TEXAS HIPLEX
MONTHLY PROGRESS REPORT
LP-57

Prepared by:

TEXAS DEPARTMENT OF WATER RESOURCES
POST OFFICE BOX 13087
CAPITOL STATION
AUSTIN, TEXAS 78711

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Interim Progress Report for October 1, 1977-March 31, 1978

Prepared for:

DIVISION OF ATMOSPHERIC WATER RESOURCES MANAGEMENT
BUREAU OF RECLAMATION
BUILDING 67, DENVER FEDERAL CENTER
DENVER, COLORADO 80225

Texas HIPLEX Interim Progress Report

October 1, 1977 - March 31, 1978

by the staff of

Weather Modification & Technology Section

Texas Department of Water Resources

LP-57

April 10, 1978

TEXAS DEPARTMENT OF WATER RESOURCES
1700 N. Congress Avenue
Austin, Texas

April 10, 1978

Dr. Archie M. Kahan, Chief
Division of Atmospheric Water
Resources Management
Bureau of Reclamation
Building 67, Denver Federal Center
Denver, Colorado 80225

Dear Dr. Kahan:

In compliance with Amendatory Agreement No. 1 to Contract No. 14-06-D-7587 between the Bureau and the Department, we are herewith submitting twenty (20) copies of the interim progress report on the Texas High Plains Cooperative Program (HIPLEX). The report discloses work performed, all data and information obtained, and all results achieved during the period October 1, 1977 - March 31, 1978 and is composed of four sections:

(1) A description of activity in each of the program areas addressed in the Texas HIPLEX 1977-78 Operations Plan;
(2) A brief statement of work planned for the next, 6-month reporting period (April 1 - September 30, 1978);
(3) A list of personnel involved in the Texas HIPLEX Program; and,
(4) Three appendices, consisting of studies conducted by Department staff members.

With respect to the study on ice-nuclei concentrations in the Texas HIPLEX project area (Appendix B), we seek your recommendation on the matter of maintaining ice-nuclei sampling equipment in the project area during the field portion of the 1978 Texas HIPLEX Program. Your response to this request at the earliest possible time will be appreciated.

If you have any questions concerning the interim progress report or if you need additional details, please do not hesitate to contact us.

Sincerely,

Herbert W. Grubb

Herbert W. Grubb
Director, Planning and
Development Division

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SECTION I

WORK PERFORMED DURING THE PERIOD
OCTOBER 1, 1977 - MARCH 31, 1978

TEXAS DEPARTMENT OF WATER RESOURCES

"MANAGEMENT OF THE TEXAS HIPLEX PROGRAM AND SUPPORT STUDIES"

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Several studies related to the Texas HIPLEX Program were concluded and plans for the 1978 Texas HIPLEX Program were formulated during the period October 1, 1977 through March 31, 1978.

During the 6-month period the Department staff negotiated and awarded five contracts for work and services in support of the Program (Table 1). The contract (No. 14-80001) between the Department and Texas Tech University's Department of Geosciences for the development of a precipitation climatology for the Texas HIPLEX study region was extended from the original termination date of December 31, 1977 to February 28, 1978 to allow the inclusion of data collected from the Texas HIPLEX recording rain-gage network during 1977.

Amendment Number 6 was made to Contract Number 14-06-D-7587 between the Bureau and the Department on January 18, 1978, thereby awarding the Department a total of $685,500 in funds for the conduct of the 1978 Texas HIPLEX Program.

The Department's Texas HIPLEX Advisory Committee was dissolved on January 19, 1978 by the Department's Executive Director. The functions and responsibilities of the Committee were assigned to the Texas HIPLEX Program's Chief Scientist and the Department's Weather Modification Advisory Committee.

In cooperation with the Texas Water Conservation Association and Texas A&M University, the Department sponsored a conference on "Weather Modification Today" in Austin on November 8, 1977. The one-day seminar served as a forum for the dissemination of the latest information on the state-of-the-art of weather modification with emphasis on the

TABLE 1. Contracts Awarded by the TDWR During the Period October 1, 1977-March 31, 1978 for HIPLEX Support Services

Contract Number	Organization	Period Begin	Period End	Purpose
14-80001	Department of Geosciences Texas Tech University	10-3-77	12-31-77	complete development of a rainfall climatology of the Texas HIPLEX area
14-80026	Department of Geosciences Texas Tech University	1-16-78	8-31-78	analyze satellite data gathered during the 1977 Program
14-80038	Meteorology Research, Incorporated	11-1-77	10-31-78	collect radar data during the 1978 Program and analyze/process 1976/1977 data
14-80039	Department of Meteorology Texas A&M University	2-6-78	8-31-79	provide Chief Scientist and collect/analyze mesoscale data during 1978 Program
14-80040	Colorado River Municipal Water District	2-10-78	12-31-78	perform cloud-seeding operations and collect rainfall and rawinsonde data during the 1978 Program

operational, research, socioeconomic, and legal aspects of the technology.

Three Department meteorologists attended and participated in the December 5-9, 1977 HIPLEX Workshop in Dillon-Frisco, Colorado.

The Department sponsored a 3-day Texas HIPLEX planning session of participants in the Texas HIPLEX Program in Austin on January 16-18, 1978. Status reports on all continuing studies in support of the Texas HIPLEX Program were given by the principal investigators of those studies, and plans for conducting the 1978 Texas HIPLEX Program were discussed and formulated by the participants. Subsequent to this planning session, Department staff and the Chief Scientist formulated a draft of an Operations Plan for the conduct of the field portion of the 1978 Program.

A TDWR technical report summarizing all weather modification operations conducted in Texas during the period 1974-1977 was written and sent to press during the 6-month reporting period. The report describes at length the overall goals and objectives of the Texas HIPLEX Program, as well as the various aspects of the Program, for the years 1975, 1976, and 1977.

The Department's Meteorological Facility was relocated from Howard County Airport near Big Spring to the Base Operations building at vacated Webb Air Force Base near Big Spring on January 23-25, 1978.

The Department's resident meteorologist at Big Spring conducted several studies related to the Program during the 6-month period beginning October 1, 1977. He performed a statistical evaluation of forecasts issued and data collected during the 1977 Texas HIPLEX

Program. From this analysis a first-generation Texas HIPLEX Forecast Decision Tree was developed, and a report was drafted which describes the Decision Tree and procedures used in the analysis of the data. In addition, an analysis of ice-nuclei count data collected at four sites during the 1977 Texas HIPLEX Program was conducted during the period. The study is designed to provide some insight to the horizontal distribution of concentrations of ice-nuclei throughout the Texas HIPLEX project area. The resident meteorologist also collected and archived local climatological data and National Weather Service facsimile and teletype products.

At Department headquarters in Austin, staff meteorologists, computer analysts, and economists completed several research projects having import for the Texas HIPLEX Program. Upper-atmospheric weather data were obtained from staff files of synoptic charts and analyzed to refine the thunderstorm prediction model developed earlier in 1977. Data on the issuance by the National Weather Service Forecast Offices at Midland and San Angelo of severe weather warnings were catalogued to ascertain the frequency with which cloud-seeding operations during the summer of 1978 might have to be curtailed because of the presence of severe weather in the region. Phase 3 of a Federal-State cost-sharing study of the economic effects of weather modification activities in the Big Spring-HIPLEX area was also concluded to assess the effects of rainfall on the level of municipal and industrial water supplies and water use patterns in the HIPLEX study region.

A paper which describes the results from the utilization of the thunderstorm-prediction model is provided as Appendix A to this interim progress report. The tabulation and examination of severe weather events in the Texas HIPLEX project area are provided as Appendix B. The analysis of the horizontal distribution of concentrations of ice-nuclei in the project area is included as Appendix C.

TEXAS TECH UNIVERSITY

"SATELLITE-DERIVED CLOUD CLIMATOLOGY

FOR THE SOUTHERN HIPLEX REGION"

The following paper, entitled "Satellite Studies in the Texas HIPLEX Area," is an interim progress report written by the Principal Investigator of the "Satellite-Derived Cloud Climatology" portion of the 1977-78 Texas HIPLEX Program.

SATELLITE STUDIES
IN THE
TEXAS HIPLEX AREA

An Interim Report
for the Period October 1977 - March 1978

Submitted to the
Weather Modification and Technology Division
Texas Department of Water Resources
P.O. Box 13087 Capitol Station
Austin, Texas 78711

by

Gerald M. Jurica
Department of Geosciences
Texas Tech University

April 1978

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ABSTRACT

This report under Interagency Contracts IAC(77-78)0745 and IAC(78-79)1055 is an interim report describing work performed in the Texas HIPLEX Satellite Project during the period October 1977 - March 1978. Two primary areas of activity are discussed. The first is a cloud characteristics study based upon 1977 satellite imagery. This work is a continuation and extension of a similar study performed upon 1976 satellite imagery. The second effort is an intensive case study effort based upon 1976 satellite radiance measurements.

The accomplishments in these two areas during the past six months are discussed, and plans for further work in the near future are described.

1. INTRODUCTION

The Texas HIPLEX Satellite Project was initiated in June 1976 at Texas Tech University (TTU) with the objective of providing support to the Texas HIPLEX program through analysis of geostationary satellite data. The study area of the project is a 300 kilometer by 300 kilometer area centered at Big Spring, Texas (see Figure 1). The study area encompasses the Texas HIPLEX field site which is located primary in region 5 with extensions into region 2 to the north and region 6 to the east. The satellite system selected is the Goestationary Operational Environmental Satellite (GOES). Data from GOES have been acquired in two formats: (1) photographic imagery from GOES EAST (sub-satellite point at 75°W), and (2) radiance measurements from GOES WEST (sub-satellite point at 115°W). The imagery is available at 30-minute intervals as alternating visible (during daylight hours) and infrared photographs. The radiance data are obtained by the Visible Infrared Spin Scan Radiometer which produces simultaneous sets of both visible and infrared measurements, also at 30-minute intervals.

All available photographs have been collected for the period 1 June to 15 July for the years 1976 and 1977. They have been acquired by providing the necessary expendible supplies to the National Weather Service Forecast Office in Lubbock, Texas. NWS personnel have voluntarily assumed responsibility for the laserfax equipment which produces the images. These data have formed the basis for a satellite cloud characteristics study described later in this report.

The radiance data for selected dates within the 1 June to 15 July 1976 period have been acquired from the Department of Atmospheric Science at Colorado State University. These data have formed the basis for an intensive case study data analysis project described later in the report.

2. ANALYSIS OF 1977 IMAGERY

The Texas HIPLEX program conducted its 1976 summer field program from 1 June

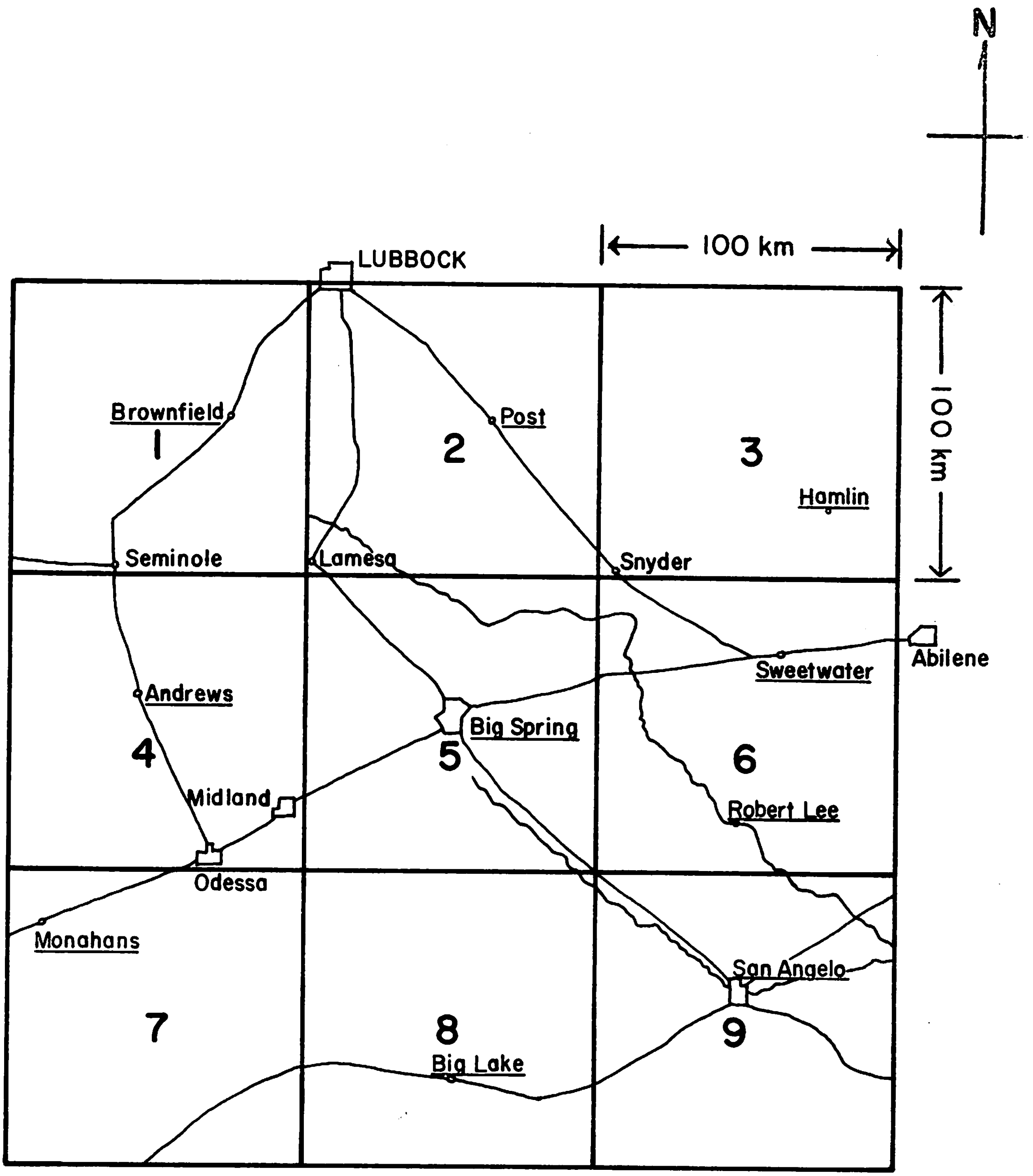

Figure 1. The area of study. Each region is denoted by number as well as by a city name.

to 15 July. During this period all available GOES imagery was obtained through the NWS Forecast Office in Lubbock. Subsequently, the visible photograph, available at one-hour intervals on-the-hour during daylight hours (1200 to 2400 GMT), were investigated, cloud parameters extracted and the results analysed. This work was reported in the April 1977 interim report of this project.

Infrared photographs were also available at one-hour intervals on-the-half-hour during both day and night. However, they were not incorporated into the study because they appeared to contain limited quantitative information. Enhanced infrared images on-the-hour replaced the visible images during the night. They appeared to offer promise because estimates of cloud-top temperatures could be derived. But, they also were excluded from the study because of their availability only during night.

The Texas HIPLEX program conducted its 1977 Summer field program from 1 June to 15 July, as in 1976. Once again, all available satellite imagery was obtained through the NWS Forecast Office in Lubbock. Visible photographs were again available during daylight hours at one-hour intervals on-the-hour. By this point, however, enhanced infrared imagery was available around the clock on-the-half-hour and on-the-hour during the night. Because it would now be possible to obtain quantitative data during daylight hours from infrared imagery, they were included in the study as described below.

2.1. Cloud Cover Categories.

Five general types of cloud condition were defined: (1) Clear Skies, or a total absence of cloudiness in the study area; (2) Isolated Clouds, small (generally less than 15-20 kilometers diameter) clouds completely separate from one another and randomly distributed - fair weather cumulus are common isolated clouds; (3) Area Clouds, larger clouds than isolated clouds and not distinctly separate - stratus and cumulonimbus cirrus shields are in this category; (4) Cloud Cluster, several isolated clouds clearly associated or grouped together; (5) Cloud Line, long and relatively narrow clouds normally tens of kilometers long and a few kilometers across -

a squall line is in this category.

It is recognized that a considerable degree of subjectivity is inherent in the categories defined above. However, consistency in the results was attained by having all imagery analysis performed by one individual; a summer's work. Further, the categories established are designed to focus attention on the primary targets of HIPLEX, the isolated cumulus cloud and the complex of convective cloud elements.

2.2. <u>Parameters Extracted from the Imagery</u>.

Each satellite photograph was overlaid with a plastic sheet upon which the boundaries of Texas and the study area of Figure 1 were drawn. The Texas boundary was matched to the state boundary grid provided by the National Environmental Satellite Service (NESS) and the study area was analysed. Errors in the location of the NESS grid can be corrected in daylight hours using the Gulf of Mexico coastline and recognizable landmarks such as White Sands, New Mexico. However, at night the possibility of location errors of as much as 75 kilometers appears very real.

The cloud type data as well as several other parameters were entered on a data sheet, hour by hour (see Figure 2). Each box in Figure 2 denotes one of the nine study area regions, and is coded as described in the example shown below. In the upper left is the number of clouds in each category found in the region, in the lower left is the dominant cloud type, in the upper right is the total number of clouds of all classes in the region, in the lower right is the percentage of the region covered by clouds, and in the center is cloud top temperature derived from the enhanced infrared imagery and coded as given in Table 1. In this example, there are three isolated clouds, two line clouds, one area cloud, a total of six discernible clouds which cover approximately 65 percent of the region, and cloud top temperatures in categories 4 and 5(-31.2 to -52.2°C). The tenth column

3 isold 2 line		6
	4→5	
area		65

											Comments	Speed & Dir	
030Z 07 IR	5678 area 100	78 area 100	0→6 area 100	3→7 area 100	3→7 area 100	0→6 area 100	1→7 area 100	0→7 area 80	01234 area 90	area 97	visible large [illegible] oriented [illegible]	NE 15-20 km/hr	6-22-77
130 01 IR	567 area 100	5678 area 100	3→8 area 100	3→7 area 100	4567 area 100	3→6 area 100	2345 area 90	0→7 area 80	12345 area 75	2 area 94	(IR)	NE 30 km/hr	
230 02 IR	3→7 area 100	4567 area 100	4567 area 100	234 area 100	3456 area 100	4567 area 100	234 area 100	34567 area 100	0→6 area 90	1 area 99	(IR)	NE 30 km/hr	
330 03 IR	2345 area 95	34567 area 100	4567 area 100	123 area 95	3456 area 95	[illegible]5 area 95	12 area 95	3456 area 95	2→7 area 70	1 area 92	(IR)	NE 30 km/hr	
430 04 IR	345 area 85	345 area 100	234 area 100	123 area 70	34567 area 100	0→5	1234 area 80	1→6 area 100	1→5 area 70	1 area 88	(IR)	NE 15 km/hr	
530 05 IR					N A								
630 06 IR					N A								
730 07 IR	012 area 35	0123 area 60	3456 area 100	012 area 85	12 area 95	012 area 90	012 area 90	012 area 95	01234 area 80	9 area 82	no 07 EIR, used 730 EIR no 730 IR. (IR)	NE drift	
08 830 IR	0123 area 55	0123 area 60	01234 area 100	012 area 75	012 area 80	012 area 80	01234 area 90	012 area 90	123 area 70	13 area 72	(IR)	NE drift	
930 09 IR	0123 line 50	0123 area 45	0123 area 95	0123 area 55	0123 area 70	[illegible] area 90	0→5 area 65	01234 area 95	0123 area 55	10 area 66	(IR)	NNE drift ~10 km/hr	
1030 10 IR	01234 area 20	0123 area 55	012 area 95	01234 area 70	01234 area 75	123 area 99	012345 area 120	01234 area 100	012 area 60	9 area 74	(IR)	NNE drift	
1130 11 IR	12345 area 80	0123 area 85	3	34 area 99	0→4 area 95	123 area 95	34 area 95	234 area 95	0123 area 60	5 area 89	(IR)	NNE drift	
1230 12 IR	01234 area 90	012 area 80	123	1234 area 95	0123 area 95	123 area 95	345 area 100	12345 area 100	0123 area 65	6 area 90	visible too dark, used IR	NNE drift	

Figure 2. Sample data sheet used in the satellite imagery study. See text for description.

Table 1

National Environmental Satellite Service
Enhanced Infrared Imagery Gray Scale Code

Category Code	Photograph Color	Temperature Range (°C)
1	Black	58.8 to 28.2
2	Gray	28.2 to 6.8
3	White	6.8 to -31.2
4	Dark Gray	-31.2 to -41.2
5	Light Gray	-41.2 to -52.2
6	Dark Gray	-52.2 to -58.2
7	Black	-58.2 to -62.2
8	Gray	-62.2 to -80.2
9	White	-80.2 to -109.2

of entries on the data sheet gives total cloud number for the entire study area. These numbers can differ from the total of all individual regions because some area and line clouds overlap into two or more regions. The comments section describes cloud orientation, thunderstorm location and intensity tendency as well as the minimum temperature found in the study area. Finally, cloud motion vectors are given as accurately as possible. However, errors in grid placement and the difficulty in estimating cloud motion from successive photographs limit the reliability of these last data values.

Several factors arose during the data extraction process which should be mentioned, because they introduce limitations to the technique. Firstly, the resolution inherent in the photographs limited the smallest detectable cloud to a diameter of three to five kilometers, thus effectively rendering invisible small fair weather cumulus cloud. This fact should be recalled when evaluating the cloud number data. Secondly, nocturnal low-level clouds were often too warm to be distinguished from the underlying surface and went undetected. Although nighttime hours may not be of primary concern for eventual cloud seeding activities, this factor does introduce a bias into the cloud number data. Finally, thunderstorms in West Texas normally develop extensive cirrus shields. These shields often develop quickly and give an erroneous impression of rapid movement of the cloud system which may be more nearly stationary. Another effect is to prevent one from establishing the location of precipitation within the area covered by the cirrus shield.

2.3. Statistical Summary.

Despite the admitted limitations in the satellite imagery approach, we believe useful information can be derived from this study. Consequently, a statistical summary of the data extracted from the photographs is being prepared at this time. The summary will display both diurnal and geographical variations of the selected cloud parameters during the Texas HIPLEX 1977 field program. Temporal and spatial variability on these scales can be of significant importance to the development of an operational cloud seeding methodology. Further discussion of planned future work on this effort is described in the final section of the report.

3. ANALYSIS OF 1976 RADIANCE DATA

The Texas HIPLEX 1976 field program took place during the period 1 June to 15 July. An intensive mesoscale data acquisition was conducted at this time, making surface, upper air and radar measurements. At the same time Colorado State University (CSU) personnel operated the ground station at White Sands Missile Range, New Mexico, gathering visible (VIS) and infrared (IR) radiance measurements from GOES WEST. On the basis of optimum availability of all data forms, several days were selected as potential intensive case study days: 3 June, 22 June, 23 June and 1 July. The raw data tapes were obtained from CSU and preprocessing and reformatting was done to prepare the data for analysis on the TTU computer system. Preliminary data analysis led to the selection of 22 June as the best case for study. The VIS and IR data are being studied with the objective of determining physical cumulus cloud properties in the Texas HIPLEX area. Cloud parameters of interest are initial time and location of development, vertical and horizontal growth rates, speed and direction of movement, and the relationship of cloud properties to meso/synoptic scale meteorological events.

3.1. Cloud/No Cloud Critical Value Study.

The visible appearance of a satellite-viewed cloud depends upon several factors, including physical cloud properties such as thickness and water phase which determine albedo, as well as non-cloud factors such as solar zenith angle which determines cloud viewing geometry and atmospheric attenuation. In order to investigate cloud properties through radiance data analysis, the non-cloud produced variations must be dealt with. The effect of cloud illumination and viewing geometry upon measured visible radiances is receiving attention. However, this factor is not yet considered in our method. A first-order effect is the atmospheric attenuation change with solar zenith angle.

A simple means of correcting for attenuation variations caused by solar zenith angle change through Beer's law has been applied to the data. According to Beer's law. When a target viewed at a zenith angle θ is illuminated at a solar zenith angle θ_o, the measured direct-beam radiance R is given by

$$R = \alpha R_o e^{-\tau \sec\theta} \; e^{-\tau \sec\theta_o} , \tag{1}$$

where R_o is the unattenuated irradiance, α is the target albedo and τ is the effective optical thickness of the atmosphere, which is essentially constant for a given day. For the GOES system viewing the Texas HIPLEX area, θ is essentially constant and variations in R are produced by the diurnal variation of θ_o. The ratio of R at different solar zenith angles is

$$\frac{R(\theta_{o2})}{R(\theta_{o1})} = \frac{\alpha R_o e^{-\tau \sec\theta} \; e^{-\tau \sec\theta_{o2}}}{\alpha R_o e^{-\tau \sec\theta} \; e^{-\tau \sec\theta_{o1}}} \tag{2}$$

or

$$R(\theta_{o2}) = R(\theta_{o1}) e^{-\tau(\sec\theta_{o2} - \sec\theta_{o1})} \tag{3}$$

Eq. (3) is valid if target albedo is constant and second-order scattering effect can be ignored. Finally, because the VISSR data value is proportional to radiance, (3) can be written

$$VIS_2 = VIS_1 \; e^{-\tau(\sec\theta_{o2} - \sec\theta_{o1})} , \tag{4}$$

where VIS_1 and VIS_2 are visible data values at solar zenith angles θ_{o1} and θ_{o2}, respectively.

The Automated Digital Video Imaging System for Atmospheric Research (ADVISAR) at CSU was used to determine VIS_1 and VIS_2 at two times on June 22. The particular VIS values sought were those which distinguished between cloud and non-cloud pixels. The times selected corresponded to minimum and maximum solar zenith angle for the day and were 1845GMT and 0115GMT (June 23), respectively. Choice of these times minimized error in determining τ whose value was found to be 0.124.

Critical VIS values delineating between cloud and non-cloud pixels were computed for all times of interest and are given in Table 2. The VIS data range from 0 to 255 in increments of 4. Also, some slight adjustments were made for low-sun conditions. The adjusted values are listed in the last column of Table 2, and were used for subsequent analysis.

3.2. Cloud Summary Program Results.

A computer program to summarize cloud radiance data was obtained some time ago from CSU. The program has been adapted and modified for use at TTU. The cloud summary program searches an array of VIS data and locates clouds. An important input parameter is the critical value, VIS_{crit}, discussed in Section 3.1, to distinguish between cloud and non-cloud pixels. The program algorithm locates isopleths of VIS_{crit} and defines them to be cloud boundaries. Program outputs include size, mean and maximum brightness and geometric center for each cloud found. A summary of the results for 22 June are presented in Table 3 and displayed in Figure 3. Of interest are the diurnal variation of cloud number, percent cloud cover and cloud/non-cloud brightness ratio. The number of clouds in the study area decreases slightly through the afternoon. Percent cloud cover decreases until approximately 2200GMT (5 p.m. CDT) and then rises sharply. The cloud/non-cloud brightness ratio also decreases until 2200GMT and then increases rapidly. The mutual behavior of these three parameters indicates the arrival of a brightness mass of rather large clouds in the late afternoon. The Big Spring field site monitored the gust-front cloud system well into the night hours.

The radiance-derived results will be compared to imagery-derived results and described in subsequent reports.

3.3. Temperature-Time Cross Sections

Utilization of the IR data is principally focussed upon the extraction of cloud-top temperatures. The IR data can be converted to temperature values using the available NESS standard calibration curve. Temperatures can then be related to altitude to infer cloud height if sounding data are available. Such information is available through

Table 2

Critical Values in the Visible Radiance Data
to Distinguish between Cloud and Non-Cloud Points
on 22 June 1976

Time (GMT)	θ_o	sec θ_o	Critical Value	Adjusted Value
1745	16.0	1.040	115.6	116
1815	11.0	1.019	115.8	116
1845	8.5	1.011	116.0	116
1915	11.0	1.019	115.8	116
1945	16.0	1.040	115.6	116
2015	21.5	1.075	115.1	116
2045	27.5	1.127	114.2	116
2115	33.5	1.199	113.3	116
2145	40.0	1.305	111.8	112
2215	46.5	1.453	109.8	112
2245	53.0	1.662	107.0	108
2315	59.5	1.970	103.0	104
2345	65.5	2.411	97.5	96
23 JUN 0015	71.5	3.152	88.0	84
23 JUN 0045	77.5	4.620	74.1	68
23 JUN 0115	83.5	8.834	44.0	44

Table 3

Radiance-Derived Cloud Summary Results
for 22 June 1976 in the Texas HIPLEX Area

Time (GMT)	Critical VIS Value	Percent Cloud Cover	Number of Clouds	Mean Area Brightness	Mean Cloud Brightness	Mean Non-Cloud Brightness	Cloud to Non-Cloud Ratio
1745	116	28	66	110	144	96	1.50
1815	116	29	77	111	143	98	1.46
1845	116	28	58	110	140	98	1.43
1945	116	28	51	112	143	100	1.43
2015	116	26	73	110	141	100	1.41
2045	116	24	60	109	140	99	1.41
2115	116	22	46	107	138	98	1.41
2145	112	20	68	102	131	95	1.38
2215	112	16	66	98	128	92	1.39
2245	108	18	50	93	126	87	1.45
2315	104	20	58	89	122	80	1.53
2345	96	21	44	81	111	73	1.52
23 JUN 0015	84	22	52	70	97	63	1.54
23 JUN 0045	68	31	40	59	81	50	1.62
23 JUN 0115	44	38	58	43	57	35	1.63

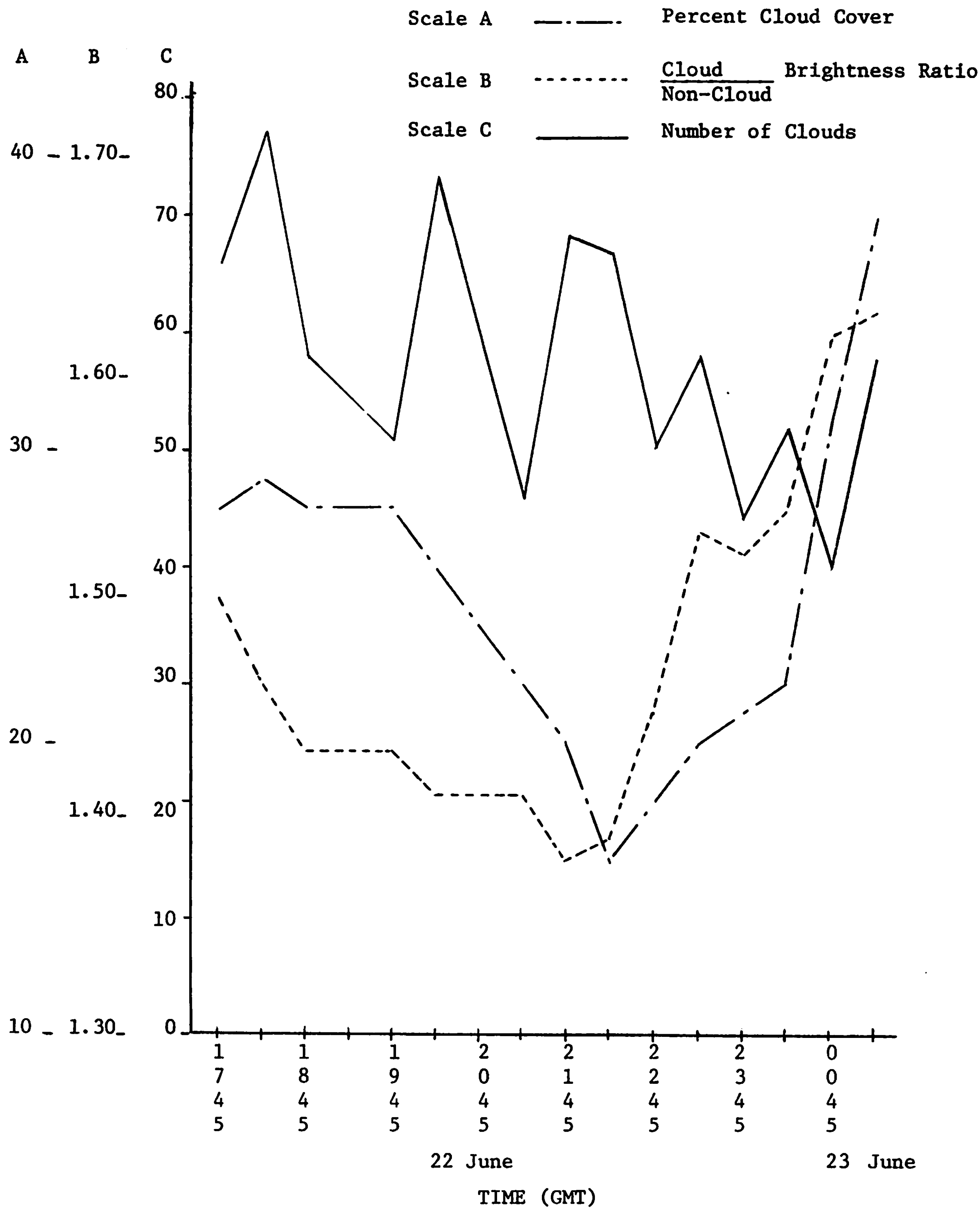

Figure 3. Variation on 22 June 1976 in the Texas HIPLEX Area of radiance-derived cloud number, percent cloud cover and cloud/non-cloud brightness ratio.

the mesoscale project conducted by Texas A&M University (TAMU). Soundings were taken at 3-hour intervals at Big Spring, Midland, Post and Robert Lee. Temperature versus time cross-sections have been constructed for each station and are displayed in Figures 4, 5, 6 and 7. We see that the isotherms are nearly horizontal with time and very similar from station to station. It appears justified to use a single sounding throughout the day for the entire study area, considering inherent limitations in accuracy of both the radiosonde and satellite data. This "average" sounding is shown in Figure 8. Regions of departure from the average can be accounted for using Figures 4 through 7, if deemed necessary.

