changnon, S. A., Jr. (Principal Investigator), 1986. Precipitation Augmentation for Crops Experiment: Pre-Experimental Phase. Final Report on NOAA Contract NA-85RAH05060, SWS Contract Report 404, Illinois State Water Survey, Champaign, 269 pp.
- Huff, Floyd A., 1987. Summary of Several Radar Echo Studies for Weather Modification Application in Illinois. Journal of Weather Modification, Vol. 19, No. 1, April.



*Fig. 1. Location of 1986 Field Experiment.*