ILLINOIS STATE WATER SURVEY
ATMOSPHERIC SCIENCES SECTION

# ILLINOIS PRECIPITATION ENHANCEMENT PROGRAM
# PHASE I

October 10, 1972

Interim Report

for

1 September 1971 - 30 June 1972

To

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

Contract 14-06-D-7197

STATE OF ILLINOIS
DEPARTMENT OF
REGISTRATION AND EDUCATION
WILLIAM H. ROBINSON
DIRECTOR, SPRINGFIELD


# Illinois State Water Survey

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WILLIAM C. ACKERMANN, CHIEF

October 10, 1972

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 First Interim Report for the Illinois Precipitation Enhancement Program: Phase I. It covers the research activities pursued during the 1 September 1971 - 30 June 1972 period.

The report is organized around the 10 major study areas of this program. The scientists responsible for each study area are the authors of each section. Under each study area, the FY-72 activities and the work planned for FY-73 are described. The final section (appendix) describes project personnel.

Sincerely,
ILLINOIS STATE WATER SURVEY
Stanley A. Changnon, Jr.

Stanley A. Changnon, Jr., Head
Atmospheric Sciences Section

SAC/rr
Enclosure

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# LEGISLATIVE ASPECTS OF WEATHER MODIFICATION IN ILLINOIS

Stanley A. Changnon, Jr.

## Introduction

Presently, only 30 states have any form of legislation concerning weather modification, and Illinois is not among them. A requirement for the proper execution of any modification activities is the procurement of legislation conducive to such work, as envisioned for Phase II of PEP beyond 1976. Therefore, a program to secure a weather modification statute for Illinois was included as one aspect of Phase I of the Precipitation Enhancement Program (PEP).

The completion of this task is considered vital to Illinois and to the design and pursuance of Phase II of the Program. Therefore, suitable state legislation must be enacted before the starting date of an actual precipitation enhancement experiment. Should Illinois have no statute at that time, it might be unwise to perform an experiment and risk contamination of the study area by another nearby weather modification effort, and potential legal-problems that might hamper the conduct of the experiment can be better averted.

## Activities

Several tasks are necessary prior to actually preparing a statute for submission to the legislature, including 1) a thorough study of existing weather modification laws enacted in other states; 2) discussions with various state organizations and interest groups who will be affected directly or indirectly by weather modification and thus by such legislation; and 3) discussions with experts in both weather modification and its legal aspects.

Because of the complex nature of the problem, the service of an expert in the legal aspects of weather modification was enlisted. Professor Ray Jay Davis of the University of Arizona College of Law agreed to work as a consultant with the Water Survey, and in this capacity to prepare a draft of the statute hoped for passage into Illinois law.

Preliminary meetings between PEP scientists and Davis were used to formulate basic decisions regarding the statute, and to affix an approximate time schedule for completion of the work. It was decided that:

1) Illinois should have a permissive-control type of weather modification law, rather than rely on common-law, and if finances were available, it should be developed as a "model law";

2) this law should be broad in scope, delegating development of the details of administration of it to the state agency chosen to handle the activity;

3) the Department of Registration and Education within the state government was the likely agency for the responsibility of this statute; and

4) the statute should be entered into the legislative process by January 31, 1973.

After discussions of these preliminary decisions, Survey staff members presented their thoughts and recommendations to state departmental staff members in Springfield in December. The recommended approach involving Davis and the tentative decisions regarding legislation were found to be suitable and plans to proceed were formulated.

Professor Davis performed the following activities during the January-June 1972 period:

1) became familiar with Illinois law, paying particular attention to those facets in any way relevant to weather modification (e.g. liability and tort law);

2) worked closely with Department of Registration and Education legal counsel to integrate the departments' administrative/regulatory role into the statute;

3) wrote a rough draft of the model law by April, with commentary describing each section; and

4) after receiving reviews and comments in June by PEP scientists and departmental staff in Springfield, he began to finalize the statute's wording to be ready for submission to the legislature.

Water Survey scientists read existing weather modification legislation from other states, with particular regard to including good portions in the Illinois law and omitting undesirable sections. We also talked with other state groups (Texas and Colorado) as to provisions in their laws.

## Future Plans

Activities will include securing reviews of the proposed statute from other Illinois interested groups including the Illinois Agricultural Association. When these are accomplished Dr. Davis will finalize the statute and its commentary. Then it will undergo final review by all interested parties.

It is hoped to enter the bill into the state legislature when it convenes in January 1973 for passage in early 1973. It would likely take effect in July 1973. Involved in this process is securing the assistant of a group/s who will aid in the process of getting the statute into the legislature and then its passage.

# SOCIAL IMPACT OF WEATHER MODIFICATION

Stanley A. Changnon, Jr.

## Introduction

If a weather modification experiment (Phase II of PEP) is to begin in Illinois in 1976, the project must be accepted and understood by the citizens of the state, and particularly by those persons living within the experimental area. In general, the overall result to be obtained in this study area of Phase I of the Precipitation Enhancement Program is to make the public aware, in an objective manner, of weather modification and our intentions for conducting experimentation within Illinois. More specifically, the Social Impact Study has two goals: 1) to ensure statewide, regional, and local understanding of the proposed Precipitation Enhancement Experiment; and 2) to establish public relations channels which can be utilized before, during, and after the experiment is conducted.

## Activities

Although no extensive public information activities had been envisioned for FY-72, considerable activity was initiated. This occurred for two reasons: 1) developing public interest in weather modification and 2) need to spread knowledge of PEP at higher levels to secure understudy and support for the developing legislation. Since benefits of rain increase appeared greatest to agriculture, various contacts were made in this area.

First, a short, informative text entitled the "Status of Weather-Modification in 1971", was prepared. Copies of this information document were used in our discussions with various public and state individuals and groups.

A general information pamphlet for PEP was also needed for wide distribution to state citizens. Presentations of PEP before agricultural groups throughout the state planned in the spring and summer indicated this need. The PEP pamphlet was aimed at informing the general public about weather (rain) modification and PEP. It was made as short as possible and filled with visual aids (diagrams and photos). It was then used for both mailings and distribution at talks given by Survey staff. It was designed and 10,000 copies printed by March 1.

A series of slides depicting the status of weather modification and describing all facets of PEP have been prepared so that Survey staff members can use these in public presentations. Dr. William C. Ackermann described PEP at a speaking engagement at Rotary Club of Champaign-Urbana on February 7, and Glenn Stout described PEP at a presentation to officials of the Illinois Board of Economic Development in Springfield on February 2. On 14 February Dr. Ackermann and Mr. Changnon briefed the Dean and other officials of the College of Agriculture of the University of Illinois on PEP with specific reference to the legislative aspects. Their understanding and support of PEP and the legislation are considered important.

Changnon was invited to attend a meeting on 1 March at the State offices of the Soil Conservation Services and talked about PEP to the senior staff and all the Area Conservationists for Illinois.

On both 8 and 9 March Changnon made presentations at the Annual Area Workshops of the Directors of the Soil and Water Conservation Districts. The meeting on 8 March was in Mt. Vernon and included Directors from Area IV, the southern third of Illinois, and the meeting on 9 March was in Mattoon and was for the Directors in Area III, the central-eastern fourth of Illinois. Pamphlets were distributed at these meetings.

On 15 March, Dr. Ackermann attended the Northern Illinois Annual Workshop of the Soil and Water Conservation Service. At this meeting, held in Ottawa, he presented a talk on weather modification and PEP, and distributed approximately 100 of the pamphlets "Cloud Seeding - A Decision for Illinois." On the 16th, Changnon attended a similar meeting for the western region of Illinois, and he spoke about PEP and distributed more pamphlets. Thus, in 5 meetings held within a 16-day period, almost 450 key people in the Soil and Water Conservation Service were informed of our work and plans in weather modification.

On 29 March, Changnon made a TV-tape interview concerning PEP. This tape was done for the public information group of the Illinois Agricultural Association and the tape is being distributed to TV stations throughout Illinois. On 4 April, Changnon presented a detailed Seminar on PEP to the staff of the Illinois State Water Survey.

On 13 April, John Wilson described PEP to the Central Illinois Chapter of the Illinois Society of Professional Engineers. Considerable interest was generated by the 55 in attendance, and PEP pamphlets were distributed. Captain H. W. Albers, Executive Secretary of ICAS, requested 50 copies of our PEP pamphlet and these were supplied to him along with a 11-page document describing Phase I of PEP. The Illinois Agricultural Association was contacted to develop a meeting between their top-level personnel and Survey scientists to discuss and explain PEP.

On 11 May, Wilson traveled to Dixon, Illinois, for a meeting of the Northwestern Illinois Section of the Soil Conservation Society of America. He addressed members of that organization, and described PEP to them. Copies of our information pamphlet were distributed to those persons present.

At our invitation, Mr. Harold Steele, President of the Illinois Agricultural Association, and Mr. Len Gardner of that Association visited the Survey on 26 May to discuss PEP with Dr. William Ackermann and Changnon. Arrangements were made for a formal presentation of our PEP plans to the Association's staff in Bloomington in August. They are also quite interested in our proposed weather modification act, and are reviewing it. The PEP information pamphlets (200) were distributed by the College of Agriculture to the county agents of the 102 Illinois counties in June.

Future Plans

Continued oral presentations about PEP to state and regional groups are planned for FY-73. Emphasis on local (county) presentations are not envisioned. Further radio and TV presentations are envisioned to bring awareness across the **state.**

# POTENTIAL BENEFITS ON WATER SUPPLY

Floyd A. Huff

## Introduction

This study involves an evaluation of the potential benefits of precipitation augmentation on water supplies under typical midwestern conditions. Basically, Illinois data are being employed to assess 1) the general magnitude of water-supply augmentation that could be realized under various assumed seeding-induced increases in natural precipitation, and 2) the relative effects of climatic, physiographic, and geomorphic features upon seeding-induced benefits. Standard mathematical and statistical techniques are being employed to derive regression equations that reflect the importance of various meteorological and hydrological factors in defining basin runoff. A total of 14 Illinois basins were selected to provide a measure of potential water-supply benefits under various basin characteristics. Particular emphasis is being placed upon the southern and south central parts of the state where surface waters are the primary source of water supply. Seeding-induced precipitation would be most beneficial in the southern one-third of the state from both water supply and agricultural considerations. Table 1 provides a brief description of the 14 study basins.

## Analytical Techniques

Stepwise correlation and regression techniques are being used in deriving equations which relate basin runoff to antecedent indices, precipitation parameters, and temperature conditions. The antecedent indices employed are runoff and rainfall in the month preceding the period of interest. Mean seasonal temperature for winter and summer are used as temperature variables. Precipitation parameters include seasonal totals, sub-seasonal amounts, monthly totals, maximum monthly precipitation, snowfall (cold season), and number of days with precipitation. This provided a group of 15 variables in the cold season and 14 variables in the warm season for relating to the seasonal runoff. Although the best correlator with seasonal runoff is usually total seasonal precipitation, it is obvious that the nature and magnitude of the seasonal runoff is also dictated to a large extent by how this total precipitation is distributed throughout the season. Thus, although the various precipitation parameters are not strictly independent in the statistical sense, combinations of these distribution measures were considered both desirable and necessary to reflect the hydrological-meteorological relationships with which we are concerned. That is, we must determine within the limitations of available data the best means of assessing the conversion of the meteorological input (precipitation) into the hydrological output (runoff) which determines available surface water supplies.

In the Illinois study, the year has been divided into two basic seasons. The cold season includes the months from October through March and the warm season encompasses the April-September period. Shallow-aquifer replenishment is favored in the cold season, particularly in the December-March period used in sub-season analyses. Also, special analyses are being performed for the July-August period when evapotranspiration losses are normally greatest.

For the cold and warm seasons, several types of basin regression equations have been developed and are being tested for optimum applicability in the water supply study. Initially, for each basin an equation was determined based upon data for all years of record. Testing indicated that the standard error of the regressions is usually reduced by insignificant amounts after four "independent" variables have been introduced into the basin equations. Consequently, basin equations throughout the study have been restricted to this number of variables. Table 2 illustrates the multiple correlation coefficients and variance explained (%) obtained for the cold and warm season equations for the 14 basins, based upon use of data from all years of continuous record and using four "independent" variables for each basin. A relatively high degree of correlation is indicated in both seasons for most basins. A typical equation is shown below for the cold season on the Big Muddy.

$$R = -8.46 + 0.62\, P_{O-M} + 3.01\, R_S + 0.43\, P_J + 0.23\, P_{S-N}$$

where R = seasonal runoff, $P_{O-M}$ * total precipitation for October-March, $R_S$ = September runoff, $P_J$ = January precipitation, $P_{S-N}$ = fall rainfall (September-November).

Hypothetical seeding models applied to these basin relations then provide an estimate of the seeding effects realized from a continuous year-to-year seeding operation. Constant-change seeding models which assume seeding-induced increases in the precipitation variables of 10%, 20%, 30%, and 50% are being used in the study. These models are applied to actual precipitation occurrences in each year of record. From the seeding-induced changes in runoff obtained in this manner, probability distributions of runoff increases are determined for each basin and each seeding model in each season, similar to the method used in an earlier study of potential effects of weather modification on agriculture (Huff and Changnon, 1971).

For the cold and warm seasons, basin equations have been developed also for the data stratified according to the upper, middle, and lower one-third of the seasonal runoff. Unfortunately, with this grouping, the data sample for equation derivations was too small to obtain stable relationships in the warm season, but relatively high correlations were maintained with most basins in the cold season. However, analyses performed on those years in which the runoff was near normal or below normal (lower 2/3 of seasonal runoffs) provided equations which maintained a relatively high level of correlation in both seasons. These are years in which augmentation of water supplies through weather modification would be most beneficial. Consequently, much.of the analyses are being concentrated on evaluation of seeding potential in these years. The same procedure is followed as used in the analyses of all years combined.

Table 1. Study Basins

| Basin | Area ($mi^2$) | Continuous Record (yrs) | Major Water-Supply Source | Geomorphic Type | State Location |
|---|---|---|---|---|---|
| Sangamon | 5120 | 1939-70 | Mixture | Glacial Plain (2 stages) | East Central |
| Upper Kaskaskia | 1980 | 1914-70 | Mixture | Glacial Plain (2) | East Central-South Central |
| Big Muddy | 785 | 1914-70 | Surface | Glacial Plain (1) | South |
| Little Wabash | 3111 | 1939-70 | Surface | Glacial Plain (1) | Southeast |
| Skillet Fork | 464 | 1928-70 | Surface | Glacial Plain (1) | South |
| Embarras | 1513 | 1914-70 | Mixture | Glacial Plain (1,2) | East |
| Spoon | 1600 | 1914-70 | Mixture | Glacial Plain (1) | Northwest |
| La Moine | 1310 | 1921-70 | Surface | Glacial Plain (1) | West |
| Green | 958 | 1936-70 | Ground | Fluvial-Lacustrine Plain (Glacial-Fluvial) | Northwest |
| Macoupin | 875 | 1940-70 | Mixture | Glacial Plain (1) | Southwest |
| Cache | 243 | 1924-70 | Mixture | Dome Uplift | Extreme South |
| Henderson Creek | 428 | 1935-70 | Surface | Glacial Plain (1) | Northwest |
| Vermillion (North) | 568 | 1942-70 | Ground | Glacial Plain (2) | East Central |
| Kishwaukee | 1090 | 1940-70 | Ground | Glacial Plain (2) | Extreme North |

Physiographic Regions

Springfield Plain - Embarras, Kaskaskia, Macoupin Creek, Sangamon (plus Bloomington Ridged Plain)

Mt. Vernon Hills (mostly claypan soils) - Little Wabash, Skillet Fork, Big Muddy.

Shawnee Hills - Cache River. Galesburg Plain - La Moine, Spoon, Henderson Creek

Rock River Hills - Kishwaukee. Green River Lowland - Green River. Kankakee Plain - Vermillion

Table 2. Multiple Correlations for Cold and Warm Season Regressions Based on all Years of Record.

| | Cold Season | | Warm Season | |
|---|---|---|---|---|
| Basin | r | $r^2$(%) | r | $r^2$(%) |
| Big Muddy | 0.93 | 86 | 0.93 | 86 |
| Little Wabash | 0.96 | 92 | 0.96 | 92 |
| Embarras | 0.94 | 88 | 0.94 | 88 |
| Skillet Fork | 0.94 | 88 | 0.95 | 90 |
| Cache | 0.94 | 88 | 0.92 | 85 |
| Sangamon | 0.91 | 83 | 0.93 | 86 |
| Macoupin | 0.91 | 83 | 0.95 | 90 |
| Upper Kaskaskia | 0.95 | 90 | 0.93 | 86 |
| Vermillion | 0.90 | 81 | 0.95 | 90 |
| Henderson Creek | 0.90 | 81 | 0.89 | 79 |
| Green | 0.93 | 86 | 0.88 | 77 |
| Spoon | 0.88 | 77 | 0.88 | 77 |
| La Moine | 0.93 | 86 | 0.92 | 85 |
| Kishwaukee | 0.94 | 88 | 0.78 | 61 |
| Median | 0.93 | 86 | 0.93 | 86 |

Grouping of Basins

Initially, analyses were made to determine whether the 14 basins could be grouped according to their physical properties or climatic conditions. Examination was made of possible grouping according to physiographic regions, (Leighton, et al., 1948), geomorphic regions (Von Englen, 1942), a basin climatic index (Thornwaite, 1931), and the general character of the soils. The runoff/rainfall ratio (R/P) and the Thornwaite climatic index (BCD were used to characterize potential groupings. Huff and Changnon (1964) have shown the applicability of R/P values in characterizing basic runoff properties under low flow conditions. R/P was examined for average conditions during the period of basin records and for its modified value after applying the seeding models in the basin regression equations.

No type of grouping proved completely satisfactory. In general the groupings according to BCI, physiographic region, and soils appeared most applicable. Thus, R/P values for the claypan soil region of southern Illinois were found to be very similar for the three basins completely (or nearly so) in that region (Big Muddy, Skillet Fork, Little Wabash) and for the Embarras with over 50% of its area in the claypan region (Table 3). The Kaskaskia has very similar BCI and R/P values to those for the four basins grouped in the claypan region above, although only a small portion of its area is in that region.

Table 3. Basin groupings according to climatic index and average runoff/precipitation ratios.

| Basin | Annual BCI | Annual R/P | Oct-Mar | Seasonal R/P Values Dec-Mar | Apr-Sept | July-Aug |
|---|---|---|---|---|---|---|
| Big Muddy | 86 | 0.29 | 0.38 | 0.51 | 0.22 | 0.11 |
| Little Wabash | 87 | 0.27 | 0.33 | 0.44 | 0.21 | 0.12 |
| Skillet Fork | 87 | 0.27 | 0.34 | 0.46 | 0.21 | 0.09 |
| Embarras | 86 | 0.27 | 0.35 | 0.47 | 0.22 | 0.12 |
| Kaskaskia | 85 | 0.25 | 0.28 | 0.42 | 0.21 | 0.12 |

## Regression Equation Variables

Evaluation was made of the relative importance of the various independent variables used in the stepwise correlation and regression analyses. In doing this, the four most important variables were determined for each basin and each season.

A rank score was determined by alloting a score of 4, 3, 2, and 1, respectively, for ranks 1 through 4 in each basin equation. For the cold season, total seasonal precipitation ranked first among 11 of the 14 basins and had the highest rank score. The other most important variables, in general, were the antecedent index represented by September runoff, fall precipitation, and winter precipitation. Total season precipitation was especially strong in the four southernmost basins (Big Muddy, Skillet Fork, Little Wabash, and Cache). All but the Cache lie in the claypan soil region.

For the warm season, the most important definitive variable was again total seasonal precipitation, but spring precipitation replaced the antecedent index as the second most important factor. The subseason, December-March, was similar to the total cold season in that total seasonal precipitation and antecedent index (November runoff) were the two strongest variables. The July-August period with its tendency for highly variable year-to-year precipitation and high evapotranspiration and infiltration rates had lower correlations than the other seasons and less dependence upon the subseason total precipitation which ranked third in importance behind July rainfall and June rainfall (antecedent index).

## Minimum Runoff Conditions

In a Kansas study (Smith, 1970) it was pointed out that many of their streams were running dry during drought periods, so that seeding for increasing water supplies would have little or no effect. That is, 10% to 20% rainfall increases would be mostly if not completely used by infiltration and evapotranspiration before reaching the streams as runoff.

Monthly runoff data for the 14 experimental basins used in the Illinois study were scanned to determine the minimum monthly runoff on record for the 14 basins. Results showed that the minimum was zero or near zero for all basins in southern Illinois and most of the other areas. The severe drought of 1953-54 produced the minimum most frequently, and the 1940 drought ranked second in the number of record low monthly runoffs.

Next, the 1953-54 drought which was especially severe in south and south central Illinois (Huff and Changnon, 1963) was examined to determine minimum runoff for periods of 1, 2, and 3 months. For the three consecutive months of minimum streamflow (September-November 1953) the total runoff was less than 0.01 inch in the most southern basins (Big Muddy, Little Wabash, Skillet Fork, and Cache) and only 0.02 to 0.04 inch in the central and south central basins (Macoupin, Kaskaskia, and Sangamon).

Except for Cache, the total cold season runoff (October-March) in the 1953-54 period was less than 0.10 inch at the southern and central basins. Mean runoff for the cold season ranges from 3.3 inches for Macoupin to 10.13 inches for Cache. Thus, it would appear that in very severe drought conditions, such as experienced in 1953-54, seeding-induced precipitation would have little or no effect on increasing water supplies from surface water and shallow groundwater aquifers unless large rainfall increases could be generated.

## Rainfall-Runoff Relations in Near-Normal to Below-Normal Warm Seasons

Using the five study basins with longest continuous records (Big Muddy, Embarras, Kaskaskia, La Moine, and Spoon), analyses have been made of rainfall-runoff relations for those warm seasons with near normal to below normal runoff. That is, the lower two-thirds of the ranked runoffs were used. Regression equations were then determined for each basin from these data and hypothetical seeding experiments performed. Water supply would be benefitted most by increasing storage in periods of near-normal rainfall and by any additional rainfall that could be induced under below-normal conditions. It was believed that use of two-thirds of the years would provide a sample of sufficient size to use as a first approximations of seeding effects with the stepwise regression technique. If results appeared reliable, this procedure would be expanded to include the other nine basins with somewhat shorter records (see Table 1).