3.4. Computer-Generated Plots

The display of radiance in a hard-copy format is of significant value to the data analysis. The ADVISAR system at CSU has been modified to generate color videotapes of the monitor. In this way, a record of activity there can be maintained for reference at TTU. In addition, printed maps of the raw data have been produced for detailed analysis.

In addition, computer-generated plotted maps of the Texas HIPLEX area have been developed. Examples of one type of plot for 1745GMT on 22 June 1976 are given in Figures 9 and 10 for VIS and IR data, respectively. In Figure 9, each box represents a region within which the average of VIS data points exceeded the VIS_{crit} of 116 for this time. The 300 km X 300 km study area corresponds to a VIS data array of 216 X 216 values. These were averaged to a 54 X 54 area, which matches the much poorer resolution of the IR data array. The 54 X 54 data array was used to produce Figure 9. Thus, each box represents the average of an 8 row X 4 column array, or a 6 X 6 km area. Figure 10 is a plot of the IR data, whose inherent resolution for the 300 X 300 km study area yields a 54 X 54 array. Empty boxes represent a temperature value between 0 and -10°C, boxes with a dot in the center represent a temperature between -10 and -20°C and blank areas represent temperature greater than 0°C. Different symbols are available for other temperature intervals.

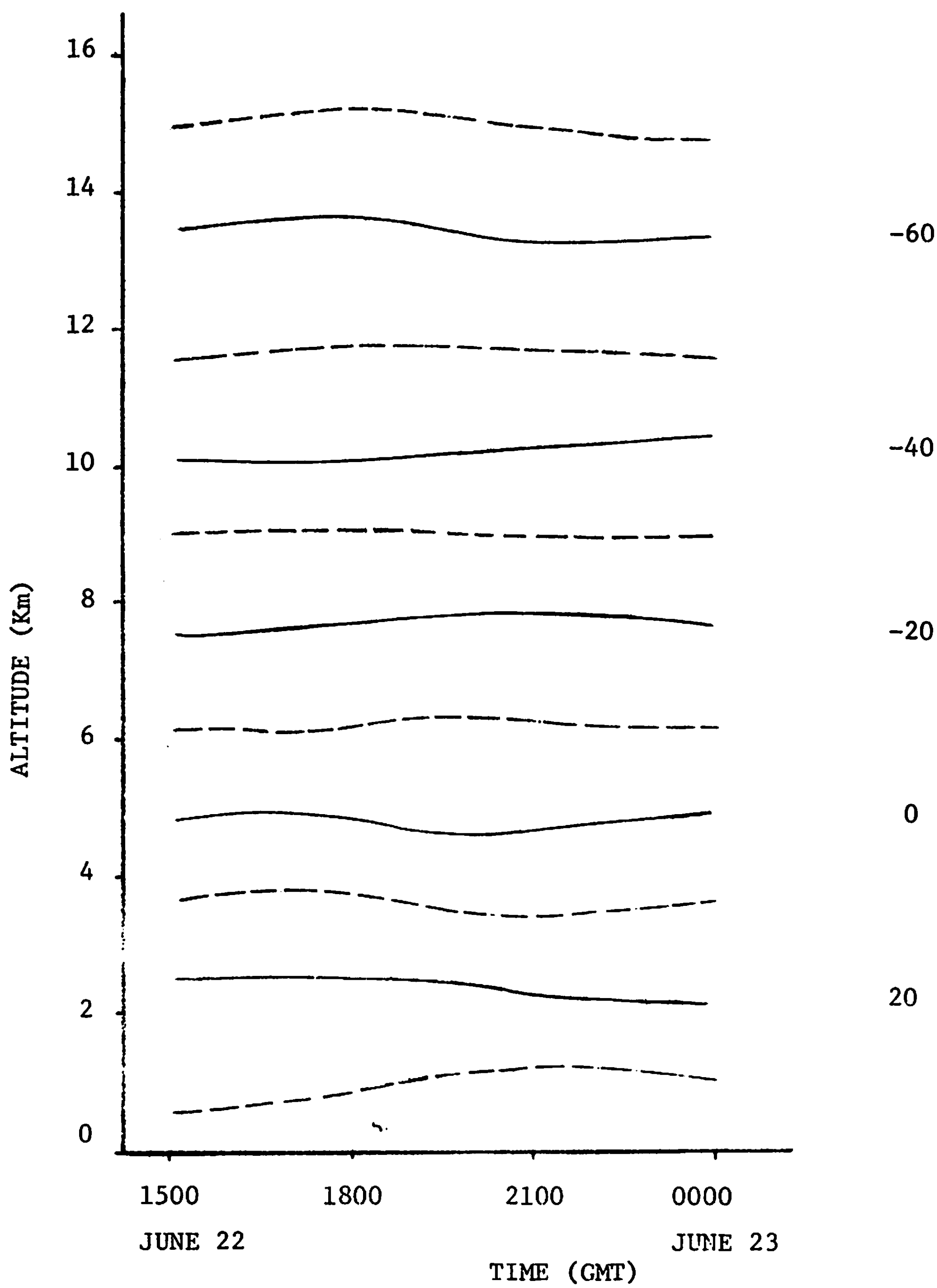

Figure 4. Altitude and time variation of temperature on 22 June 1976 at Big Spring, Texas.

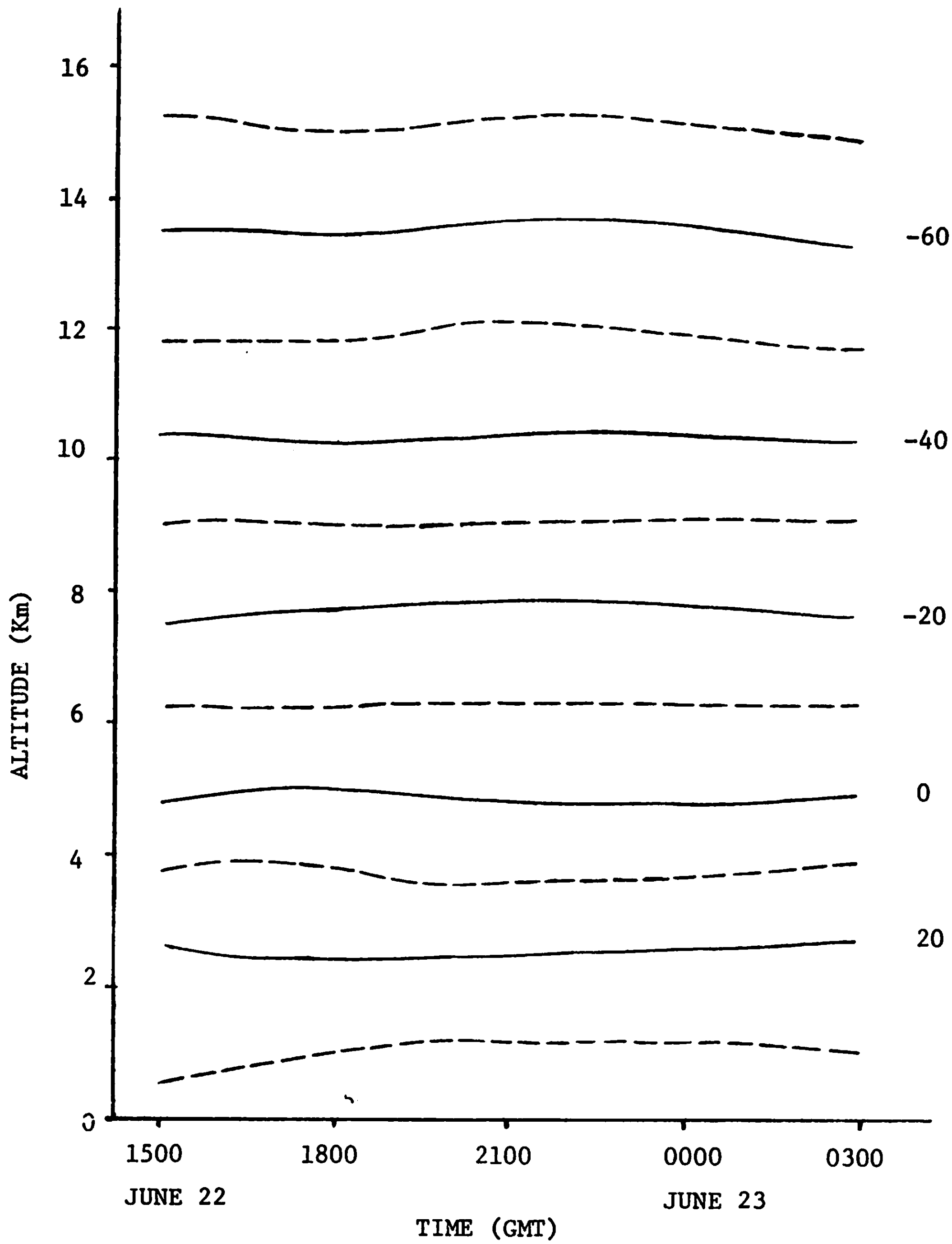

Figure 5. Same as Figure 4 for Midland, Texas.

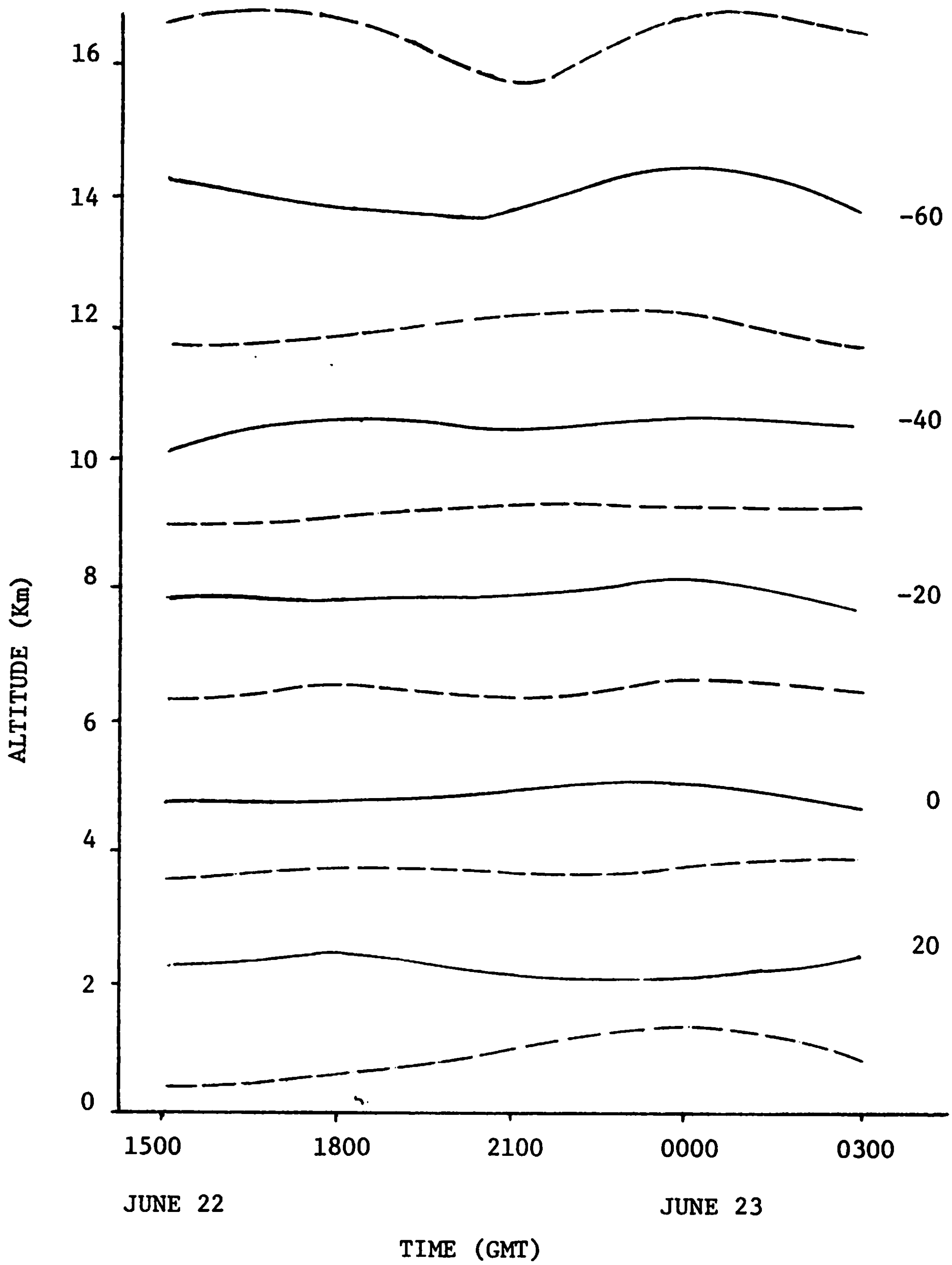

Figure 6. Same as Figure 4 for Robert Lee, Texas.

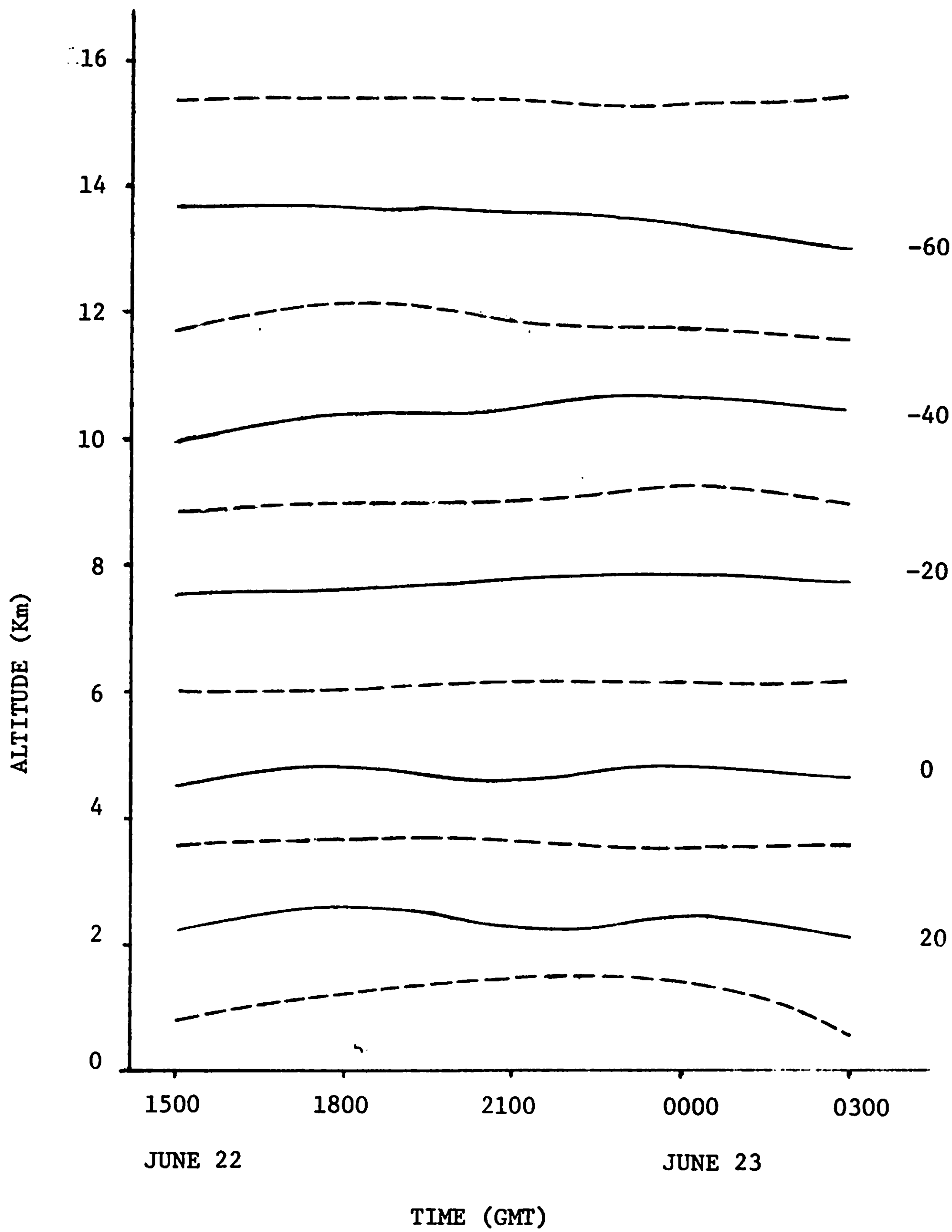

Figure 7. Same as Figure 4 for Post, Texas.

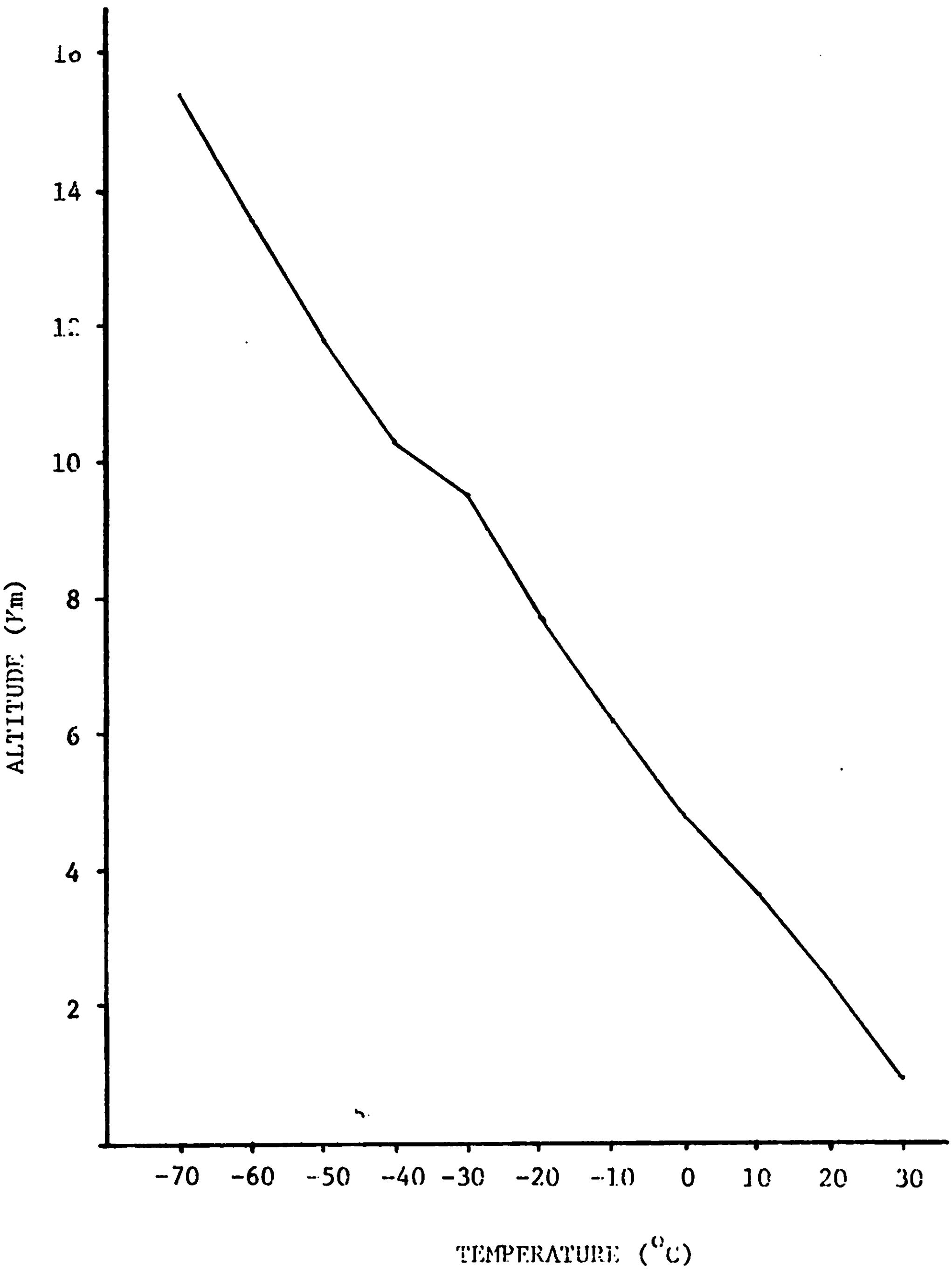

Figure 8. The "average" sounding for the Texas HIPLEX area on 22 June 1976.

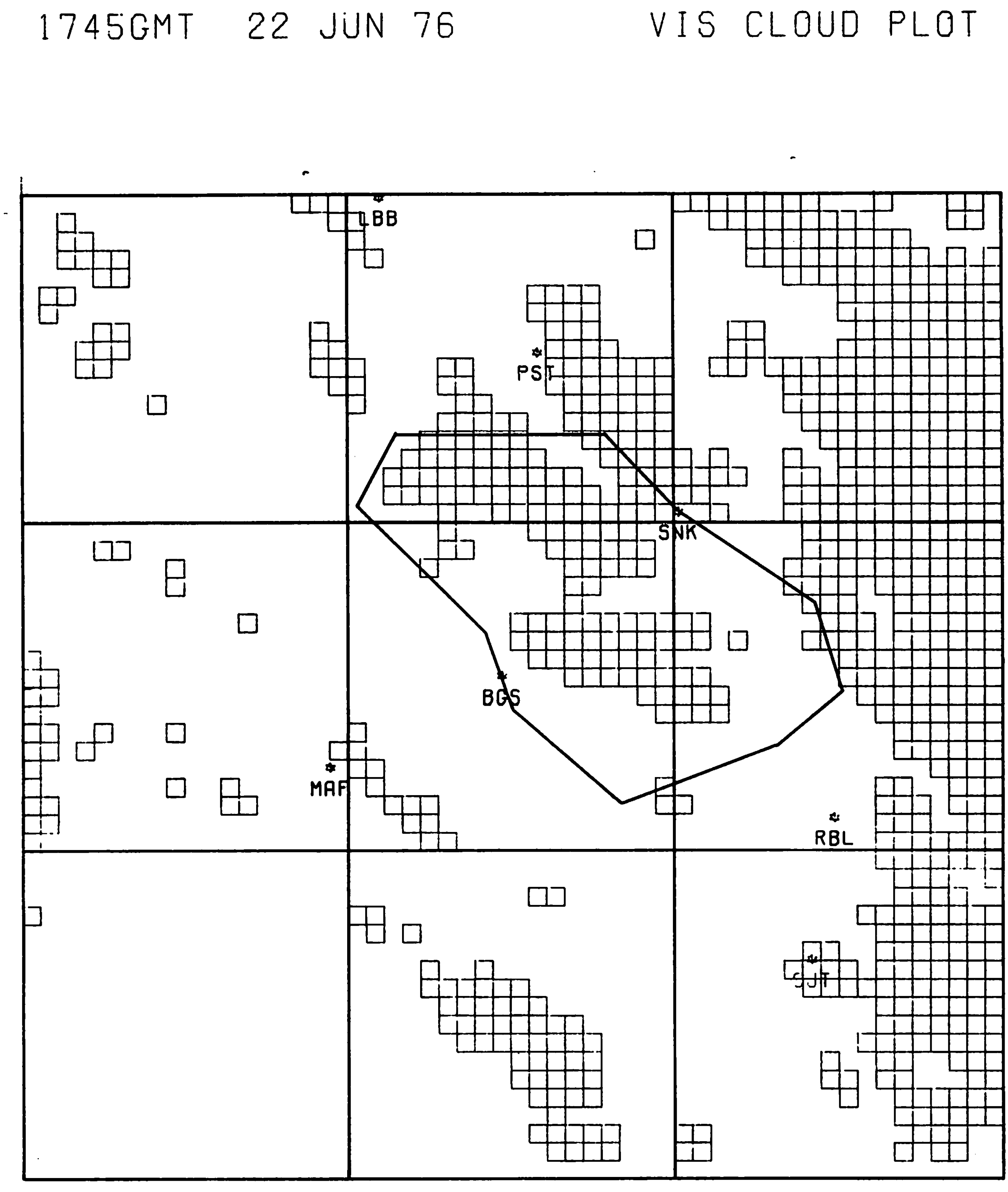

Figure 9. Computer-generated plot of VIS data at 1745GMT on 22 June 1976 in the study area.

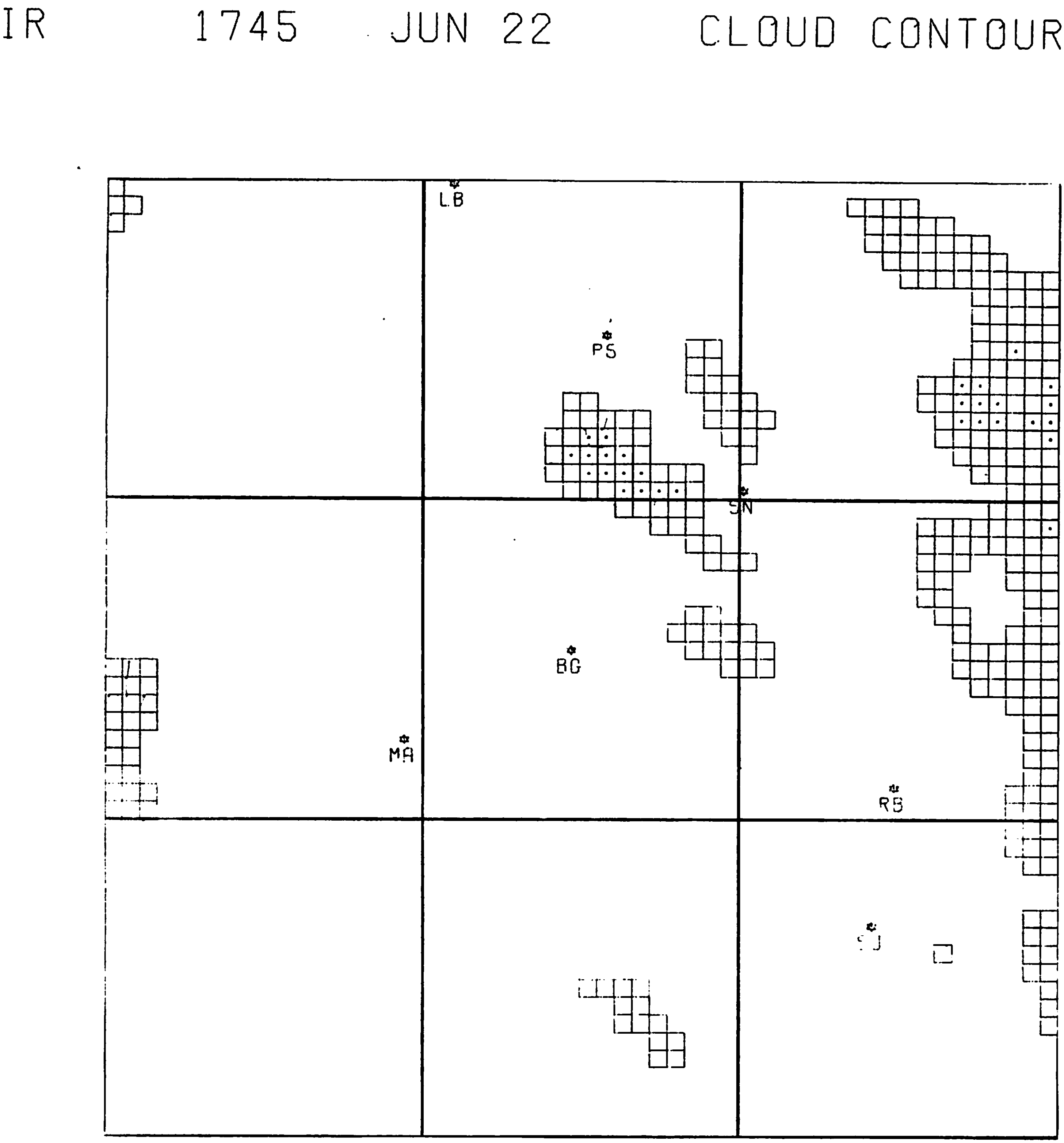

Figure 10. Same as Figure 9 for IR data.

Study of VIS data plots such as Figure 9 throughout the data period revealed a problem. The VIS data had been averaged to produce an array of practical size for the computer algorithm and of comparable resolution to the IR data. However, small cloud features were found to have been lost in the averaging process. Consequently, another plotting approach was sought. An isopleth contouring algorithm is being modified to our needs at this time. Examples of the current, but unfinished, status of the plots are shown in Figures 11 and 12, which correspond to Figures 9 and 10, respectively. At present isopleths of radiance (isorads) are unlabelled. This and other improvements are currently underway.

3.5. Infrared Data Location Error.

The VIS and IR sensors aboard GOES simultaneously scan a west to east path, then step down and scan again. However, a hardware misalignment causes an east-west offset in the data. Preliminary investigation indicates an offset of the IR sensor some 2 or 3 IR pixels (12 to 18 km) to the right of the VIS sensors.

Accurate correction of this problem will require well-matched data sets of comparable resolution. Consequently, both to solve this difficulty and to improve the efficiency of the computer-generated plotting techniques discussed in Section 3.4, an optimum array size is being sought for both VIS and IR data. At this time an array of 108 X 108 pixels appears best. Generation of arrays of this size will require averaging in the VIS data to reduce its array size and interpolation in the IR data to increase its array size. Optimal techniques are being sought for each case. Care must be exercised in this matter, because of the strong radiance gradients which exist across cloud boundaries. When matched data sets are produced by this approach, the IR data offset problem can be solved in a straightforward manner.

3.6. Cloud Motion Vector Study.

A major interest in analysis of radiance data is the determination of cloud motion in an objective manner. The difficulties encountered in attempting to estimate cloud motion with imagery have served to reinforce the importance of this objective. Present efforts involve the determination of all cloud brightness center

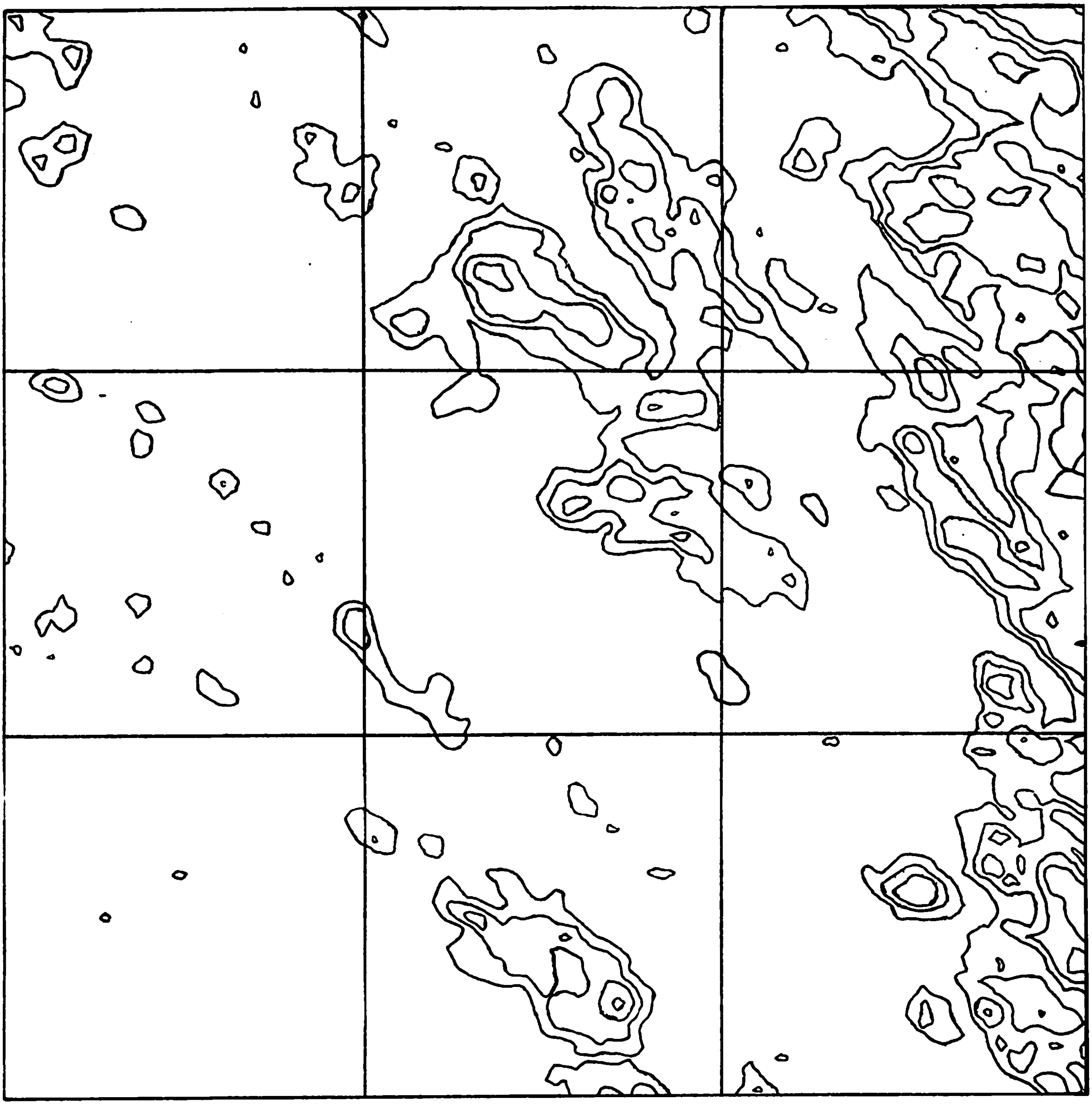

Figure 11. Computer-generated isopleth analysis of VIS data at 1745GMT on 22 June 1976 in the study area.

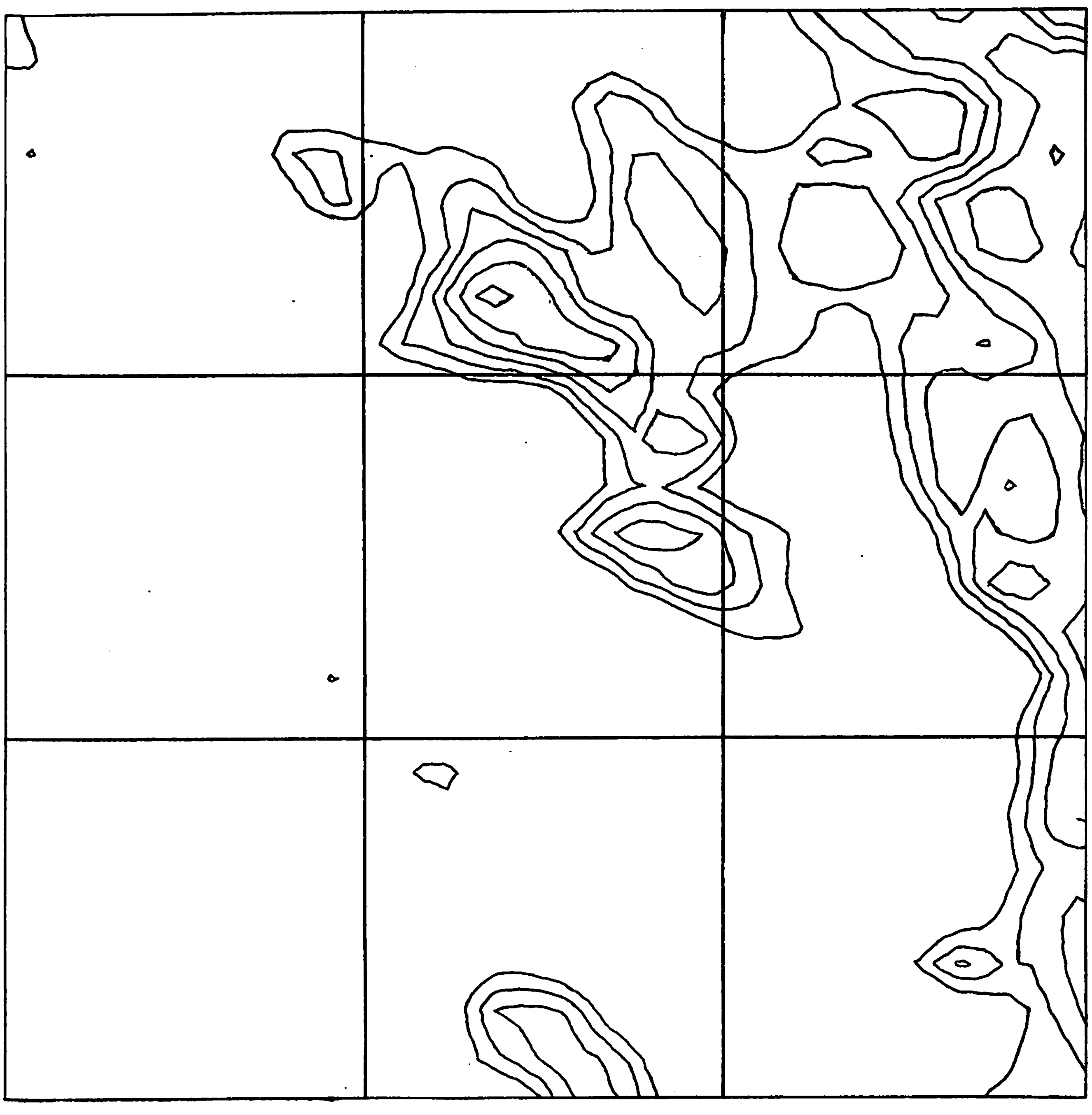

Figure 12. Same as Figure 11 for IR data.

locations in two successive sets of VIS data. A technique is being developed to search for the spatial displacement in the two arrays which maximizes the corelation of their two patterns of brightness center location. Division of the spatial displacement by the time interval between data sets yields a mean cloud motion vector for the area. This effort is just being initiated and will be pursued in the following months.

4. PLANNED WORK

Future work in the next 6-months consists of six main tasks, described below.

4.1. Comparison of Imagery Results from 1976 and 1977.

The analysis of cloud parameter data extracted from imagery gathered during the 1977 Texas HIPLEX field program is near completion. As soon as this task is completed, a comparison between 1976 and 1977 imagery-derived cloud characteristics will be undertaken. Such a comparison will reveal year-to-year variability in the cloud populations as well as similarities in the two sets of data. The 1976 summary was based upon visible imagery alone, while both visible and enhanced IR imagery were available in 1977. Although a complicating factor in the comparison exists because of this fact, it may well serve to document the extent to which enhanced infrared imagery increased the capability of imagery studies. When the comparison is completed a technical report treating the two-year imagery will be prepared and submitted for approval.

4.2. Computer-Generated Plots.

Several improvements remain to be added to the plotting algorithms described in Section 3.4. One particularly valuable feature will be the labelling of isorads. The availability of good hard copy records of the data will add to analysis capabilities.

4.3. Infrared Cloud Summary Program.

It is planned to develop a computer algorithm to search the IR data arrays in a similar manner to that already operational for VIS data. The results from such IR cloud properties will be of significant value to the tasks described in Sections 4.4, 4.5 and 4.6.

4.4. Radar Data Comparison.

The main goal of the Texas HIPLEX Satellite Project is to develop techniques by which satellite data can be integrated into an operational water resources management program. To achieve this end it is necessary to demonstrate that the satellite data: (1) are consistent with conventional data, such as weather radar, surface measurements and upper air soundings, and (2) can yield information in addition to that derivable from these observation platforms.

To this point, the majority of effort has been devoted to development of analysis techniques for the satellite data. The availability of digitized radar data from the Meteorology Research, Incorporated (MRI) installation at Snyder, Texas, provides an excellent opportunity for inter-system comparison. This comparison will be initiated on a case study basis in the near future.

4.5. Cloud Motion Vector Study.

The cloud motion vector effort has been initiated and is described briefly in Section 3.6. This task will benefit substantially in its progress from the successful completion of the availability of computer-generated plots, an IR data summary computer algorithm and radar/satellite data comparisons.

4.6. Cirrus Study.

The presence of cirrus clouds in the study area substantially complicates the data analysis process. Cirrus clouds cover underlying area of interest where convection is occurring and prevent the determination of cloud properties below. The presence of cirrus at upper levels may well influence physical processes below; for example, the reduced solar irradiance upon the shadowed surface may lead to reduced free convection.

Once the results are available from the tasks described in Sections 4.2, 4.3 and 4.4, the presence of cirrus clouds within the study area will be given serious attention. Techniques will be developed to detect cirrus and account for its presence in the data analysis.

5. ACKNOWLEDGMENTS

Mr. Shwe-Yi Chi and Mr. Shih-Cheng Chao have made major contributions to this effort both in analysis of data and preparation of this report. The extraction of cloud parameters by Mr. Russell Pfost and computer programming by Ms. Vicki Thrasher and Mr. Don Williams has been most helpful. In the support of Mr. Robert Suddarth in preparation of figures and of Ms. Debbie Kerr in typing the manuscript is most appreciated. Finally, I wish to recognize the assistance of Mr. Bill Crouch, Meteorologist in Charge of the National Weather Service Forecast Office in Lubbock in acquiring satellite imagery.

TEXAS TECH UNIVERSITY

"PRECIPITATION CLIMATOLOGY

FOR THE SOUTHERN HIPLEX REGION (TTU)"

The following report is the result of studies by the Principal Investigator of the program to develop a precipitation climatology for the Southern HIPLEX Region. The work was conducted under two contracts (numbers 14-70029 and 14-80001) between the Department and the Department of Geosciences, Texas Tech University during the period May 5, 1977 through February 28, 1978. Negotiations were begun during the reporting period with Dr. Haragan for the expansion of the precipitation climatology to include a detailed investigation of storms passing through the Texas HIPLEX precipitation-gage network and an analysis of case studies in conjunction with radar and mesoscale data studies being performed at Texas A&M University and satellite studies at Texas Tech University.

PRECIPITATION CLIMATOGRAPHY FOR THE HIPLEX SOUTHERN REGION

Donald R. Haragan
Texas Tech University
Lubbock, Texas 79409

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ABSTRACT

A climatography of clouds and precipitation was prepared for the Hiplex Southern Region. Results include the frequency of rain periods, the distribution of rainfall amounts during a rain period, the duration of rain periods and the variation of precipitation based on 7-day running means during the rainy season. Patterns of clouds and precipitation which characterize the Hiplex Southern Region and meso-synoptic events responsible for precipitation are identified. A study of precipitating cloud cells utilizing 15-minute recording rain gage data was initiated to provide information on the frequency, intensity, size, velocity and duration of storms affecting the area.

Key words: Weather Modification, Precipitation, Clouds, Water Resources

PREFACE

Advances in the science of weather modification have provided an opportunity for significant progress in the area of precipitation management. The problem of designing and evaluating cloud-seeding experiments has been accentuated, however, by a lack of adequate statistical data to define quantitatively the natural variability of precipitation in the target and surrounding areas. The climatography presented here provides a data base for the natural variability of clouds and precipitation in the Hiplex Southern Region.

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I. INTRODUCTION

The proper design and subsequent evaluation of weather modification experiments are dependent ultimately on a knowledge of the natural variation of precipitation within the experimental or operational area. The purpose of this study is to provide a quantitative cloud and precipitation climatography for the Hiplex Southern Region in order to establish a "natural variability" base upon which a cloud seeding experiment can be designed and evaluated.

The primary objective is to describe as completely and concisely as possible the patterns of clouds and precipitation which characterize the Hiplex Southern Region and their variability in space and time. The following analyses and/or tasks were undertaken in order to satisfy this objective:

(1) Derivation of patterns of mean monthly precipitation based upon 30-years of monthly precipitation data from the cooperative observer network.

(2) Computation of inter-station correlation coefficients based upon the monthly precipitation data with implications regarding scale and storm track analysis.

(3) Computation of rainfall statistics based on approximately 55 years of daily rainfall records at Big Spring, Snyder and Lamesa, Texas. Results include the frequency of rain periods, the distribution of rainfall amounts during a rain period, the duration of rain periods and the temporal variation of precipitation based on 7-day running means from 1911 to 1969.

(4) Identification of meso-synoptic patterns responsible for precipitation events.

(5) Analysis of the seasonal and diurnal variation of clouds and weather events based upon hourly observations at Midland, Lubbock and Abilene.

(6) Initiation of a comprehensive study of precipitating cloud cells utilizing 15-minute recording rain gage data. These analyses include information on frequency, intensity, size, velocity and duration of storms affecting the area.

II. SEASONAL VARIATION OF PRECIPITATION

The Hiplex region of West Texas, shown in Figure 1, is characterized by rapid changes in temperature, marked extremes and large temperature ranges both daily and annually. The average annual rainfall at Big Spring is 17.39 inches, two thirds of which occurs during the six-month period, April through September. The spring and summer rainfall is made up of a few relatively large storm systems while September rains reflect the occasional flow of moist, tropical air into the area from the Gulf of Mexico. The period of interest in this investigation extends from May to September with particular emphasis in the late spring and early summer.

Figures 2 and 3 show seven-day running means of daily precipitation totals for the five-month period May through September at Big Spring and Snyder respectively. These curves are based upon 55 years of daily precipitation records at the two stations. Both curves show a maximum in mid-May decreasing to a minimum in late June. In both cases there are secondary maxima centered on July 4 and July 22 with a relative minimum on July 14 and during the first week of August. Precipitation increases from the early-August minimum to a broad maximum in late August and early September. From the standpoint of opportunities, the period from mid-May to mid-June is probably the most desirable time in which to conduct a rainfall augmentation experiment. As will be seen later, however, the efficiency of natural rain producing mechanisms is quite high during this period.

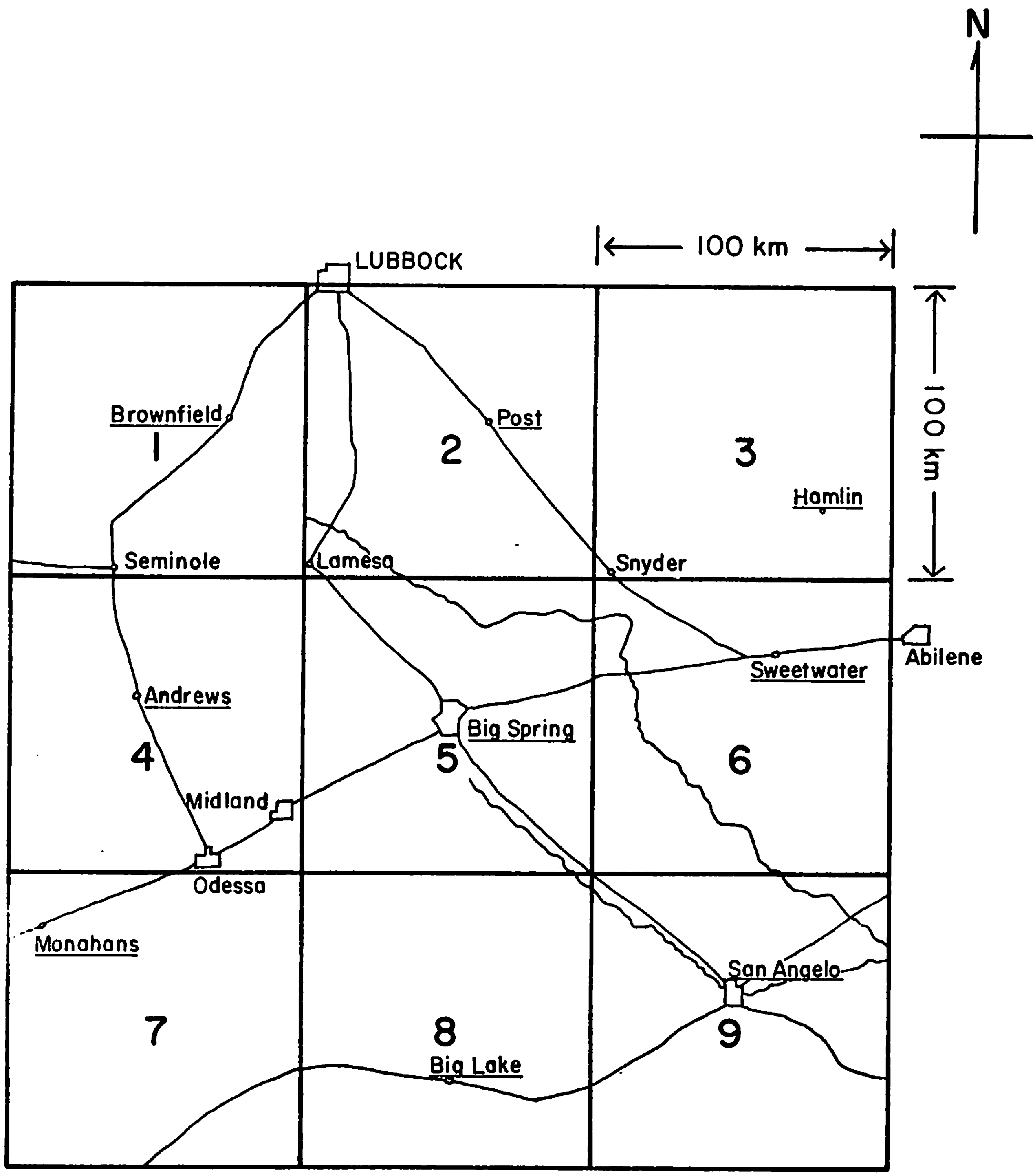

Figure 1. The area of study. Each region is denoted by number as well as by a city name.

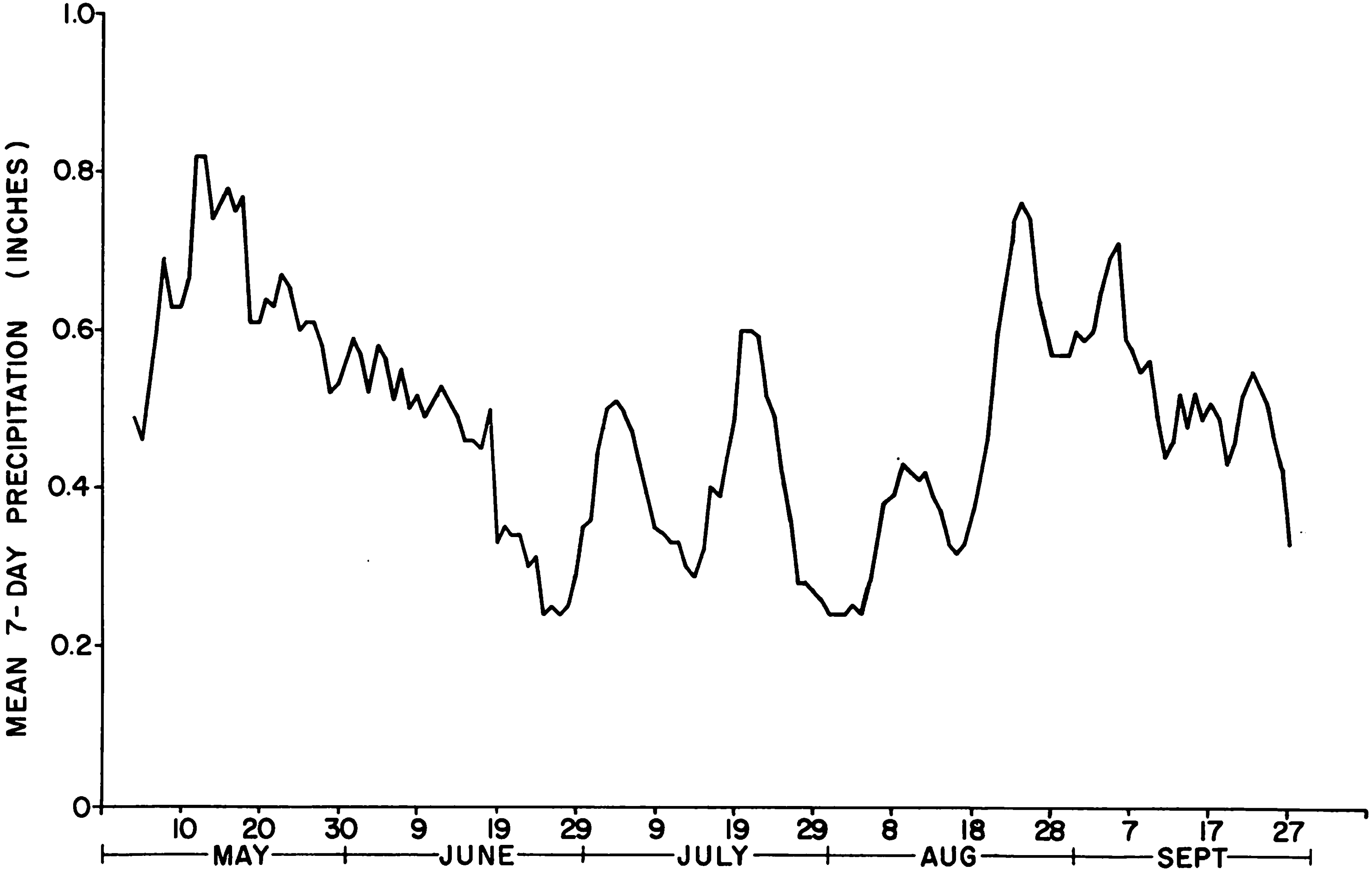

FIG. 2. DAILY PRECIPITATION 7-DAY RUNNING MEANS
BIG SPRING

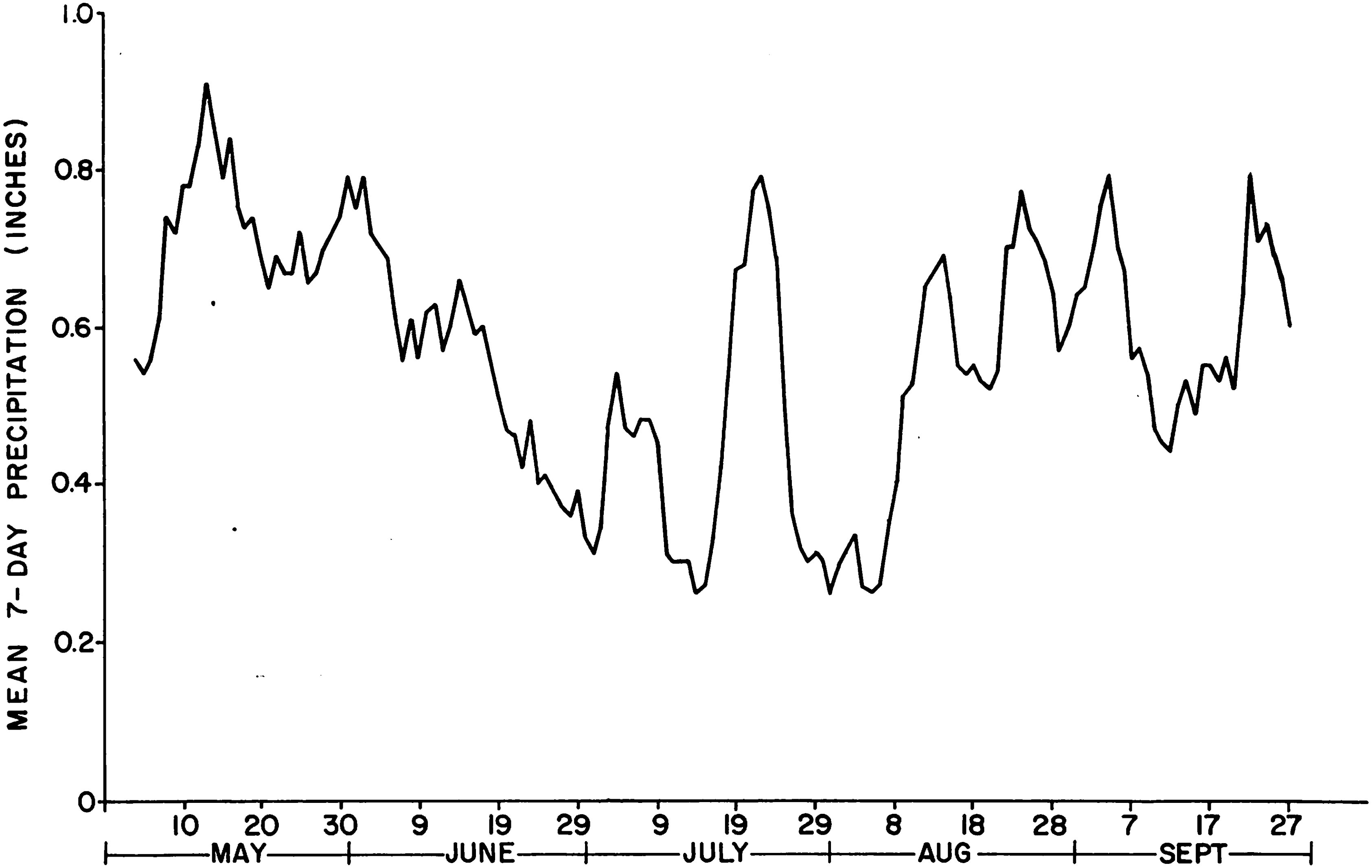

FIG. 3. DAILY PRECIPITATION 7-DAY RUNNING MEANS
SNYDER

III. SPATIAL DISTRIBUTION OF MEAN MONTHLY PRECIPITATION

Figures 4 through 8 show the distribution of mean monthly precipitation for the months of May through September based upon the 27-year period from 1944 to 1970. Data from more than 70 reporting stations are used in these analyses. Extending the period of record to include the years after 1970 was undesirable because of the contamination-potential of an operational rainfall augmentation program which began in 1971 under sponsorship of the Colorado River Municipal Water District.

It is important to realize that the sequence of meteorological events leading to precipitation in one season of the year are not the same as those producing precipitation at other times of the year (Haragan, 1976). Precipitation during spring and early summer is usually due to violent convective activity set off by frontal or upper air disturbances. Once the vertical motion is provided, precipitation usually results. Summer rains are generally scattered shower developments which depend mainly on daytime heating, low-level moisture and an absence of subsidence aloft.

The distribution in May shows a rather uniform decrease in precipitation from east to west across the Hiplex area. While Midland receives only slightly more than 2 inches, Big Spring receives about 2.5 inches and Snyder receives more than 3 inches. In June, total amounts of precipitation are less, but the variation across the Hiplex region is about the same as in May except for a shift to more of a northeast-southwest orientation. The July pattern is much less organized as indicated by the 2-inch isohyet. This reflects the scattered nature of precipitation characterizing the summer season. August is a bit more organized with a broad maximum running from Muleshoe to Seymour and generally lesser amounts of rainfall than in July. Precipitation increases in September and once again exhibits a definite east to west gradient.