Table 4 shows average runoff (R), precipitation (P), runoff/rainfall ratios (R/P), and multiple correlation coefficients for the five basin regressions, based upon use of the lower two-thirds of the warm seasonal runoffs. Also included for comparison purposes are R/P and correlation coefficients obtained from use of all warm season data in the analyses of the rainfall-runoff relations.

Elimination of one-third of the data sample resulted in a decrease in correlation coefficient of 0.07-0.13 which is equivalent to decreases in variance explained by 10% to 20%. However, correlations remained relatively high except for the Spoon River Basin. The R/P values decreased approximately 0.06, or a reduction of approximately 6% in the amount of precipitation converted to runoff. Note the close similarity in the R/P values for the five basins, which indicates similarity in reaction to warm season precipitation amounts among the basins under the conditions analyzed. The most important variables in the equation for near-normal to below-normal runoffs were spring rainfall and summer mean temperature. March-May precipitation was among the four variables used in all five basins and summer temperature appeared in four of the stepwise regressions. Rank scores were 16 and 10, respectively, for spring rainfall and summer mean temperature, based upon scores of 4, 3, 2, and 1 for ranks 1, 2, 3, and 4 among the variables. Maximum possible rank score would be 20 for any variable.

Table 4. Comparison of rainfall-runoff relations, based on lower two-thirds and all warm season runoffs.

| | Lower two-thirds of runoffs | | | | All runoffs | |
|---|---|---|---|---|---|---|
| Basin | R (in.) | P (in.) | R/P | Multiple correlation coefficient | R/P | Multiple correlation coefficient |
| Big Muddy | 2.93 | 20.27 | 0.14 | 0.84 | 0.22 | 0.93 |
| Embarras | 3.23 | 20.44 | 0.16 | 0.87 | 0.22 | 0.94 |
| Kaskaskia | 3.11 | 20.73 | 0.15 | 0.87 | 0.21 | 0.93 |
| La Moine | 2.80 | 21.00 | 0.13 | 0.84 | 0.19 | 0.92 |
| Spoon | 3.04 | 20.33 | 0.15 | 0.75 | 0.21 | 0.88 |

Table 5 shows a comparison of the average seeding-induced increase in runoff in both inches and percentage, based on calculations under average conditions in all years (complete sample) and in those years with near-normal to below-normal rainfall. Calculations are shown for hypothetical seeding-induced increases of 10% to 30% in the warm season precipitation variables, and assuming a continuous year-to-year seeding operations throughout the warm season on the five basins.

Table 5 shows pronounced differences in the seeding-induced averages between the two sets of data. However, within each data set the similarity among basins is strong. With warm season seeding operations every year, the seeding-induced increases in inches average 2.6 greater than in the near-normal to below-normal years. Similarly, the percentage of seasonal precipitation converted to runoff is much greater, as shown in the lower portion of Table 5. For example, the 10% seeding-induced increase in precipitation results in a runoff increase of 24% on the Big Muddy when all years are used, compared with a 14% increase in the near-normal to below-normal years.

From the hypothetical seeding results obtained with the basin regression equations for near-normal to below-normal runoff, probability distributions of seeding-induced runoff were calculated for each assumed percentage increase in natural precipitation during the warm season. A typical set of probability curves is shown in Fig. 1, based upon calculations for the Big Muddy. Thus, Fig. 1 indicates that with a 20% increase in natural precipitation there is a 5% probability of a seeding-induced runoff increase of 0.43 inch for the

April-October period. Similarly, there is a 5% chance (95% probability level) that the runoff increase will equal or exceed 1.20 inches. Obviously, the lower probability runoffs are most likely to occur in those seasons with much below normal precipitation, whereas the heavier runoffs would usually occur in the near-normal precipitation seasons. The sampling period was not considered adequate to divide the years further according to degree of wetness or dryness.

Table 5. Comparison of average seeding-induced increases in runoff between all warm seasons and seasons of near to below normal runoff.

| | All years | | | | Near to below normal years | | | |
|---|---|---|---|---|---|---|---|---|
| | No-seed runoff (inches) | Runoff increase (in.) for given rainfall increase | | | No-seed runoff (inches) | Runoff increase (in.) for given rainfall increase | | |
| Basin | | 10% | 20% | 30% | | 10% | 20% | 30% |
| Big Muddy | 5.00 | 1.19 | 2.39 | 3.58 | 2.92 | 0.40 | 0.80 | 1.19 |
| Embarras | 4.93 | 1.33 | 2.66 | 3.99 | 3.23 | 0.46 | 0.91 | 1.37 |
| Kaskaskia | 4.76 | 1.26 | 2.51 | 3.77 | 3.12 | 0.51 | 1.01 | 1.52 |
| La Moine | 4.50 | 1.15 | 2.29 | 3.44 | 2.80 | 0.51 | 1.01 | 1.52 |
| Spoon | 4.68 | 1.24 | 2.48 | 3.72 | 3.03 | 0.47 | 0.94 | 1.41 |
| Median | 4.76 | 1.24 | 2.48 | 3.72 | 3.03 | 0.47 | 0.94 | 1.41 |

| | Runoff ratio for given rainfall increase | | | Runoff ratio for given rainfall increase | | |
|---|---|---|---|---|---|---|
| | 10% | 20% | 30% | 10% | 20% | 30% |
| Big Muddy | 1.24 | 1.48 | 1.72 | 1.14 | 1.27 | 1.41 |
| Embarras | 1.24 | 1.54 | 1.81 | 1.14 | 1.28 | 1.42 |
| Kaskaskia | 1.26 | 1.53 | 1.79 | 1.16 | 1.32 | 1.49 |
| La Moine | 1.26 | 1.51 | 1.76 | 1.18 | 1.36 | 1.54 |
| Spoon | 1.26 | 1.53 | 1.79 | 1.16 | 1.31 | 1.47 |
| Median | 1.26 | 1.53 | 1.79 | 1.16 | 1.31 | 1.47 |

## Comparison of Continuous and Intermittent Seeding Effects

Table 6 provides a comparison of average seeding-induced increases in runoff resulting from seeding in 1) all years, and 2) seasons of near to below normal runoff. This comparison of warm season relations is for three basins with long continuous records. They are located wholly or partially in the claypan soil region, a primary surface water supply region in south central and southern Illinois. Table 6 shows the natural runoff (no-seed) along with runoff increases resulting from seeding-induced rainfall increases of 10 to

30 percent. Values are presented in both actual magnitudes (inches) and percentage changes (runoff/rainfall ratio). Thus, for the Big Muddy a 20% increase in warm season rainfall is estimated to produce an average increase in runoff of 2.39 inches, or 48%, in a continuous year-to-year seeding program. If restricted to near and below normal years, the runoff increase would only be 0.80 inch, or a 27% increase over the natural no-seed runoff.

Table 6. Comparison of average seeding-induced increases in runoff between all warm seasons and seasons of near to below normal- runoff.

| | All years | | | | Near to below normal years | | | |
|---|---|---|---|---|---|---|---|---|
| | | Runoff increase (in.) for given rainfall increase | | | | Runoff increase (in.) for given rainfall increase | | |
| Basin | No-seed runoff (inches) | 10% | 20% | 30% | No-seed runoff (inches) | 10% | 20% | 30% |
| Big Muddy | 5.00 | 1.19 | 2.39 | 3.58 | 2.92 | 0.40 | 0.80 | 1.19 |
| Embarras | 4.93 | 1.33 | 2.66 | 3.99 | 3.23 | 0.46 | 0.91 | 1.37 |
| Kaskaskia | 4.76 | 1.26 | 2.51 | 3.77 | 3.12 | 0.51 | 1.01 | 1.52 |
| | | Runoff/Rainfall ratio for given rainfall increase | | | | Runoff/Rainfall ratio for given rainfall increase | | |
| | | 10% | 20% | 30% | | 10% | 20% | 30% |
| Big Muddy | | 1.24 | 1.48 | 1.72 | | 1.14 | 1.27 | 1.41 |
| Embarras | | 1.24 | 1.54 | 1.81 | | 1.14 | 1.28 | 1.42 |
| Kaskaskia | | 1.26 | 1.53 | 1.79 | | 1.16 | 1.32 | 1.49 |

## Work Plans for Next Period

The most immediate task is to complete the seasonal analyses of potential benefits from weather modification in near-normal to below-normal years. Work will continue on efforts to obtain gross estimates of economic benefits from seeding-induced precipitation contributions to water supply. Efforts will be made also to obtain a measure of erosion and sedimentation disbenefits that could result from weather modification.

A new study will be initiated to determine the distribution of near-normal to above-normal rainfall periods within severe droughts of 12 to 24 months. If such periods are common to these droughts, then weather modification could be potentially a major asset through implementing the natural precipitation in these periods of favorable synoptic weather conditions, and, thus, contribute to reservoir supplies. Present plans are to study conditions in the 10 most severe droughts in the 1906-55 period, identified in an earlier study (Huff and Changnon, 1963).

It is anticipated that analyses and preparation of a technical report summarizing results of the research will be completed by Spring 1973.

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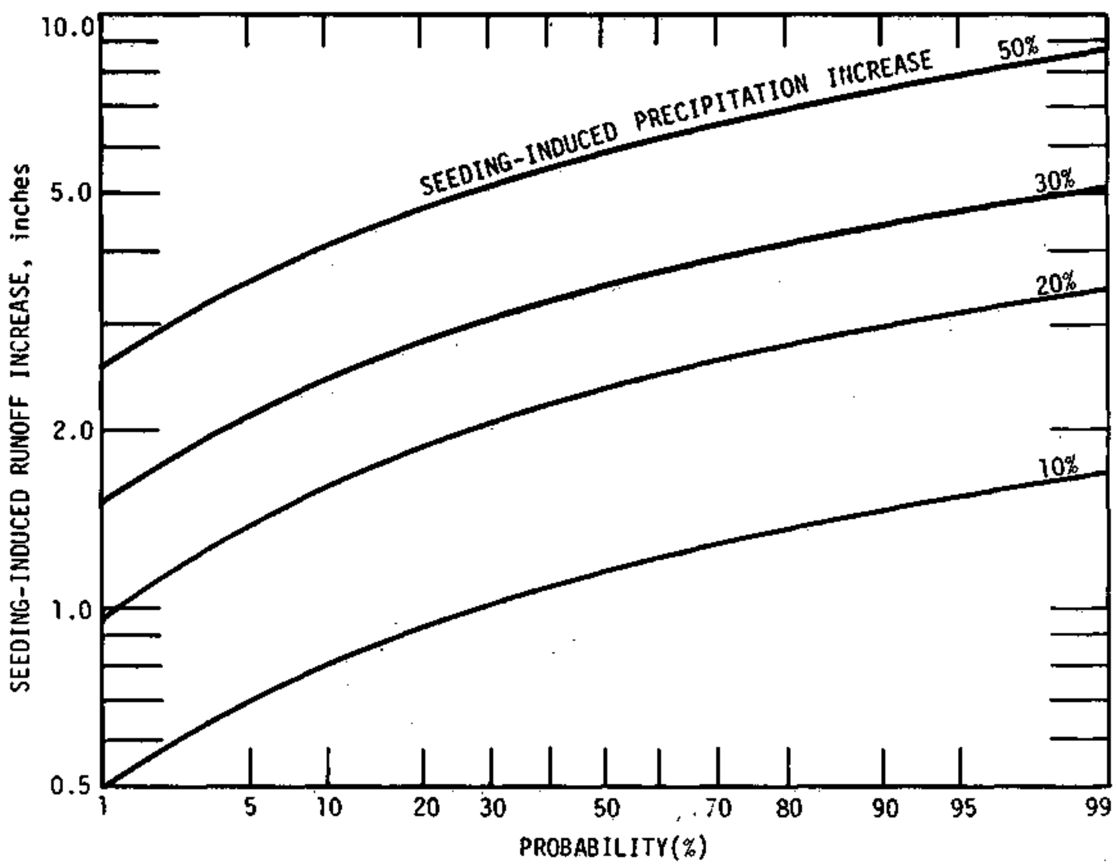


Fig. 1. Warm Season Relations on Big Muddy in Moderate to Dry Warm Seasons•

# ECOLOGICAL STUDY

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## Introduction

The objective of the study is to determine the effects, if any, of some weather factors on six species of game animals in Illinois—Cottontail rabbit (Sylvilagus floridanus), bobwhite quail (Colinus virginianus), ring-necked pheasant (Phasianus colchicus), mourning dove (Zenaidura macroura), and fox and gray squirrels (Sciurus niger and S. carolinensis). These species were chosen for study because various population indices were available for Illinois for the 14-year period (in some cases for 15 years, 1955-69), 1956-69, in the recent publication by Preno and Labisky (1971). The first weather factors being studied include temperature, precipitation, and snowfall. The first species being studied is the cottontail rabbit whose population indices over a 16-year span, 1955-70, are being correlated with weather parameters.

## Activities

At the beginning of the study, a literature review of the effects of weather on rabbits and other game species was conducted. Pertinent facts such as the critical periods in the life cycles of the animals when they would be most susceptible to environmental conditions were noted. Weather conditions affecting the populations of game species were accumulated. Climatological publications were reviewed to learn the weather factors recorded, the format of the data presentation, and the procedures for making weather observations. The computer facilities at the State Water Survey and the methods of storing climatological data on computer tapes and cards were examined.

The data for the game species of Illinois to be used in the study are available in Preno and Labisky (1971). These authors partitioned the state into seven contiguous geographic units, each containing several counties. These units were termed game regions (Fig. 1). Preno and Labisky (1971) based the partitioning of the state into game regions primarily on the relative distribution and abundance of the game species studied. The different game regions represent somewhat different habitats and portray differences in topography, agriculture, forestation, and climate. Within each game region, and on a statewide basis, population and harvest statistics are available for cottontail rabbits, fox and gray squirrels, bobwhite quail, ring-necked pheasants, and mourning doves.

The population statistics for the game species were collected on 73 20-mile-long game census routes geographically and ecologically distributed in the seven game regions throughout the state. Many of the 73 routes underwent either no changes or only minor changes during the entire study period. Census counts for the cottontail rabbit are available for March, June, and July of each year during the study period.

The harvest figures of the game species were based on a random sample of resident licensees who completed and returned questionnaires. The number of responses averaged 3,065 annually for the 14-year study period. Harvest values for rabbits for the game regions are reported as the mean number of cottontails killed per individual hunter trip, the total kill of cottontails shot by hunters, and the number of cottontails killed by hunters per 1,000 acres.

A meeting between climatologists and wildlife ecologists established some guidelines for the project. The cottontail rabbit was chosen as the first species to be studied because of the ample population and harvest data available and its wide distribution throughout the state. Game Region 2 was selected as the first area of study since this region is the area of primary concern for the PEP project in Illinois, and Region 2 also has the highest population of rabbits in the state. Approximately 38 percent of all rabbits killed in Illinois from 1956-69 were shot in this region (Preno and Labisky, 1971). Certain weather variables likely to affect rabbits were chosen. The number of weather stations selected for each game region was based on the land area in each region (Fig. 1). In this manner, the larger game regions have proportionally more weather stations contributing climatological data. Eight weather stations were chosen for Game Region 2. The weather stations used in the study were selected by their locations and their available data. Stations that were distributed in a pattern representative of the game regions and that measured snowfall, precipitation, and temperature were chosen. The weather data for all weather stations selected in each region will be averaged to develop mean weather values for each region. Daily weather values for each of the weather stations will be averaged into 7-day mean values for the game region. Monthly weather values will also be considered.

The meeting between the climatologists and ecologists revealed some feelings that the change in the population indices of rabbits over the 15-year study period may be due to a combination of weather, changing habitat, and the population cycles of the rabbit. Some ecologists suggested removing the effect of the changing habitat in Illinois from the declining population indices of the cottontail before correlating the population changes with weather variables. This was done in Game Region 2 by accumulating the acreage of the various types of crops, pasture, and all other land in each county of the region for each year of the study period (Illinois Department of Agriculture).

It was found that summation of the acreages of the ecologically similar crops for the previous year of all harvested hay; seed crops of grasses and legumes; silage crops of legumes, grasses, and small grains; and plowland pasture contributed 25 percent to the June census of rabbits ($\underline{R}^2$ = .246, $\underline{P}$ < .05 with 15 df). No significance was found between land use and the March census or the July census. However, the fall harvest values of the cottontails were highly correlated with the total acreages the same year of small grains; all harvested hay; silage crops of legumes, grasses, and small grains; seed crops of grasses and legumes; and total pasture—all of which have been decreasing in acreage over the interval of the study period. In Game Region 2, this composite land use factor contributed 80 percent to the mean number of cottontails killed per individual hunter trip ($\underline{R}^2$ = .796, $\underline{P}$ < .01 with 13 df), 87 percent to the number of cottontails killed per 1,000 acres ($R^2$ = .867, $P$ < .01 with 13 df), and 87 percent to the total number of rabbits killed ($R^2$ = .869, $P$ < .01 with 13 df). The most important variable in this composite land use factor was the acreage of total pasture with plowland pasture being of more value than grassland pasture. The individual factors of this composite land use variable are ecologically similar in that they provide good nest and escape cover, a food source, and an overwinter habitat. The 72.5 percent decrease in the number of rabbits killed in Game Region 2 from 1956 to 1970 parallels a 39.4 percent decrease in the total acreage of this composite land use factor over the same time span.

## Future Plans

Mean monthly weather variables for Game Region 2 are being placed on computer cards (Table 1). Monthly weather variables are being used since they are more readily available than daily weather information, which has not yet been completely compiled on computer tapes. It is possible that monthly weather values may reveal some important rabbit-climate relationships. The infrequent periods of the collection of rabbit data (March, June, July, and the fall harvest values) may make the monthly weather values more suitable for statistical analysis than the summation of daily values into weekly means. The monthly weather variables over various time intervals will be compared with the different rabbit variables by means of a stepwise multiple regression program. The actual rabbit values from Preno and Labisky (1971) will be used as well as the deviation of the actual values from those values predicted by the land-use model. The most important monthly weather variables will, therefore, be determined, and a weather model for the given game region will be formulated. It is probable that a different model for each game region will be necessary because weather factors may affect rabbits differently in each region due to the dissimilarity of habitat, soil, and climate. The remaining game regions will be analyzed in a manner identical to the procedure used for Game Region 2. The entire state will then be considered as one region. After the completion of the analysis of the rabbit data with monthly weather values, either daily weather values averaged into 7-day intervals will be used for each game region or a new game species will be investigated with the monthly weather values.

The weather factors and the population parameters to be used and the analyses to be run will, to a large degree, be determined by the results of the first analyses. Thus, weather factors that indicate little or no effect on the population indices may be eliminated from future analyses, whereas weather factors that indicate substantial effects on the population indices may be analyzed in more detail. Similarly, those combinations of weather data (weekly means, monthly means, seasonal means, and perhaps even annual means) that show the best correlations with population indices will be examined in more detail and the others may be eliminated from consideration. The population indices that show the best correlations with the weather data will be used in future analyses.

It is recognized that the various weather factors will probably affect each animal species differently and that the same species will no doubt respond differently to the same weather factor in the various seasons.

Table 1. Monthly weather variables used for analysis with game species data.

| Number | Variable |
|---|---|
| 1 | Average maximum temperature |
| 2 | Average minimum temperature |
| 3 | Average mean temperature |
| 4 | Temperature departure from normal |
| 5 | Total precipitation |
| 6 | Precipitation departure from normal |
| 7 | Number of days with precipitation ≥ 0.10 inch |
| 8 | Number of days with precipitation ≥ 0.50 inch |
| 9 | Number of days with precipitation ≥ 1.00 inch |
| 10 | Total snowfall |
| 11 | Number of days with snowcover ≥ 1.0 inch |

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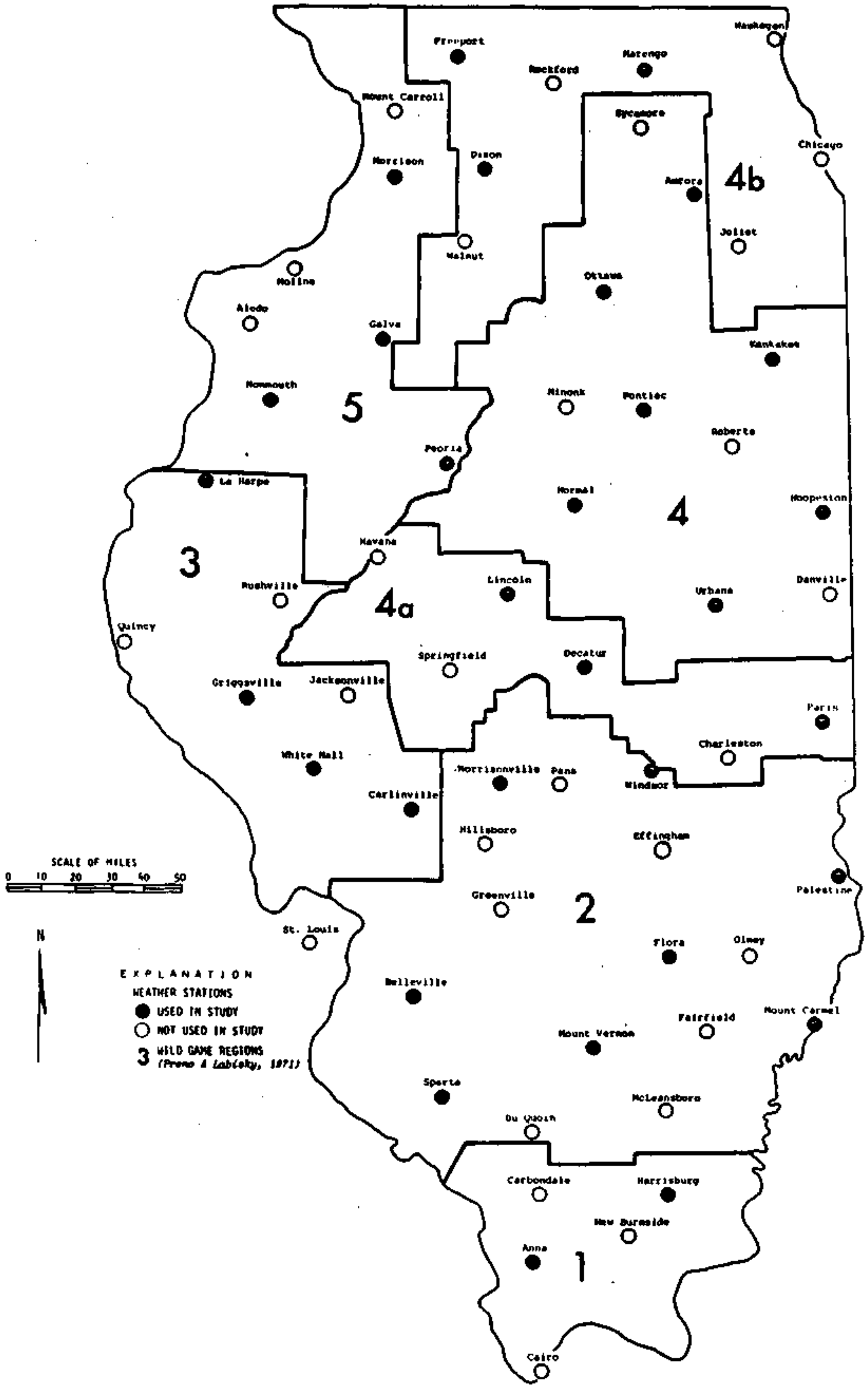


Figure 1. Game regions and selected weather stations for game species-weather analysis.