Further insight into the nature of the spatial distribution of rainfall is provided by space-autocorrelation analysis. Correlation coefficients utilizing more than 2600 station-pairs were computed and smoothed to yield the correlation-distance curves shown in Figure 9. These curves have been smoothed by averaging the correlations over 10-mile distance intervals independent of direction. Since monthly rainfall totals were used, the coefficients are below those for individual events but yield information on the average sizes and paths of the storms. The shape of the curves, showing a rapid decrease of mean correlation

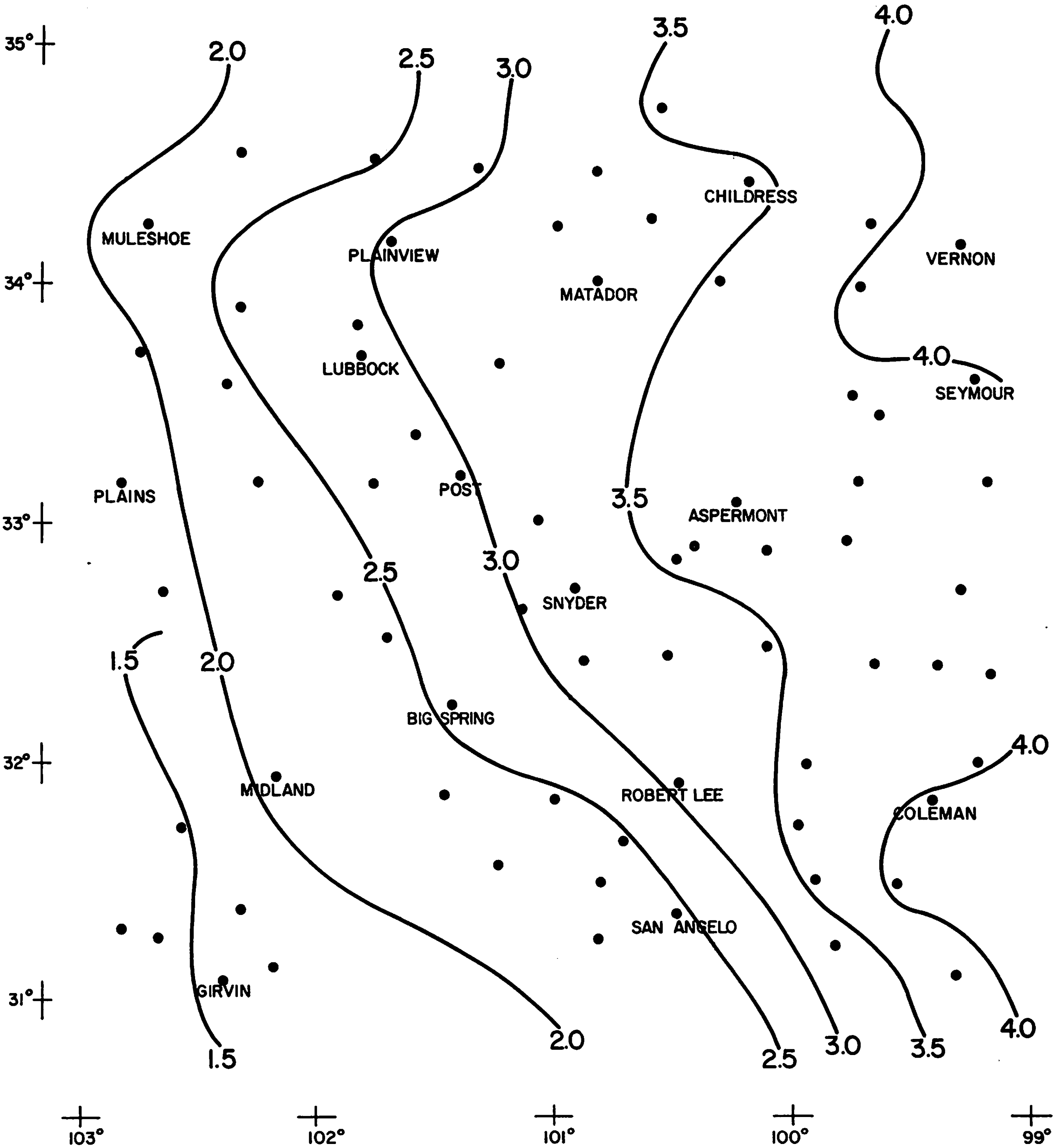

FIG. 4. MEAN MONTHLY PRECIPITATION - MAY

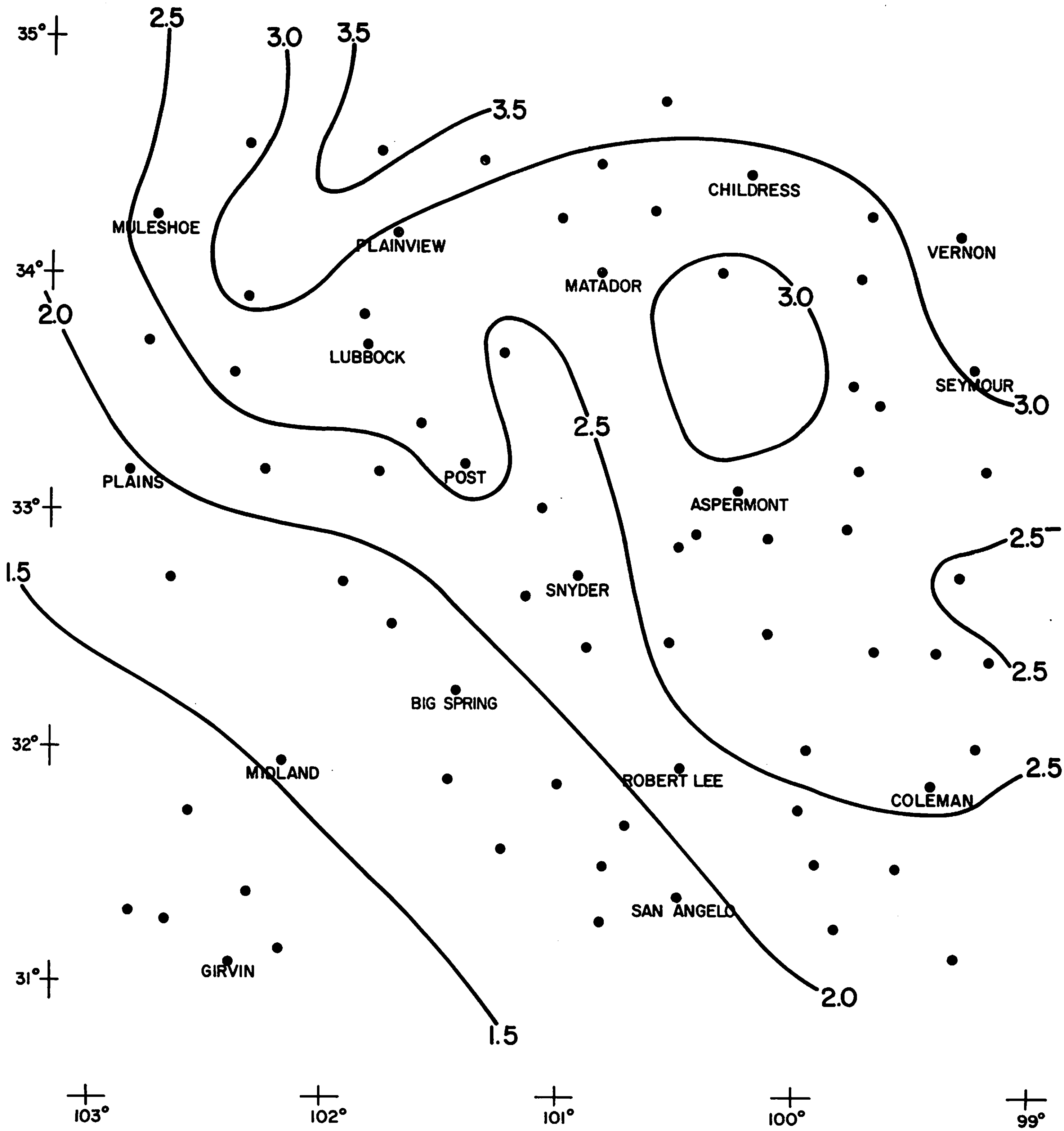

FIG. 5. MEAN MONTHLY PRECIPITATION - JUNE

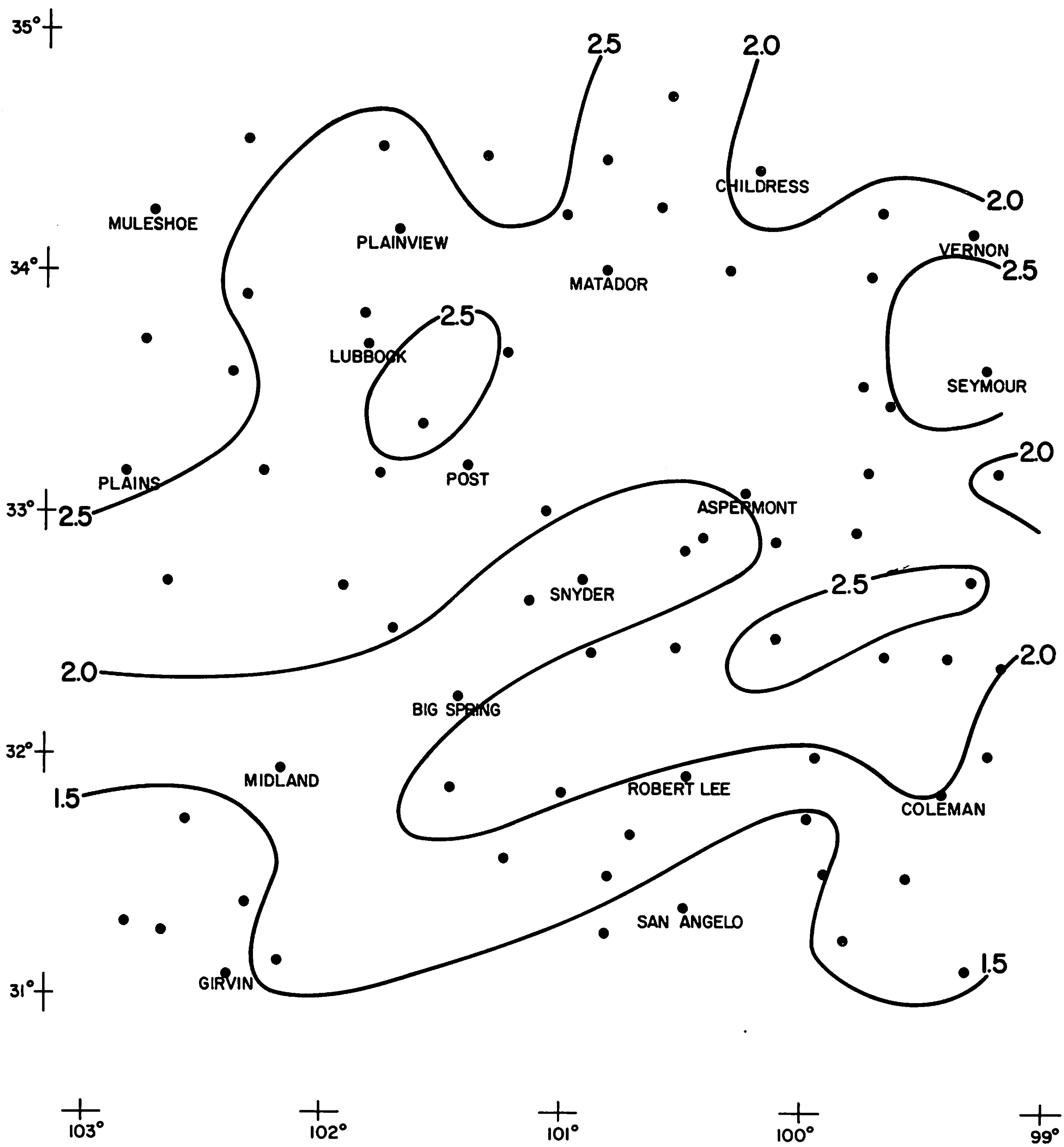

FIG. 6. MEAN MONTHLY PRECIPITATION - JULY

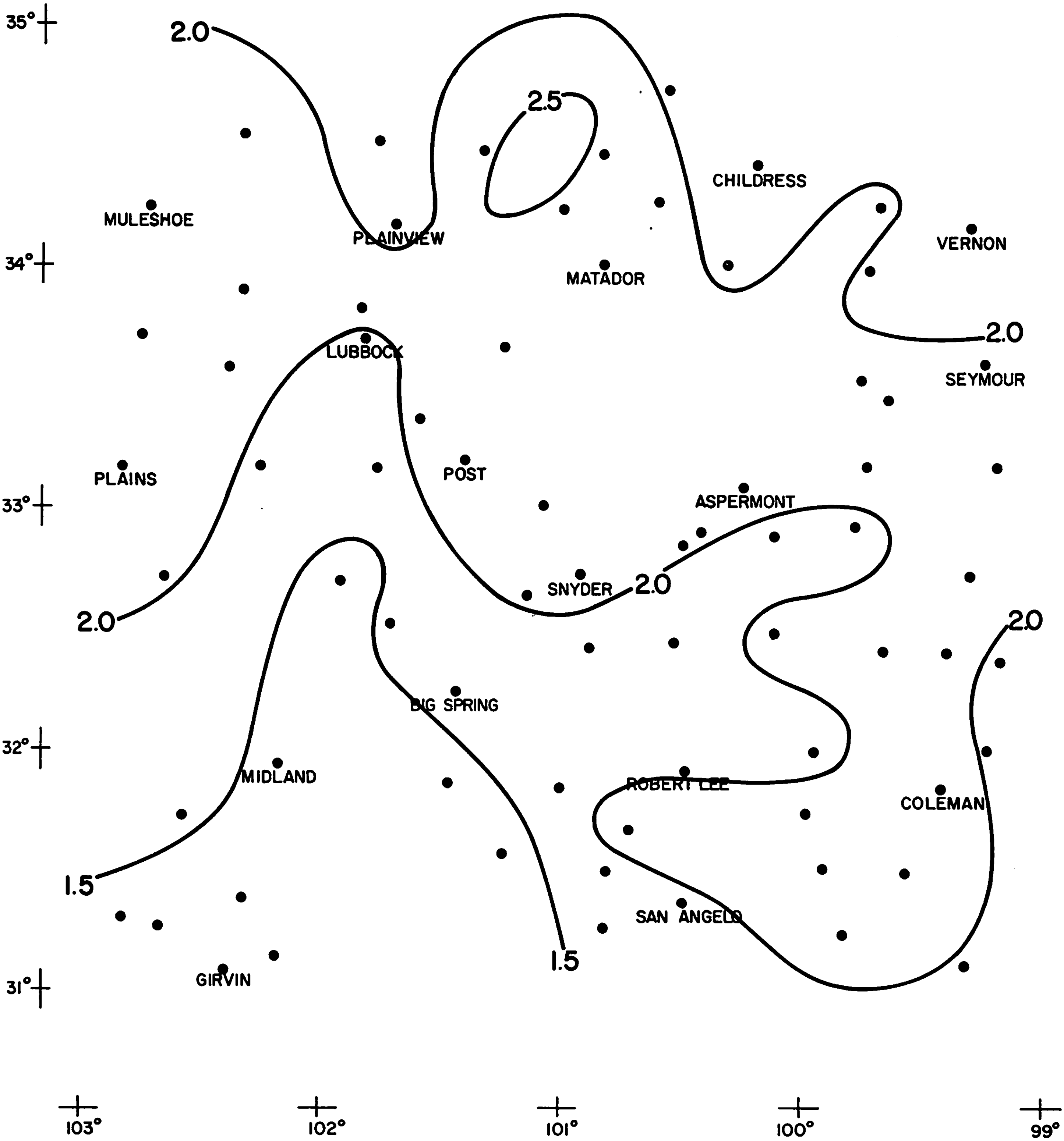

FIG. 7. MEAN MONTHLY PRECIPITATION - AUGUST

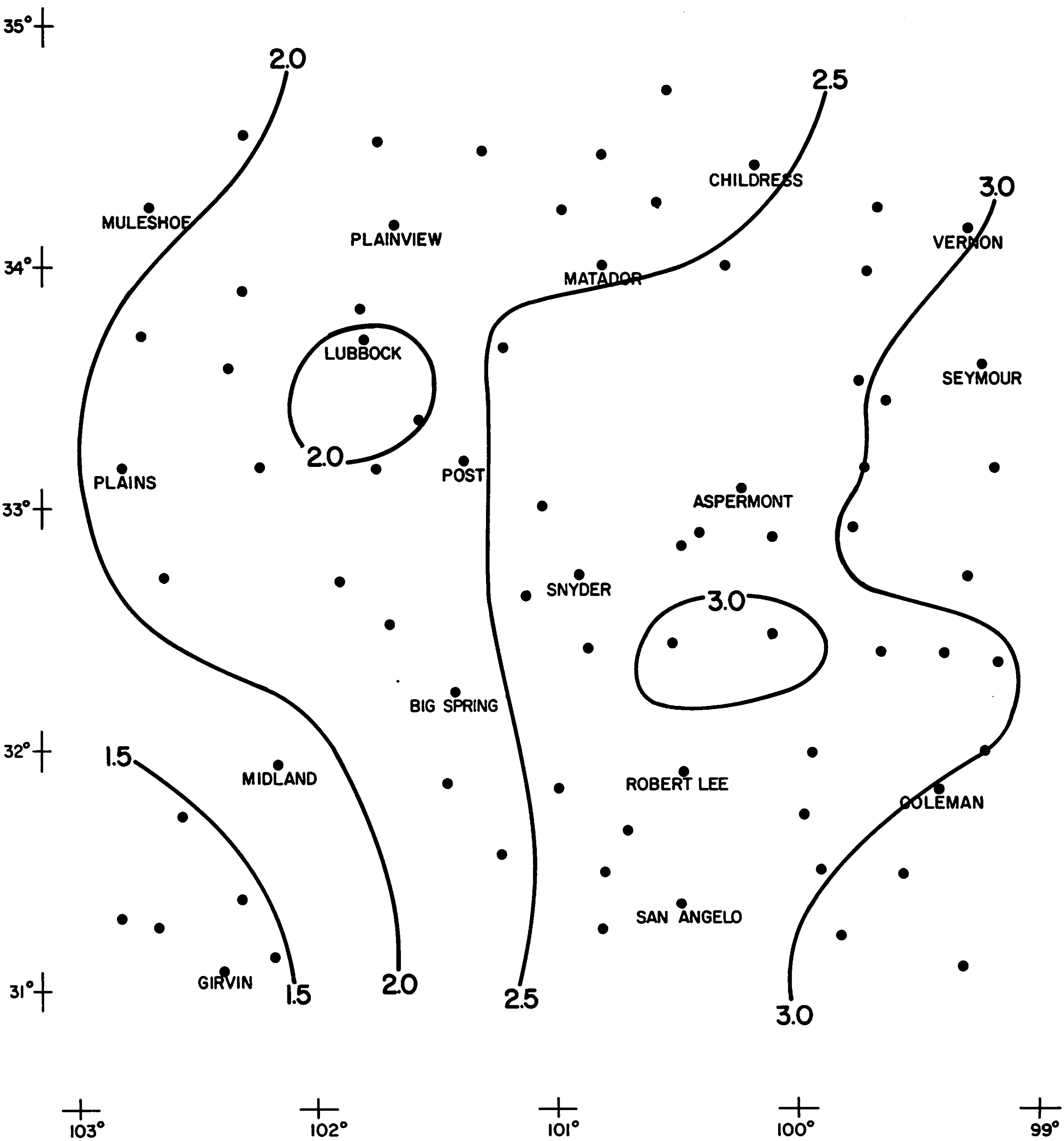

FIG. 8. MEAN MONTHLY PRECIPITATION - SEPTEMBER

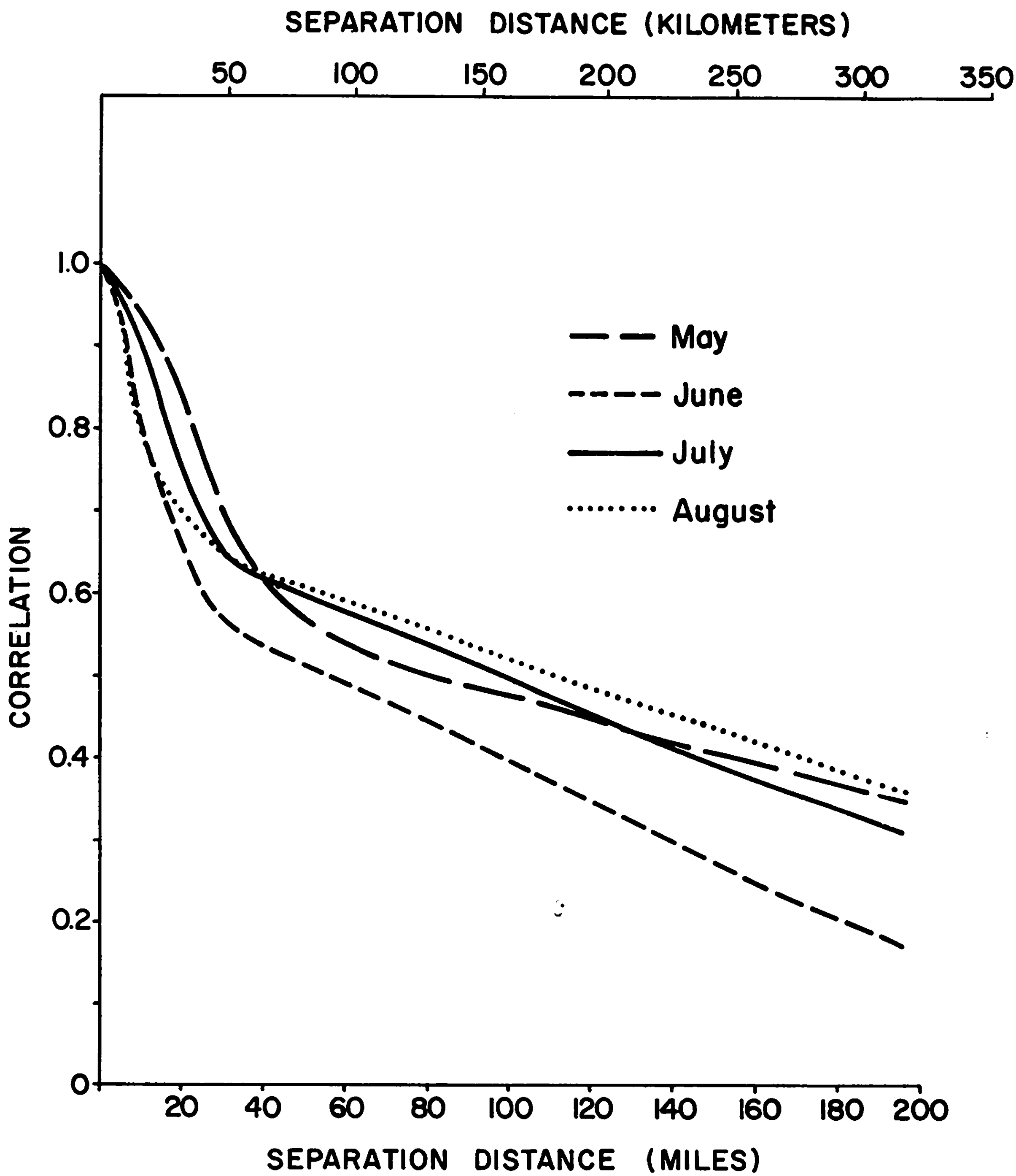

FIG. 9. MEAN MONTHLY PRECIPITATION CORRELATION (MAY - AUGUST)

with distance out to approximately 70 km, results from high precipitation gradients indicative of local convection. Late fall and winter storms, characterized by stable air converging toward a center of low pressure or by frontal waves with a continuous supply of moisture, results in correlations which are higher and vary more slowly with distance (Haragan, 1976).

Figures 10 and 11 show the correlations (expressed as percentages) of all stations in the network with Big Spring for May and June. In May, the major correlation axis is oriented southwest to northeast suggesting the mean direction of storm movement. It is interesting and still somewhat curious to note that the apparent storm track in June has shifted to a northwest-southeast orientation. Coefficients are also smaller in June reflecting the preponderance of local showers with higher precipitation gradients.

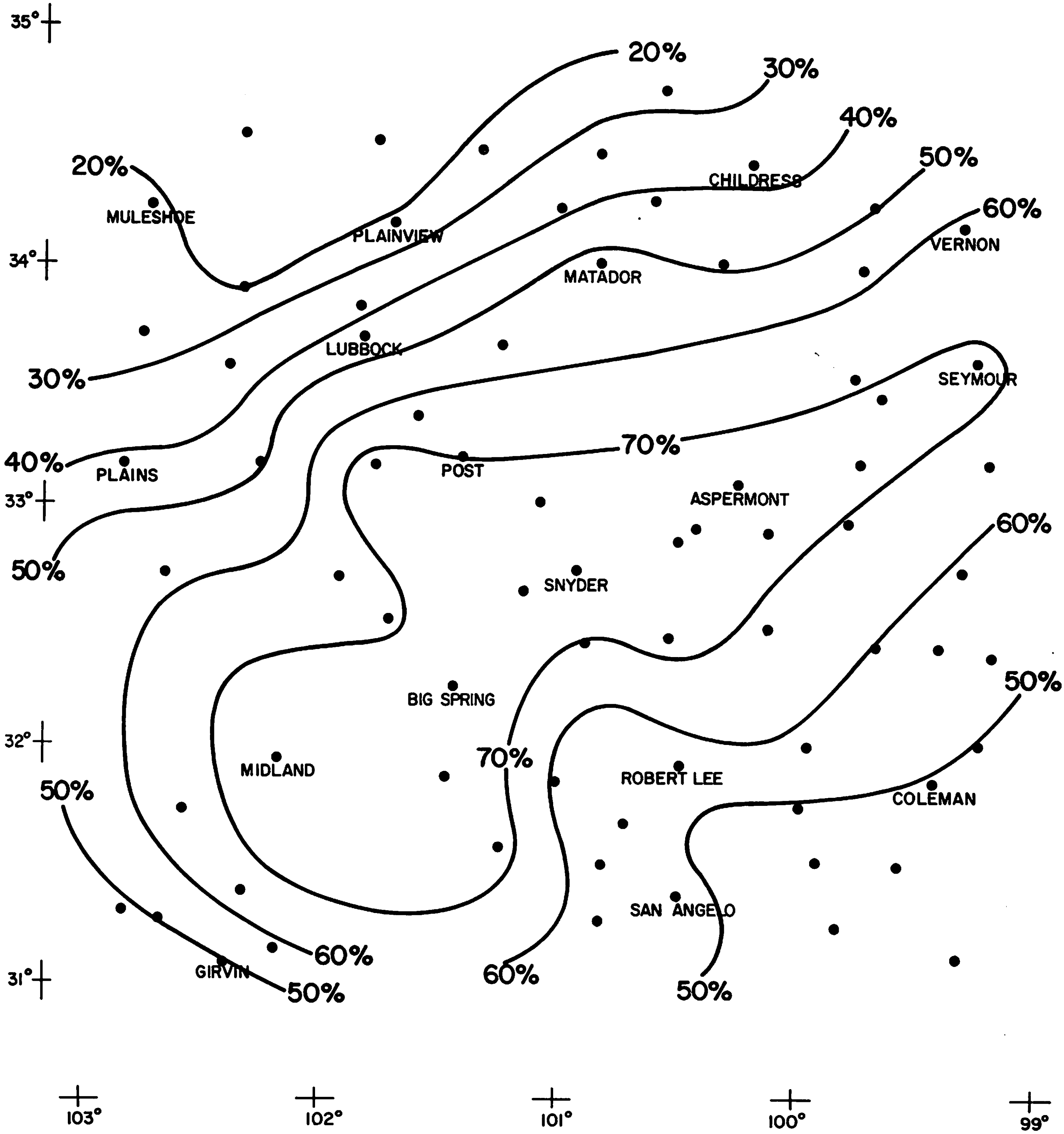

FIG. 10. PRECIPITATION CORRELATION WITH BIG SPRING - MAY

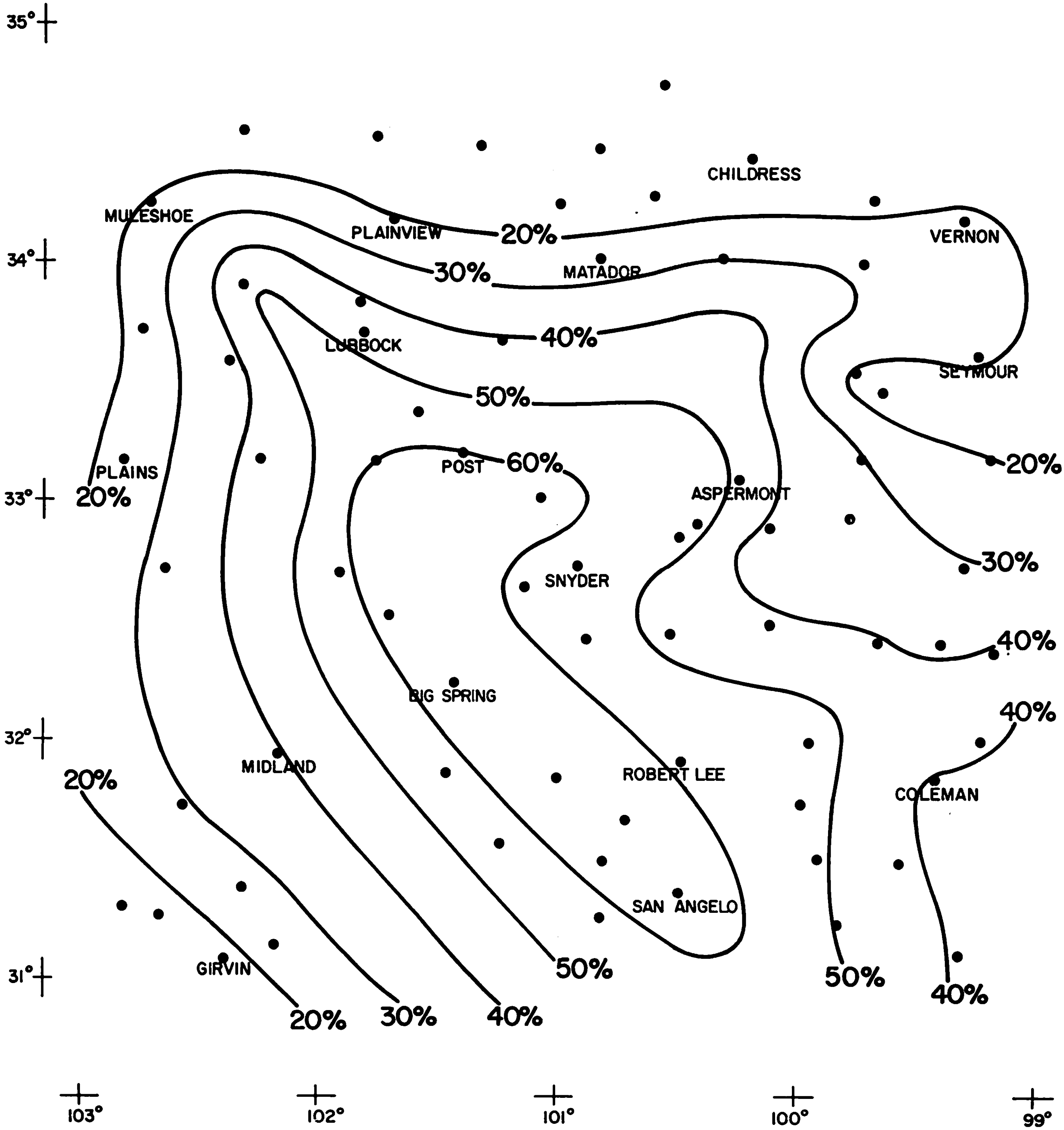

FIG. 11. PRECIPITATION CORRELATION WITH BIG SPRING - JUNE

IV. ANALYSIS OF PRECIPITATION DAYS

Results of a North Dakota experiment to increase precipitation by cloud seeding revealed a greater number of rainfall events during seeding periods (Schleusener and Miller, 1974). More rainfall and a larger proportion of large rain events were positively correlated with seeding. With this in mind, a climatology of daily rainfall events was produced for the Hiplex region. Tables 1, 2 and 3 summarize the required data for three stations in the vicinity; Big Spring, Snyder and Lamesa. Table 1 shows the percent frequency of various numbers of rainfall periods per month based on the total period of record at each station. A rainfall period refers to a sequence of days all having a measurable amount of rain. Thus, the ten-day sequence of rainfall,

1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
0	0	.05	.08	0	0	1.06	0	0	0

contains two rainfall periods. In considering the number of rainfall periods per month, a period extending into the next month counts only for the month in which it began. Note that during some months there were no rainfall periods, whereas during others, more than seven periods were observed. The rainfall periods tabulated in Table 1 brought widely differing amounts of rain shown in Table 3. Note that there is considerable variability among the three stations in the distribution of rainfall events and the amount of rain received per event. The spatial variation is coupled also with a temporal variation among the five months in the study. It is apparent once again that the natural variability of rainfall is extremely difficult to evaluate. Table 2 shows the distribution of the duration of rainfall events at Big Spring and Snyder only. With the exception of September, there is not a significant difference between the two stations.

TABLE 1

PERCENT FREQUENCY OF RAINFALL PERIODS

STATION	RAINFALL PERIODS PER MONTH	MAY	JUNE	JULY	AUGUST	SEPTEMBER
Big Spring (1914)	0	0	3	5	2	8
	1	2	13	10	10	16
	2	18	24	16	22	22
	3	18	24	27	25	19
	4	24	17	31	25	20
	5	17	11	3	9	8
	6	12	5	5	3	5
	7	6	3	3	2	2
	>7	3	0	0	2	0
Lamesa (1910)	0	2	2	0	3	2
	1	14	10	13	14	19
	2	13	25	21	34	25
	3	22	28	27	14	24
	4	22	14	24	13	14
	5	11	16	13	9	11
	6	13	5	1	8	4
	7	3	0	1	2	1
	>7	0	0	0	3	0
Snyder (1914)	0	0	2	5	5	10
	1	0	13	13	16	8
	2	13	16	27	16	22
	3	23	27	31	29	25
	4	24	18	15	18	21
	5	24	10	7	11	11
	6	8	10	0	3	3
	7	8	2	0	2	0
	>7	0	2	2	0	0

TABLE 2
PERCENT FREQUENCY OF DAILY RAINFALL DURATION

STATION	DURATION (DAYS)	MAY	JUNE	JULY	AUGUST	SEPTEMBER
Big Spring	1	64	69	63	68	49
	2	21	20	23	20	31
	3	10	6	11	6	11
	4	3	3	2	3	7
	5	1	2	0	2	1
	>5	1	0	1	1	1
Snyder	1	66	73	66	67	63
	2	23	19	24	24	23
	3	6	5	6	4	8
	4	3	2	2	2	3
	5	1	1	0	2	1
	>5	1	0	2	1	2

TABLE 3

PERCENT FREQUENCY OF RAINFALL PERIODS PER AMOUNT

STATION	AMOUNT PER PERIOD (INCHES)	MAY	JUNE	JULY	AUGUST	SEPTEMBER
Big Spring (1914)	0.00-0.24	50	48	45	49	45
	0.25-0.49	17	14	22	12	23
	0.50-0.99	16	16	16	23	14
	1.00-1.49	8	11	7	5	6
	1.50-1.99	4	6	4	4	3
	2.00-2.99	5	3	3	3	6
	3.00-3.99	0	1	2	3	1
	>3.99	0	1	1	1	2
Lamesa (1910)	0.00-0.24	45	40	39	40	30
	0.25-0.49	18	23	20	20	24
	0.50-0.99	19	17	20	21	21
	1.00-1.49	9	9	9	8	9
	1.50-1.99	4	5	4	3	5
	2.00-2.99	2	4	4	5	7
	3.00-3.99	1	1	3	2	2
	>3.99	2	1	1	1	2
Snyder (1914)	0.00-0.24	29	30	39	28	23
	0.25-0.49	22	22	24	26	21
	0.50-0.99	29	24	17	13	25
	1.00-1.49	8	12	7	23	18
	1.50-1.99	8	6	5	5	6
	2.00-2.99	3	6	4	3	2
	3.00-3.99	1	0	2	1	3
	>3.99	0	0	2	1	2

V. MESO-SYNOPTIC PATTERNS RESPONSIBLE FOR PRECIPITATION EVENTS

Rainfall events during the months of May through September were studied for the six-year periods from 1972 through 1977 in order to identify the mechanism responsible for the onset of precipitation. Four categories were identified as follows: frontal, dry line, upper-level wave and air mass convection. A summary of results is shown in Table 4.

Table 4 Meso-Synoptic Patterns Producing Precipitation

	Number of Occurrences			
Year	Frontal	Dry Line	Upper Wave	Air Mass
1972	10	0	21	3
1973	9	0	28	3
1974	7	0	19	3
1975	5	1	28	2
1976	4	0	30	0
1977	5	0	23	4
Total	40(19%)	1(<1%)	149(72%)	15(7%)

Upper level waves were responsible for nearly three-fourths of the precipitation during this period. Of this number, 68% were westerly waves and 32% easterly waves. Westerly waves were dominant during May, June and September with easterly waves dominant during July. August was almost evenly divided between easterly and westerly disturbances.

Only one case could be attributed to the passage of a dry line, this occurring on May 22, 1975. Most of the frontal rainfall occurred in August followed by July, May, September and June in that order. Air mass convection made a significant contribution only during July and August.

VI. SUMMARY OF CLOUDS AND WEATHER EVENTS IN THE HIPLEX REGION

In order to better define the precipitation climatology of the Hiplex region, a summary of hourly weather events and cloud occurrences over a ten year period was prepared. These summaries are provided for Midland (MAF), Lubbock (LBB), and Abilene (ABI) and are given in Appendix A. Occurrences of the following clouds or weather events have been summarized:

(1) Cumulus Clouds
(2) Cumulonimbus Clouds
(3) Stratocumulus Clouds
(4) Altocumulus Clouds
(5) Altocumulus castellatus Clouds
(6) Cirrus Clouds
(7) Thunderstorms
(8) Rain showers
(9) Rain and drizzle
(10) Fog

Figures in the tables represent the number of occurrences (hourly observations) of a particular event during the 10-year period.

Figures 12 through 17 present a graphical summary of the seasonal and diurnal variation of cumulus and cumulonimbus clouds. Percentage occurrence is shown as a function of the time of year (month) and the time of day (local time). As an example, in July and August between 1:00 PM and 3:00 PM cumulus clouds are reported at Lubbock (Figure 14) about 70% of the time. It is obvious from Figure 13 that the cumulonimbus maximum occurs much later in the day, between about 5:00 PM and 7:00 PM. Similar patterns are evident at Midland and Abilene.

Further insight into the development of cumulus convection is shown by Figures 18, 19, and 20. These figures show the diurnal distribution of cumulus and cumulonimbus clouds for Midland, Lubbock and Abilene respectively. The month of May, June, July and August are illustrated in each case. Note that there is approximately a four-hour lag time from the cumulus maximum to the cumulonimbus maximum. If we define a convection efficiency index as the ratio of cumulonimbus frequency to cumulus frequency and express the index as a percentage at each of the three stations, the following results are obtained:

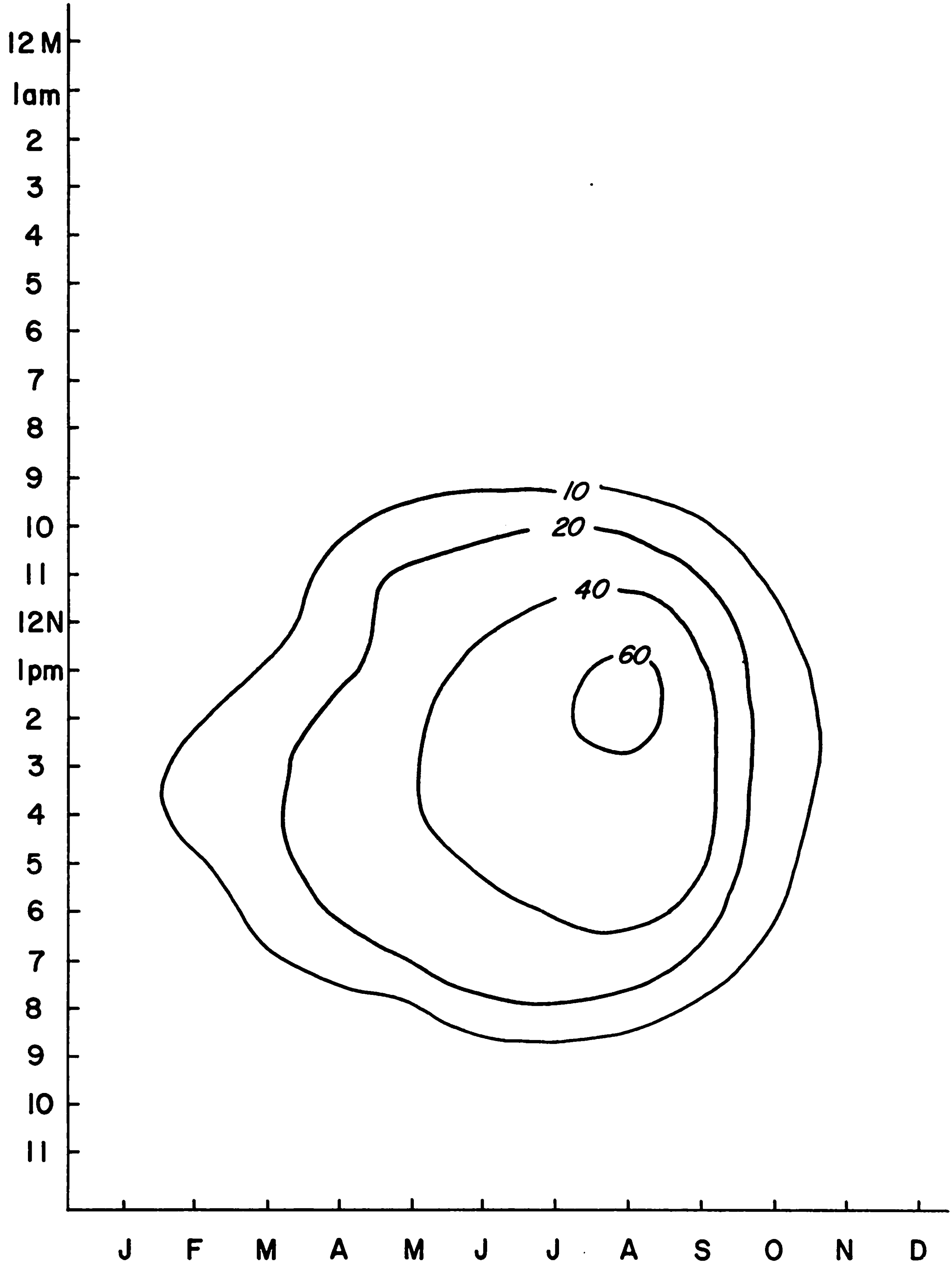

FIG. 12. Percentage Occurrence of Cumulus
Midland, Texas

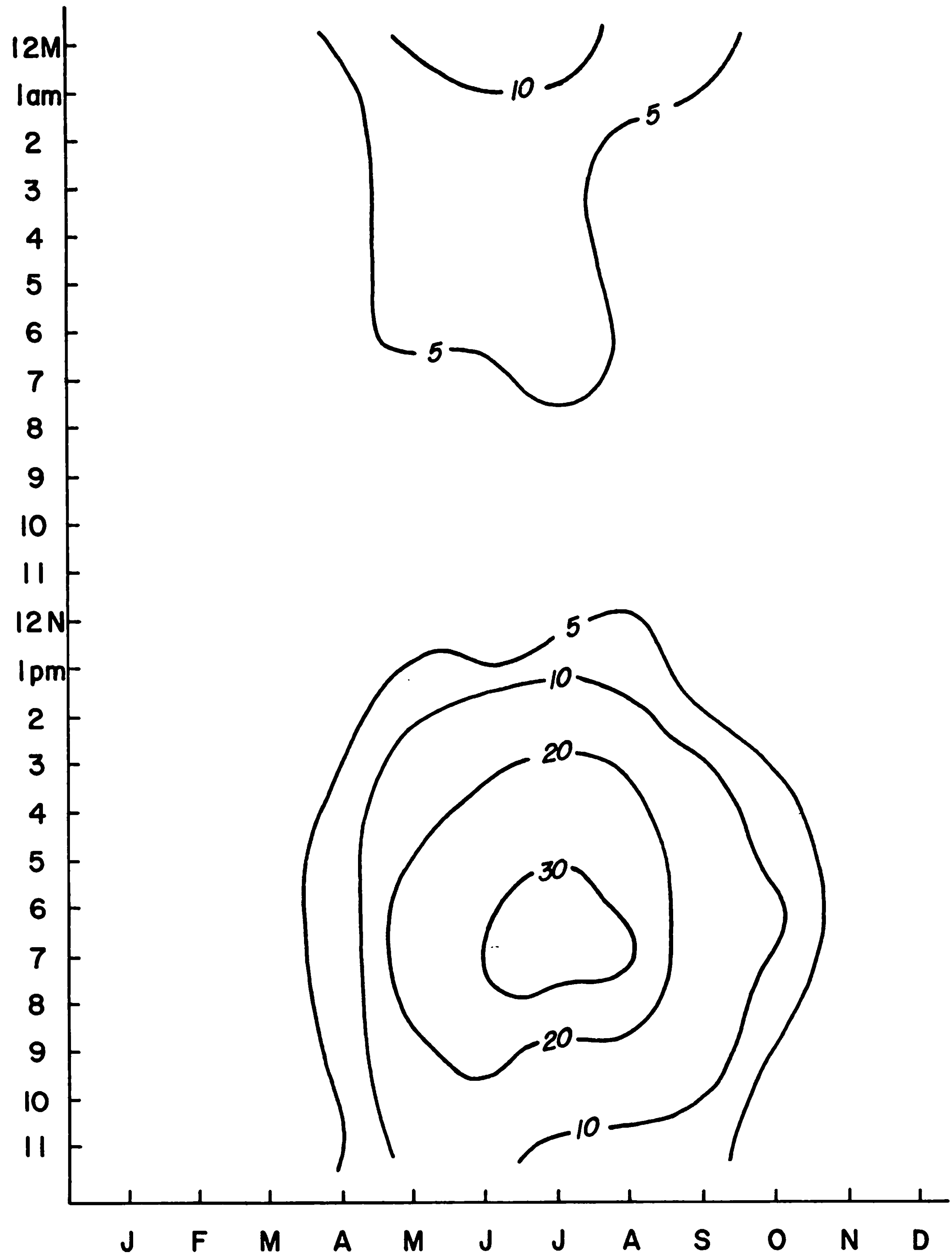

FIG. 13. **Percentage Occurrence of Cumulonimbus Midland, Texas**

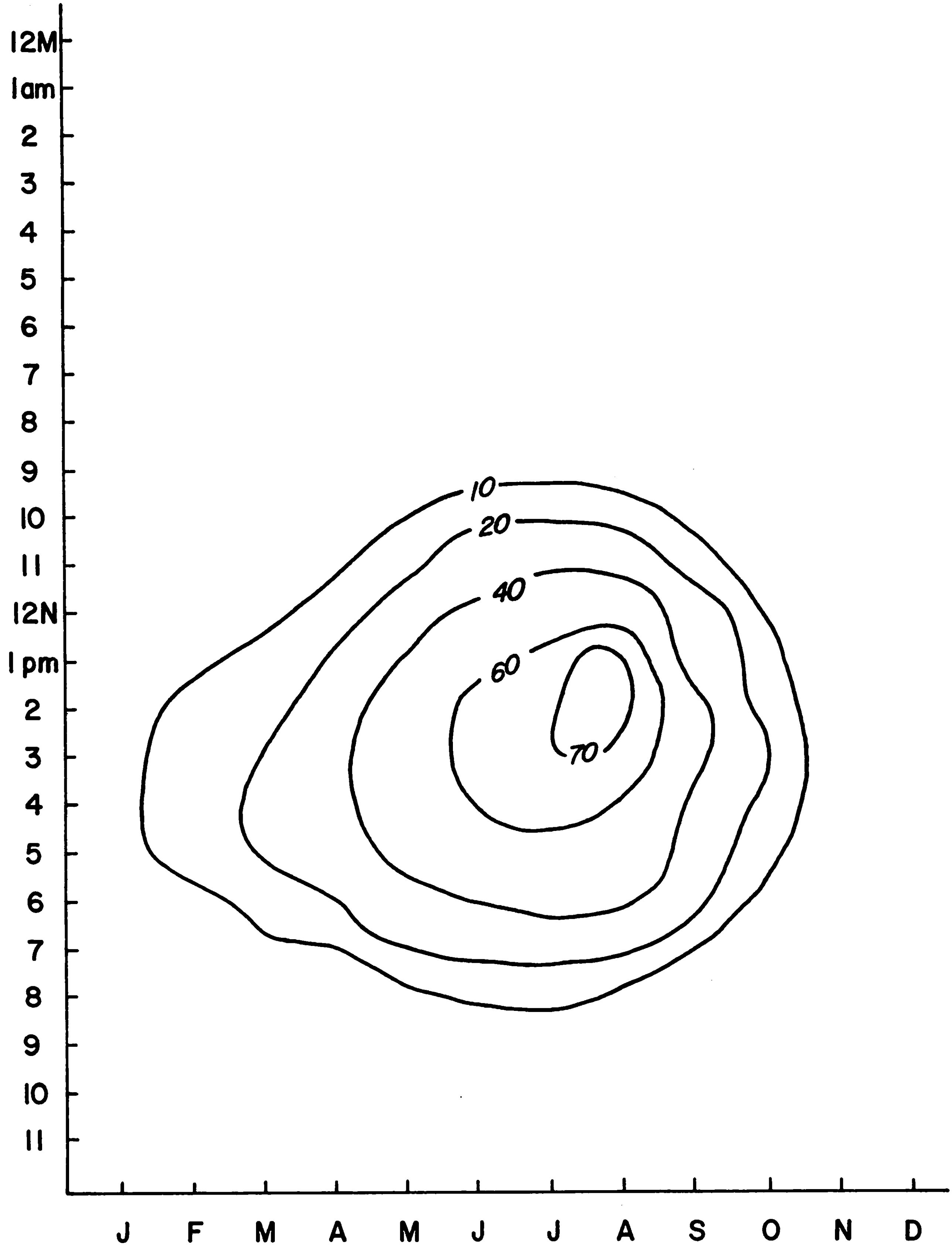

FIG. 14. Percentage Occurrence of Cumulus
Lubbock, Texas

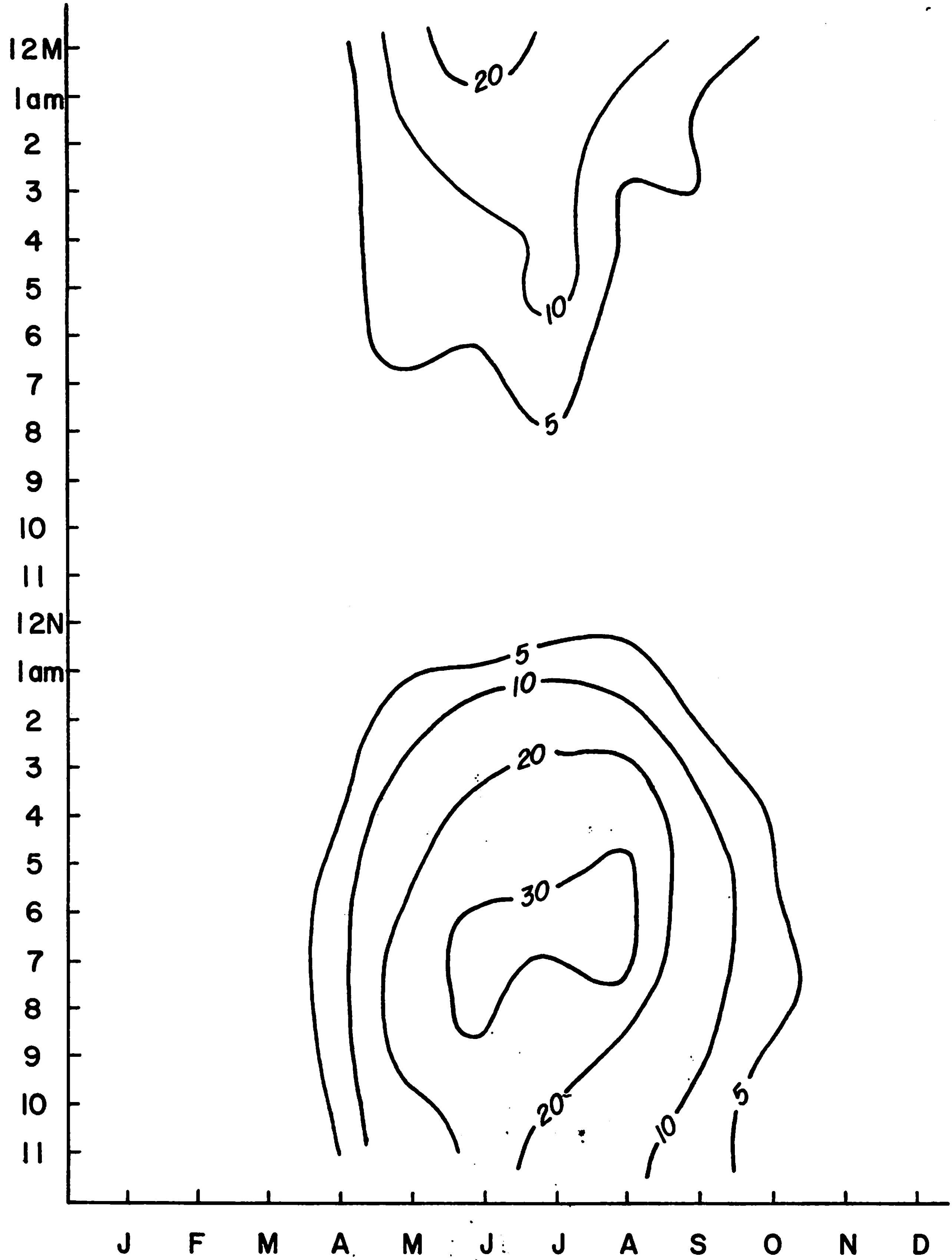

FIG. 15. **Percentage Occurrence of Cumulonimbus Lubbock, Texas**

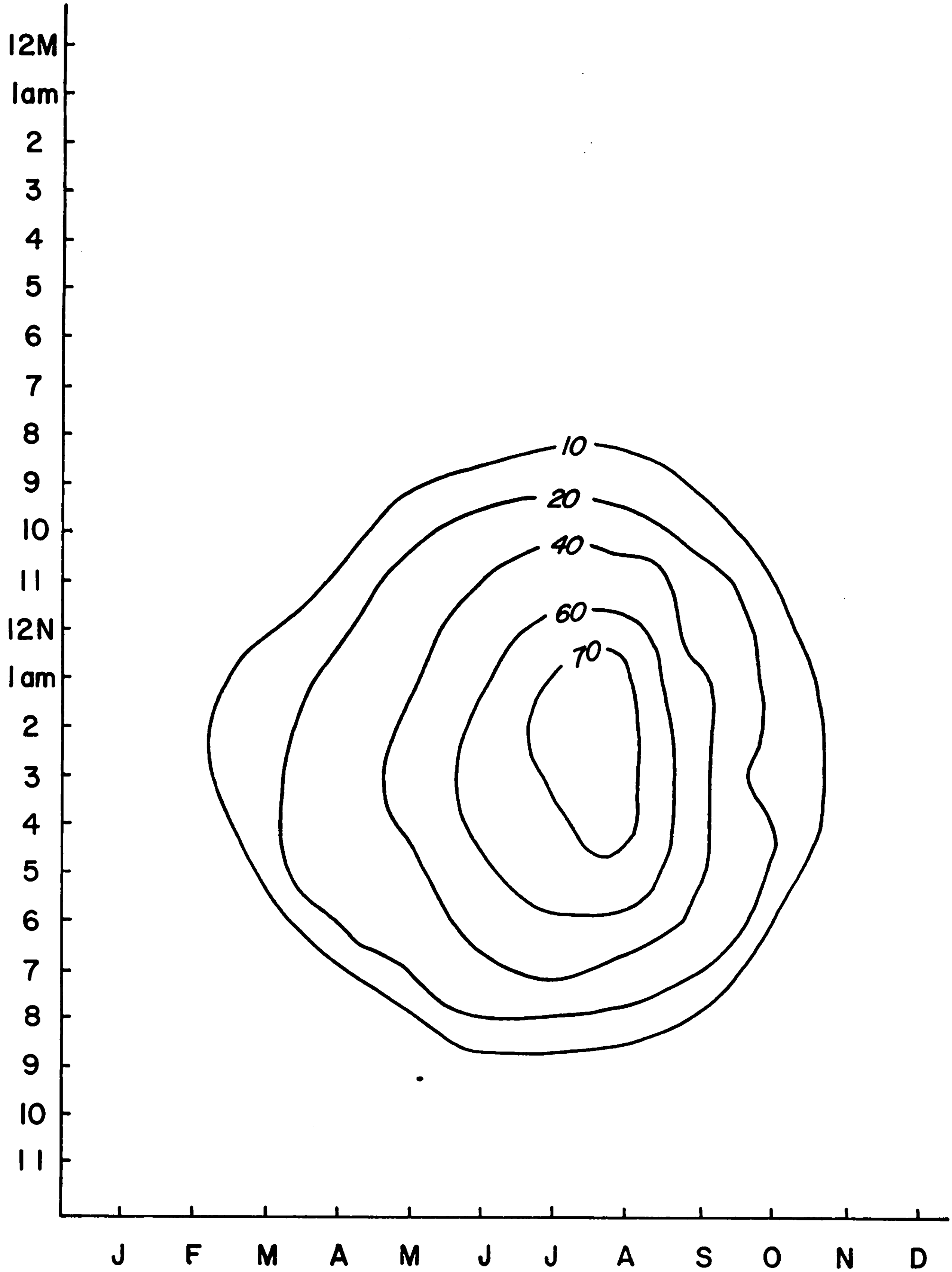

FIG. 16. **Percentage Occurrence of Cumulus Abilene, Texas**

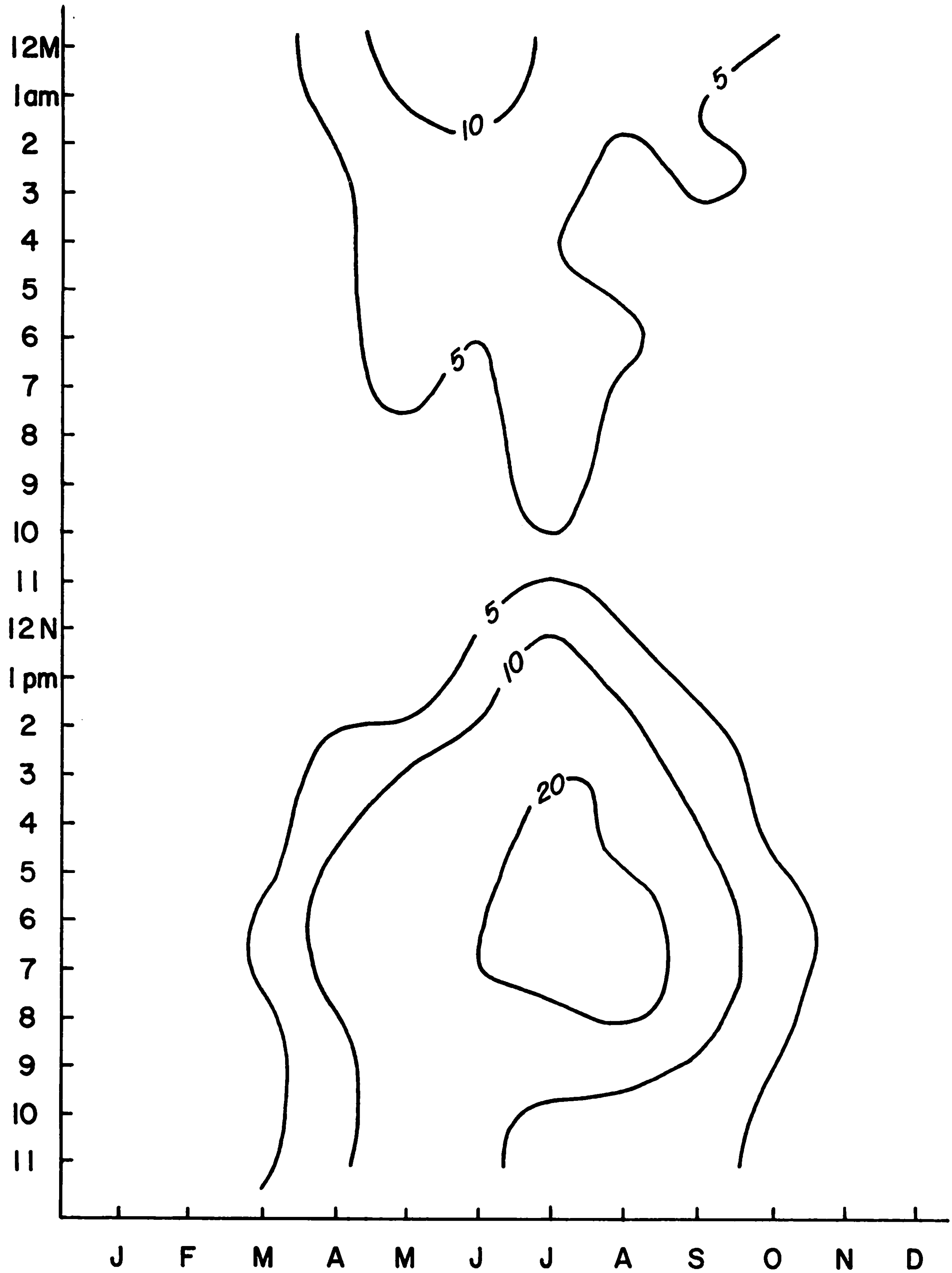

FIG. 17 **Percentage Occurrence of Cumulonimbus Abilene , Texas**

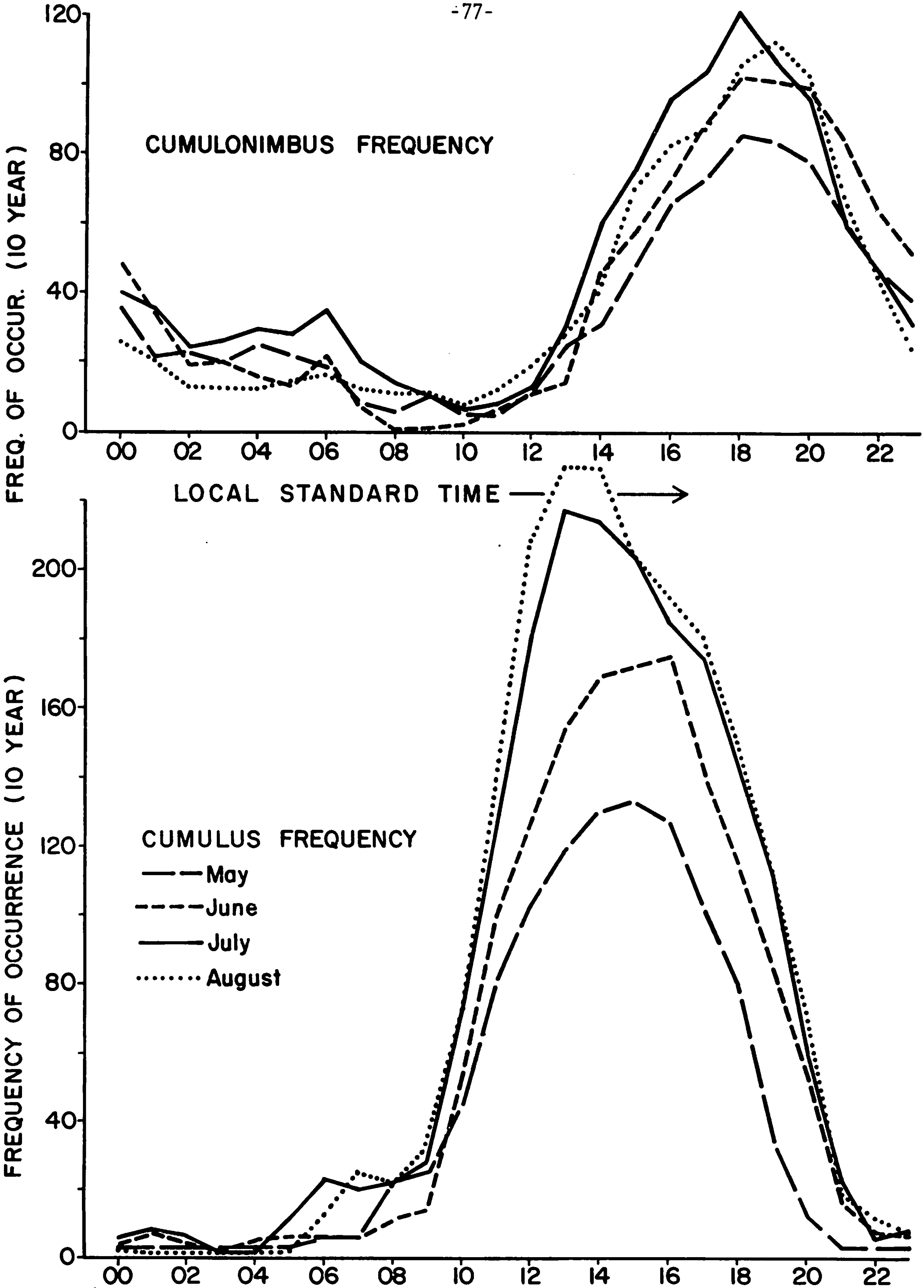

FIG. 18. FREQUENCY OF OCCURRENCE OF CUMULUS AND CUMULONIMBUS - MIDLAND

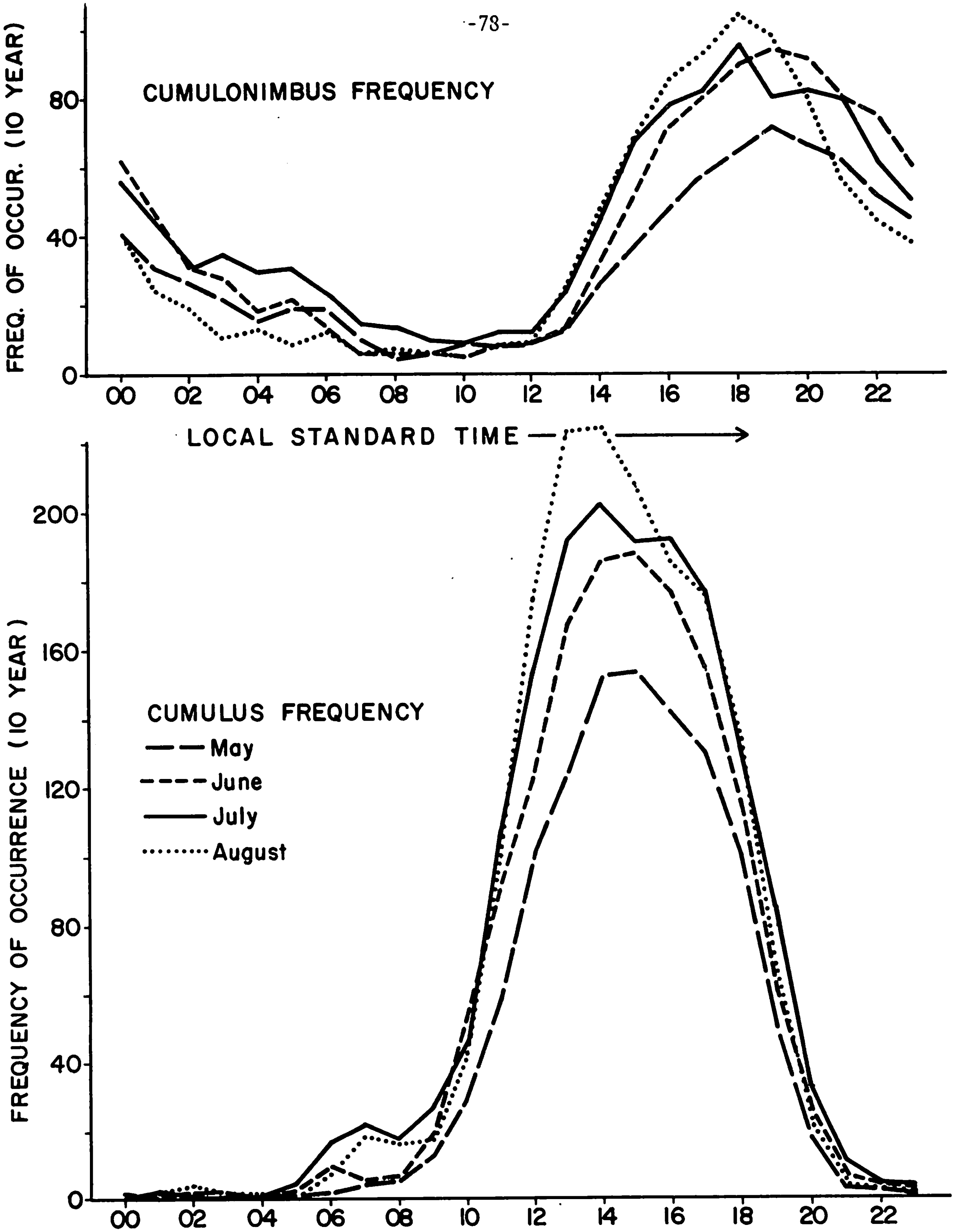

FIG. 19. FREQUENCY OF OCCURRENCE OF CUMULUS AND CUMULONIMBUS - LUBBOCK

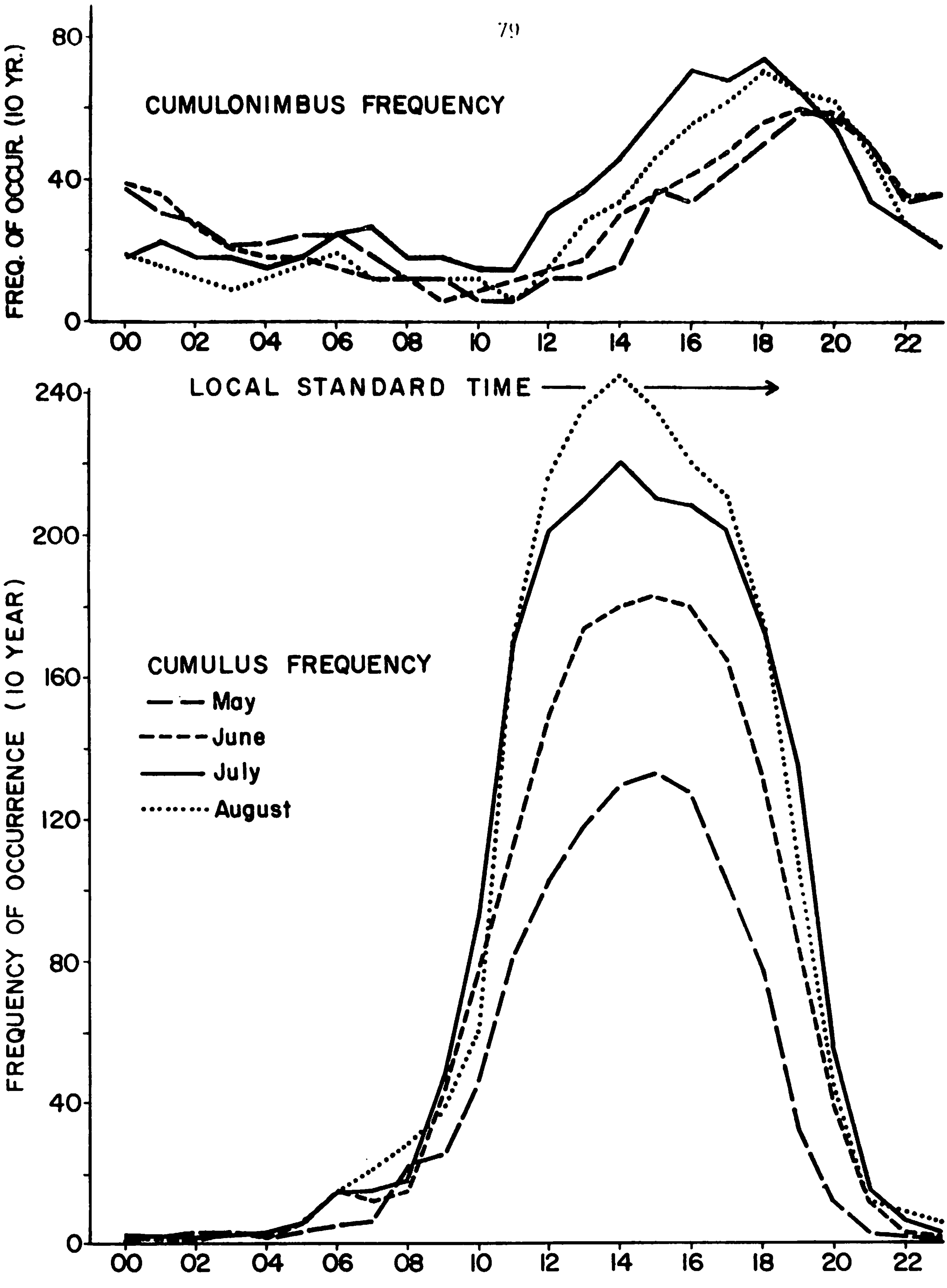

FIG. 20. FREQUENCY OF OCCURRENCE OF CUMULUS AND CUMULONIMBUS - ABILENE

Month	Lubbock	Midland	Abilene
May	70%	72%	66%
June	71%	69%	44%
July	66%	60%	41%
August	56%	50%	25%

The index distribution for Lubbock and Midland is much the same. At Abilene, however, the index drops off significantly during June, July and August.

Values of mean-monthly precipitable water (expressed in centimeters) are tabulated for Midland in Appendix B. Computations were made for the 18-year period from 1954 through 1971. Whereas in most instances the variations from year to year are small, there are some significant exceptions. Variations of 25-35% are evident between maximum and minimum values at all levels.

VII. STORM PRECIPITATION ANALYSIS - A CASE STUDY

A meso-scale investigation of storm precipitation is now underway utilizing rainfall data from the Hiplex recording rain gage network. Spatial resolution varies from approximately 1.5 km to 12 km (for the 1976 network) and the temporal resolution is 15 minutes.

Figure 21 illustrates the network rain gages and shows the path of a storm which occurred during the morning of July 3, 1976. Position X_1 is the location of the storm between 10:45 and 11:00 AM CDT. Subsequent positions are shown for every 15 minutes until the storm leaves the network at approximately noon (position 6). Precipitation amounts greater than 3 inches were recorded at some gages in the path of the storm. Progress of the storm is shown by the isohyetal patterns for each 15 minute period in Figures 22 through 29. Contours are labeled in hundredths of inches. Storms were generated on the morning of July 3 by an upper level westerly wave. The cell which passed through the network developed rapidly as it moved from northwest to southeast with an average speed of 5 mps (11 mph). The rainfall intensity increased from a rate of 2.5 inches per hour between 10:45 and 11:00 AM to about 5 inches per hour during the interval from 11:45 AM to noon. This was probably the time of maximum intensity although it is not certain since the storm center moved out of the network during the next 15-minute interval. Dimensions of the precipitation area varied. The average diameter of the rain area was approximately 24 km (15 miles). At the time of maximum intensity, precipitation was falling over an area of approximately 290 km^2 (112 mi^2).