# EXTRA-AREA EFFECTS FROM SEEDING: CLIMATIC STUDIES

Paul T. Schickedanz and F. A. Huff

## Introduction

A primary concern, on both scientific and public-interest levels, is whether the alteration of precipitation in one area affects the precipitation in other off-target areas. This question is being investigated through use of both climatological data and techniques and mesoscale numerical modeling. The climatic investigations were begun in this 10-month period, and these will be coupled with modeling work in the latter years of Phase I.

There are three phases in the climatic studies, and two were begun during the 10-month report period. The 3 phases include 1) a study of the natural distribution of bands and centers of relatively high and low precipitation in an area within a 250 mile radius of Salem, Illinois; 2) investigations of the persistence and spatial distribution of high and low centers of natural precipitation downwind from where rainfall had been inadvertently modified by major urban-industrial centers, including an evaluation of whether the inadvertent precipitation modification has affected crop yields and surface water augmentation (runoff); and 3) investigation of potential increases in summer rainfall associated with widespread increases in irrigation in the Great Plains during the past 35 years. Extensive efforts were made on Phases I and II.

## Analyses and Results

In Phase I of the climatic studies, the monthly and summer rainfall for the months June-August are being investigated. These data have been plotted on base maps of the available precipitation reporting stations in an area of 250 mile radius of Salem, Illinois. Isohyetals have been constructed on each monthly map and the data reduced to points on a 20 x 20 mile grid. These data were entered on punch cards, and this processing step has permitted greater flexibility and versatility in the various analyses.

One of the basic analyses that has been performed is a linear trend surface analysis for the study area. This analysis consists of fitting a plane to the isohyetal rainfall patterns for the PEP study area and investigating the residuals from the surface of the plane. The linear trend surface analysis is nearly complete for all summer months and summer seasons during the period 1950-1969. In addition, trend surface analyses are being performed for 5-year rainfall patterns by month and season for the periods 1950-54, 1955-59, 1960-64, and 1965-69. The interpretation, formulation of hypotheses, and determination and description of frequency distributions of residuals (precipitation highs and lows) in time and space continues.

An important aspect of the frequency distribution of highs and lows is their areal distribution over the study area. For example, is there a uniform spacing of highs or lows along lines, or do they appear to occur at random, independent of the highs surrounding them? The presence of a uniform spacing might be the result of a natural pulsation in the amplitude of the overall precipitation associated with squall line movement. Such pulsations have been noted by Elliot (1971) and Newton and Newton (1959). It is of interest to determine whether these pulsations occur systematically enough from storm to storm in a given locale so as to be evident in monthly and seasonal precipitation patterns. Some of the preliminary results from the climatic studies would suggest that pulsations are evident in monthly and seasonal data.

Figures 1, 2, and 3 show the distribution of highs over the study area for the 5-year periods of 1955-59, 1960-64, and 1965-69. Only those highs which have an areal extent $\leq 800\ mi^2$ were included on these figures. Visual inspection of the figures indicates that the highs are oriented along various E-W lines. In order to test for randomness in the distribution of these highs, as opposed to uniformity of highs, the near-neighbor statistic was applied. Near-neighbor analysis indicates the degree to which an observed distribution of points (highs) deviate from what might be expected if those points were distributed in random manner within the same area. The mean of the distances from each high to its nearest neighbor provides the basis for the near-neighbor statistic, which is the ratio of the mean observed distance to the mean distance expected under random conditions. The application of this statistic indicated that the probability of obtaining a test statistic as large as those calculated was less than .01 for all three cases. Thus, all three distributions clearly depart from random expectation so far as nearest neighbor is concerned. Although causes for the non-randomness are still being investigated, it is clear that the positioning of the target area in a fortuitious place (such as Salem) would give the appearance of downwind highs due to a dynamic effect created by seeding in the target.

If an extra-area effect exists, it may very well be due to redistribution of the precipitation over an area, rather than a large scale increase in the overall rainfall. If this is true, then it is reasonable to assume that precipitation highs and lows will have a tendency to occur naturally in pairs. That is, a high in the precipitation pattern will tend to be compensated by a low in the immediate vicinity, or vice versa. Some of the preliminary results from the climatic studies would suggest that highs and lows tend to appear in pairs. For example, figure 4 shows the distribution of highs and lows on the same map for the 1955-59 period. There is a distinct tendency for the highs and lows to be grouped. If such a grouping of highs and lows occurs naturally, then it is also likely that lows may be created in the immediate area of seeding-produced highs or vice versa. Analyses similar to these are being performed for individual months and seasons.

Another interesting feature of the figures is that although there is uniform spacing of highs in certain regions of the study area, the positioning of the highs tends to vary over the area. Some notable exceptions to this is the St. Louis high which persists through all three of the 5-year periods, Kansas City high which appears in 2 of the three 5-year periods, and the Memphis high which appears in 2 of the three 5-year periods.

In phase 2 of the climatic studies, the mean areal precipitation in various sampling areas (see Monthly Report for August), near and downwind of St. Louis and Kansas City is being determined. The purpose of these analyses is to compare the areal means in the various sampling areas to check for differences according to distance and placement downwind of these cities. Because this work was initiated during July, 1972, it will not be reported on at this time.

## Plans for FY-73

The plans for FY-73 include the continuation of the summarizing and interpreting of the results from the frequency distributions of highs and lows. This will include summaries and descriptions according to spacing, time persistence, etc. The averaging by sampling areas will also be continued, and these results will be summarized. In addition an investigation of possible downwind effects on a daily and storm basis will be performed in the St. Louis area. Current plans call for the completion of the analyses, and the publication of a technical report for Phase I by the end of FY-73 (June 1973). The third climatic study (irrigation effects) will be initiated during January 1973.

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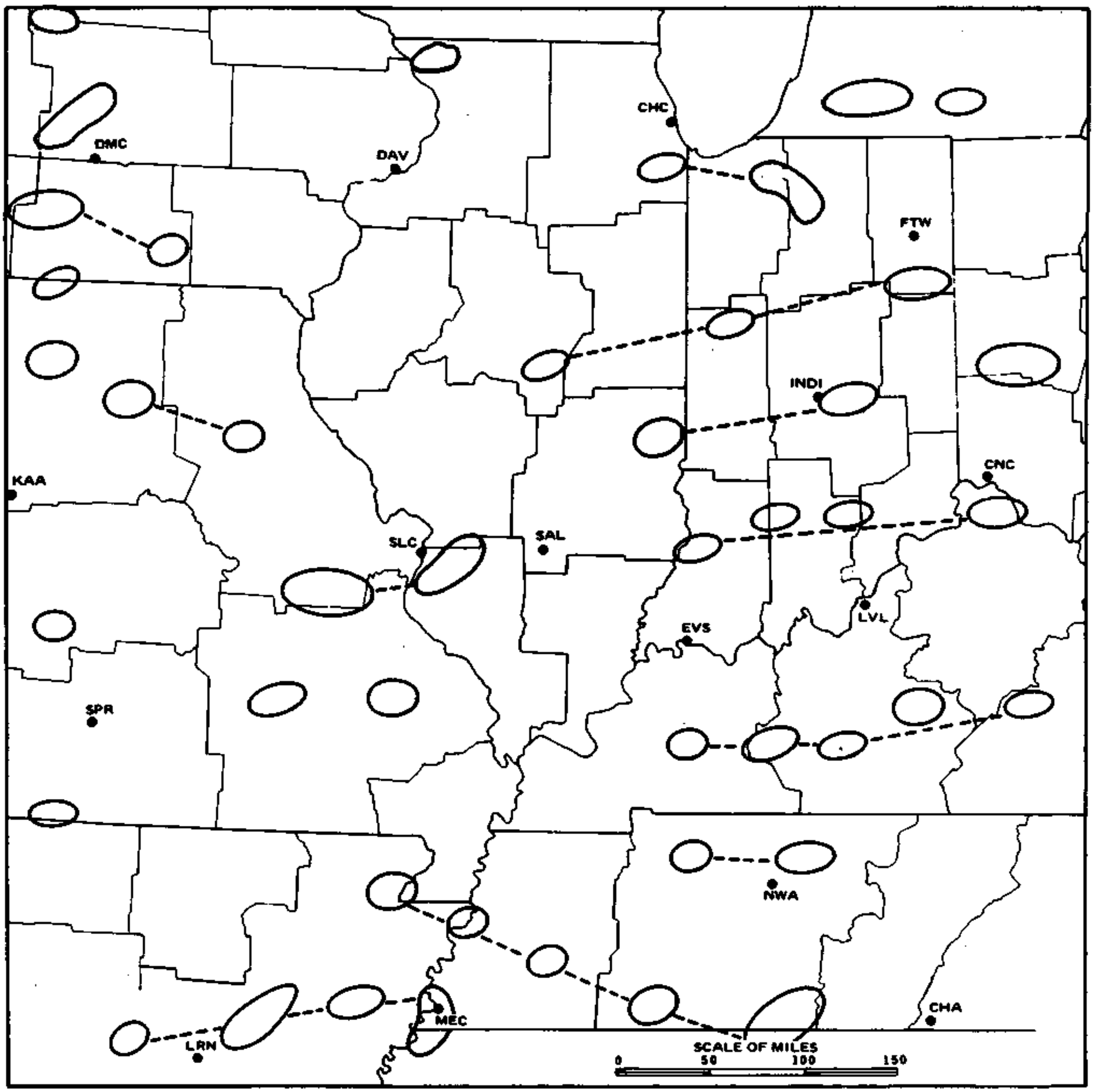


Fig. 1. Isolated precipitation highs from 5-year summer seasonal average pattern 1955-59.

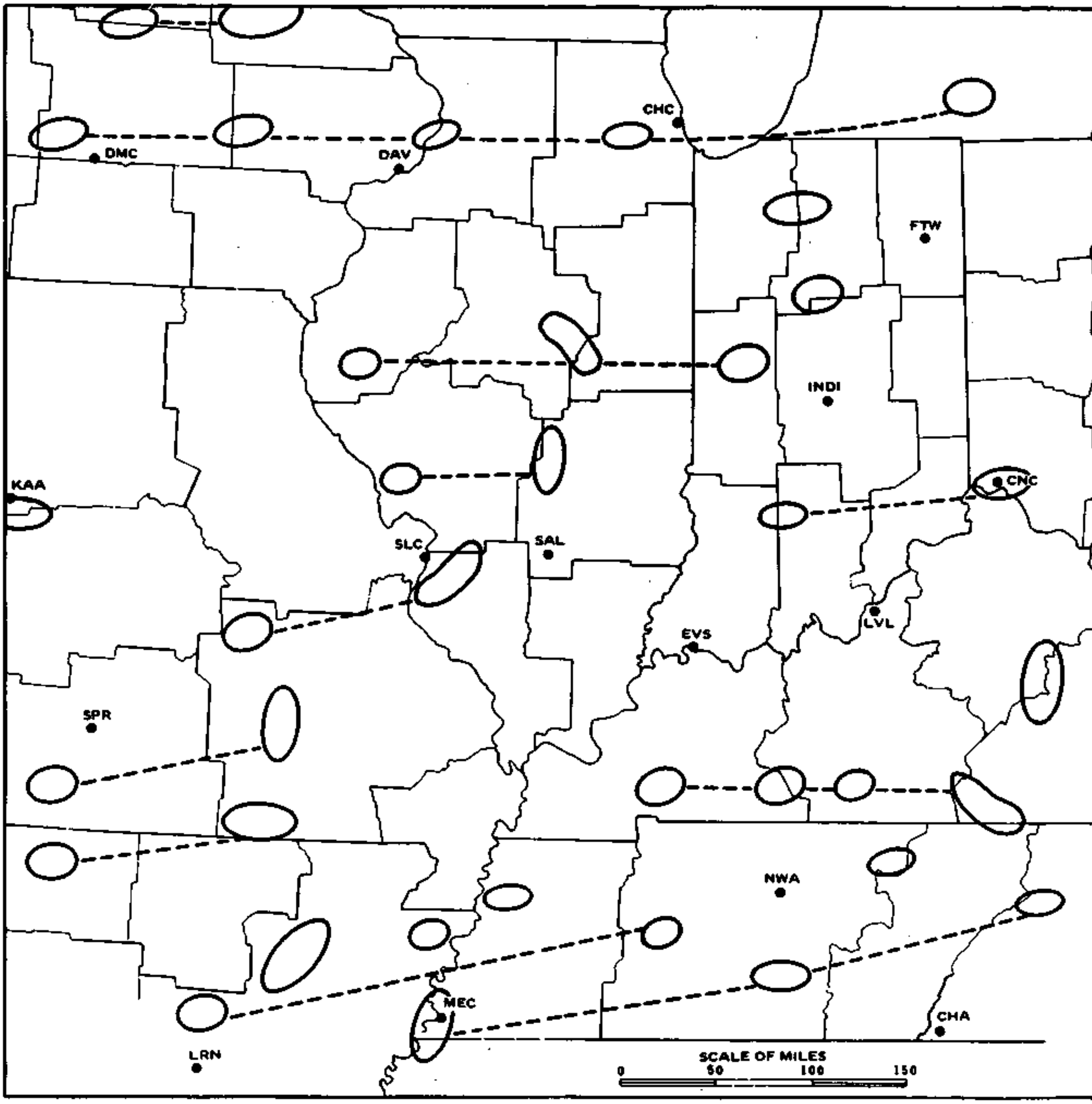


Fig. 2. Isolated precipitation highs from 5-year summer seasonal average pattern, 1960-64.

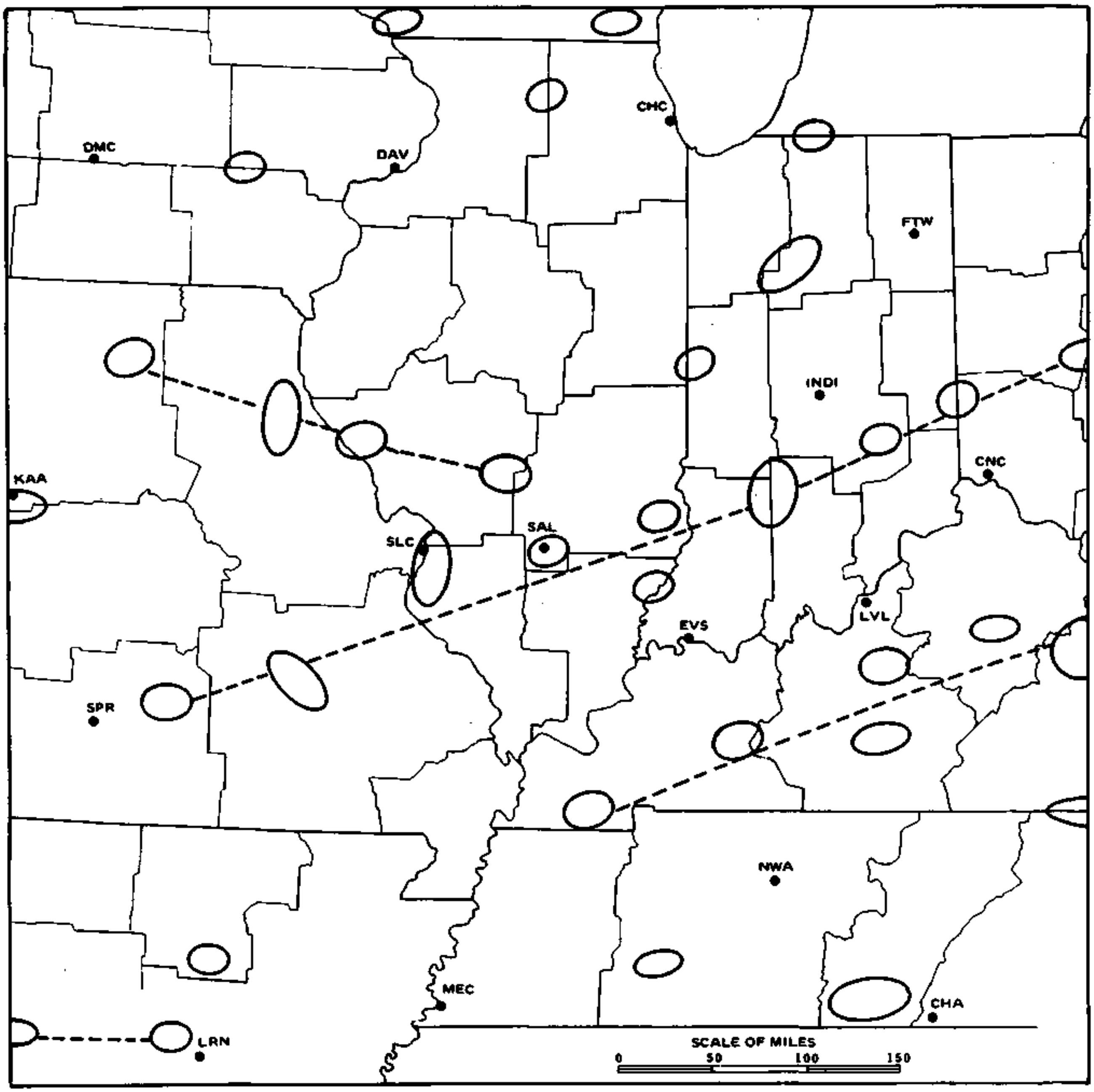


Fig. 3. Isolated precipitation highs from 5-year summer seasonal average pattern, 1965-69.

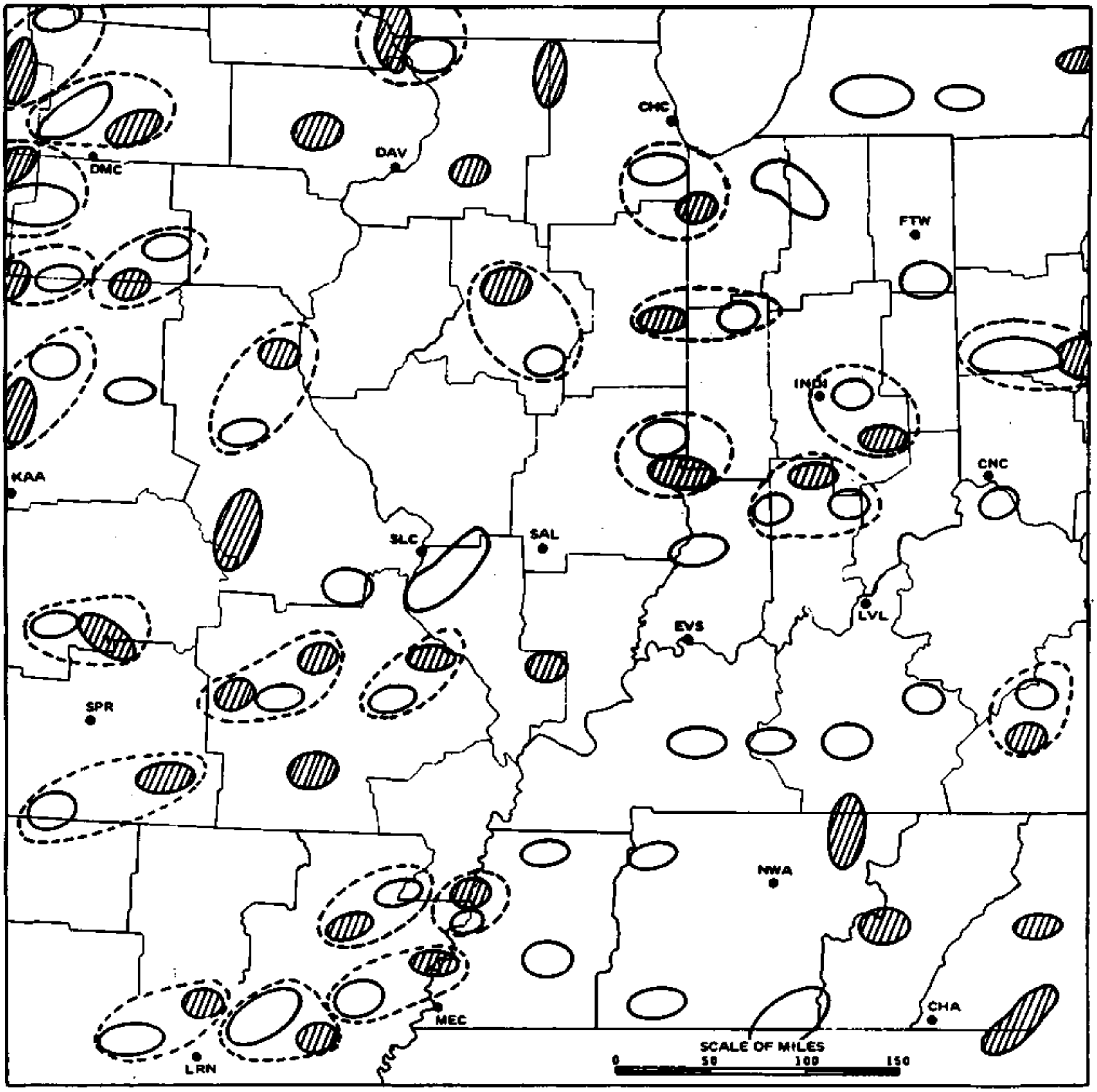


Fig. 4. Isolated precipitation highs and lows from the 5-year summer seasonal average pattern, 1955-59.

# ATMOSPHERIC SAMPLING PROGRAM

Richard G. Semonin

## Activities

Although the original schedule did not incorporate much effort during the first fiscal year, considerable time was devoted to the atmospheric sampling project. The first two months were consumed in the search for a qualified instruments engineer to undertake the responsibility of conceiving, acquiring, installing, and maintaining the aircraft instrument package. Simultaneously, with the pursuit of personnel, discussions were initiated with the University of Illinois Institute of Aviation concerning their interests and capabilities in supporting such a research aircraft within their flight facility.