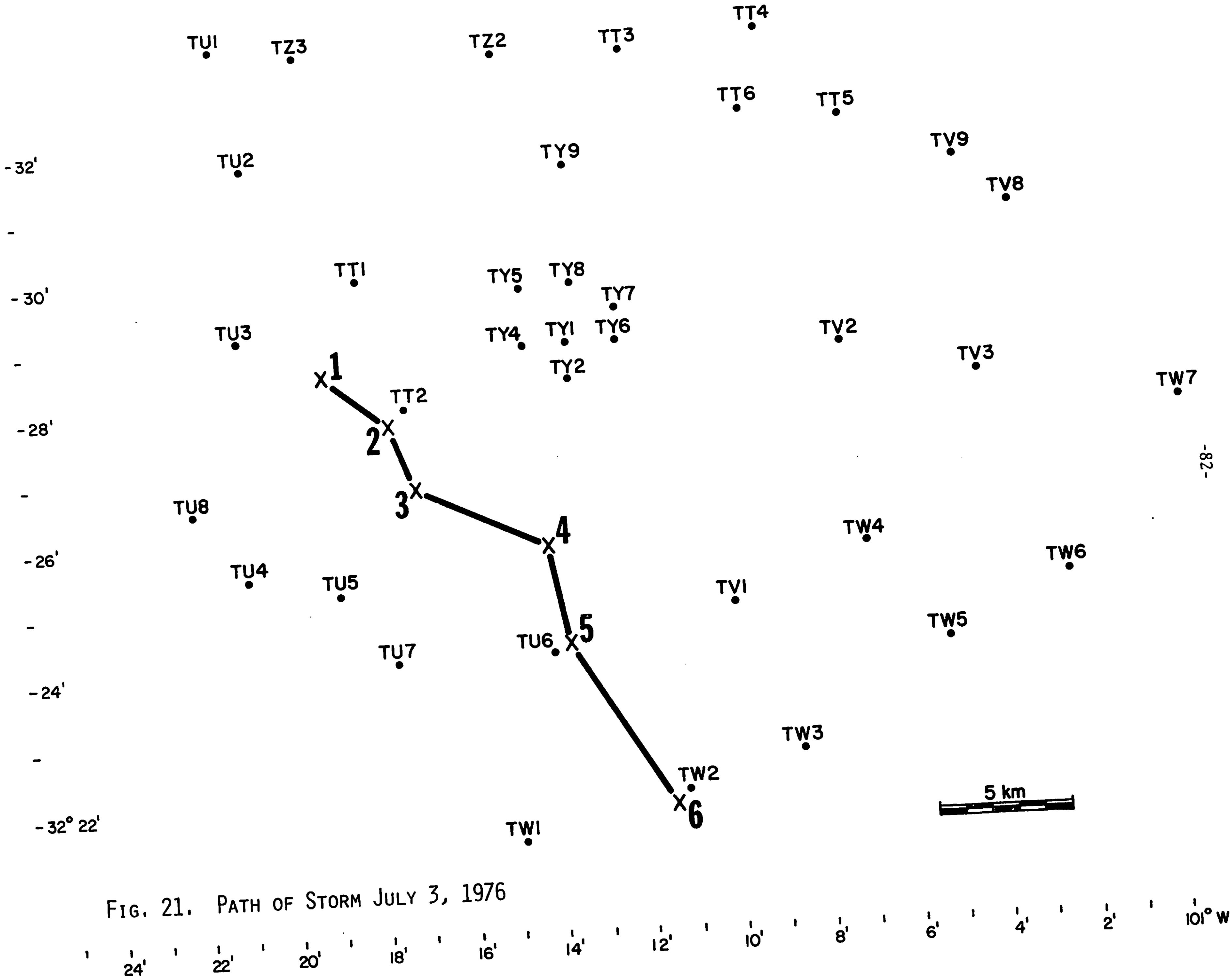

FIG. 21. PATH OF STORM JULY 3, 1976

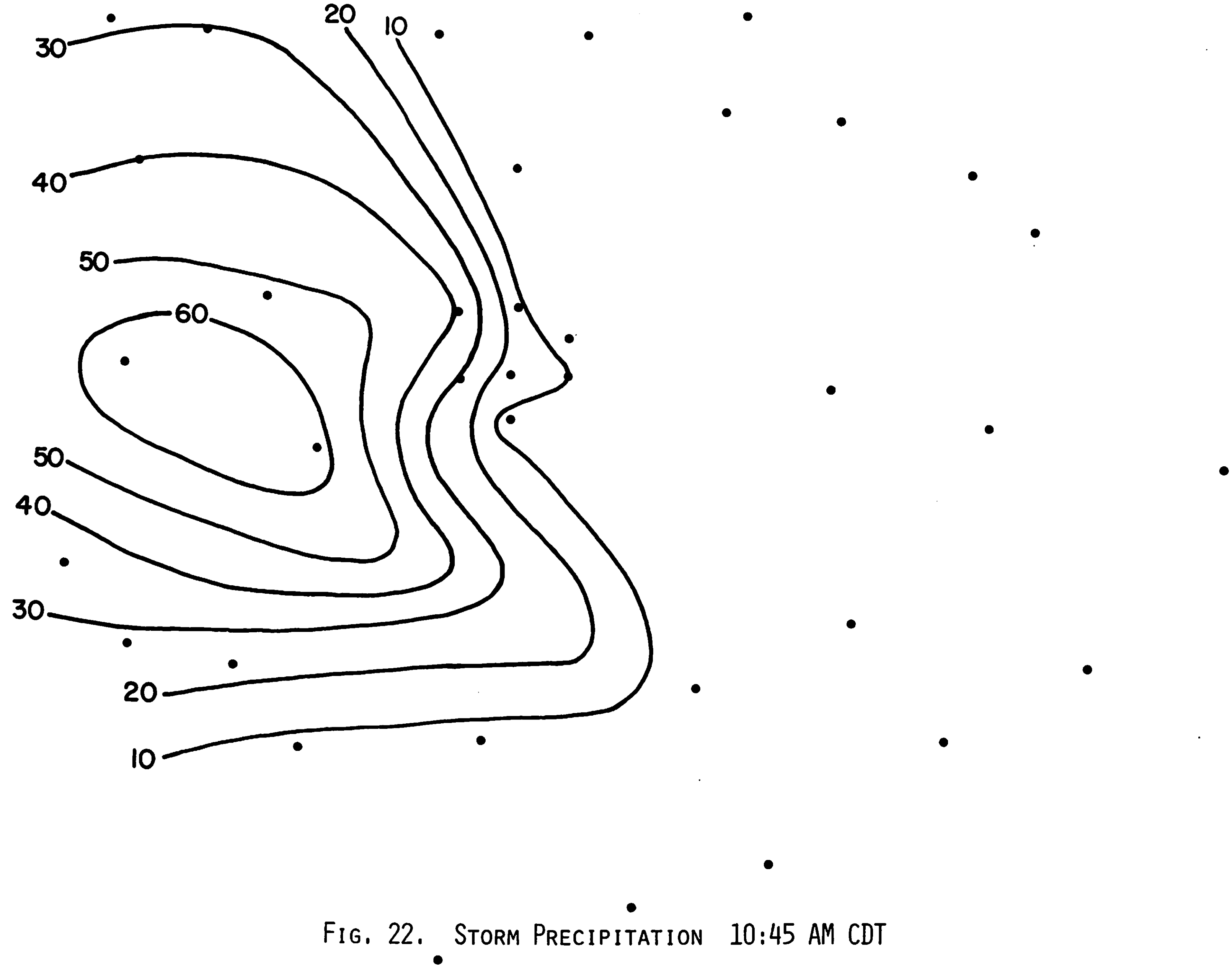

Fig. 22. Storm Precipitation 10:45 AM CDT

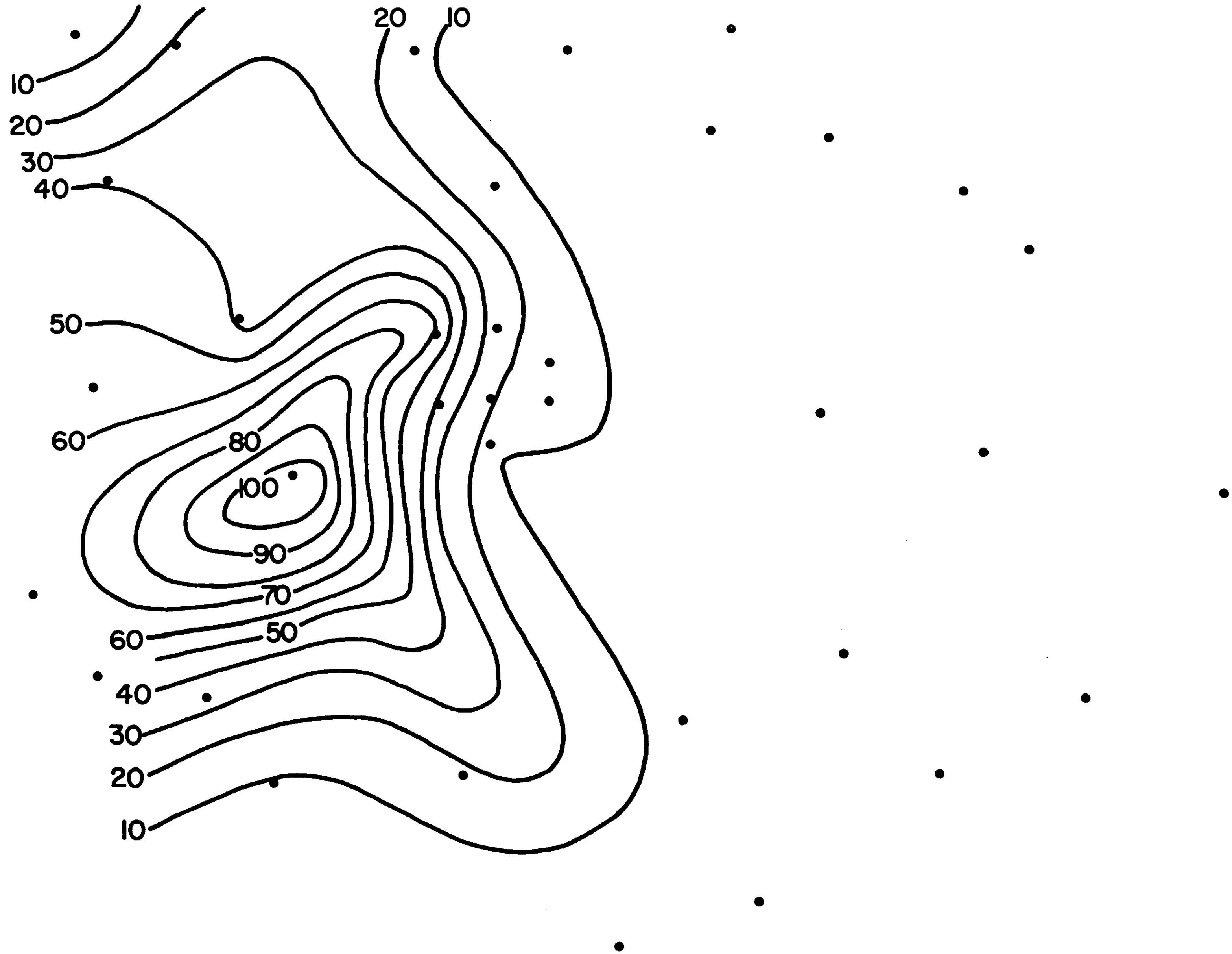

Fig. 23. Storm Precipitation 11:00 AM CDT

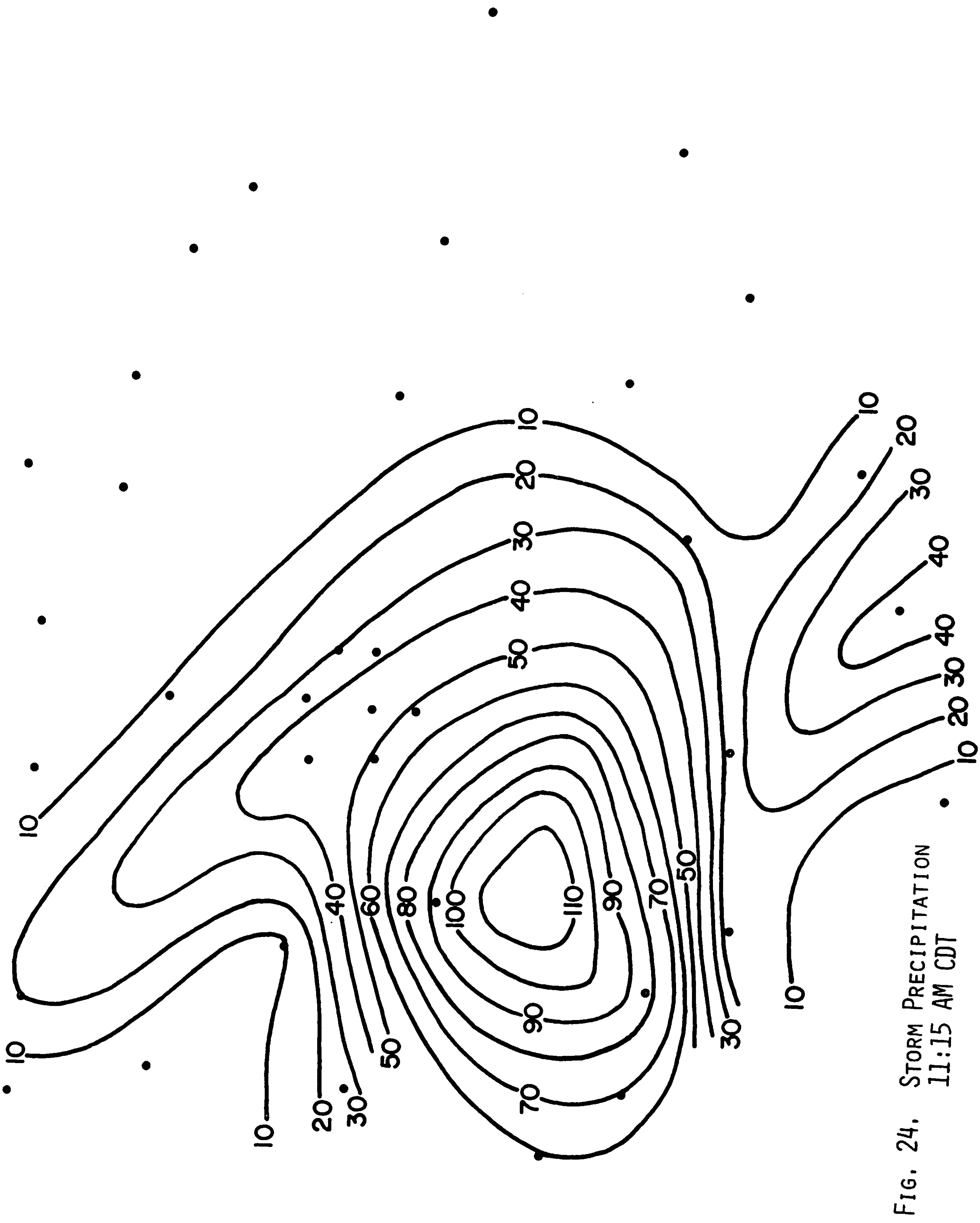

Fig. 24. Storm Precipitation
11:15 AM CDT

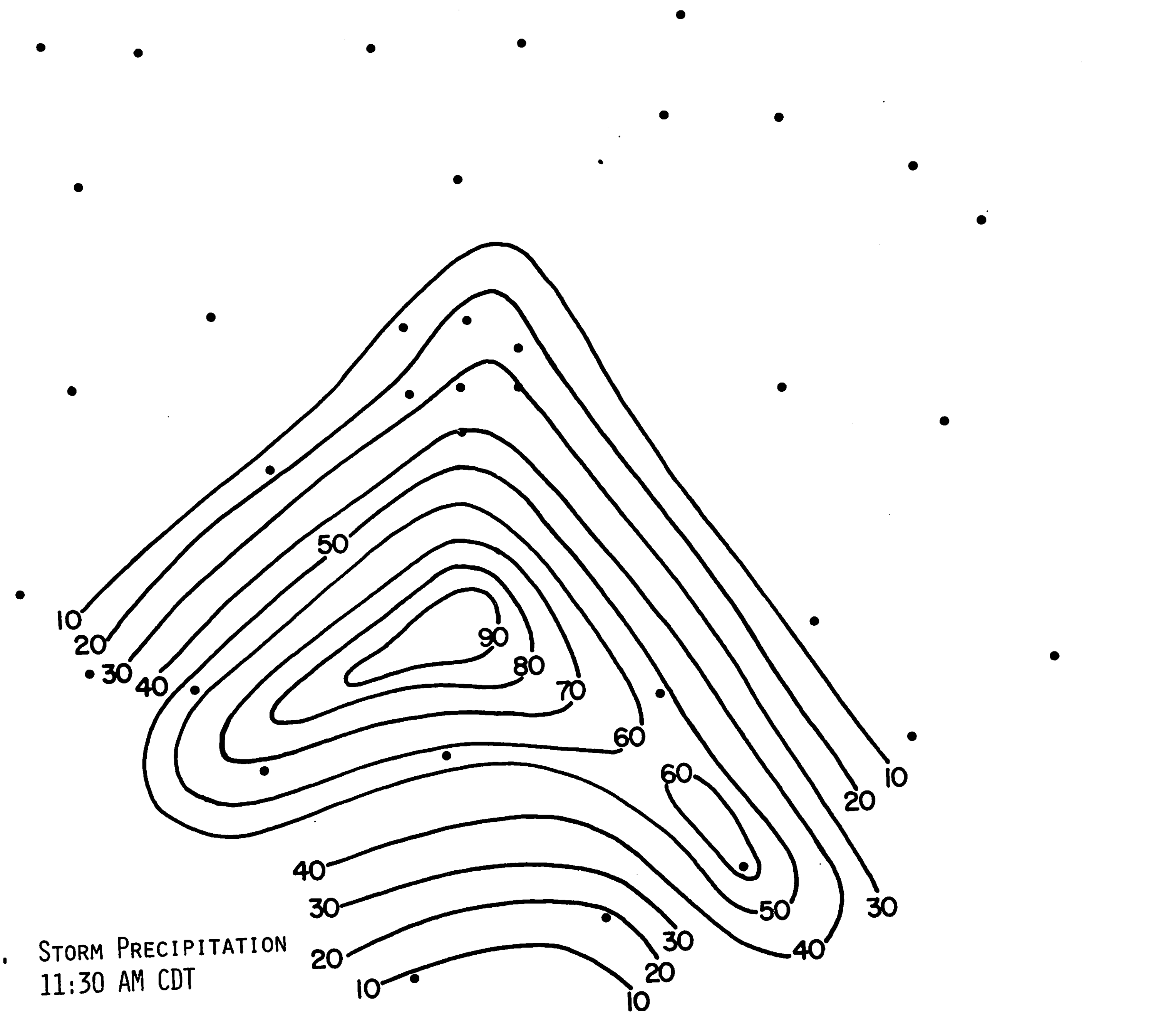

Fig. 25. Storm Precipitation
11:30 AM CDT

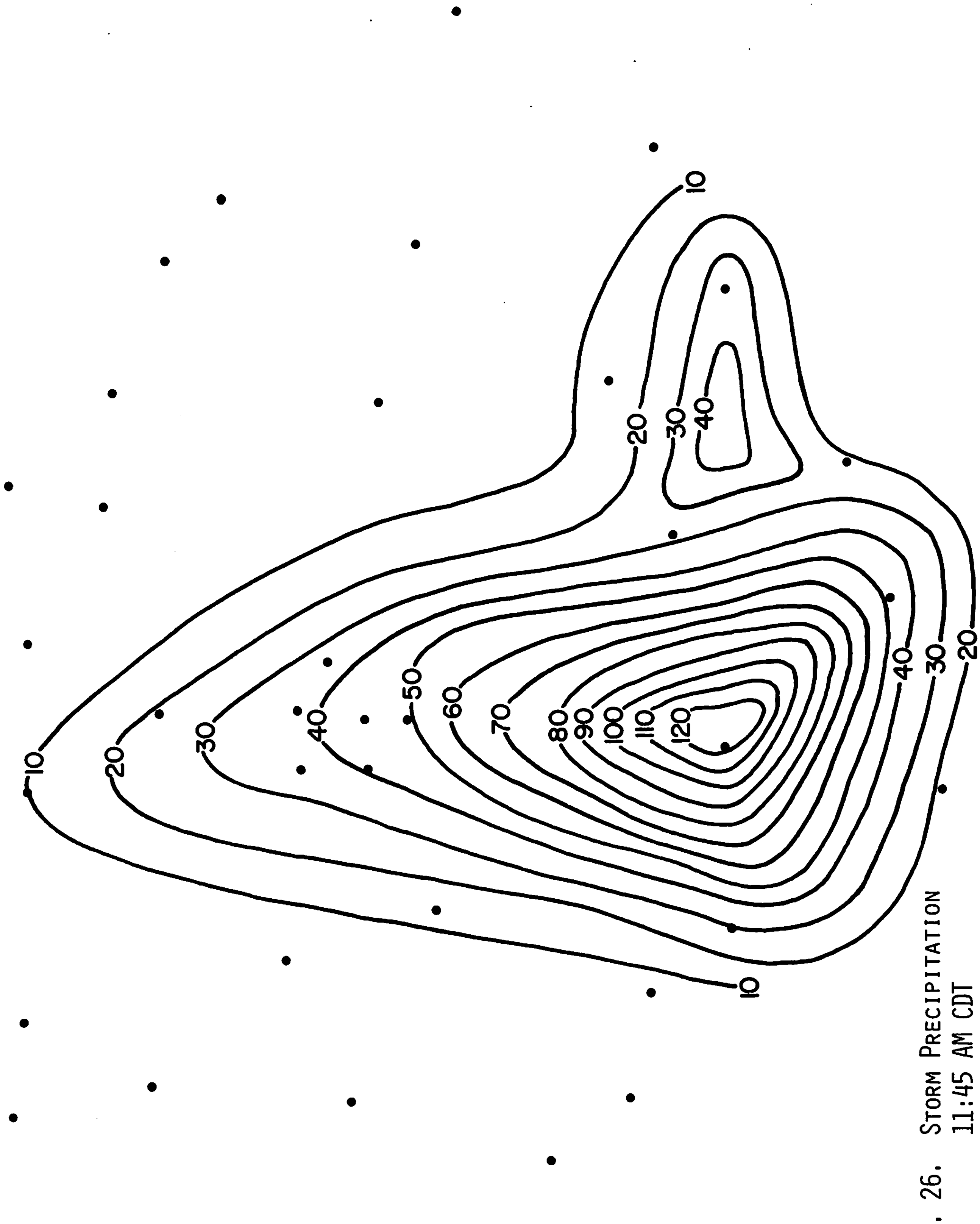

Fig. 26. Storm Precipitation
11:45 AM CDT

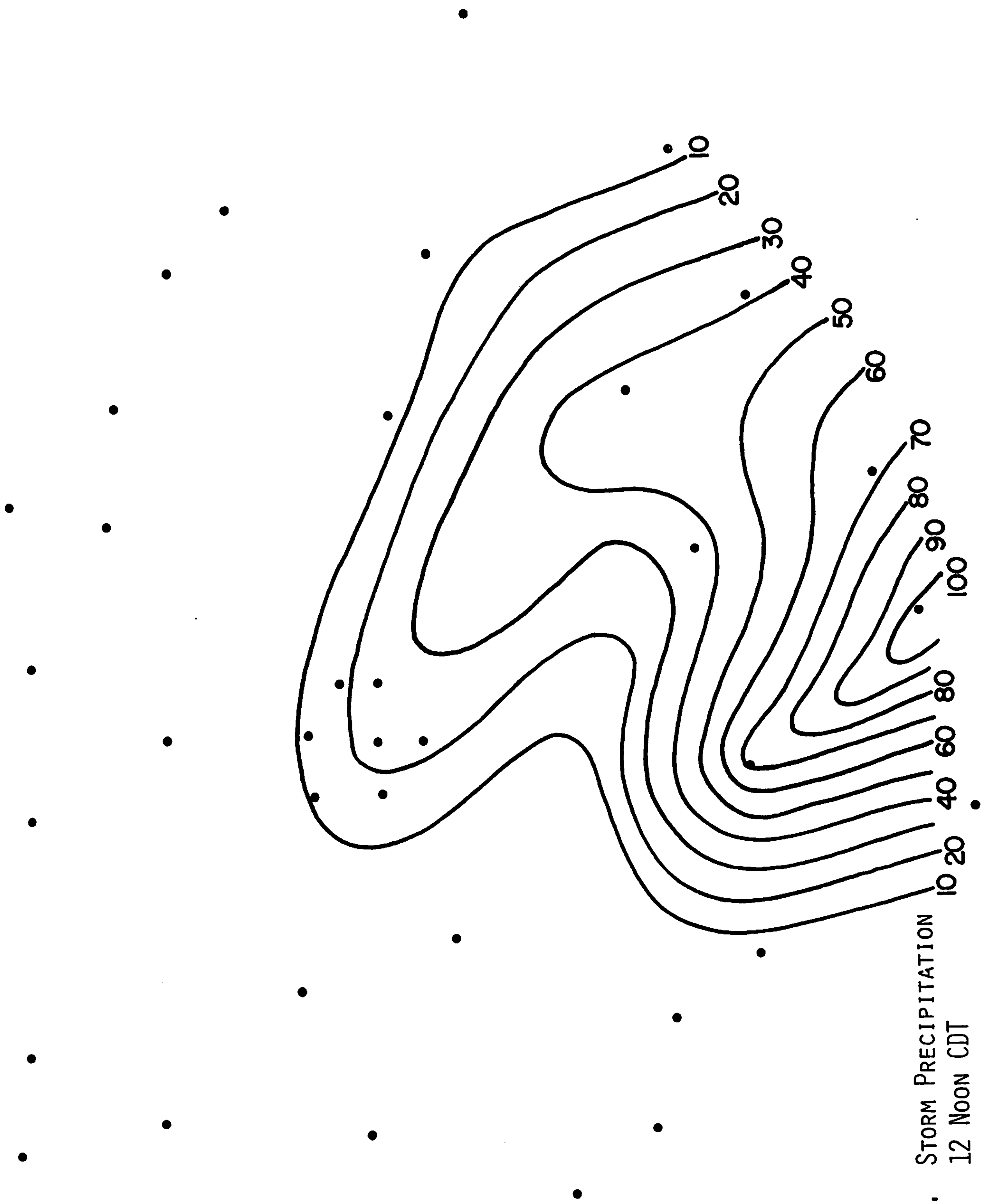

FIG. 27. STORM PRECIPITATION
12 NOON CDT

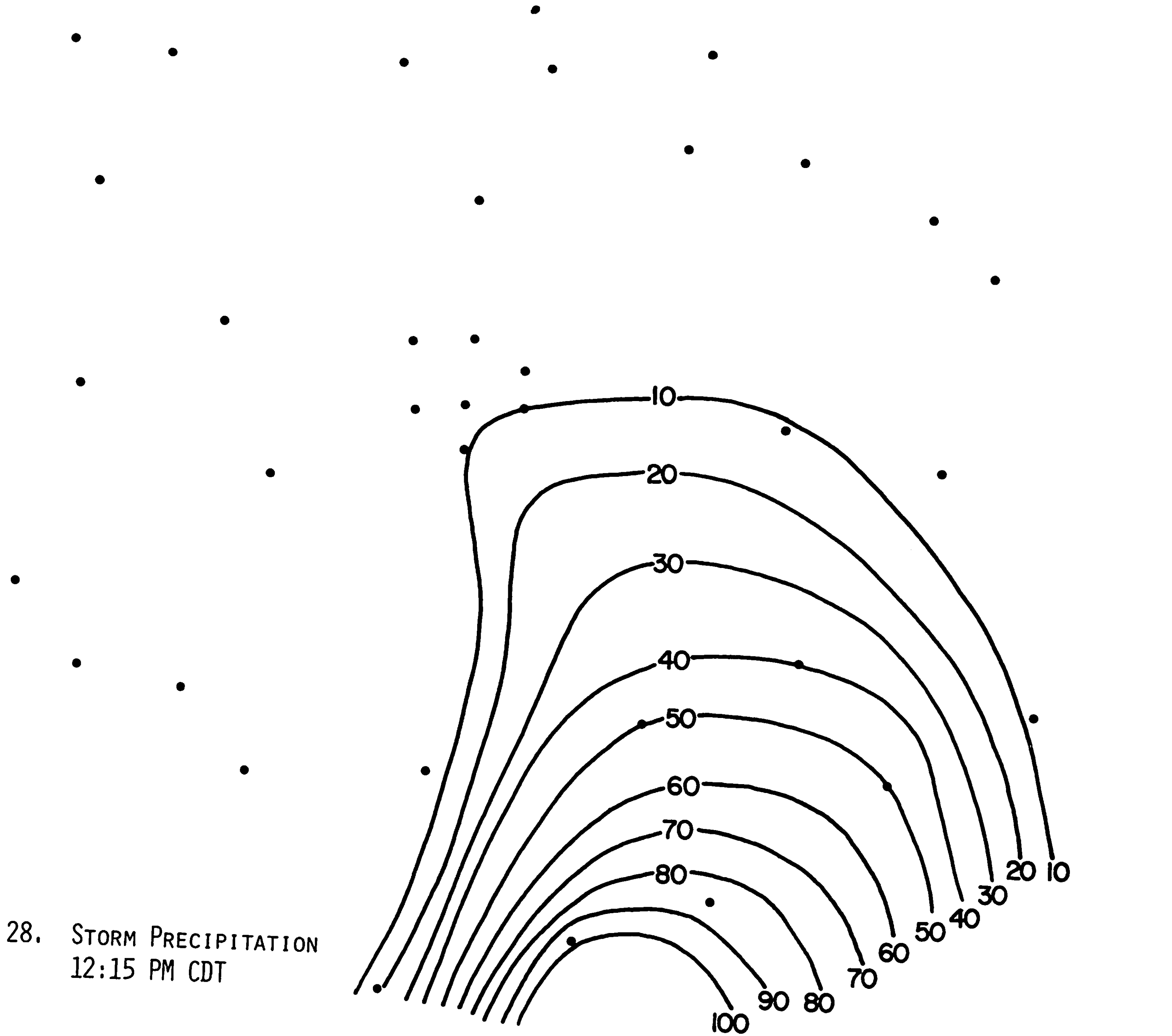

FIG. 28. STORM PRECIPITATION
12:15 PM CDT

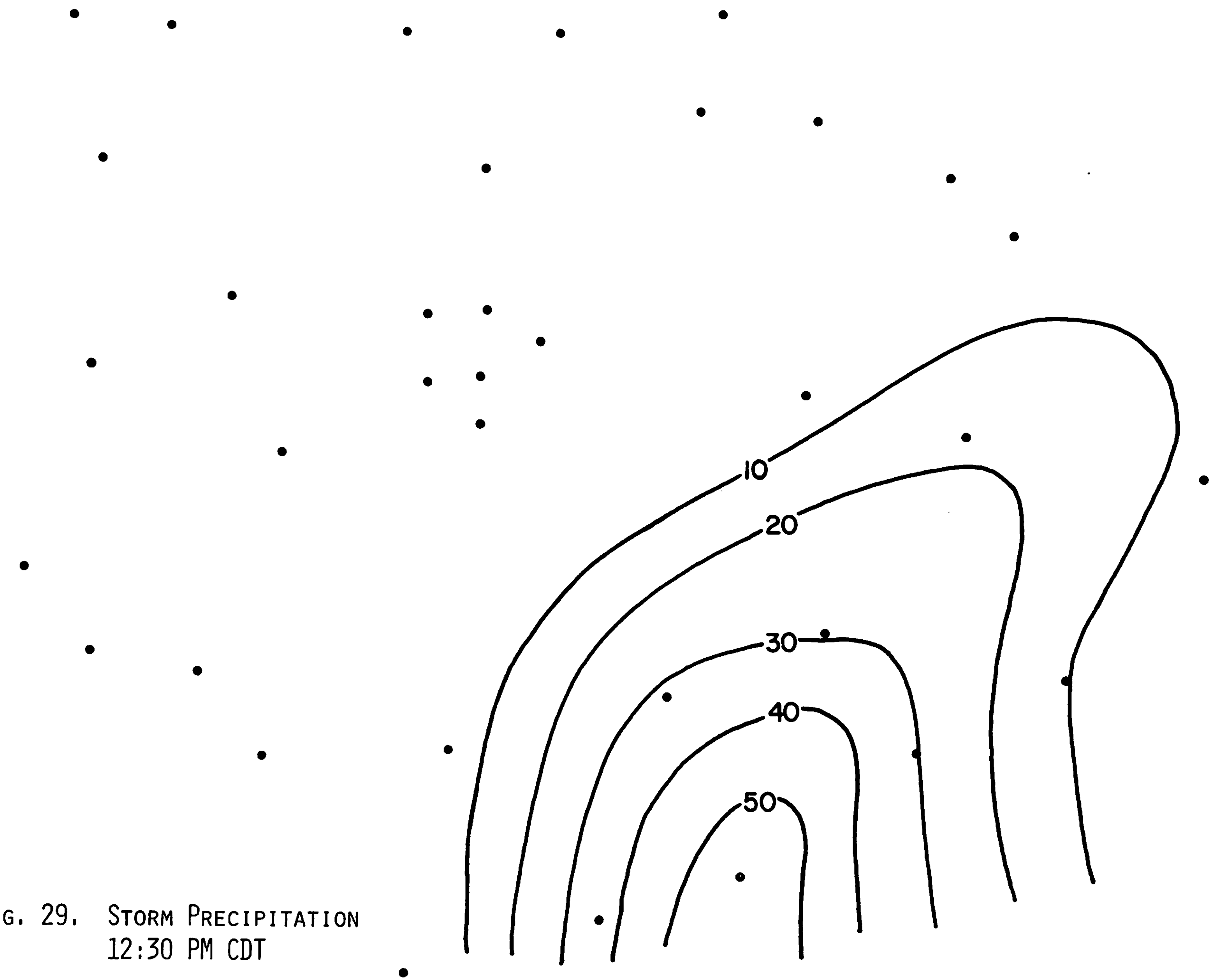

Fig. 29. Storm Precipitation
12:30 PM CDT

VIII. SUMMARY AND RECOMMENDATIONS FOR FURTHER INVESTIGATION

This investigation has answered the following questions for the Hiplex Southern region of Texas:

1) When does it rain? (Temporal Distribution)
2) Where does it rain? (Spatial Distribution)
3) Why does it rain? (Meso-Synoptic Patterns)
4) How often does it rain?
5) How much rain occurs during a rainfall period?
6) What is the duration (daily) of rainfall periods?
7) What is the frequency of occurrence of thunderstorms, rain showers, rain and drizzle and convective clouds?
8) What is the distribution of precipitable water?
9) How can precipitating cells be identified and analyzed utilizing the 15-minute resolution rain gage network?

Further work should focus on the recording rain gage network in order to produce a rain-cell climatology indicating the size, intensity, frequency and duration of rainfall events. Additional work should include case studies in conjunction with the parallel investigations utilizing radar, satellite and meso-network data.

APPENDIX A

SUMMARY OF HOURLY WEATHER EVENTS AND CLOUD OCCURRENCES

FREQUENCY OF OCCURRENCE OF CUMULUS CLOUDS

DURING 10-YEAR PERIOD

LOCAL		MAY			JUNE			JULY			AUGUST			SEPTEMBER	
TIME	MAF	LBB	ABI	MAF	LBB	ABI	MAF	LBB	ABI	MAF	LBB	ABI	MAF	LBB	ABI
00	1	0	3	4	2	3	6	1	3	2	1	3	0	2	3
01	2	1	3	7	0	3	8	3	3	1	3	3	2	2	3
02	4	2	3	4	1	3	6	1	3	1	4	3	2	2	3
03	6	2	3	2	0	3	1	0	3	1	1	3	0	2	3
04	4	0	3	5	1	3	1	1	3	1	1	3	1	0	3
05	5	1	3	6	3	6	11	5	6	1	0	3	1	0	3
06	7	2	6	6	10	15	23	17	15	12	7	15	7	1	6
07	16	4	6	6	6	12	20	22	15	25	19	22	13	6	9
08	16	5	22	11	7	15	22	18	18	22	16	28	14	4	12
09	28	13	25	13	20	42	28	27	46	32	18	37	18	5	21
10	58	30	46	54	53	78	71	46	93	73	42	61	42	17	48
11	80	58	81	100	91	114	126	106	170	137	98	170	88	48	96
12	106	101	102	128	124	150	181	153	201	208	175	217	128	76	117
13	121	124	118	155	167	174	217	191	210	230	223	236	154	107	141
14	140	152	130	169	186	180	214	202	220	229	224	245	161	121	147
15	144	153	133	173	188	183	204	191	210	204	208	236	160	122	138
16	138	142	127	175	177	180	185	192	208	192	185	220	151	106	132
17	118	130	102	140	154	165	175	177	201	180	175	211	151	93	123
18	96	99	78	114	113	132	145	132	174	149	134	177	125	60	99
19	60	52	34	85	61	84	113	85	136	113	68	108	60	27	45
20	30	18	12	52	25	39	60	33	56	68	21	43	13	5	18
21	5	3	3	16	7	12	21	11	15	19	4	12	5	1	6
22	5	2	3	7	4	3	6	4	6	11	2	9	4	0	3
23	2	0	3	6	3	3	8	4	3	7	1	6	0	0	6

FREQUENCY OF OCCURRENCE OF CUMULONIMBUS CLOUDS

DURING 10-YEAR PERIOD

LOCAL	MAY			JUNE			JULY			AUGUST			SEPTEMBER		
TIME	MAF	LBB	ABI	MAF	LBB	ABI	MAF	LBB	ABI	MAF	LBB	ABI	MAF	LBB	ABI
00	36	41	37	48	62	39	40	56	18	25	41	19	20	22	21
01	22	31	31	34	47	36	35	44	22	20	24	15	16	12	15
02	23	27	28	19	31	27	24	32	18	13	19	12	14	11	15
03	20	22	22	20	28	21	26	35	18	12	11	9	13	12	15
04	25	16	22	16	19	18	29	30	15	12	13	12	8	12	9
05	22	19	25	13	22	18	28	31	18	14	9	15	12	11	9
06	19	19	25	22	13	15	35	24	24	16	12	19	11	12	12
07	8	10	19	7	6	12	20	15	27	12	6	12	7	10	12
08	6	5	12	1	6	12	14	14	18	11	7	12	4	8	6
09	10	6	12	1	6	6	10	10	18	11	6	12	4	6	9
10	5	9	6	2	5	9	6	9	15	8	5	12	4	4	3
11	5	8	6	6	8	12	8	12	15	12	8	6	2	2	3
12	11	9	12	12	8	15	13	12	31	19	9	15	1	4	6
13	25	13	12	14	13	18	30	24	37	28	23	28	5	9	9
14	31	26	16	46	32	30	60	45	46	41	47	34	16	13	2
15	49	37	37	58	52	36	76	68	59	71	68	47	36	25	27
16	66	48	34	73	72	42	96	78	71	83	85	56	44	38	36
17	73	58	43	90	80	48	104	82	68	88	93	62	47	49	36
18	86	65	50	103	90	57	121	96	74	107	104	71	60	53	45
19	84	72	59	102	94	60	108	80	65	113	98	65	65	50	51
20	78	66	59	100	91	57	96	82	56	103	80	62	46	36	39
21	62	62	50	85	80	51	61	80	34	68	56	47	42	33	27
22	47	52	34	64	75	36	46	62	28	43	44	28	32	24	24
23	38	45	37	52	60	36	31	50	22	23	38	22	24	18	21

FREQUENCY OF OCCURRENCE OF STRATOCUMULUS CLOUDS

DURING 10-YEAR PERIOD

LOCAL		MAY			JUNE			JULY			AUGUST			SEPTEMBER	
TIME	MAF	LBB	ABI	MAF	LBB	ABI	MAF	LBB	ABI	MAF	LBB	ABI	MAF	LBB	ABI
00	16	29	28	11	18	18	7	11	9	3	11	6	22	13	24
01	28	31	28	13	14	18	11	13	12	6	15	10	20	22	22
02	29	29	28	14	17	21	12	15	15	12	15	11	18	23	21
03	36	26	28	25	26	27	16	14	15	8	18	12	25	28	24
04	38	32	31	30	28	21	17	19	22	10	19	12	24	20	30
05	59	41	34	41	40	42	12	22	19	13	27	19	26	19	27
06	71	55	43	54	48	42	23	25	31	28	31	28	36	30	27
07	74	47	53	61	41	48	48	26	37	29	31	25	47	31	32
08	73	62	65	72	43	48	62	21	37	37	30	25	70	32	33
09	80	68	74	74	46	63	64	33	40	41	31	37	72	40	42
10	59	64	81	50	41	63	42	31	43	30	33	37	66	46	57
11	46	62	74	30	37	57	28	27	31	17	22	31	48	42	53
12	29	48	65	23	22	48	16	24	28	8	13	22	31	36	54
13	18	41	56	14	14	36	8	18	19	7	9	15	24	25	39
14	13	24	50	12	11	27	6	13	15	6	4	15	18	24	33
15	11	20	46	14	8	24	2	7	12	3	6	15	12	17	30
16	10	22	50	10	11	21	5	8	9	4	7	12	13	20	30
17	8	24	53	12	11	21	8	9	12	7	7	12	14	17	27
18	14	32	50	12	23	24	12	22	12	12	24	19	23	21	24
19	10	38	43	17	23	24	11	19	22	20	40	37	32	31	33
20	18	33	31	18	26	24	20	16	22	22	25	28	23	23	21
21	20	29	28	14	20	18	11	15	22	13	16	22	22	17	24
22	18	27	25	11	15	15	7	12	12	7	12	15	24	15	27
23	14	26	31	8	19	15	6	10	12	5	14	9	20	14	27

FREQUENCY OF OCCURRENCE OF ALTOCUMULUS CLOUDS

DURING 10-YEAR PERIOD

LOCAL	MAY			JUNE			JULY			AUGUST			SEPTEMBER		
TIME	MAF	LBB	ABI	MAF	LBB	ABI	MAF	LBB	ABI	MAF	LBB	ABI	MAF	LBB	ABI
00	42	52	34	52	53	24	64	62	49	77	77	53	46	45	32
01	34	59	40	50	61	36	67	76	50	72	70	53	56	39	33
02	40	55	40	53	61	36	71	76	52	86	80	53	46	45	33
03	42	56	40	56	61	33	80	82	56	86	87	65	54	46	36
04	50	59	43	67	66	45	77	93	59	86	82	65	64	47	42
05	82	102	65	140	129	81	140	149	99	103	119	93	61	57	48
06	97	103	74	131	130	93	145	167	105	155	174	118	109	109	78
07	74	88	68	101	123	81	122	155	99	130	159	121	116	113	87
08	82	70	62	94	107	75	118	144	105	118	140	108	100	90	72
09	61	66	65	79	81	66	91	126	96	92	124	108	101	84	72
10	52	74	51	79	85	57	101	122	96	89	107	96	78	92	78
11	42	62	59	76	78	48	95	114	74	79	109	87	79	86	78
12	32	52	56	59	71	48	66	93	71	62	98	71	83	79	69
13	38	45	46	53	64	42	61	84	56	59	73	56	72	76	67
14	41	42	56	49	51	36	62	69	56	50	59	53	66	74	66
15	46	40	40	35	39	36	55	65	53	48	53	40	64	57	57
16	47	32	40	36	28	33	60	53	56	52	40	43	61	50	55
17	50	34	40	40	30	33	65	50	50	55	39	59	61	58	54
18	59	40	40	41	41	39	72	61	53	66	50	62	68	60	69
19	76	48	53	55	53	45	77	62	65	90	71	71	79	60	66
20	84	63	50	83	69	51	104	74	71	89	80	68	66	51	48
21	64	50	34	78	61	42	85	66	53	73	60	56	60	46	39
22	52	44	28	54	52	33	68	68	53	71	70	46	49	41	42
23	42	43	34	49	41	33	66	67	50	77	66	46	49	49	39

FREQUENCY OF OCCURRENCE OF ALTOCUMULUS CASTELLATUS CLOUDS

DURING 10-YEAR PERIOD

LOCAL		MAY			JUNE			JULY			AUGUST			SEPTEMBER	
TIME	MAF	LBB	ABI	MAF	LBB	ABI	MAF	LBB	ABI	MAF	LBB	ABI	MAF	LBB	ABI
00	0	0	2	0	0	2	0	2	1	0	0	2	0	0	1
01	0	0	2	0	0	3	0	0	2	0	0	2	0	0	1
02	0	0	3	0	0	2	1	0	2	0	0	3	0	0	3
03	0	0	3	0	1	3	0	0	3	1	0	3	0	0	2
04	0	0	3	0	0	3	0	0	3	0	0	3	0	0	3
05	5	1	3	7	5	9	4	3	9	2	0	3	0	0	3
06	22	4	6	28	12	18	28	14	31	36	13	9	6	8	8
07	20	3	9	32	9	15	32	20	28	48	20	15	22	6	9
08	18	6	12	37	12	21	34	19	22	38	21	19	19	9	12
09	24	15	12	31	22	27	43	18	19	54	25	22	19	9	14
10	25	5	9	32	9	18	41	17	19	41	21	19	22	5	15
11	25	7	9	26	10	15	32	9	15	36	17	15	19	5	12
12	34	13	9	31	15	18	34	15	12	36	13	15	19	10	10
13	24	9	6	24	10	18	22	12	6	17	5	9	14	7	9
14	13	2	6	22	3	15	17	9	6	13	6	3	12	7	6
15	12	4	9	20	4	15	14	4	6	7	5	6	10	12	7
16	13	1	9	12	0	12	12	0	6	5	2	3	11	5	9
17	16	1	3	5	0	9	5	0	6	2	1	3	6	0	9
18	13	3	6	6	2	6	7	0	3	2	1	6	2	2	6
19	8	1	3	2	1	3	3	2	6	2	0	3	2	1	3
20	4	1	3	6	1	3	1	0	3	1	0	3	1	0	3
21	0	0	3	3	0	3	0	0	2	0	1	3	0	0	3
22	0	0	3	1	0	2	0	0	3	0	0	2	0	0	2
23	0	0	2	0	0	2	1	0	3	0	0	2	0	0	1

FREQUENCY OF OCCURRENCE OF CURRUS CLOUDS

DURING 10-YEAR PERIOD

LOCAL	MAY			JUNE			JULY			AUGUST			SEPTEMBER		
TIME	MAF	LBB	ABI	MAF	LBB	ABI	MAF	LBB	ABI	MAF	LBB	ABI	MAF	LBB	ABI
00	61	71	37	86	66	39	86	64	50	78	72	40	37	38	18
01	55	64	28	76	59	39	88	63	53	62	62	34	34	38	21
02	55	66	19	65	63	45	82	52	46	53	57	31	32	34	18
03	47	59	28	65	56	36	74	61	37	54	60	34	30	33	18
04	46	61	31	61	61	54	77	66	50	55	60	34	30	32	21
05	84	90	59	115	92	99	133	92	105	76	89	71	35	29	27
06	125	99	74	152	108	114	187	127	133	156	133	140	64	34	54
07	118	104	68	120	94	96	170	113	105	170	122	118	86	43	63
08	107	102	62	116	85	81	160	109	90	162	105	99	72	44	51
09	113	106	56	116	85	81	164	115	99	164	115	108	74	40	57
10	112	103	65	112	85	87	175	112	102	163	112	105	83	41	57
11	112	99	62	121	84	69	181	106	99	163	115	105	73	49	60
12	122	102	68	119	82	75	179	102	90	163	115	96	82	61	57
13	122	99	65	116	77	75	169	105	84	152	104	93	84	61	42
14	125	105	65	114	85	72	161	110	93	134	95	87	78	61	54
15	127	104	62	115	93	72	156	109	99	145	103	99	85	65	60
16	130	98	59	114	91	75	166	109	90	138	120	93	95	71	54
17	145	106	65	139	99	78	173	119	87	150	121	90	106	81	57
18	150	129	78	146	114	93	181	131	102	174	148	90	128	89	66
19	156	134	78	168	122	99	194	158	118	197	163	102	128	96	63
20	146	133	74	190	140	108	203	172	118	191	158	90	73	71	45
21	100	103	53	142	111	78	156	144	90	109	129	62	61	52	33
22	79	90	46	94	84	60	104	116	68	88	106	40	50	51	24
23	73	87	37	80	80	48	96	98	59	77	95	40	41	49	21

FREQUENCY OF OCCURRENCE OF THUNDERSTORMS

DURING 10-YEAR PERIOD

LOCAL	MAY			JUNE			JULY			AUGUST			SEPTEMBER		
TIME	MAF	LBB	ABI	MAF	LBB	ABI	MAF	LBB	ABI	MAF	LBB	ABI	MAF	LBB	ABI
00	7	8	8	5	13	8	5	14	4	2	5	3	4	3	5
01	4	10	9	5	12	7	4	8	4	5	4	1	2	2	6
02	5	10	8	5	6	5	5	7	3	7	2	1	2	4	3
03	8	7	12	1	7	3	6	7	4	3	1	1	1	5	1
04	9	8	14	1	4	4	5	6	3	2	5	4	0	4	0
05	3	5	12	0	2	4	4	5	9	1	1	3	3	2	2
06	2	6	9	1	2	3	3	5	7	0	2	2	2	2	0
07	0	2	7	0	0	1	2	5	5	2	1	1	0	1	0
08	3	4	3	0	1	1	3	1	4	2	0	2	1	1	2
09	4	2	4	1	1	0	2	1	4	1	0	2	0	0	0
10	2	2	6	0	1	1	3	2	1	1	1	0	0	1	0
11	1	2	2	0	1	3	2	2	2	0	0	1	0	1	0
12	3	4	4	1	0	2	3	0	2	0	0	1	0	0	0
13	4	3	2	0	0	5	5	4	4	1	3	1	0	1	1
14	3	6	1	1	5	3	8	4	4	3	3	2	2	1	3
15	3	4	6	1	11	4	8	1	7	4	4	4	1	0	1
16	3	8	4	3	15	4	9	4	6	7	7	5	3	0	3
17	8	8	7	7	15	4	13	7	8	13	10	3	2	1	2
18	8	12	6	7	23	5	11	5	6	14	11	6	2	2	1
19	6	9	9	12	14	11	12	8	4	11	8	6	6	8	4
20	4	13	7	9	21	11	15	11	5	9	4	4	6	3	2
21	4	11	10	6	18	10	10	10	4	5	2	3	6	3	2
22	8	9	9	8	19	6	4	14	3	6	3	3	4	4	5
23	15	12	5	4	12	5	4	14	4	2	3	4	4	2	6

FREQUENCY OF OCCURRENCE OF RAIN SHOWERS

DURING 10-YEAR PERIOD

LOCAL		MAY			JUNE			JULY			AUGUST			SEPTEMBER	
TIME	MAF	LBB	ABI	MAF	LBB	ABI	MAF	LBB	ABI	MAF	LBB	ABI	MAF	LBB	ABI
00	12	12	9	4	15	9	9	17	4	2	9	3	9	4	8
01	6	12	9	6	15	10	6	17	3	7	9	1	4	1	9
02	5	10	15	4	10	10	5	11	6	6	8	3	4	2	8
03	11	7	11	3	7	5	8	11	4	5	8	4	3	2	7
04	11	11	16	1	5	8	7	10	5	5	6	4	3	5	4
05	6	10	14	1	3	11	3	8	5	3	5	6	3	4	3
06	7	10	17	3	3	5	3	10	9	6	5	2	5	2	3
07	2	4	11	2	3	6	7	11	7	6	6	5	4	3	4
08	4	7	9	3	4	3	9	8	9	2	4	4	5	4	3
09	5	4	7	3	4	4	4	3	12	0	3	3	3	2	3
10	4	4	9	4	2	2	4	5	7	0	3	3	2	4	2
11	2	3	9	4	2	5	5	6	6	3	1	3	4	2	2
12	4	5	7	6	3	5	4	7	5	0	1	3	6	3	7
13	6	4	5	4	2	9	8	4	5	4	2	6	2	3	2
14	4	8	7	4	5	6	7	6	6	5	2	3	5	5	3
15	7	10	8	1	7	5	6	4	3	6	3	6	5	3	9
16	8	9	9	5	12	6	11	6	6	7	7	4	4	6	7
17	9	6	9	8	14	4	14	11	15	8	9	8	5	3	8
18	9	12	9	9	14	6	11	10	11	10	11	5	2	6	3
19	9	15	6	9	15	8	12	7	4	12	8	4	7	6	6
20	7	12	9	7	18	11	12	8	6	11	5	3	8	7	4
21	7	10	13	6	18	10	12	14	5	5	4	4	8	6	7
22	11	9	12	9	20	11	11	18	3	4	6	3	3	4	5
23	14	14	10	7	13	8	8	18	6	2	7	4	8	4	9

FREQUENCY OF OCCURRENCE OF RAIN

AND DRIZZLE DURING 10-YEAR PERIOD

LOCAL		MAY			JUNE			JULY			AUGUST			SEPTEMBER	
TIME	MAF	LBB	ABI	MAF	LBB	ABI	MAF	LBB	ABI	MAF	LBB	ABI	MAF	LBB	ABI
00	4	8	7	8	1	4	0	3	1	1	1	0	0	5	5
01	6	7	6	4	1	4	2	3	4	0	2	0	3	4	3
02	7	7	5	6	3	4	4	3	2	0	1	0	4	5	4
03	5	8	8	5	4	5	5	4	3	1	2	0	6	5	4
04	6	7	7	4	6	7	5	5	3	1	1	0	4	2	4
05	5	9	7	3	5	3	6	6	2	0	1	0	5	3	8
06	6	7	8	4	5	6	7	7	3	1	1	0	3	7	7
07	7	9	13	6	6	5	6	7	3	1	1	1	9	6	8
08	5	10	9	6	6	5	6	7	5	2	0	1	10	8	8
09	5	9	11	5	6	6	5	7	1	2	0	2	4	5	11
10	5	9	7	3	4	9	5	7	4	1	0	1	4	3	7
11	5	3	8	1	3	7	3	4	5	1	1	0	6	3	8
12	4	3	7	1	3	3	2	3	3	1	0	0	3	1	9
13	2	3	6	1	3	7	2	2	1	1	1	0	4	1	9
14	2	1	6	2	3	4	1	0	1	1	1	0	4	2	9
15	1	1	5	2	2	2	0	0	0	1	1	0	4	1	8
16	1	2	6	4	2	3	0	1	0	1	0	0	2	4	7
17	1	3	1	3	4	4	0	1	0	1	1	0	3	3	7
18	2	5	2	5	3	3	1	1	0	0	1	1	2	2	6
19	1	7	1	2	3	2	2	2	0	0	0	1	1	4	6
20	2	6	4	4	4	3	1	2	1	2	0	1	2	5	6
21	4	4	4	6	3	6	1	1	1	0	1	2	2	1	6
22	7	5	7	5	3	5	0	0	3	0	1	0	2	4	6
23	2	7	2	8	3	2	0	3	2	0	0	0	1	4	5