With the encouragement of the Division of Atmospheric Water Resources Management, (AWRM) the concept of instrumenting an aircraft for use by other contractors when not active in Illinois was investigated. After rather lengthy discussions, this approach was rejected due to: 1) the additional demands placed on the aircraft to fulfill all AWRM requirements; and 2) the lack of desire on the part of the University of Illinois to become a leasee of research aircraft. The first of these reasons resulted in prohibitive costs and the second reason, of course, is in keeping with the function of the University to provide education and not operational facilities to private and public institutions.

Midway during the reporting period, the decision was reached to contract the flight program to another institute or to the private sector with the option of providing the instrumentation from this contract. The guiding principal for this approach is to design modular instrument packages which can be readily transferred to other airframes.

Contact was established with other operators of aircraft suitable for cloud physics measurements for the purpose of seeking advice on the acquisition of instrument hardware. Visits to each of the institutes were planned early in the next reporting period for on-site inspection of the aircraft facilities. Three institutes were approached to sub-contract the sampling program, but each was reluctant to become collectors of scientific data for another group. The reluctance of these institutes is understandable since the aircraft facility is used for scientific inquiry by their own investigators.

An engineer was employed on this contract during the latter half of the reporting period. He has subsequently established himself as more than qualified to undertake the difficult tasks that lie ahead.

The aircraft data gathering system is composed of three separate and distinct electrical sub-systems. These each present their own unique problems to the engineer. The three are as follows: 1) the instrument sensor system; 2) the data acquisition, processor, and recording system; and 3) the power supply system.

The requirements of the research and sampling program dictate the essential meteorological variables which must be measured. The sensor system includes the air navigational equipment as well as measurements of the aircraft performance. A brief list of the variables pertinent to the cloud sampling program are 1) the aircraft position (in three dimensions as a function of time), 2) temperature, 3) moisture, 4) ice particle and cloud droplet concentrations, 5) ice and cloud nuclei concentrations, and 6) cloud liquid water content. Additional measurements will be deduced from the basic data set with varying degrees of accuracy. For example, the updraft speed and areal extent will be determined by recording the rate-of-climb and air speed.

Some of the basic sensors are available to this contract from previous flight programs conducted by the Survey. Prices for the remaining instruments have been solicited and their acquisition will be completed during FY-73.

The final data recording requirements are basically a function of the number of channels or tracks of information and the bandwidth or sample rate for each track. The recording capability for each parameter listed above was tabulated to determine the baseline requirement for any available recording system.

Since most of the parameters measured are ultimately derived from an electrical voltage or current, magnetic tape is clearly the most straight-forward storage medium for the system. Many commerical multi-track instrument quality recorders (both analog and digital) could fulfill the measurement system recording requirements. Unfortunately, the environmental restrictions imposed by aircraft installations severely limits the family of suitable devices. However, adequate aircraft qualified recorders are available to provide the necessary capabilities.

The entire question of direct analog recording versus digital recording on computer compatable tape is receiving careful attention. Basically the problem centers on the availability of ground-based data processing facilities. Analog recording of data requires a considerable amount of hardware to convert the signals to usable form. In contrast to this approach, the availability of compact, rugged digital recorders, along with the commonly available computers, offers many practical advantages over direct recording techniques.

A work plan was developed during FY-72 and submitted for approval. The aircraft sampling program was further developed and justified in an internal report to AWRM entitled "Precipitation Management in Illinois: An Initial Review". The specific problems confronting the development of a planned precipitation enhancement program in Illinois were detailed in this report and in discussions with AWRM personnel. General agreement was reached on the work plan and the effort to implement the sampling program accelerated tremendously at the end of this report period.

The original proposed research contained a separate task on the use of radar for the Precipitation Enhancement Program in Illinois. However, this effort was deleted from the final contract and consequently, the support of a radar facility to the aircraft sampling program was inadvertently lost.

The needs for reinstatement of some radar effort are extreme. The aircraft measurements only provide one tool to delineate the characteristics of precipitation systems whereas the radar extends the possible interpretation of aircraft measurements to a more extensive volume of the atmosphere. In addition, radar is a more accessible tool for field seeding operations than a sophisticated aircraft facility. Hence, interpretive relationships between aircraft measurements and radar observations must be developed. Most importantly, the radar is a necessity for the guidance of the aircraft to suitable storms for sampling purposes and for avoidance of singularly severe storms.

This aspect of the atmospheric sampling program has been discussed with AWRM personnel.. While the necessity for this adjunct to the program is undeniable, the exact method of fulfilling the need was not resolved. Various avenues were explored such as acquiring surplus equipment or using existing radar facilities. Both of these approaches will be examined, but the final decision will rest upon the most desirable and economical means of supplementing the aircraft program without endangering the satisfactory completion of this important task.

## Planned Activities

The aircraft instrument engineer will visit the University of Washington, University of Wyoming, University of Colorado, and NCAR to discuss hardware availability and enlist material assistance in the design of our meteorological package. These visits will take place in the first quarter of FY-73.

Simultaneously with the above, letters of inquiry will be sent to all prospective bidders of aircraft services. Following the receipt of the replies, and decisions regarding the specific instrumentation requirements, requests for prices will be transmitted to those firms having a demonstrable capability to fulfill the needs of the contract. The aircraft and meteorological equipment will be negotiated and acquired by the end of the second quarter of FY-73. The flight program will be initiated during the third or fourth quarter of the next reporting period.

The AWRM will attempt to provide a surplus radar system for use on the contract. The surplus ground-based radar system will be acquired and tested prior to implementation in the field. Some reduction in the total aircraft operations is anticipated to fill the budgetary requirements necessitated by the radar operations. Alternatives to radar operations specifically for the aircraft sampling program will be considered. For example, excellent radar coverage is available in the St. Louis area and in Champaign in conjunction with other Survey research efforts. The aircraft operations could be carried out within areas covered by one of the existing radar facilities as a means to expedite the program and conserve money.

## Personnel

R. G. Semonin has devoted 5% effort to this phase of the contract during the report period. T. Flach (M.S.E.E.) was employed as the aircraft instrument engineer and has devoted 100% effort in this endeavor since 1 February.

# MODELING STUDIES

Harry T. Ochs and Richard G. Semonin

## Introduction

To fulfill the modeling requirements of Phase I of PEP, both diagnostic and prognostic numerical models are envisioned. These models will also be required in the second phase of PEP. An extensive developmental effort is required to adapt current numerical techniques and existing models to accurately depict Illinois atmospheric conditions.

The models to be developed in Phase I of PEP have three major applications. The first concerns the development of a seeding climatology for the Midwest. A relatively uncomplicated one-dimensional steady-state cumulus cloud model is being adapted for use with Midwest radiosonde soundings for this study. The model was supplied by J. H. Hirsch at the South Dakota School of Mines and Technology.

The second application concerns the development of both prognostic and diagnostic models for use in Phase II. The models which are being developed to fulfill specific requirements in Phase I will form the basis for the operational models required by Phase II. As results of Phase I indicate the modeling requirements for Phase II other current operational models may have to be adopted for use in Illinois.

The main thrust of the modeling work performed in the first year of Phase I concerns the third modeling application. The initial phases in the development of a sophisticated two-dimensional time dependent cumulus cloud model for use in the extra-study area are near completion. If advances in computer technology, speed and size allow expansion of this model to sufficient dimensions to encompass two clouds then one can be seeded and the effect on the other can be observed. This effect can then be parameterized in a larger scale model to depict the extend of the extra area effect of cloud seeding. It will begin in FY-73.

## Activities

Initial two-dimensional cloud model. After an extensive literature search and a detailed theoretical development an initial set of equations were chosen for use in a 2-dimensional time dependent cumulus cloud model. These equations were similar to those used by Orville (1965). One major difference was that the a vorticity equation suitable for use with deep atmospheric convection was adopted (Takeda, 1969, 1971). Takeda (1969, 1971) suggests the simplifying approximation of neglecting the perturbation pressure and this approximation is adopted here.

The variables (which are all defined at the end of the section) are expressed as the sum of a reference value and a perturbation from the reference.

Thus, the temperature would be expressed as

$$T = T_o + T' \tag{1}$$

where T is the temperature, $T_o$ the reference temperature and T' the perturbation temperature.

The following equations formulating convection in the x-z plain were those used for the initial simple atmospheric model. The continuity equation is

$$\frac{\partial \rho_o u}{\partial x} + \frac{\partial \rho_o w}{\partial z} = 0 \ , \tag{2}$$

which allows a stream function to be defined as follows:

$$\rho_o u = \frac{\partial \psi}{\partial z} \ , \ \rho_o w = - \frac{\partial \psi}{\partial x} \ . \tag{3}$$

The components of the Navier-Stokes equation may be multiplied by $p_o$, cross differentiated, and subtracted which yields an equation for the vorticity.

$$\begin{aligned} \frac{\partial \eta}{\partial t} = & - u\frac{\partial \eta}{\partial x} - w\frac{\partial \eta}{\partial z} + \frac{2w}{\rho_o}[\eta - u\frac{\partial \rho_o}{\partial z}]\frac{\partial \rho_o}{\partial z} + wu\frac{\partial^2 \rho_o}{\partial z^2} \\ & + \rho_o g\frac{\partial \ell}{\partial x} - \rho_o F\frac{\partial r'}{\partial x} - \rho_o g\frac{\partial}{\partial x}\frac{\theta'}{\theta_o} + K\nabla^2 \eta \end{aligned} \tag{4}$$

where

$$\eta = \frac{\partial \rho_o u}{\partial z} - \frac{\partial \rho_o w}{\partial x} \tag{5}$$

and

$$\eta = \nabla^2 \psi \ . \tag{6}$$

The thermodynamic energy equation is a description of the diffusion of the variable ø which is related to the entropy.

$$\frac{\partial \phi'}{\partial t} = - u\frac{\partial \phi'}{\partial x} - w\frac{\partial \phi'}{\partial z} + K\nabla^2 \phi' \tag{7}$$

where

$$\phi' = \frac{\theta'}{\Theta_o} + \frac{L\, r}{c_p\, T_{oo}} \qquad \textbf{(unsaturated)} \tag{8}$$

and

$$\phi' = \frac{\theta'}{\Theta_o} + \frac{L\, r_s}{c_p\, T_{oo}} \qquad \textbf{(saturated).} \tag{9}$$

The definition of potential temperature and saturation mixing ratio are

$$\theta = T\ (\ \frac{P}{p}\ )^{\kappa} \tag{10}$$

and

$$r_s = \frac{R\ e_s\ (\ T_o\ )}{R_v\ P_o} \exp\ (\ \frac{LT'}{R_v\ T_o{}^2}\ ) \tag{11}$$

where

$$e_s\ (\ T_o\ ) = 6.11 \times 10^{7.5\ (\ T_o\ -\ 273\ )\ /\ (\ T_o\ -\ 36\ )} \tag{12}$$

and

$$T_o = T_{oo} - \frac{gz}{c_p}\ . \tag{13}$$

All that remains is equations governing the interaction of cloud water and water vapor with the system. These are

$$\frac{\partial q}{\partial t} = -\ u\frac{\partial q}{\partial x} - w\frac{\partial q}{\partial z} + K\nabla^2 q \tag{14}$$

where

$$q = r + \ell\ . \tag{15}$$

Note that the eddy diffusion coefficients have been assumed to be constant and equal for all of the diffusion processes.

Initially these equations were integrated on a grid which was 33 points in the horizontal and vertical directions with a 100 meter grid spacing. The equations were written in their finite difference form using upstream differencing for the advection terms and forward time differencing.

Boundary conditions similar to those used by Orville (1965) were chosen. The horizontal derivative of the string function was set to zero at both vertical sides and was held constant at the top and bottom. Initially the horizontal derivative of all atmospheric parameters was zero and the vertical distribution of water vapor, horizontal wind and potential temperature were specified.

Heating and evaporation at the ground was initiated at the beginning of each run using Orville's (1965) time dependent functions. The first grid points are 10 meters above the surface and the wind is constrained to be horizontal at this location. When equations 7 and 14 are applied at these grid points the result is the mixing of the thermodynamic variable ø and q, the total water content, to these lowest grid points. In order to specify the location where convection first occurs, heating and evaporation proceed at a slightly faster rate in an area 7 grid points wide at the middle of the lower surface.

At each grid point during computation for a new time step the water vapor content is compared with the saturation mixing ratio calculated from the equation 11. If excess water vapor is present it is condensed to cloud water and latent heat is released. On the other hand, if there is a deficiency of water vapor then any cloud water present is evaporated to maintain saturation. As can be seen in equation 11 the saturation mixing ratio is a function of the perturbation temperature. This effect is accounted for whenever condensation or evaporation occurs.

Poisson's equation (equation 6) is solved at each time step using a sub-routine supplied by the NCAR computing facility which obtains a direct solution.

Figures 1 through 16 show the results of this initial attempt. Figures 1 through 4 indicate the condition of the atmosphere 10 minutes after the initiation of heating and evaporation. Very little change from the initial conditions has occurred by this time. In each figure one division on the boundary indicates 100 meters.

Figure 1 indicates the deviation of the potential temperature from a constant value of 296°, which is the initial temperature at the ground. The initial potential temperature distribution increases 2.8°C per kilometer to the top of the grid. Thus, the atmosphere is stable unless heating occurs at the ground. Figure 2 indicates the water vapor content which was initially 12 grams per kilogram at the ground and decreased 2 grams per kilometer to the top of the grid. Figure 3 is the stream function and indicates that the wind is almost totally horizontal. The initial wind profile begun at 0 at the ground and increased linearly to 1 meter per second from left to right at the top of the grid. Figure 4 is the distribution of vertical velocity and indicates the effects of the increased heating and evaporation at the center of the grid. At this point the maximum vertical velocity is 1.2 cm per second.

Figures 5 through 8 indicate the condition of the atmosphere after 100 minutes into the run. The stream function and vertical velocity distribution show the strong area of updraft in the lower center of the grid. The peak vertical velocity at this time, which is shortly before the initial condensation occurs is 2.6 meters per second.

Figures 9 through 13 shows the condition of the atmosphere at 120 minutes since the initiation of heating at the ground. The initial condensation occurred at 109 minutes into the run. Figure 9 shows the warm center developed by the release of the latent heat in the cloud. Figures 11 and 12 indicate the continuing development and intensification of the updraft whose maximum speed is 3.2 meters per second. Figure 13 shows the cloud water content 11 minutes from the initial condensation, the maximum cloud water content is about 0.38 grams per kilogram.

Figures 14 through 16 show the cloud water content pattern at 16 minutes, 21 minutes and 24 seconds, and 23 minutes and 24 seconds since the initial condensation.

Changes and the current model. A number of problems became evident as a result of these initial runs. The strange shape of the cloud in Figure 16 is probably due to the explosive initial atmosphere chosen for this run. However, a more serious problem was noticed in the vicinity of the lower boundary. The manner in which the lower grid point was treated implied that the latent heat for the evaporation of the water vapor at the ground was supplied by the air rather than the soil. The problem could be eliminated by mixing just potential temperature at the lowest grid point (10 meters above the ground) but this solution would mean applying a different equation to these grid points than that used for the rest of the points. Rather than take this approach the thermodynamic equation was changed.

A formulation similar to that used by Takeda (1969) was chosen for the new thermodynamics. Thus, equations 7, 8, 9, and 10 along with equations 15 and 16 were replaced by the following three equations.

The thermodynamic equation is

$$\frac{\partial}{\partial t}\frac{T'}{T_o} = -u\frac{\partial}{\partial x}\frac{T'}{T_o} - w\frac{\partial}{\partial z}\frac{T'}{T_o} - \frac{w}{T_o}\left(\frac{\partial T_o}{\partial z} + \frac{g}{c_p}\right) + \nabla\cdot K_T \nabla \frac{T'}{T_o} \tag{16}$$

The equation describing mixing and advection of water vapor is

$$\frac{\partial r}{\partial t} = - u\frac{\partial r}{\partial x} - w\frac{\partial r}{\partial z} + \nabla \cdot K_r \nabla r \tag{17}$$

The equation for the cloud water content is

$$\frac{\partial \ell}{\partial t} = - u\frac{\partial \ell}{\partial x} - w\frac{\partial \ell}{\partial z} + \nabla \cdot K_\ell \nabla \ell \tag{18}$$

Equations 12 and 13 were also replaced by a more accurate impartible formula for the saturation vapor pressure.

Some further improvements in the model have been made. Orville (1970) indicates that upstream differences with its large implicit diffusion is inadequate for describing variables which should not diffuse such as falling rainwater. Therefore, in anticipation of this problem Arakawa space differencing (Arakawa, 1963) was adopted for the advection terms. In order to achieve a more accurate time integration Adams-Bashforth time differencing was incorporated into the model. The boundary conditions and heating and evaporation at the ground remain unchanged.

The eddy diffusion terms in equations 16 through 18 are written for a variable eddy viscosity. A non-linear time dependent eddy viscosity was incorporated in a manner given by Deardorff (1971). Thus, the diffusion term in equation 4 is replaced by $V \cdot k_m V_n$. The form for $k_m$ is

$$K_m = (cH)^2 \left[2\left(\frac{\partial u}{\partial x}\right)^2 + 2\left(\frac{\partial w}{\partial z}\right)^2 + \left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x}\right)^2\right]^{1/2} \tag{19}$$

The value of c being currently used is .21 and $K_T$, $K_r$, and $K_\ell$ is three times $K_m$.

The results of these changes are indicated in Figures 17 through 38. These figures also show, in a qualitative manner, the effects of the boundaries on the development of the clouds. Identical initial conditions and heating functions at the ground were used in each run, however, the second set of figures shows the results of doubling the horizontal dimension. In each run water vapor content is 12 grams per kilometer at the ground and decreases linearly to 5 gm/km at the top of the grid. The temperature is 23°C at the ground and decreases linearly to 16.3°C at 910 meters and then to 1.5°C at the top of the grid. The initial horizontal wind increases linearly from zero at the ground to 1 meter/sec at the top of the grid.

Figures 17 through 33 depict the development of small cumulus clouds using the latest improvements in the model. The grid size for this run was 33 points in horizontal and in the vertical. The grid marks on the perimeter of the figures are at 100 meter intervals.

Figures 17 through 20 show the condition of the atmosphere at 85 minutes and 54 seconds into the run, which is 3 minutes before condensation occurred. Figure 17 shows the deviation in the temperature from the initial atmosphere. The area of negative temperature deviation, which is centered at about 800 meters above the surface, results from warm air raising and cooling due to adiabatic expansion. Since the air has momentum it rises beyond its equilibrium position cools further. The maximum vertical velocity at this time is about 4.9 meter/sec.

Figures 21 through 25 show the condition of the atmosphere 17 minutes and 54 seconds after the initial condensation. Figure 21 shows the beginnings of a warm core developing in the cloud. This core is located at a height of about 1100 meters. Figure 25 shows the cloud water content at this stage of development. The contours are spaced logarithmically with a minimum contour at .1 gm/kg. This contour is labeled 100. A contour labeled 200 would indicate 1.0 gm/kg. Figure 26 shows the development of the cloud after 26 minutes and 54 seconds.

Figures 27 and 28 shows the vertical velocity and cloud water content at 31 minutes and 54 seconds. Note that a new thermal has been released from the ground and results in the left-hand portion of the cloud while the larger right-hand portion has very little remaining vertical velocity associated with it. Figures 29 and 30 show the same contours 2 minutes later. The left-hand portion of the cloud is being fed by a strong updraft whose maximum value is about 6.7 meters/sec, while the right-hand portion is now in downdraft. Figures 31 and 32 show the decline of the initial cloud and the growth of the second cloud. Figure 32 shows the second cloud at its point of maximum development while Figure 33 shows the second cloud after it too has begun to decay.

Figures 34 through 38 show the development of the cloud water content for the model run with a grid that is 33 points in the vertical and 65 points in the horizontal. The initial conditions were identical to those in the previous run. When this run is compaired to the previous series of figures the effect of the presents of vertical boundarys in the modeled atmosphere may be assessed. Since the initial convection develops in an area which is relatively small compared with the dimensions of either grid, the boundaries have little effect on the time to the onset of initial condensation. However, as the cloud developes and encompasses a larger percentage of the grid, differences between the two runs become apparent. Figure 38 shows the cloud water content after 63 minutes and 12 seconds. It has not yet reached its point of maximum development.

List of Symbols

$c_p$: specific heat of air at constant pressure

$E$: $1 - \frac{1}{m} = 0.608$

$e_s(T_o)$: saturation vapor pressure

$g$: acceleration of gravity

$H$: grid spacing (100 meters)

$K$: constant eddy diffusion coefficient

$K_\ell$: eddy diffusion coefficient for cloud water content

$K_m$: eddy diffusion coefficient for vorticity

$K_r$: eddy diffusion coefficient for water vapor

$K_T$: eddy diffusion coefficient for temperature

$L$: latent heat of condensation

$\ell$: cloud water content

$m$: ratio of the molecular weight of water and dry air

$P_o$: reference pressure of atmosphere

$R$: specific gas constant for dry air

$R_v$: specific gas constant for water vapor

$r$: water vapor content (mixing ratio)

$r_s$: saturated water vapor content

$T$: temperature

$T_o$: temperature stratification of reference atmosphere

$T_{oo}$: temperature at ground level

$u$: horizontal velocity

$w$: vertical velocity

$\eta$: y-component of vorticity

$\theta$: potential temperature

$\Theta_o$: reference potential temperature of adiabatic atmosphere

$\kappa$: $R/c_p$

$\rho_o$: density of initial atmosphere

$\phi$: thermodynamic variable (entropy divided by $c_p$)

$\psi$: stream function

$()'$: deviation of the quantity ()

$\nabla^2$: two dimensional Laplacian

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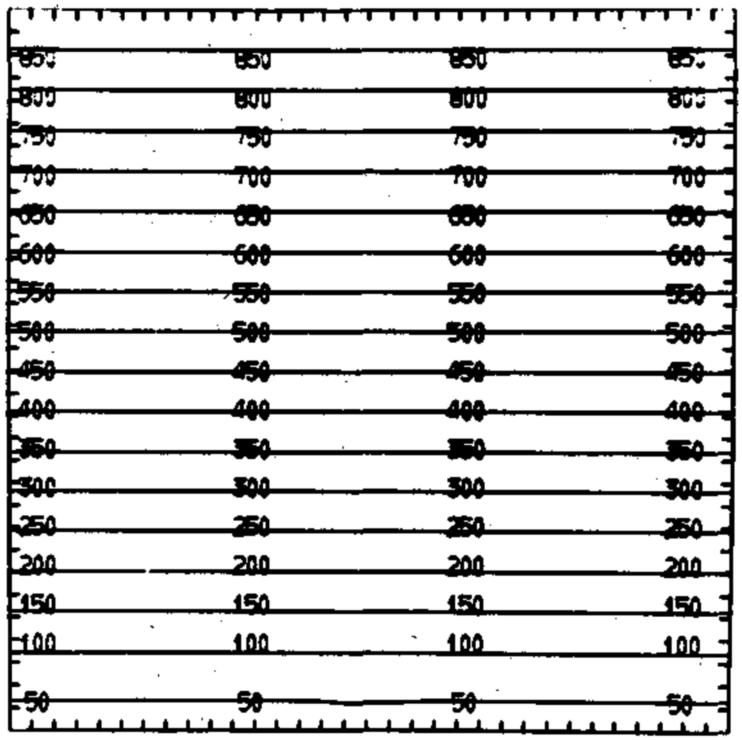


Figure 1. Potential temperature deviation in degrees centigrade scaled by $10^2$.
Atmosphere time = 10 min.

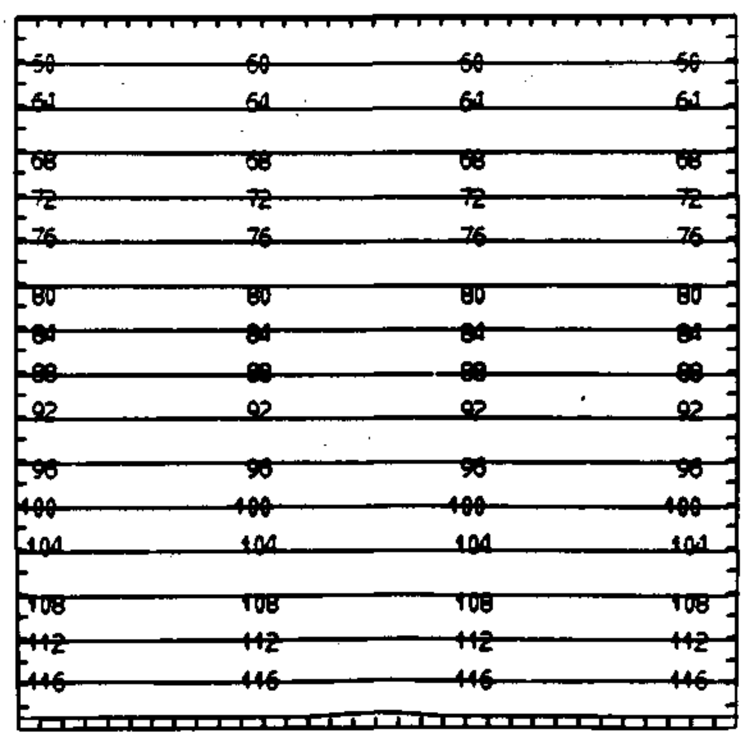


Figure 2. Water vapor content in grams per kilogram scaled by 10.
Atmosphere time = 10 min.

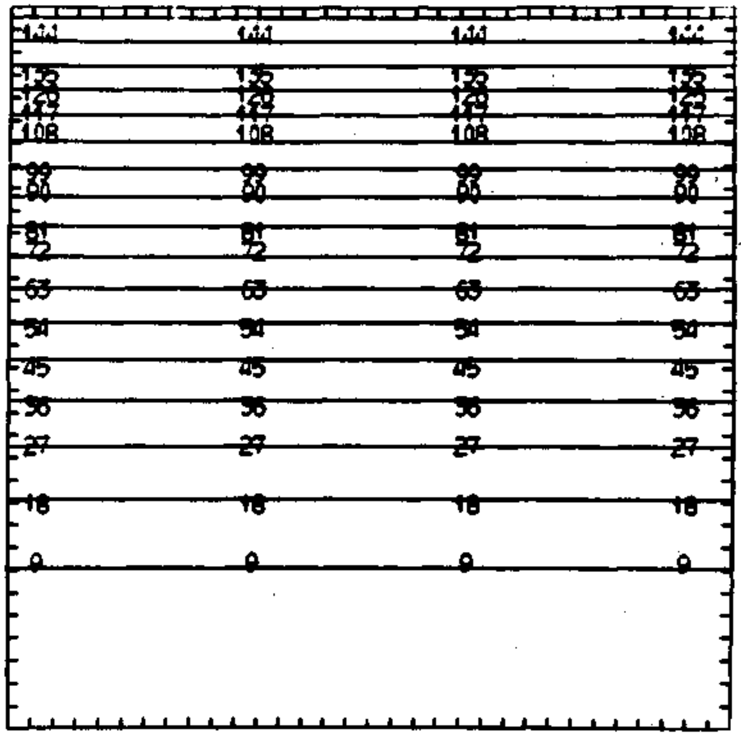


Figure 3. Stream function in kilograms per meter second scaled by $10^{-1}$.
Atmosphere time = 10 min.

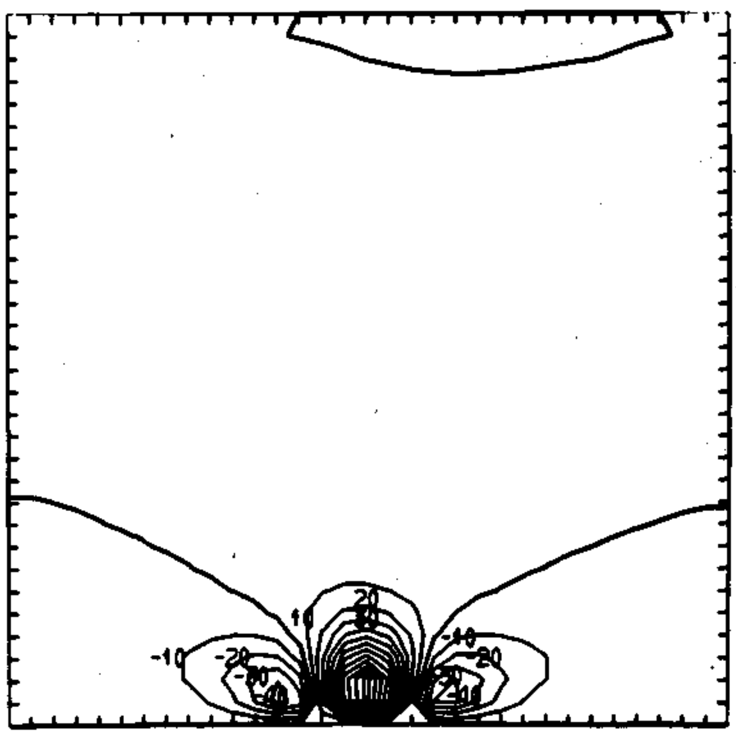


Figure 4. Vertical velocity in meters per second scaled by. $10^{4}$.
Atmosphere time = 10 min.

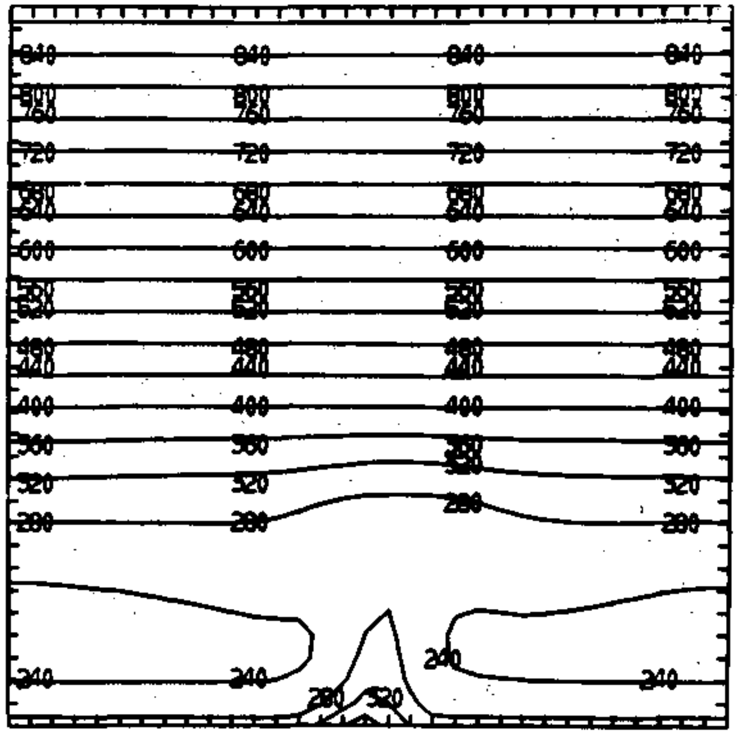

Figure 5. Potential temperature deviation in degrees centigrade scaled by 10. Atmosphere time =100 min.

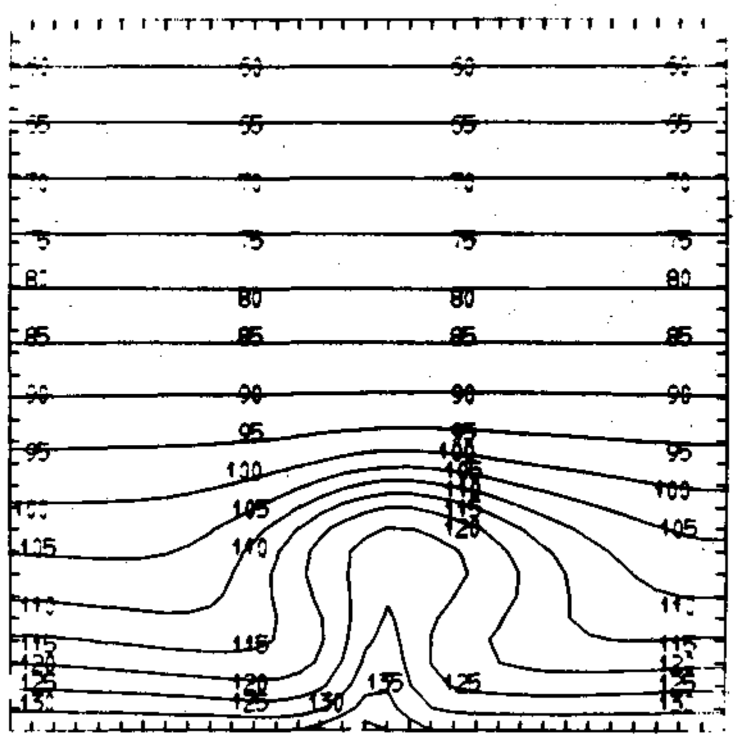

Figure 6. Water vapor content in grams per kilogram scaled by 10. Atmosphere time = 100 min.

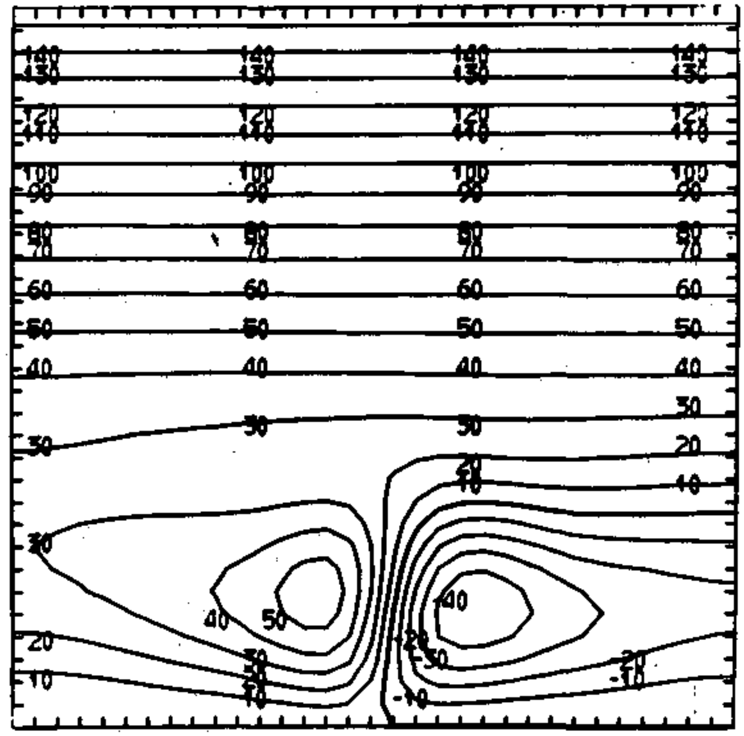


Figure 7. Stream function in kilograms per meter second scaled by $10^{-1}$.
Atmosphere time = 100 min.

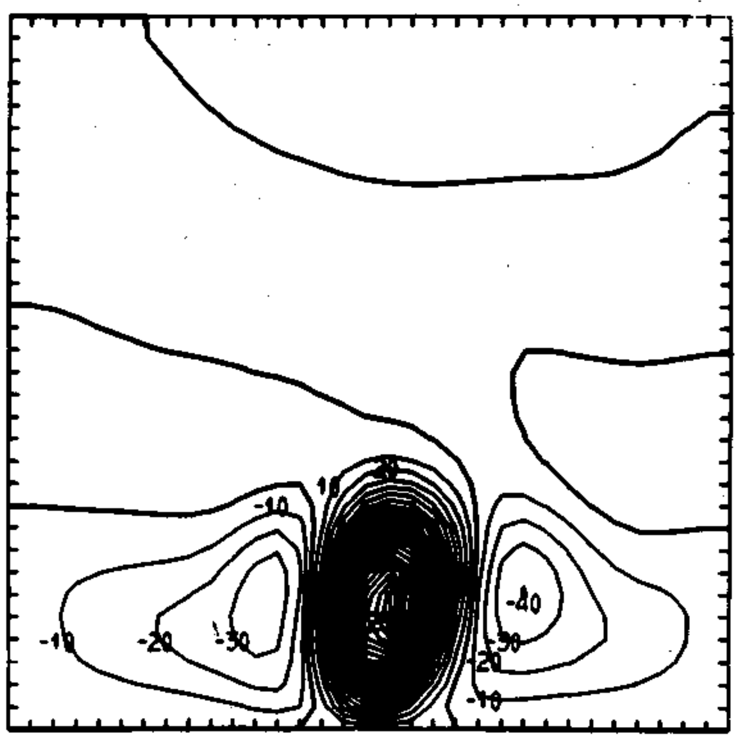


Figure 8. Vertical velocity in meters per second scaled by $10^{2}$.
Atmosphere time = 100 min.

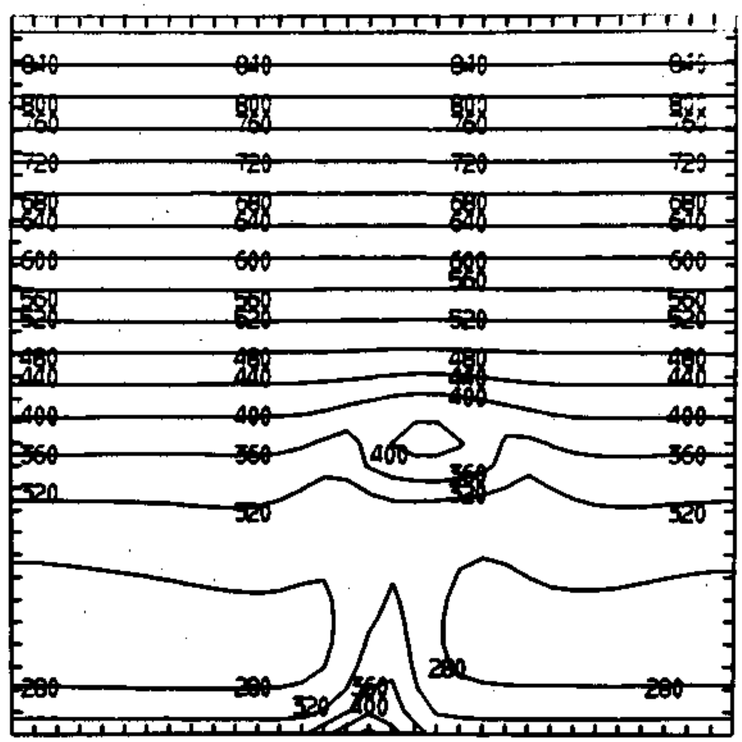

Figure 9. Potential temperature deviation in degrees centigrade scaled by $10^2$.
Atmosphere time = 120 min.
Cloud time = 11 min.

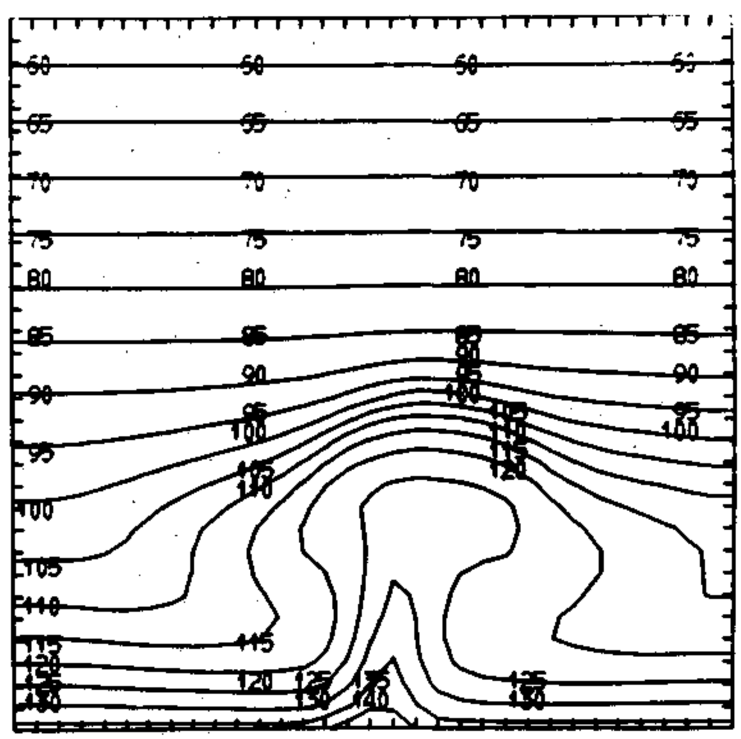

Figure 10. Water vapor content in grams per kilogram scaled by 10.
Atmosphere time = 120 min.
Cloud time = 11 min.

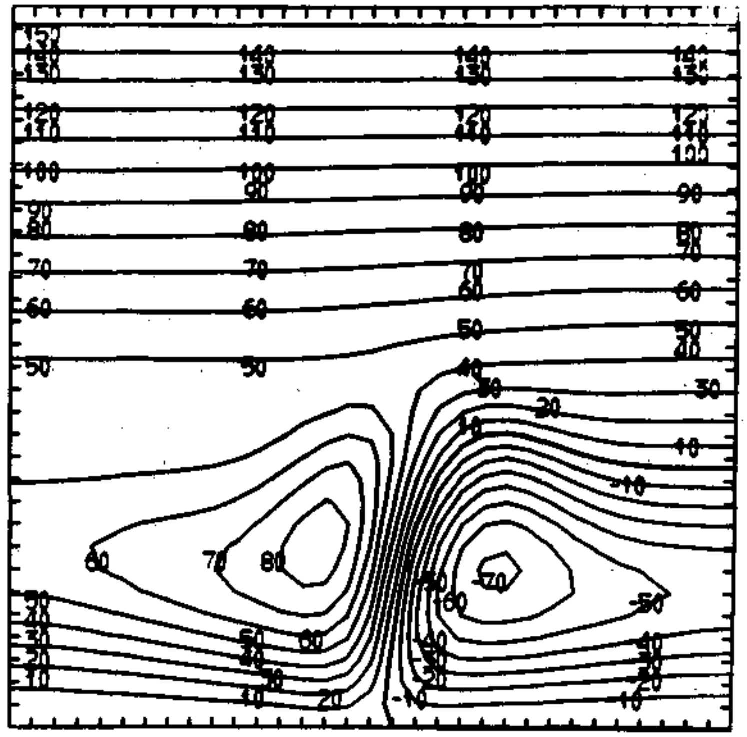

Figure 11. Stream function in kilograms per meter second scaled by $10^{-1}$.
Atmosphere time = 120 min.
Cloud time = 11 min.

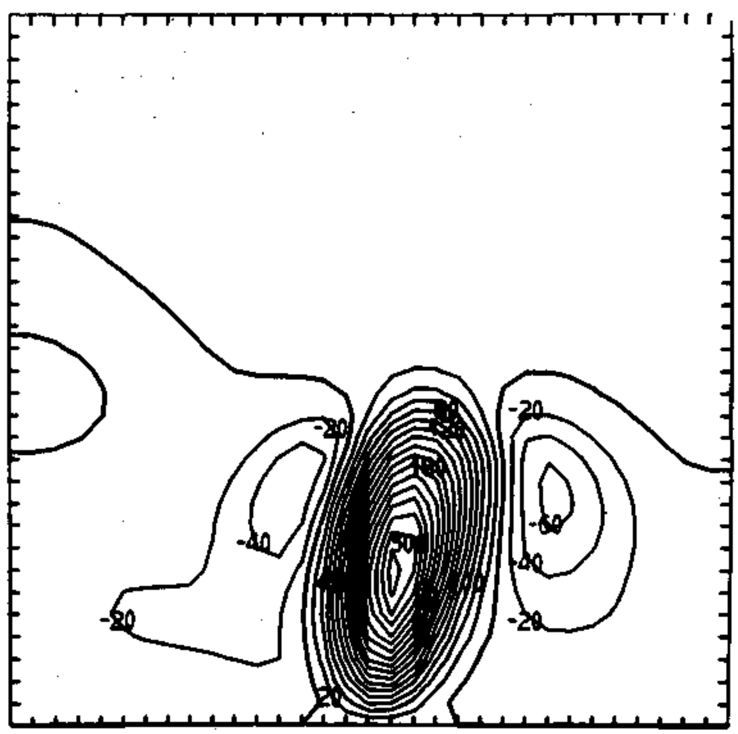

Figure 12. Vertical velocity in meters per second scaled by $10^{2}$.
Atmosphere time = 120 min.
Cloud time = 11 min.

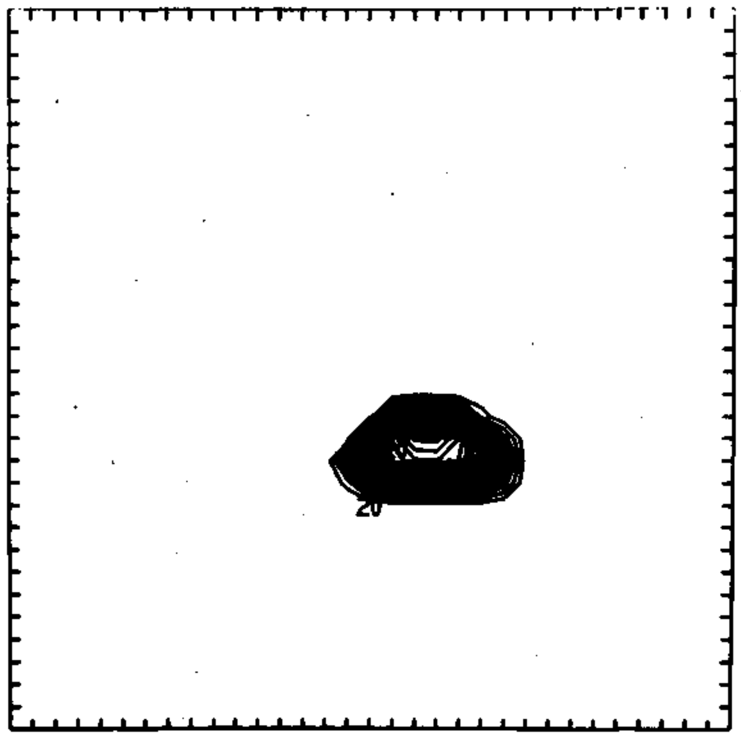


Figure 13. Cloud water content in grams per kilogram scaled by $10^3$.
Atmosphere time =120 min.
Cloud time = 11 min.

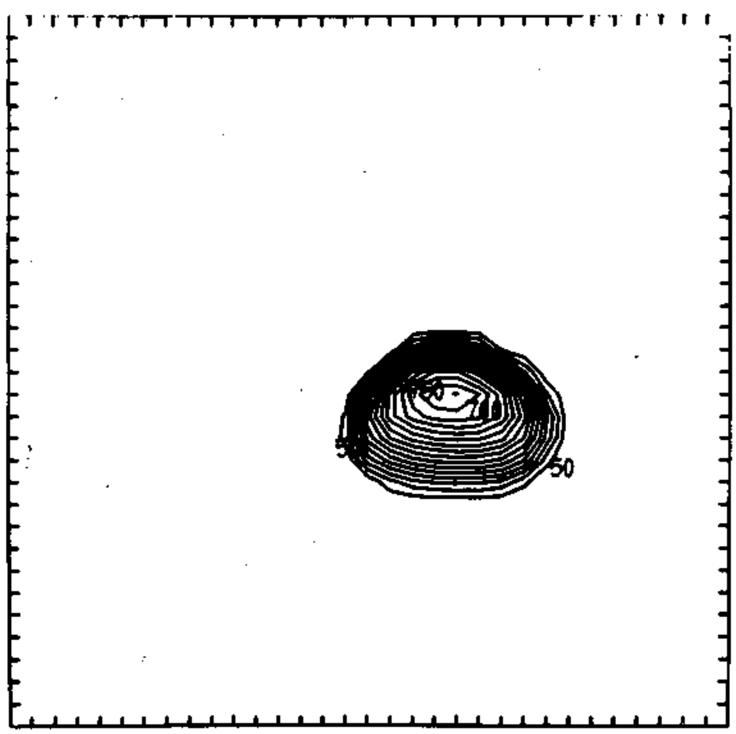


Figure 14. Cloud water content in grams per kilogram scaled by 10 .
Atmosphere time = 120 min.
Cloud time = 11 min.

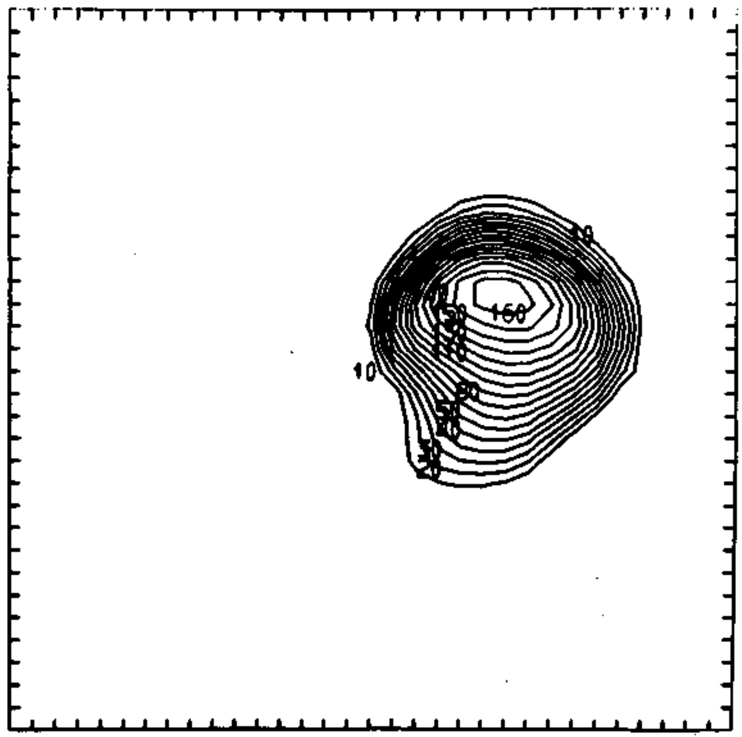


Figure 15.  Cloud water content in grams per kilogram scaled by 10 .
Atmosphere time = 130 min. 24 sec.
Cloud time = 21 min. 24 sec.

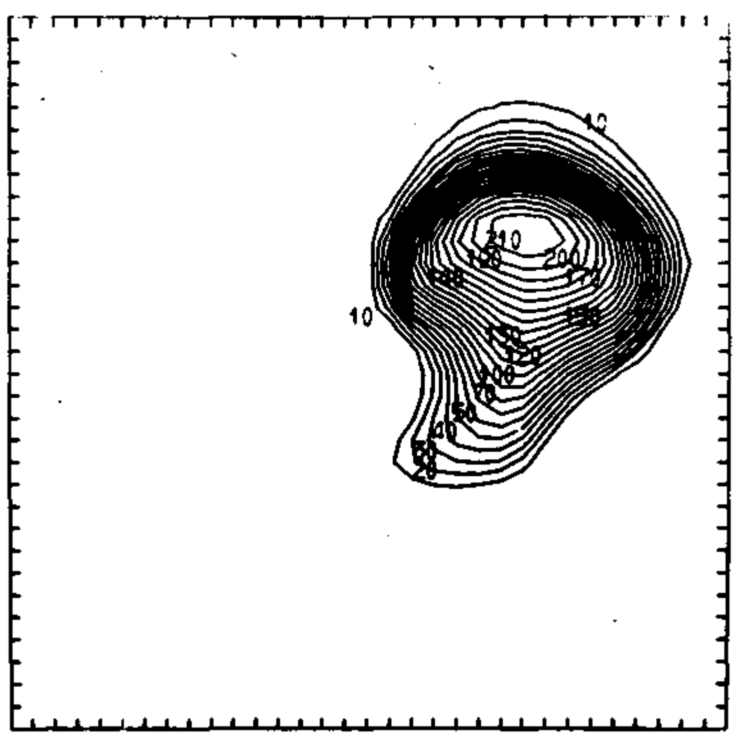


Figure 16.  Cloud water content in grams per kilogram scaled by 10 .
Atmosphere time = 132 min. 24 sec.
Cloud time = 25 min. 24 sec.

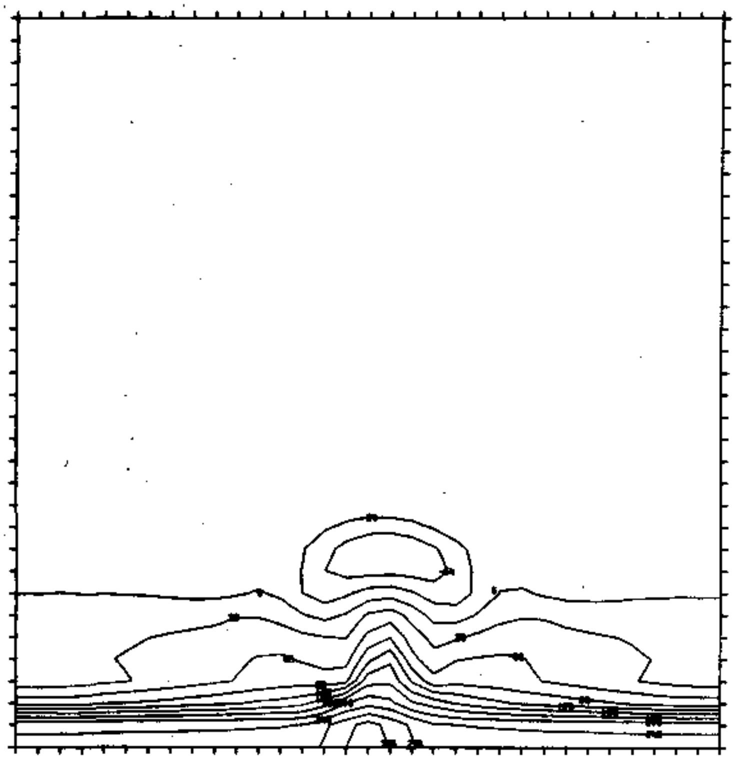

Figure 17. Temperature deviation in degrees centigrade scaled by $.10^2$.
Atmosphere time = 85 min. 54 sec.

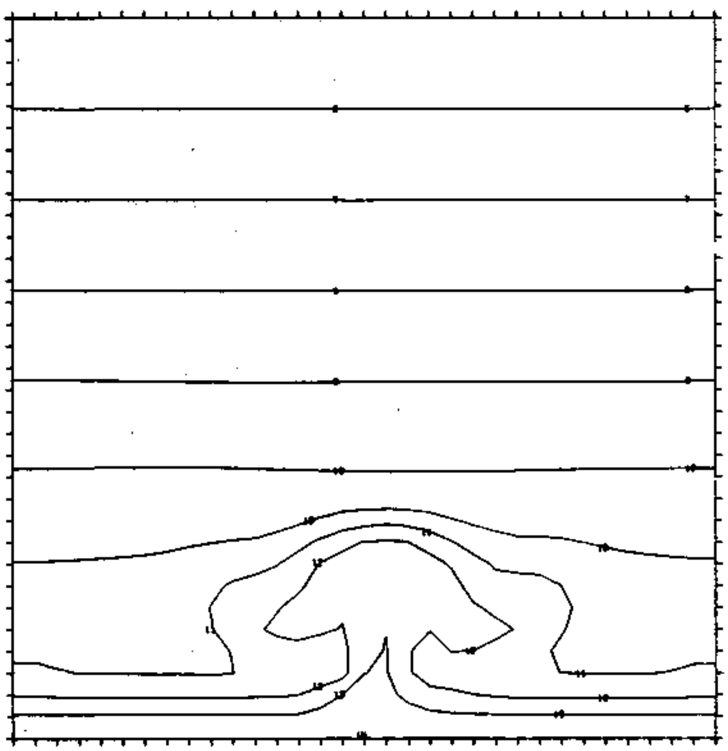

Figure 18. Water vapor content in grams per kilogram.
Atmosphere time = 85 min. 54 sec.

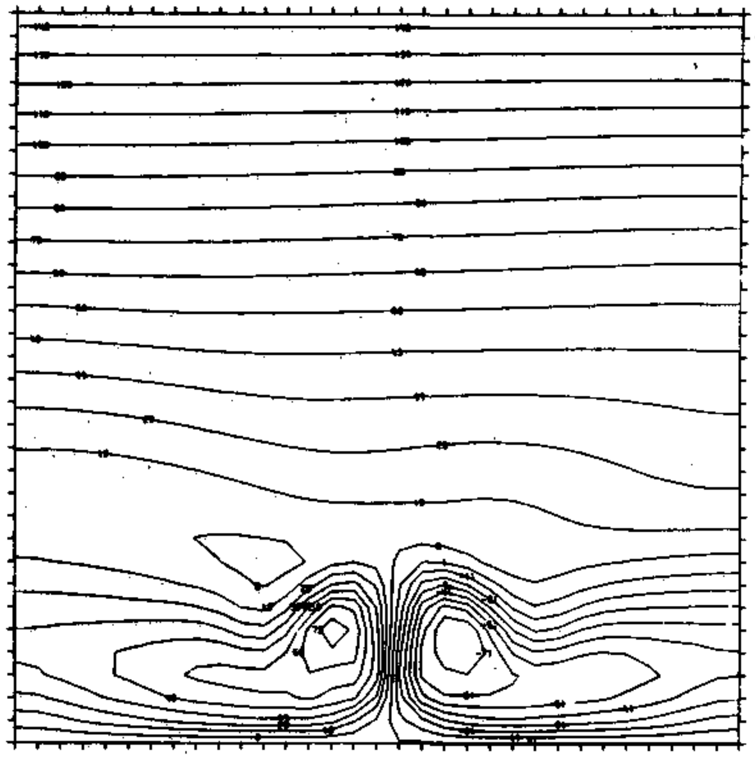

Figure 19. Stream function in kilograms per meter second scaled by $10^{-1}$.
Atmosphere time = 85 min. 54 sec.

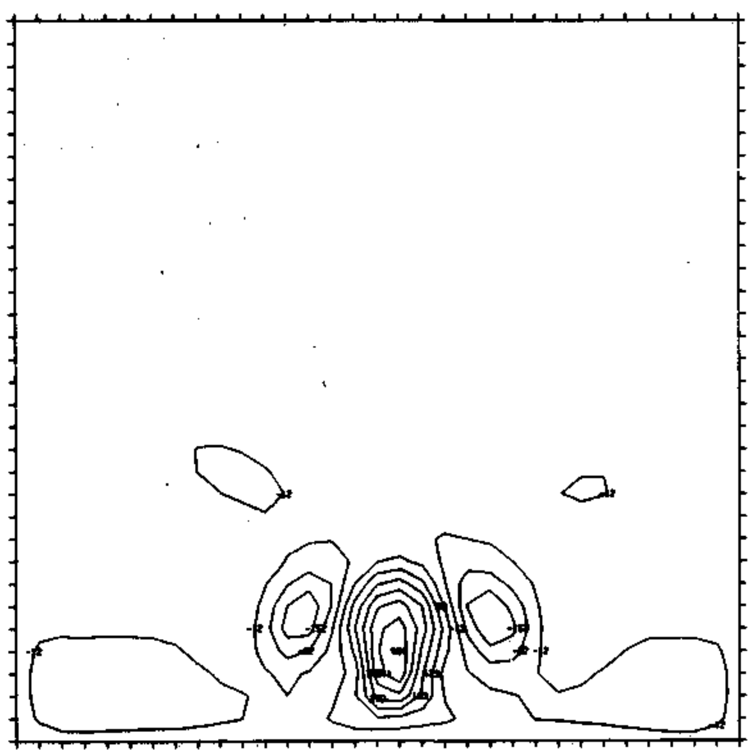

Figure 20. Vertical velocity in meters per second scaled by $10^{2}$.
Atmosphere time = 85 min. 54 sec.

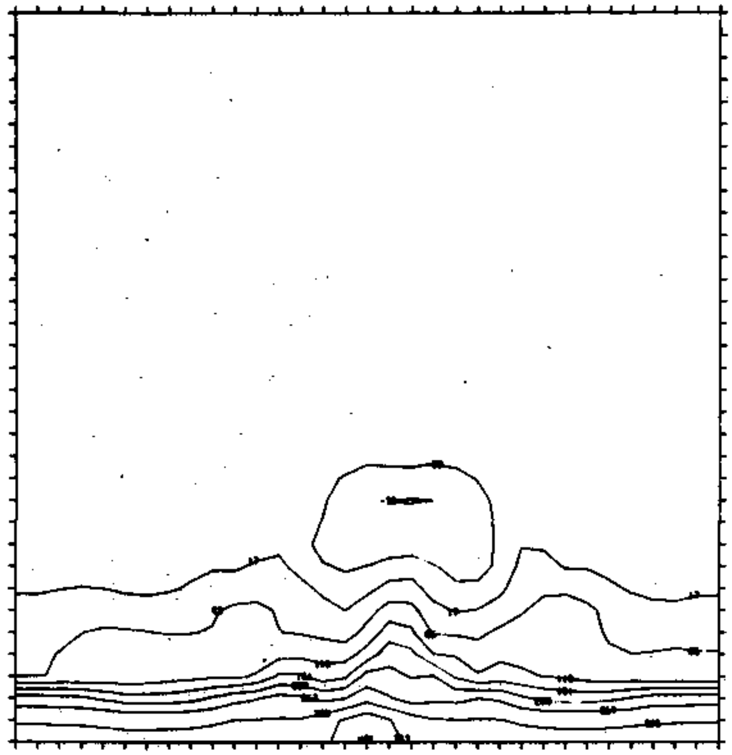

Figure 21. Temperature deviation in degrees centigrade scaled by $10^2$.
Atmosphere time = 105 min. 54 sec.
Cloud time = 17 min. 54 sec.

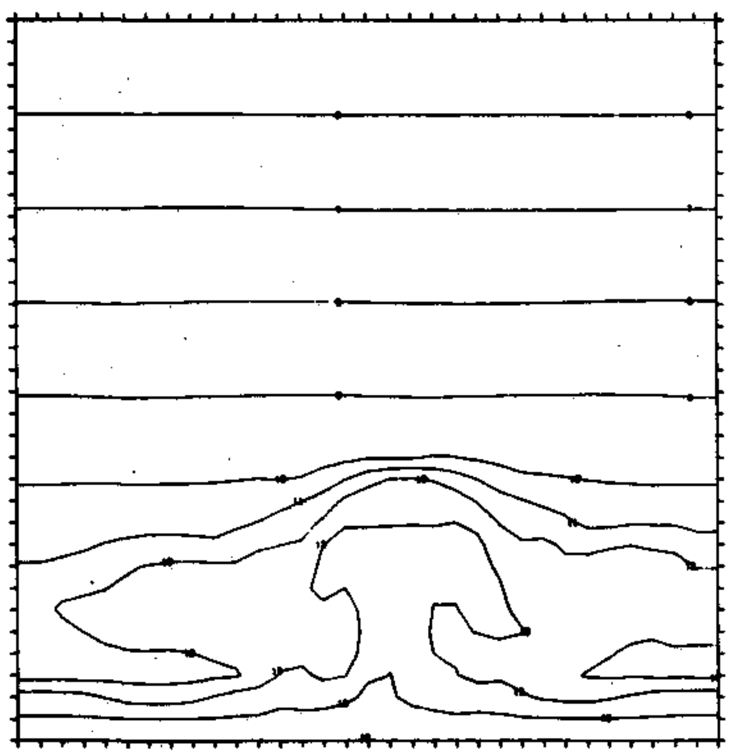

Figure 22. Water vapor content in grams per kilogram.
Atmosphere time = 105 min. 54 sec.
Cloud time = 17 min. 54 sec.

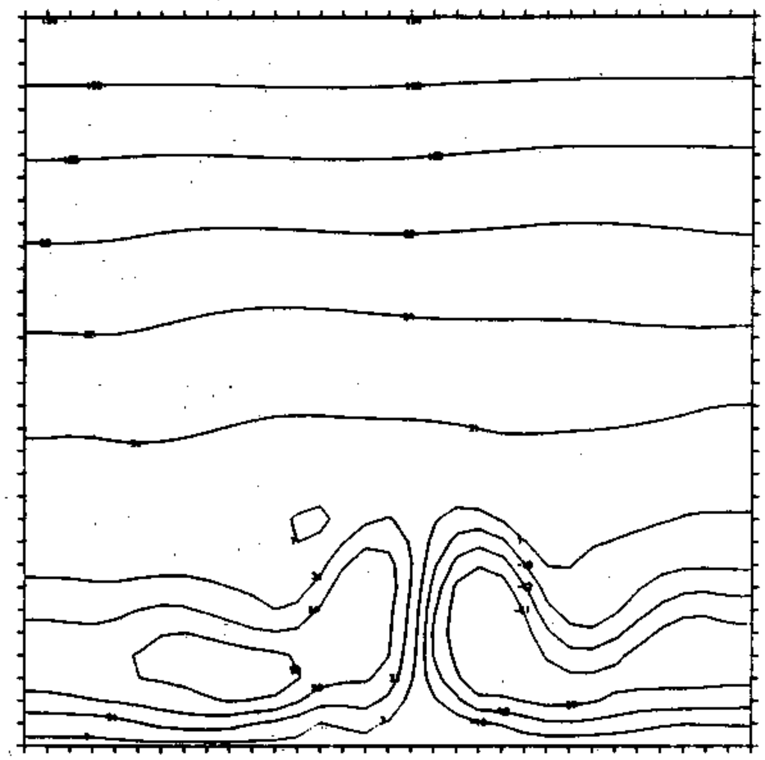

Figure 23. Stream function in kilograms per meter second scaled by $10^{-1}$.
Atmosphere time = 105 min. 54 sec.
Cloud time = 17 min. 54 sec.

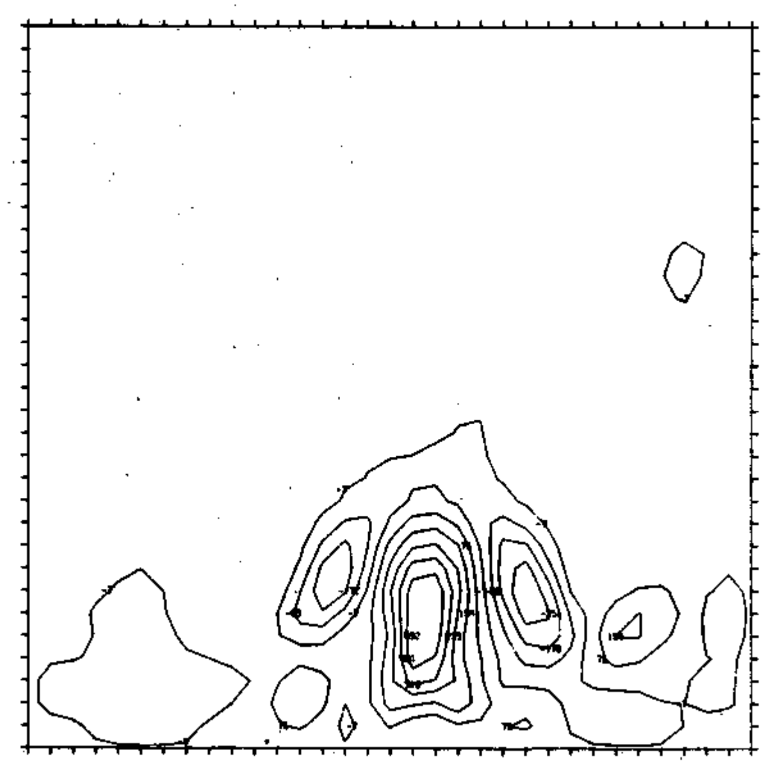

Figure 24. Vertical velocity in meters per second scaled by $10^{2}$.
Atmosphere time = 105 min. 54 sec.
Cloud time = 17 min. 54 sec.

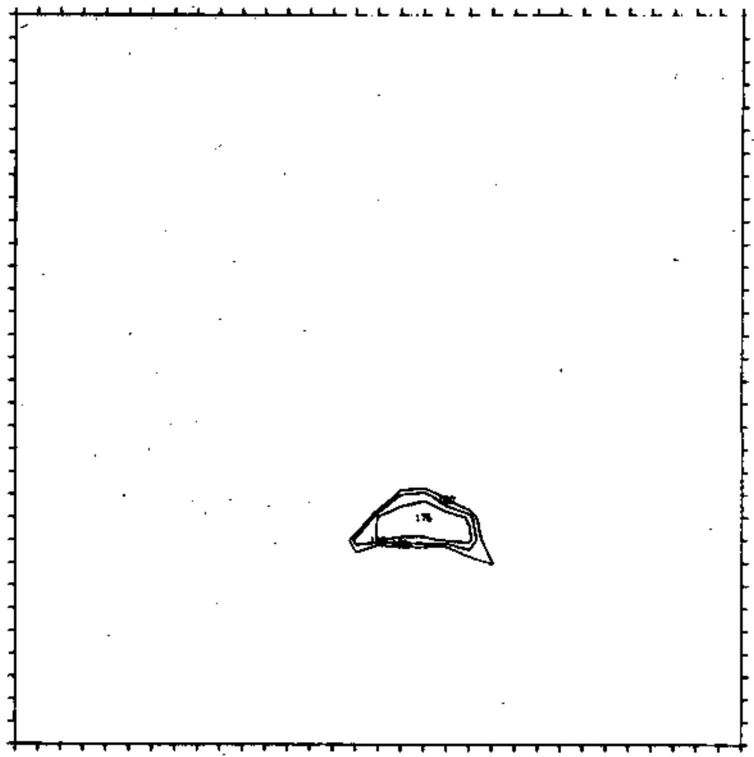

Figure 25, Cloud water content in grams per kilogram. Contours are logarithmically spaced. Contour labeled 100 is 0.1 gm/kg. Contour labeled 200 would be 1.0 gm/kg.
Atmosphere time = 105 min. 54 sec.
Cloud time = 17 min. 54 sec.

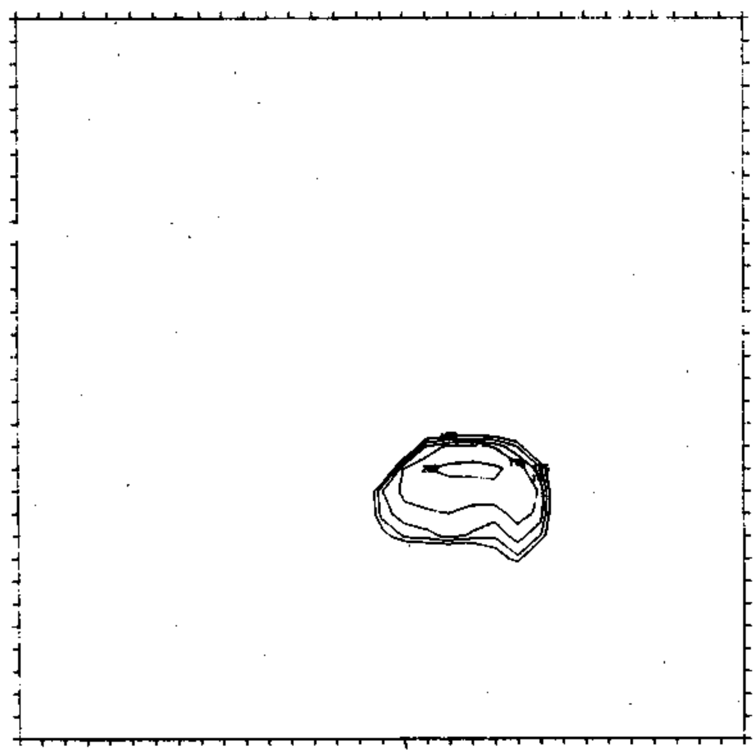

Figure 26. Cloud water content is grams per kilogram. Contours are logarithmically spaced. Contour labeled 100 is 0.1 gm/kg. Contour labeled 200 would be 1.0 gm/kg.
Atmosphere time = 115 min. 54 sec.
Cloud time = 27 min. 54 sec.

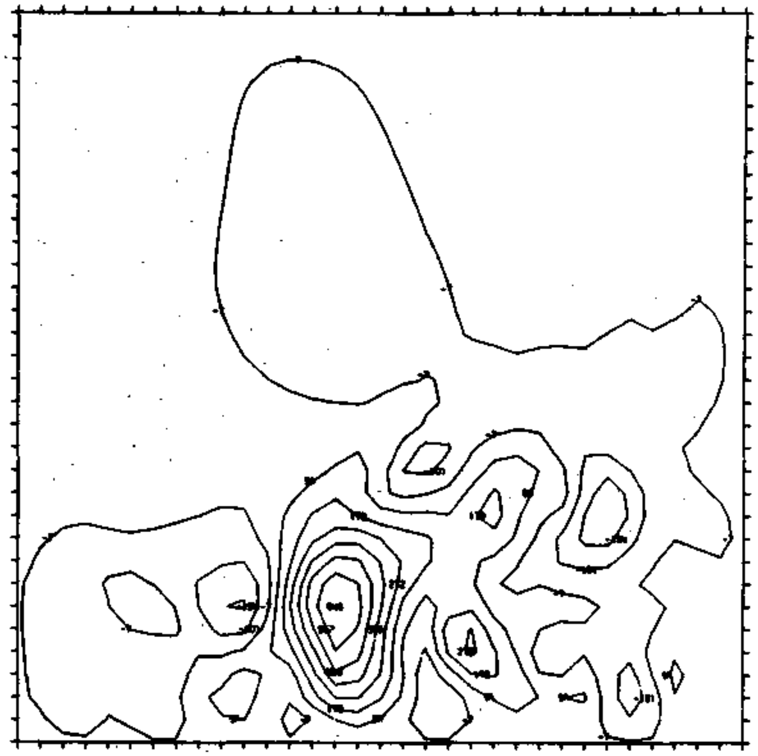

Figure 27. Vertical velocity in meters per second scaled by $10^2$.
Atmosphere time = 119 min. 54 sec.
Cloud time = 31 min. 51 sec.

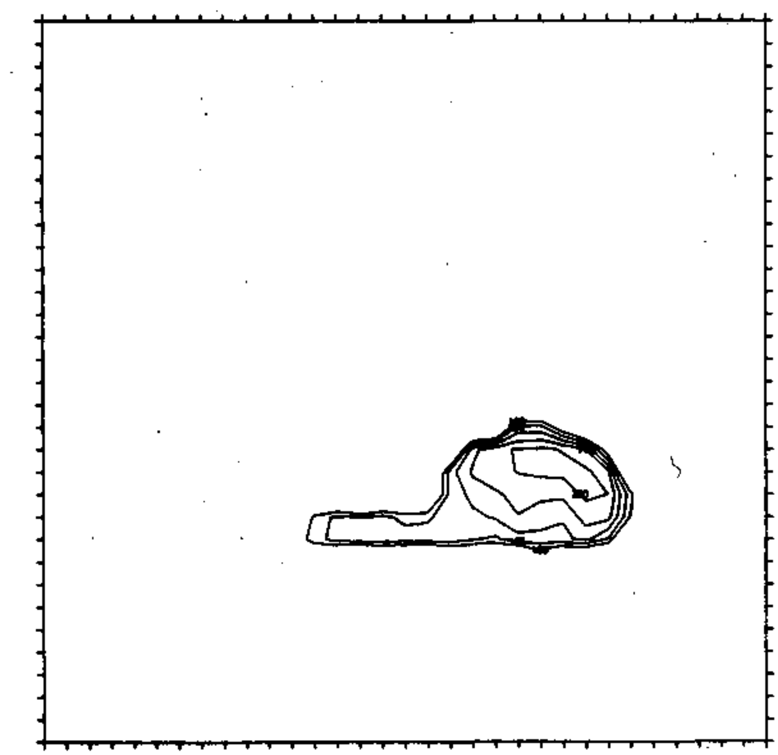

Figure 28. Cloud water content is grams per kilogram. Contours are logarithmically spaced. Contour labeled 100 is 0.1 gm/kg. Contour labeled 200 would be 1.0 gm/kg.
Atmosphere time = 119 min. 54 sec.
Cloud time = 31 min. 54 sec.

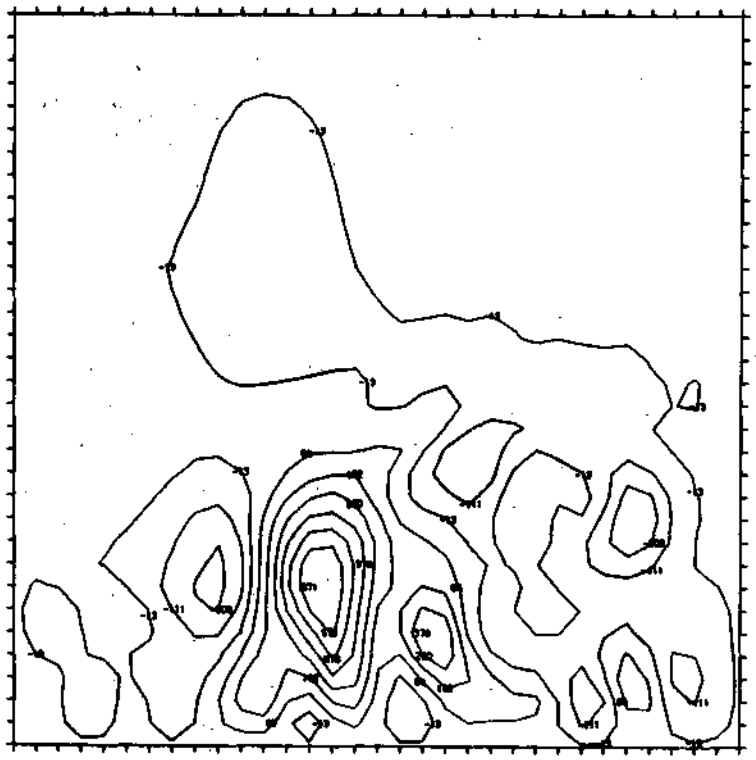

Figure 29. Vertical velocity in meters per second scaled by $10^2$.
Atmosphere time = 121 min. 54 sec.
Cloud time = 33 min. 54 sec.

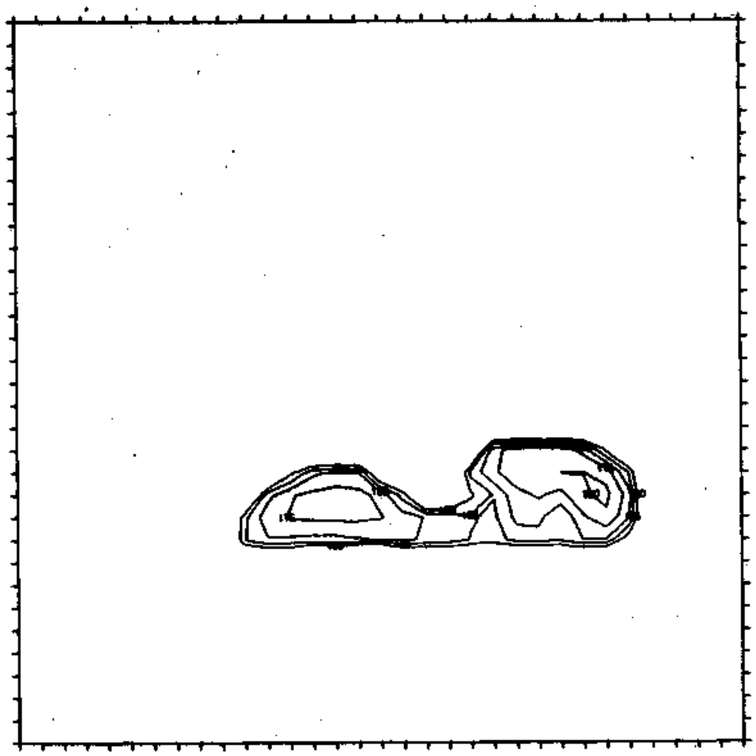

Figure 30. Cloud water content is grams per kilogram. Contours are logarithmically spaced. Contour labeled 100 is 0.1 gm/kg. Contour labeled 200 would be 1.0 gm/kg.
Atmosphere time = 121 min. 54 sec.
Cloud time = 33 min. 54 sec.

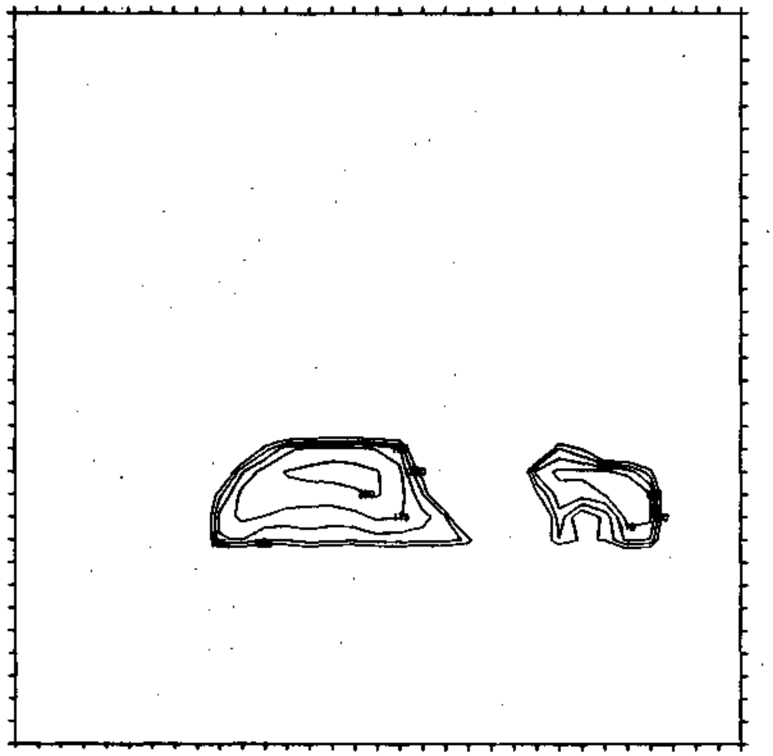

Figure 31. Cloud water content is grams per kilogram. Contours are logarithmically spaced. Contour labeled 100 is 0.1 gm/kg. Contour labeled 200 would be 1.0 gm/kg.
Atmosphere time = 123 min. 54 sec.
Cloud time = 35 min. 54 sec.

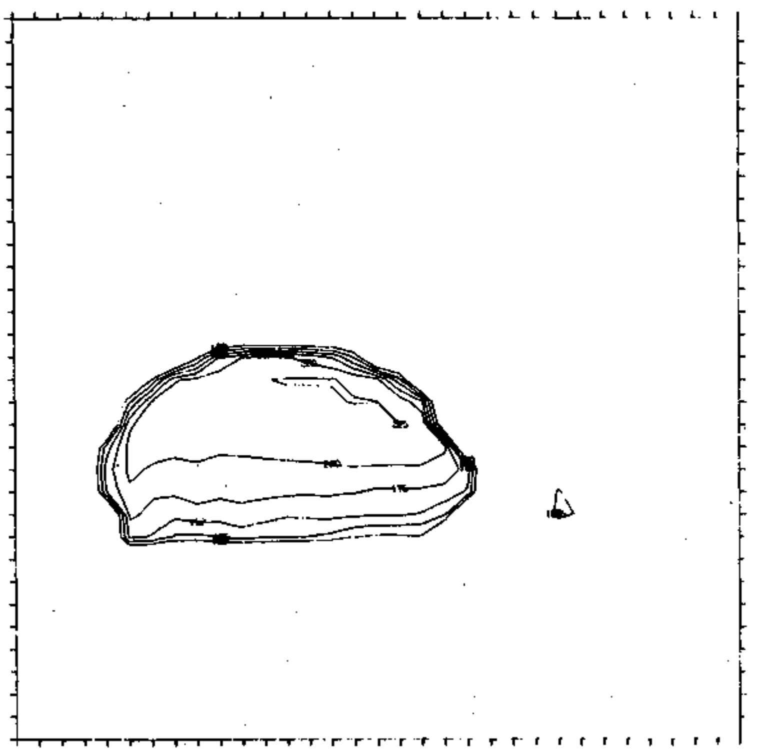

Figure 32. Cloud water content is grams per kilogram. Contours are logarithmically spaced. Contour labeled 100 is 0.1 gm/kg. Contour labeled 200 would be 1.0 gm/kg.
Atmosphere time = 137 min. 54 sec.
Cloud time = 49. min. 54 sec.

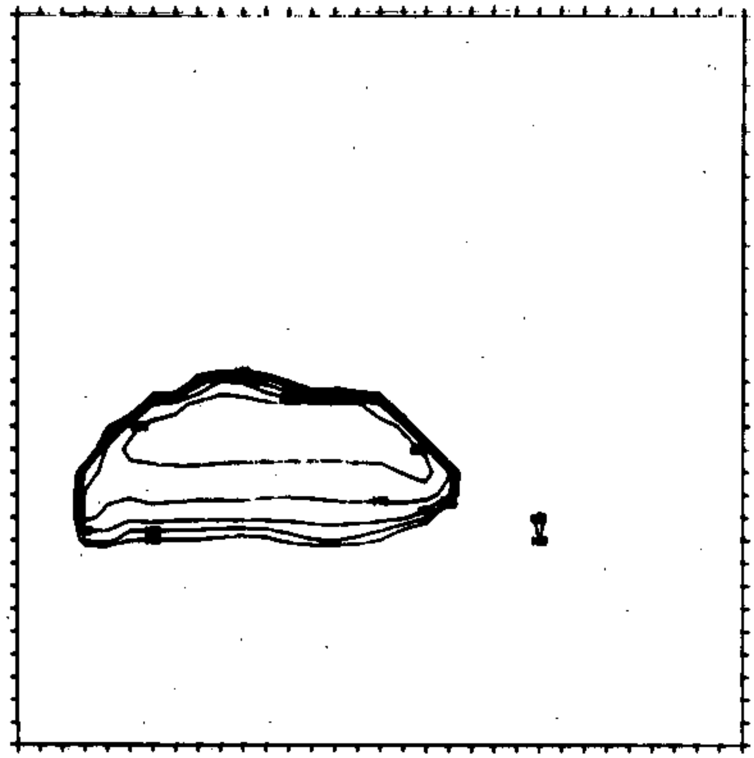

Figure 33. Cloud water content is grams per kilogram. Contours are logarithmically spaced. Contour labeled 100 is 0.1 gm/kg. Contour labeled 200 would be 1.0 gm/kg.
Atmosphere time = 145 min. 21 sec.
Cloud time = 57 min. 21 sec.

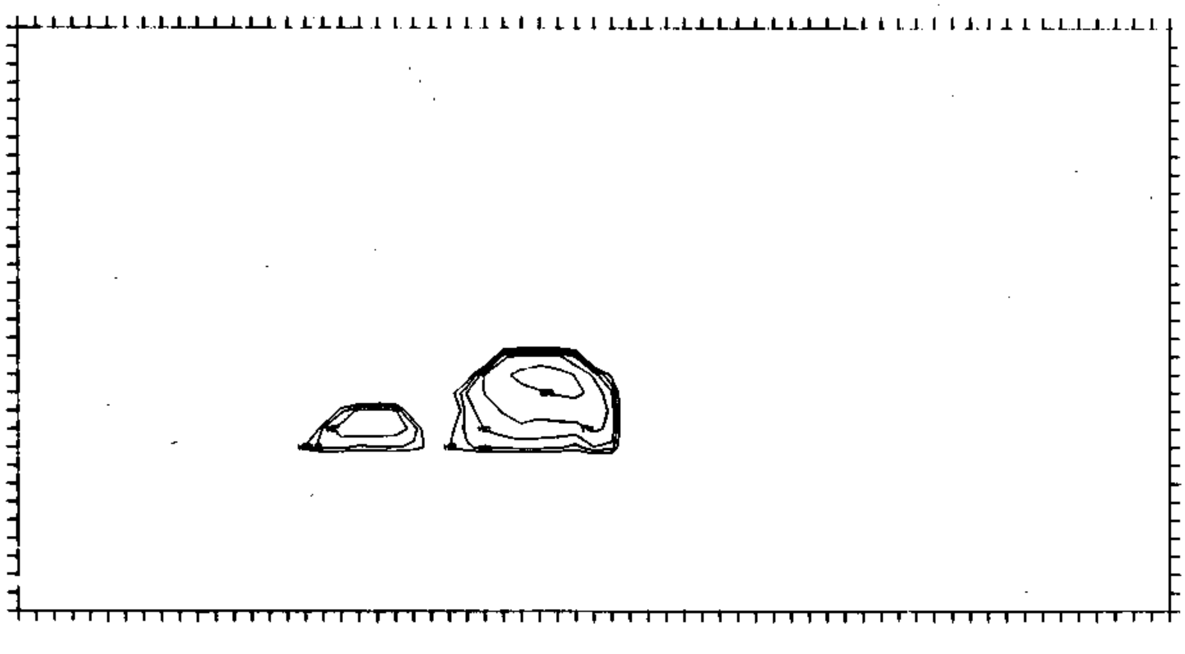

Figure 34. Cloud water content is grams per kilogram. Contours are logarithmically spaced. Contour labeled 100 is 0.1 gm/kg. Contour labeled 200 would be 1.0 gm/kg.
Atmosphere time = 131 min. 54 sec.
Cloud time = 43 min. 12 sec.

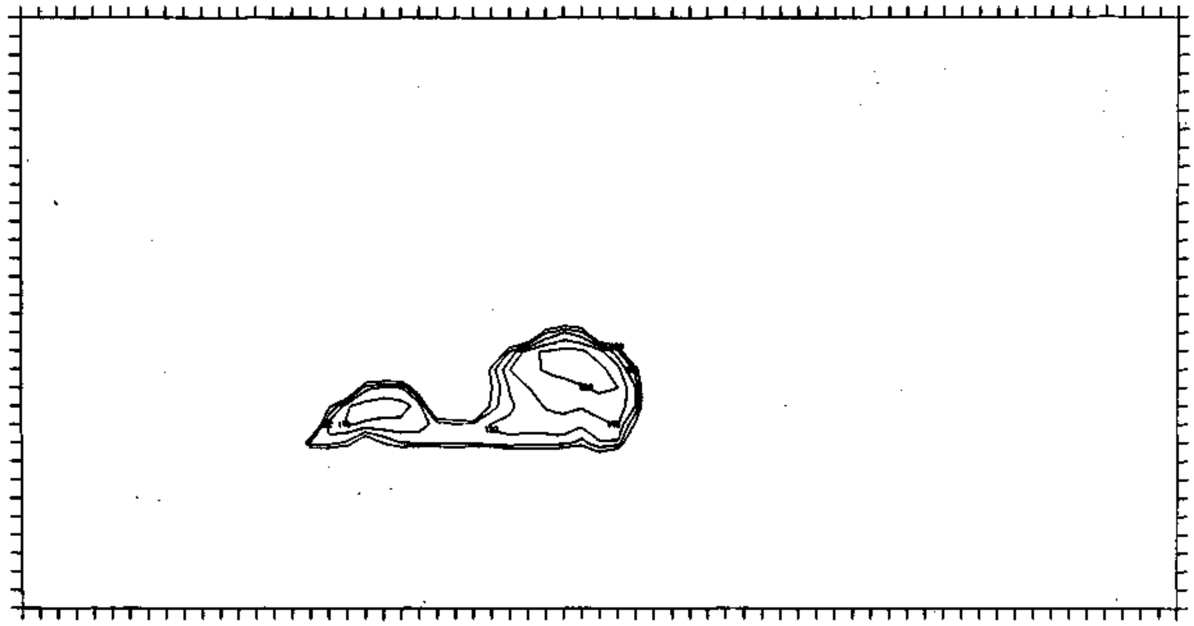

Figure 35. Cloud water content in grams per kilogram. Contours are logarithmically spaced. Contour labeled 100 is 0.1 gm/kg. Contour labeled 200 would be 1.0 gm/kg.
Atmosphere time = 133 min. 54 sec.
Cloud time = 45 min. 12 sec.

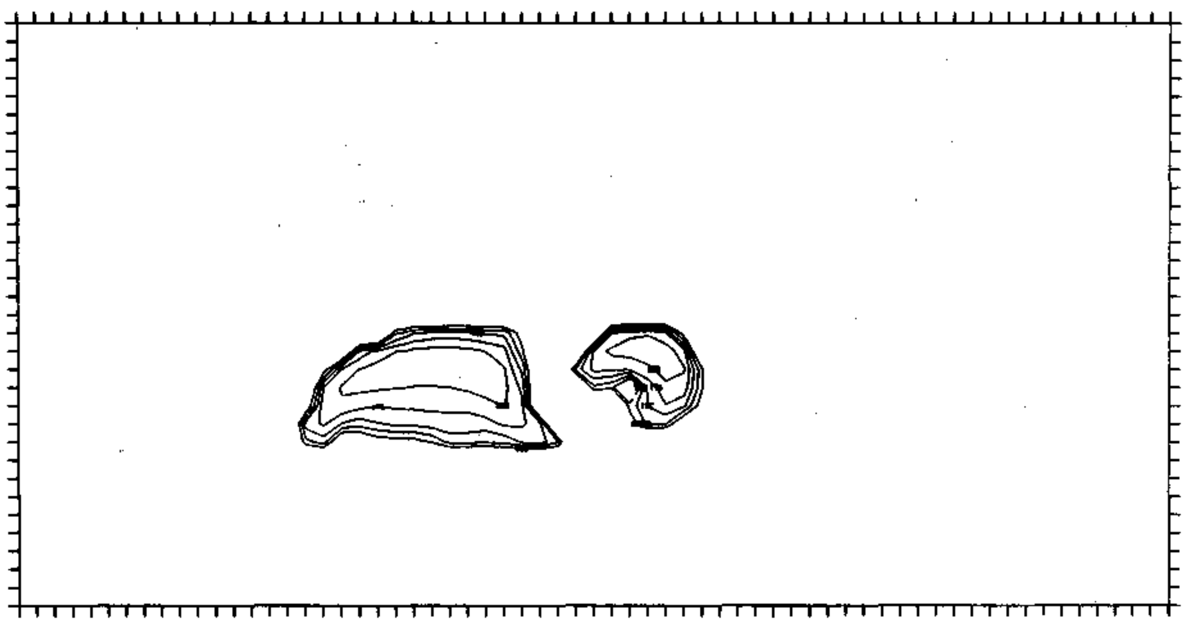

Figure 36. Cloud water content in grams per kilogram. Contours are logarithmically spaced. Contour labeled 100 is 0.1 gm/kg. Contour labeled 200 would be 1.0 gm/kg.
Atmosphere time = 139 min. 54 sec.
Cloud time = 51 min. 12 sec.

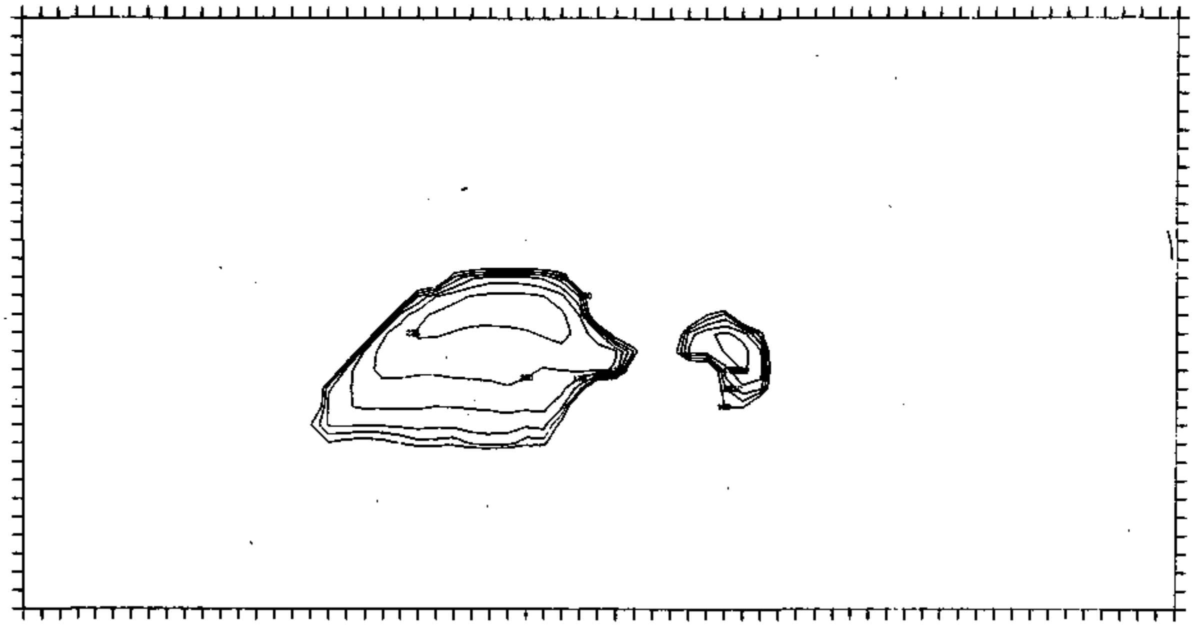

Figure 37. Cloud water content in grams per kilogram. Contours are logarithmically spaced. Contour labeled 100 is 0.1 gm/kg. Contour labeled 200 would be 1.0 gm/kg.
Atmosphere time = 145 min. 54 sec.
Cloud time = 57 min. 12 sec.

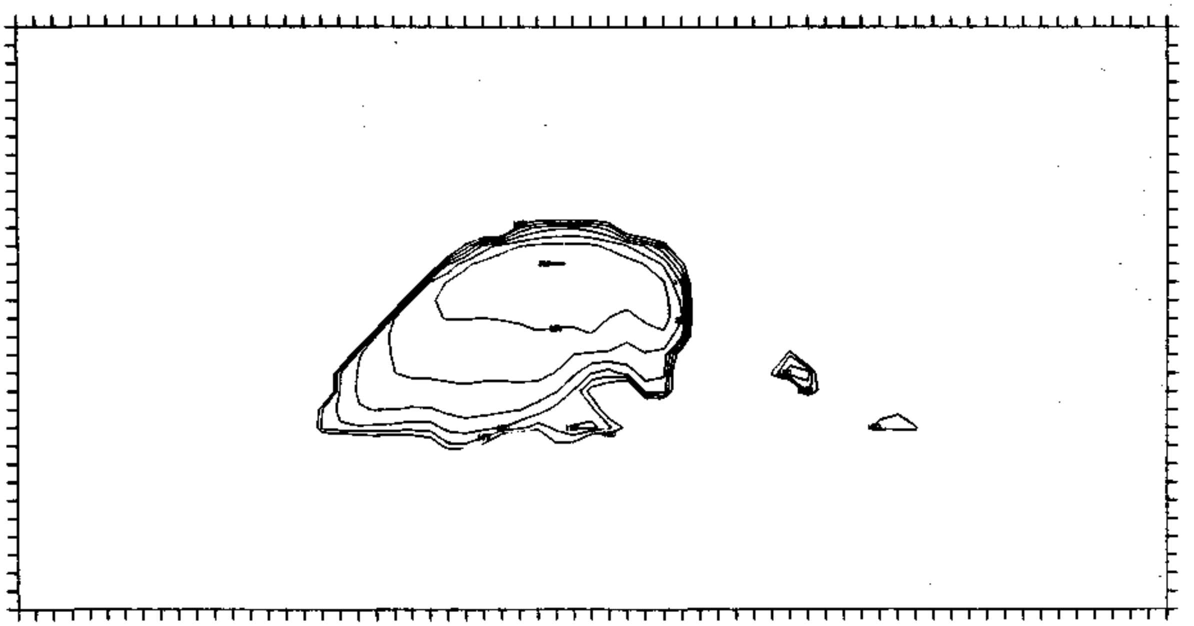

Figure 38. Cloud water content in grams per kilogram. Contours are logarithmically spaced. Contour labeled 100 is 0.1 gm/kg. Contour labeled 200 would be 1.0 gm/kg.
Atmosphere time = 151 min. 54 sec.
Cloud time = 63 min. 12 sec.

# SEEDING CONCEPTS

Richard G, Semonin

## Activities

The long-range proposal and current contract did not call for any activities on this task during the reporting period. Studies directly related to concepts and technologies of weather modification will be initiated in FY-73.

## Planned Activities

A literature search will be initiated to catalog all seeding concepts, methods, and technologies. The information will be stratified according to the intent of the seeding, and applicability to various cloud types. Insofar as possible, where various methods have been applied in a seeding operation, physical parameters of the clouds will be scrutinized for application to Midwest convective systems. Such a study, with little cost to the contract, will provide a state-of-the-art appraisal of seeding technology and allow the intelligent implementation of method most appropriate for the Illinois climate.

As new technologies become available, they will be closely examined and in more promising cases hardware tests will be carried out. For example, the newly developed acetone solution generators used by Battelle Northwest Laboratories for chemical tracer operations will be investigated as possible seeding equipment. A very efficient generator has been developed by the Naval Weapons Center in China Lake, California which has been used by the Survey in its Metromex project for the past two years. This equipment is simple to operate, very efficient, and deserves some attention as a candidate for use as a weather modification tool.

The Metromex research program has provided considerable research benefit to this contract since the tracer chemical operations are in every way identical to the updraft seeding techniques applied in many weather modification projects. The preliminary results from the Metromex tracer activities indicate that updraft seeding to modify the liquid-solid balance in the region between -5°C and -20°C is not appropriate in Illinois. Of course, the Metromex experience will be valuable to the consideration of warm cloud modification where the seeding agent must be active in the updraft of the convective system,

Various pyrotechnic mixtures and delivery systems will be tested both theoretically and physically. Such testing will require the acquisition of small quantities of materials for subsequent evaluation for use in Illinois.

## Personnel

No personnel were involved in this activity during the report period.

# TRACE ELEMENT CHEMISTRY

Richard G. Semonin

## Activities

The activities within this task area were derived from the Metromex studies and were confined to the development of analytical technique for the detection of seeding materials. The primary emphasis was on the detection of silver using flameless atomic absorption spectrophotometry. While the data obtained are *a* part of the assessment of the air and rainwater quality in the St. Louis area, the results have direct bearing on the PEP program.

The 3,900 samples collected during the summer of 1972 are currently undergoing analysis and the results will be available to this contract during the next reporting period.

## Planned Activities

A minimum network of 5 precipitation samplers will be installed within Marion and Jefferson counties in south-central Illinois. Volunteer observers will be utilized to collect samples from each storm system along with basic data concerning approximate time of precipitation and other pertinent observations of the storm. These samples will be picked up periodically and transported to Champaign for chemical analysis.

Laboratory tests are currently underway to determine the optimum technique to assure preservation of silver in the dissolved state. Various non-toxic additives are being considered for use in the field by the volunteers.

A stream will be chosen within the two county areas for sampling on a once-weekly basis as well as after passage of each precipitating system. These data will be combined with the precipitation chemistry to examine the hydrologic aspects of various chemical constituents.

This background data colleqtion task is important to the evaluation of the use of silver (or other seeding agents) as a tracer of the modified precipitation. A manufacturer of silver iodide pyrotechnics is located directly south of the proposed sampling area and frequently burn the residue from production runs. This type of operation may interfere with the natural background concentration of silver and is a cause of concern for this task. Attempts will be made to elicit from the firm the dates when burning has taken place and to provide such information to this contract in the future.

## Personnel

R. G. Semonin devoted 5% time to the supervision of the chemical analysis and development of techniques suitable for this task. The laboratory facilities and analysis personnel were made available to this task from the Metromex field project funded by the State of Illinois and other governmental agencies.

# PROJECT DESIGN

Stanley A. Changnon, Jr., Floyd A.. Huff, and Richard G. Semonin

## Introduction

The major objective of this activity area of Phase I of PEP is to coordinate results and to develop the design for Phase II of PEP. The second phase of PEP is the actual precipitation enhancement experiment that, if pursued, will begin in 1976 or 1977. Thus, the project design activities include 1) a continuing study and integration of the findings of the 9 other study areas of Phase 1,2) monitoring of on-going precipitation enhancement projects and results elsewhere, and particularly those relevant to one in the midwest, and 3) combining these data and knowledge with results of earlier Water Survey studies relating to precipitation enhancement. In essence, the project design is the on-going integration and evaluation of Phase I with respect to Phase II.

The first area of effort is to monitor the adequacy of the research in the 9 other study areas of Phase I. The 3 principal scientists (authors) of PEP to evolve the final design will constantly review the results.

The second area of effort in the project design will be review and integrating of past Water Survey research efforts concerning planned weather modification. These efforts have dealt with a variety of weather modification conditions.

The third area of effort in the project design will be the monitoring of other weather modification efforts, particularly those have facets applicable to the Illinois experiment, Phase II. This monitoring will involve 1) attendance at weather modification meetings and conferences, 2) membership in scientific weather modification groups, 3) visits to and short-term participating in ongoing relevant weather modification projects, and 4) discussions with consultants who are experts in various weather modification phases. Again, knowledge and staff skills will be improved through these associations.

The proper development of a well-planned program in precipitation enhancement in a geographical-climatic region that has not been adequately examined for summer, winter, and transition season experiments of the type envisioned for Illinois necessitates the considered opinions and advice of scientists and engineers who are nationally recognized in their field.

A call from the Bureau of Reclamation received on 22 October indicating that funding for this program during FY-72 was to be reduced substantially from that allotted, $96,891. The sum actually reserved for this contract for FY-72 was received on November 27, 1971. This sum, $65,000, is $31,891 less than that requested in the original proposal. Consequently, our Bureau supported efforts in FY-72 were reduced approximately one-third. Principal study-project areas pursued during the program for the 10 months of FY-72 (1 September - 30 June 1972) included:

1. Study of Potential Benefits to Water Supply
2. Ecological Studies
3. Legislative Aspects Study
4. Extra-Area Effects from Weather Modification (Climatic Studies)
5. Cloud Modeling Studies
6. Atmospheric Sampling Project
7. Project Design

Activities in this study area of PEP were necessarily limited in FY-72.

Specification of the general site of the future potential seeding experiment was required for the proper initiation of the ecological studies, and water supply benefit studies, and extra-area effect studies. Hence, a pilot investigation of the site was made, and the future seeding experiment would likely be centered in a 2-county area of southern Illinois where our previous climatic and agricultural studies have shown the benefits to be greatest.

A part of the Project Design activities also concerned securing advice from consultants. Dr. Roscoe Braham visited our organization on December 7, 1971, and we made detailed presentations of the various study areas of PEP. Dr. Braham made several useful suggestions, and possible future involvement of his group and facilities on PEP was discussed. Dr. Roscoe Braham was visited by Messers. Semonin and Changnon at the University of Chicago on December 16. Discussions concerned PEP and particularly the Atmospheric Sampling Project of Phase I. In particular, the goals and form of the aircraft sampling were discussed in detail.

Professor Roland List of the University of Toronto also consulted with Survey scientists on 6-7 January 1972. Discussions involved all aspects of PEP with special emphasis on modeling studies. Dr. Roscoe Braham visited the Water Survey on February 4, Discussions largely concerned the aircraft sampling project of PEP, and the potential involvement of the University of Chicago group and their aircraft in this project.

Dr. Arnold Court of San Fernando Valley State College visited on 27-28 March. During his visit extensive discussions were pursued concerning PEP and all its study.

Discussions with Project Monitors. Messrs. Olin Foehner and Stan Brown, our two PEP monitors, were in Champaign for detailed discussions on May 25 and the morning of May 26. Our discussions concerned the various projects and/or study areas of PEP. An extremely useful exchange of information and ideas occurred throughout our disucssions. Many meaningful questions were posed by Foehner and Brown..

It was agreed that we would try to arrange a meeting of Changnon, Semonin, and Bernice Ackerman with Todd and Howell in Denver to discuss our potential seeding hypotheses. Prior to this meeting, we agreed to develop a document, preliminary in nature, on this subject, and to send it to the Bureau people.

A major effort within this study area, and one that overlaps the seeding concepts and modeling efforts, concerned the development of a document that presented background data and described our initial thoughs and plans towards development of seeding hypotheses for Illinois. It essentially consisted of available data and results to help us evolve plans for the atmospheric sampling project. This preliminary document was sent to the Bureau on 19 June as a position paper for the meeting on 30 June between Bureau representatives and Survey representatives involved in our atmospheric sampling and seeding concepts efforts (Semonin, Morgan, Ackerman, and Changnon). The discussion on 30 June in Denver was a reasonably fruitful exchange and we got some interesting ideas and suggestions for PEP. We certainly intend to communicate closely with Bureau representatives on our modeling research; we will optimize our initial sampling flights using cloud model information where possible; and we will decrease our flight time to support costs of radar modification and operations. It is our understanding that the Bureau officials have requested a surplus 3-cm radar set now located in New Mexico for our use on PEP.

<u>Travel</u>. As a part of the activities within this area, Robert Cataneo, one of the meteorologists on our staff who will be involved in PEP, went to the 3-day conference at Pierre, South Dakota, on November 10-12, 1971. This conference, which dealt largely with operational aspects of the future statewide seeding program, offered an opportunity to gather first-hand information and knowledge considered potentially useful to the Project Design activities.

The 3 principal scientists on this project, Semonin, Huff, and Changnon, attended the Skywater 7 Conference on 2-3 March. We gathered some interesting research ideas for PEP from our conversations with attendees and from the conference presentations. We also met with Messers. Foehner, Brown, and Steurbering and discussed PEP.

Dr. Bernice Ackerman, Stanley Changnon, Griffith Morgan, and Richard Semonin traveled to Denver on 30 June for the aforementioned conference.

## <u>Future Plans</u>

A major future need on PEP Phase I is for a large size (small beamwidth) quality radar antenna, mount, and drive system. We have an operation 10-cm radar (FPS-18), but have only an antenna on loan (for the next 2 years) from NCAR. We need a better antenna with a bigger diameter dish and more reliable drive system or a complete radar system. The possibility of Bureau officals assisting us by securing such equipment on the government surplus market was agreed upon. RHI radar data, particularly in the warm season, now appear to be an essential feature of the Atmospheric Sampling Project beginning in the summer of 1973. If a surplus antenna or radar can be found in 1972, we can achieve this goal.

Monitoring of all results will be also continued. Consultants regarding our Modeling Research, our Atmospheric Sampling Project, and our Social Impact efforts will be sought.

# APPENDIX

An analysis of the personnel that were involved in this program in FY-72 and the amount of their involvement during the 10 months of the program appears below.

Salary Support from State of Illinois

| | Percent Time | Areas of Effort (1) | Begin | End |
|---|---|---|---|---|
| W. C. Ackermann | 2 | 3, 4 | Sept. | June |
| S. A. Changnon | 17 | 2, 3, 4, 10 | Sept. | June |
| R. G. Semonin | 12 | 6, 7, 8, 9, 10 | Sept. | June |
| F. A. Huff | 37 | 1, 5, 10 | Sept. | June |
| G. M. Morgan | 10 | 5, 6 | Sept. | June |
| A. L. Sims | 50 | 1 | Sept. | June |
| J. W. Wilson | 50 | 2, 3, 4 | Sept. | June |
| G. Stout | 1 | 4 | Sept. | June |

Salary Support from Bureau

| | | | | |
|---|---|---|---|---|
| H. T. Ochs | 100 | 7 | Sept. | June |
| T. Flach | 100 | 6 | Feb. | June |
| T. Thornburn | 80 | 7 | Sept. | June |
| P. T. Schickedanz | 25 | 5 | Sept. | June |
| M. Busch | 40 | 5 | Sept. | June |
| E. Schlessman | 100 | 1, 5 | Sept. | June |
| S. Havere | 50 | 2 | Dec. | June |

(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