FREQUENCY OF OCCURRENCE OF FOG

DURING 10-YEAR PERIOD

LOCAL	MAY			JUNE			JULY			AUGUST			SEPTEMBER		
TIME	MAF	LBB	ABI	MAF	LBB	ABI	MAF	LBB	ABI	MAF	LBB	ABI	MAF	LBB	ABI
00	2	6	4	3	0	2	0	0	0	0	1	0	0	1	0
01	2	7	4	2	0	4	1	0	1	0	1	0	1	2	0
02	4	9	8	2	1	1	1	1	1	0	1	0	1	4	0
03	5	8	9	2	0	2	1	0	1	0	1	0	2	5	0
04	6	11	14	1	2	1	1	0	0	0	1	2	5	6	1
05	4	14	12	2	2	1	0	3	0	0	2	1	5	7	2
06	9	17	19	2	7	4	1	7	3	1	3	4	6	10	3
07	11	17	16	4	3	5	2	4	2	1	4	4	8	16	8
08	6	12	15	6	2	3	2	1	1	1	2	3	7	11	7
09	2	8	12	4	0	3	0	0	1	0	0	2	0	7	7
10	2	5	6	2	0	4	0	0	0	0	0	1	1	2	1
11	1	4	4	1	0	3	0	0	0	0	0	0	2	2	2
12	1	4	4	1	0	2	0	0	0	0	0	0	1	1	3
13	0	4	2	2	0	2	0	0	0	0	0	0	1	0	3
14	0	3	3	2	0	2	0	0	0	0	0	0	0	0	1
15	0	2	2	1	0	1	0	0	0	0	0	0	0	0	2
16	0	1	2	1	0	1	0	0	0	0	0	0	1	0	1
17	0	1	1	0	0	0	0	0	0	0	0	0	1	0	2
18	0	4	1	0	1	1	0	0	0	0	0	0	1	0	3
19	0	5	1	0	1	1	0	0	0	0	0	0	1	1	1
20	1	3	1	1	0	1	0	0	0	0	0	0	1	1	2
21	1	3	1	1	0	1	0	0	0	0	0	1	1	1	1
22	1	3	1	3	0	2	0	1	0	0	0	0	1	3	1
23	2	4	1	3	0	2	0	0	0	0	0	0	1	1	2

APPENDIX B

Mean-Monthly Precipitable Water
Midland, Texas

PRECIPITABLE WATER - MIDLAND

		900-950	800-900	700-800	600-700	500-600	400-500	TOTAL
May	1954	0.14	1.21	0.73	0.47	0.28	0.11	2.94
	1955	0.13	1.13	0.62	0.41	0.26	0.12	2.67
	1956	0.17	1.32	0.66	0.43	0.25	0.11	2.94
	1957	0.14	1.18	0.73	0.42	0.22	0.10	2.79
	1958	0.14	1.18	0.80	0.50	0.28	0.12	3.02
	1959	0.14	1.28	0.79	0.48	0.26	0.12	3.07
	1960	0.08	0.82	0.54	0.39	0.23	0.10	2.16
	1961	0.11	1.03	0.63	0.36	0.23	0.13	2.49
	1962	0.09	0.99	0.60	0.37	0.24	0.11	2.40
	1963	0.14	1.18	0.75	0.45	0.28	0.13	2.93
	1964	0.11	1.09	0.71	0.45	0.26	0.14	2.76
	1965	0.12	1.26	0.80	0.45	0.24	0.12	2.99
	1966	0.13	1.09	0.70	0.42	0.26	0.12	2.72
	1967	0.08	0.81	0.53	0.36	0.22	0.12	2.12
	1968	0.11	1.18	0.67	0.38	0.23	0.10	2.67
	1969	0.12	1.08	0.67	0.39	0.22	0.09	2.57
	1970	0.10	0.86	0.55	0.35	0.21	0.10	2.17
	1971	0.08	0.84	0.52	0.34	0.21	0.09	2.08
	Mean	0.12	1.08	0.67	0.41	0.24	0.11	2.63
Standard Deviation		0.025	0.161	0.093	0.048	0.024	0.014	0.333
Coef. of Variation		0.21	0.15	0.14	0.12	0.10	0.13	0.13

PRECIPITABLE WATER - MIDLAND

		900-950	800-900	700-800	600-700	500-600	400-500	TOTAL
June	1954	0.18	1.61	1.02	0.58	0.32	0.13	3.97
	1955	0.18	1.34	0.78	0.59	0.36	0.15	3.40
	1956	0.20	1.49	0.98	0.66	0.40	0.17	3.90
	1957	0.15	1.54	1.00	0.60	0.32	0.12	3.73
	1958	0.16	1.66	1.18	0.76	0.45	0.19	4.40
	1959	0.17	1.62	1.13	0.70	0.39	0.18	4.19
	1960	0.13	1.38	0.99	0.62	0.35	0.13	3.60
	1961	0.17	1.54	1.02	0.59	0.33	0.15	3.80
	1962	0.14	1.48	1.01	0.56	0.30	0.13	3.62
	1963	0.15	1.47	0.96	0.54	0.32	0.15	3.59
	1964	0.13	1.35	0.92	0.56	0.32	0.15	3.43
	1965	0.15	1.53	0.94	0.54	0.32	0.16	3.64
	1966	0.16	1.41	0.91	0.57	0.35	0.16	3.56
	1967	0.14	1.48	1.03	0.66	0.36	0.19	3.86
	1968	0.14	1.40	0.90	0.50	0.28	0.12	3.34
	1969	0.12	1.40	0.93	0.56	0.30	0.13	3.44
	1970	0.14	1.20	0.80	0.59	0.36	0.16	3.25
	1971	0.16	1.39	0.91	0.52	0.28	0.12	3.38
	Mean	0.15	1.46	0.97	0.59	0.34	0.15	3.67
Standard Deviation		0.021	0.114	0.098	0.065	0.043	0.023	0.305
Coef. of Variation		0.14	0.08	0.10	0.11	0.13	0.15	0.08

PRECIPITABLE WATER - MIDLAND

		900-950	800-900	700-800	600-700	500-600	400-500	TOTAL
July	1954	0.22	1.61	1.06	0.71	0.38	0.18	4.16
	1955	0.24	1.82	1.25	0.83	0.46	0.22	4.82
	1956	0.22	1.53	1.05	0.71	0.42	0.17	4.10
	1957	0.18	1.52	1.11	0.66	0.39	0.21	4.07
	1958	0.18	1.66	1.18	0.78	0.45	0.20	4.45
	1959	0.23	1.76	1.27	0.80	0.45	0.21	4.72
	1960	0.20	1.64	1.19	0.72	0.42	0.20	4.37
	1961	0.20	1.58	1.15	0.65	0.33	0.15	4.06
	1962	0.18	1.54	1.20	0.85	0.52	0.23	4.52
	1963	0.16	1.50	1.10	0.76	0.46	0.24	4.22
	1964	0.16	1.41	1.03	0.68	0.38	0.19	3.85
	1965	0.16	1.34	1.01	0.67	0.37	0.16	3.71
	1966	0.16	1.52	1.19	0.82	0.47	0.22	4.38
	1967	0.18	1.44	1.15	0.78	0.39	0.18	4.12
	1968	0.21	1.60	1.21	0.79	0.48	0.23	4.52
	1969	0.18	1.59	1.24	0.80	0.40	0.19	4.40
	1970	0.17	1.36	1.03	0.72	0.36	0.15	3.79
	1971	0.17	1.37	1.06	0.68	0.36	0.16	3.80
	Mean	0.19	1.54	1.14	0.74	0.42	0.19	4.22
Standard Deviation		0.026	0.131	0.083	0.063	0.051	0.028	0.322
Coef. of Variation		0.14	0.08	0.07	0.08	0.12	0.15	0.08

PRECIPITABLE WATER - MIDLAND

		900-950	800-900	700-800	600-700	500-600	400-500	TOTAL
August	1954	0.25	1.82	1.35	0.86	0.47	0.22	4.97
	1955	0.22	1.66	1.19	0.78	0.44	0.18	4.47
	1956	0.21	1.40	0.98	0.62	0.32	0.15	3.68
	1957	0.19	1.52	1.21	0.80	0.40	0.17	4.29
	1958	0.18	1.58	1.27	0.89	0.46	0.22	4.60
	1959	0.19	1.78	1.37	0.82	0.42	0.20	4.78
	1960	0.19	1.76	1.33	0.80	0.40	0.19	4.67
	1961	0.19	1.44	1.14	0.74	0.38	0.15	4.04
	1962	0.15	1.31	1.04	0.69	0.33	0.13	3.65
	1963	0.18	1.49	1.20	0.86	0.48	0.20	4.41
	1964	0.16	1.55	1.12	0.71	0.39	0.20	4.13
	1965	0.17	1.45	1.09	0.71	0.40	0.21	4.03
	1966	0.18	1.62	1.22	0.74	0.46	0.24	4.46
	1967	0.16	1.31	1.06	0.74	0.36	0.16	3.79
	1968	0.20	1.53	1.19	0.79	0.42	0.22	4.35
	1969	0.16	1.56	1.20	0.82	0.46	0.22	4.42
	1970	0.15	1.33	1.06	0.67	0.36	0.18	3.75
	1971	0.20	1.62	1.16	0.72	0.38	0.18	4.26
Mean		0.18	1.54	1.18	0.76	0.41	0.19	4.26
Standard Deviation		0.026	0.154	0.109	0.072	0.048	0.030	0.384
Coef. of Variation		0.14	0.10	0.09	0.09	0.12	0.16	0.09

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METEOROLOGY RESEARCH, INCORPORATED

"SNYDER RADAR-DATA ANALYSIS"

mri Technical Report

BIG SPRING - HIPLEX

Interim Report No. 6 for the Period
1 October 1977 to 1 April 1978

MRI 78 IR-1552

Subcontract with
Texas Department of Water Resources
Post Office Box 13087
Capitol Station
Austin, Texas 78711

Bureau of Reclamation Contract
14-06-D-7587 as amended 1 June 1975

Date 4 May 1977

Meteorology Research, Inc.
Box 637, 464 West Woodbury Road
Altadena, California 91001
Telephone (213)791-1901 Telex 675421
A Subsidiary of Cohu, Inc.

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Introduction

Work under the present contract with the Texas Department of Water Resources was initiated in late February 1978. The following interim report therefore covers an actual work period from late February to 1 April 1978.

The objectives of the MRI portion of the Texas Hiplex program have been listed as:

a. Acquisition and processing of quantitative radar data

b. Development and interpretation of cloud and radar climatologies

c. Processing and interpretation of data related to the mesoscale experiments

Numerous problems related to the processing of the Snyder radar data have developed in the last two years. These problems have been caused in large part by errors introduced into the radar data by the digital processor, by wave guide difficulties in 1976 and, to some extent, by changes in the Bureau of Reclamation radar data format. A reevaluation of the procedures for processing the tapes took place in late September 1977. These procedures are now being implemented with considerable progress having already been made.

Development of the cloud and radar climatologies requires the information to be generated from the Bureau of Reclamation radar summaries. Since all of the Snyder tapes have not yet been processed into Bureau format little has been accomplished on the climatologies.

Analyses of mesoscale experiments have followed two lines of approach:

a. Case studies of individual mesoscale events

b. Identification and frequency of occurrence of various mesoscale patterns

Studies in both of these areas have been initiated under the present contract.

Radar Data Processing

In late September 1977 the radar data processing program was redesigned to make the procedures more efficient and more computer-oriented. The new design consists of the following steps:

a. Desyntax of the field tape

b. Error search and computer correction

c. Listing of errors and corrections

d. Averaging of three range bins into one

e. Creation of tape in Bureau format

This program is accomplished in one pass through the computer where the output of the program is a Bureau-compatible tape. Due to the various bit errors which are introduced by the digital processor during recording of the data, the error search and computer correction portion of the program has been the most complex section of the procedure. This section has been modified twice to include a search and correction procedure for two types of errors which had previously not been recognized. In addition to the tape generated by the program, a base-angle scan is plotted routinely in contour form for all available base elevation data.

Production runs of all tapes have been started for the available 1976-77 data. Two days of data had been completed by the end of April. A test tape has been forwarded to the Bureau for a check of format compatibility with the Bureau processing program.

Mesoscale Analyses

Two case studies from 1976 have been selected for mesoscale analyses. These cases represent markedly different precipitation conditions.

June 22-23, 1976

This case consisted of a squall-line passing through the Hiplex site June 22-23, 1976. A strong band of precipitation was observed on the NWS radar echo map around 0035Z, June 23 in the Hiplex site, moving rapidly toward the east. The line triggered heavy thunderstorms for a few hours and finally dissipated in the early morning of June 23.

The present analysis reveals a strong relationship between the main precipitation zone and a minimum in the surface static energy field. The line position defined by the surface pressure and wind field was well correlated with the cloud and precipitation line. The changes in stability conditions of the vertical sounding were large during and after the squall passage.

The surface pressure fields were analyzed by using ten surface mechanical weather stations and neighboring stations. A hand analysis (Figure 1) was used with special care to match the wind direction-isobar relationship.

At 0000Z the squall line was oriented approximately northeast-southwest, passing the vicinity of Post and Lamesa. At 0100Z the squall line passed Post, and still showed a northeast-southwest direction. At 0200Z, the line passed Snyder trailing down to the Big Spring area. At 0300Z, the squall line passed Sweetwater and the orientation of the line changed toward an east-west direction and by 0400Z the line passed Robert Lee.

The static energy field was deduced from the temperature and dew point data provided by the mechanical weather stations. In Figure 2 a sample time (0200Z) is shown. The analysis shows that in the vicinity of the squall line there is a large gradient of static energy in the direction of the line movement. Behind the line, there is a distinct minimum area (325 J gm^{-1}), which corresponds with a small high pressure system near Gail (see Figure 1, 0200Z). The high energy region is to the southeast of the line and the low energy region is to the northwest of the line. The distribution of the static energy and the pressure distribution suggest that the high energy is fed into the line by the southerly wind. This is believed to be the source of the kinetic energy for further development of the line system. The minimum energy area is created by the downdraft associated with precipitation formation. The enclosed minimum area also suggests that the precipitation and downdraft region is not uniform along the line system. The maximum precipitation area should correlate with the minimum static energy area.

The PPI radar plot about 0200Z is shown in Figure 3. The cross-mark is the location of Snyder and the outer ring is approximately 137 km from Snyder. The highest dbZ values are in the vicinity of Snyder and the northeast branch of the line. Local ground effects (within 24 km radius from Snyder) result in blanking out the dbZ pattern near Snyder, but areas of high reflectivities (>35 dbZ) can be observed elsewhere. From Figures 2 and 3, the minimum static energy area

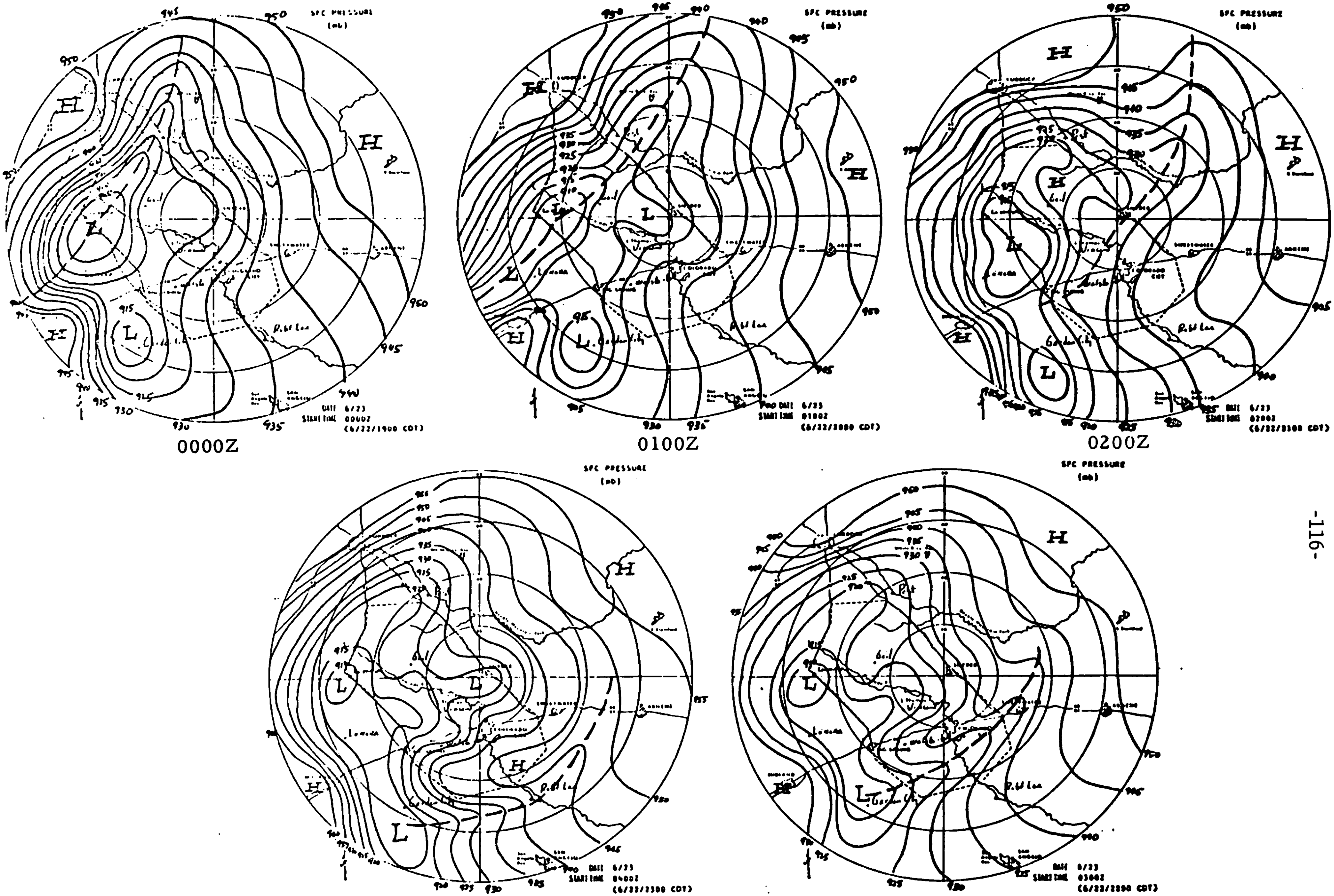

Figure 1. Surface Pressure Fields - June 22, 1976

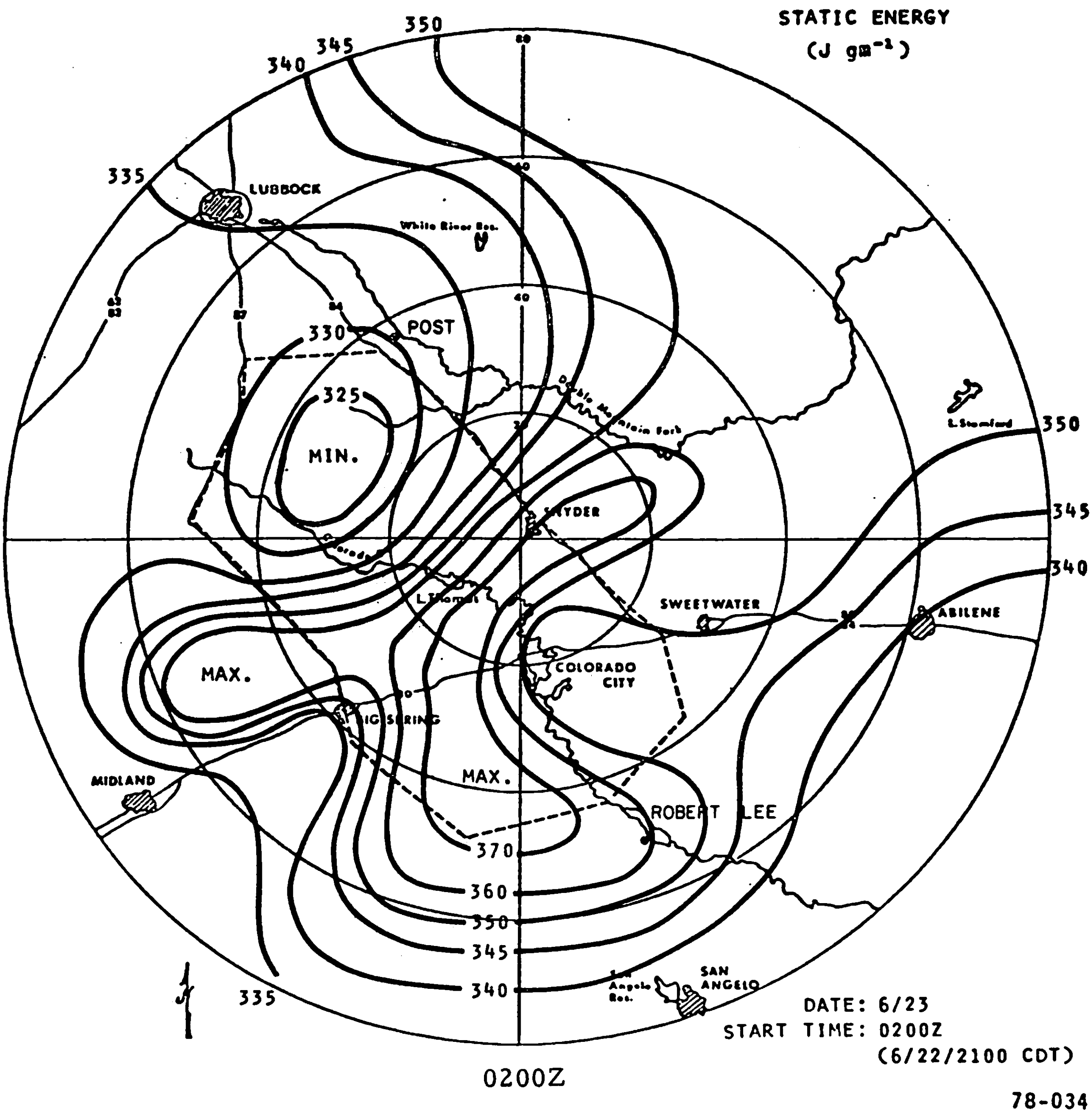

Figure 2. Static Energy Field - June 22, 1976

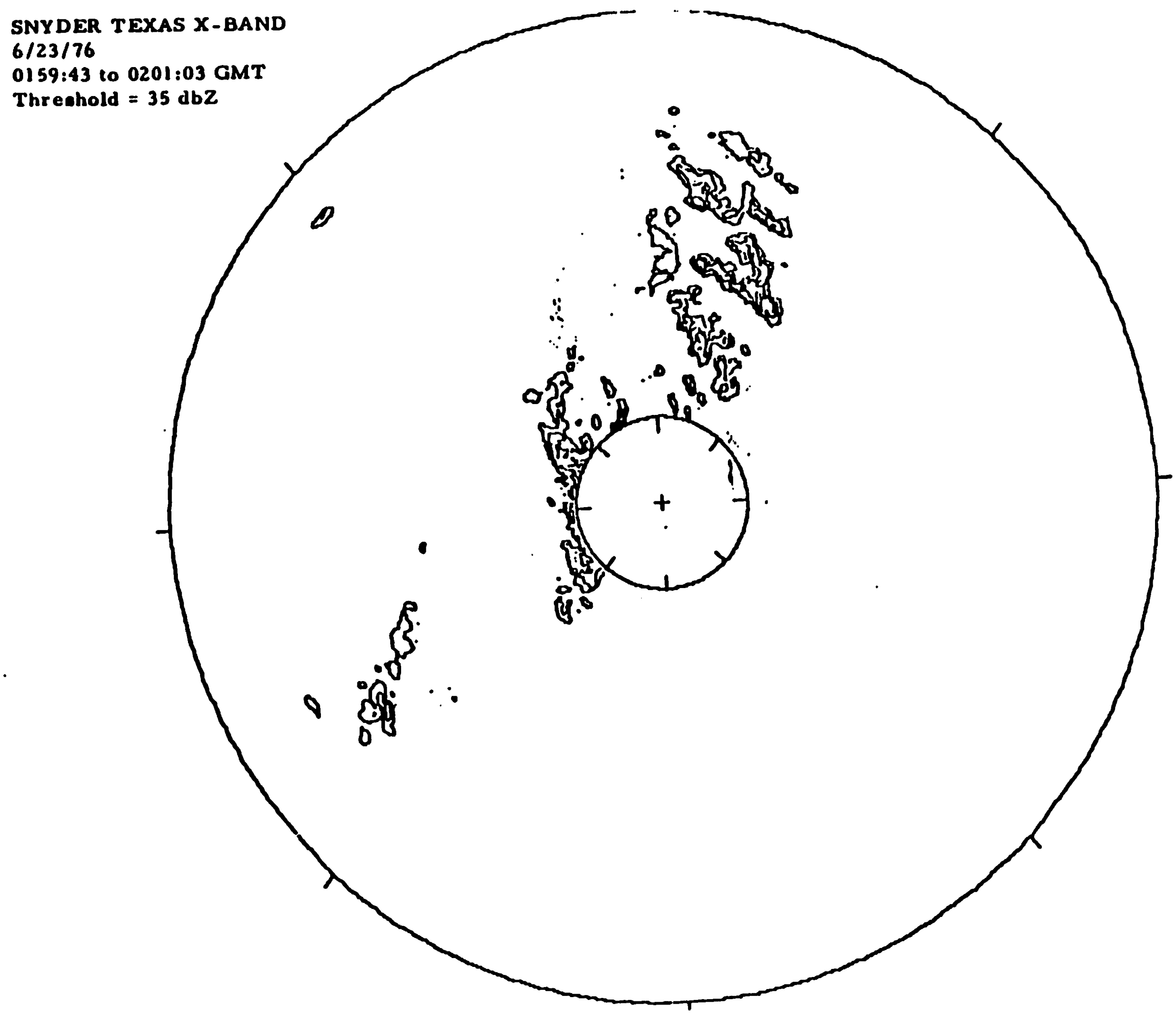

Figure 3. Radar Reflectivity Pattern - June 23, 1976

trails behind the major high reflectivity zone near Snyder. This suggests a relation with the precipitation-induced downdraft area.

Post vertical soundings at 3-hour intervals are given in Figure 4, where θ is potential temperature, θe is equivalent potential temperature and θe^* is the equivalent potential temperature calculated with saturation mixing ratio. At 2100Z, the squall line is to the west of Post. The sounding shows some instability, however this instability is not strong enough to develop a large convective system without substantial mechanical lifting.

At 0000Z, the squall line is in the proximity of Post, the sounding still shows weak convective potential, but around 500 mb the air is near saturation ($\theta e \simeq \theta e^*$). At 0300Z, the sounding is basically neutral, at 550 mb and above the air remains near-saturated, below 850 mb an inversion is observed with a very shallow unstable moist layer near the ground. The squall line passed Post shortly after 0000Z, with a high dbZ in the area at 0145Z. At 0300Z, no reflectivity was observed around Post. The stabilization of the sounding at 0300Z then can be interpreted as follows:

> The convective motion in the cloud uses up the kinetic energy and the vertical distribution of θe becomes uniform. The precipitation falls to the lower layers of the atmosphere and evaporates, cooling the air near 850 mb and moistening the low levels. Since the sounding at 0300Z has little convective potential no cells are observed.

Figure 5 shows a cross sectional view of the θe distribution at 0300Z. All the upper air stations are projected on a vertical plane through Snyder with a northwest-southeast orientation. At 0300Z the squall line was passing Snyder and its orientation was roughly northeast-southwest. The analyzed plane is therefore roughly perpendicular to the squall line. The purpose of this analysis is to show the θe distribution in the upper air as opposed to the surface analysis reported above.

The figure shows that the prefrontal maximum θe region extended to the upper air (a tongue-shaped contour of 342°K to the left of Big Spring and Station 4-Snyder). The ground level minimum is located in the back of the front. The upper air minimum (334°K contour) is just below the 400 mb level. The 338°K contour resembles the dbZ contours of some of the severe storms in the Oklahoma region. In the upper part of the figure, there are two markings signifying the locations of the high dbZ zone deduced from the PPI plot. A relation between the high dbZ values and the minimum θe zone is suggested.

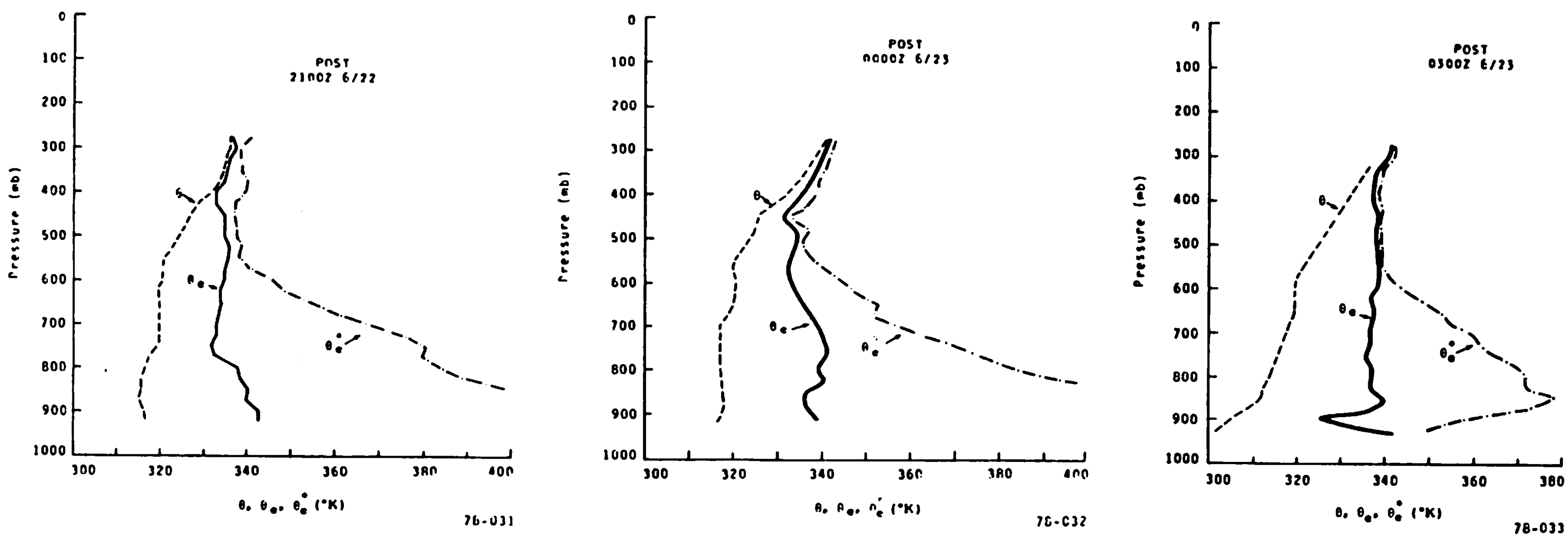

Figure 4. Vertical Soundings - June 22-23, 1976

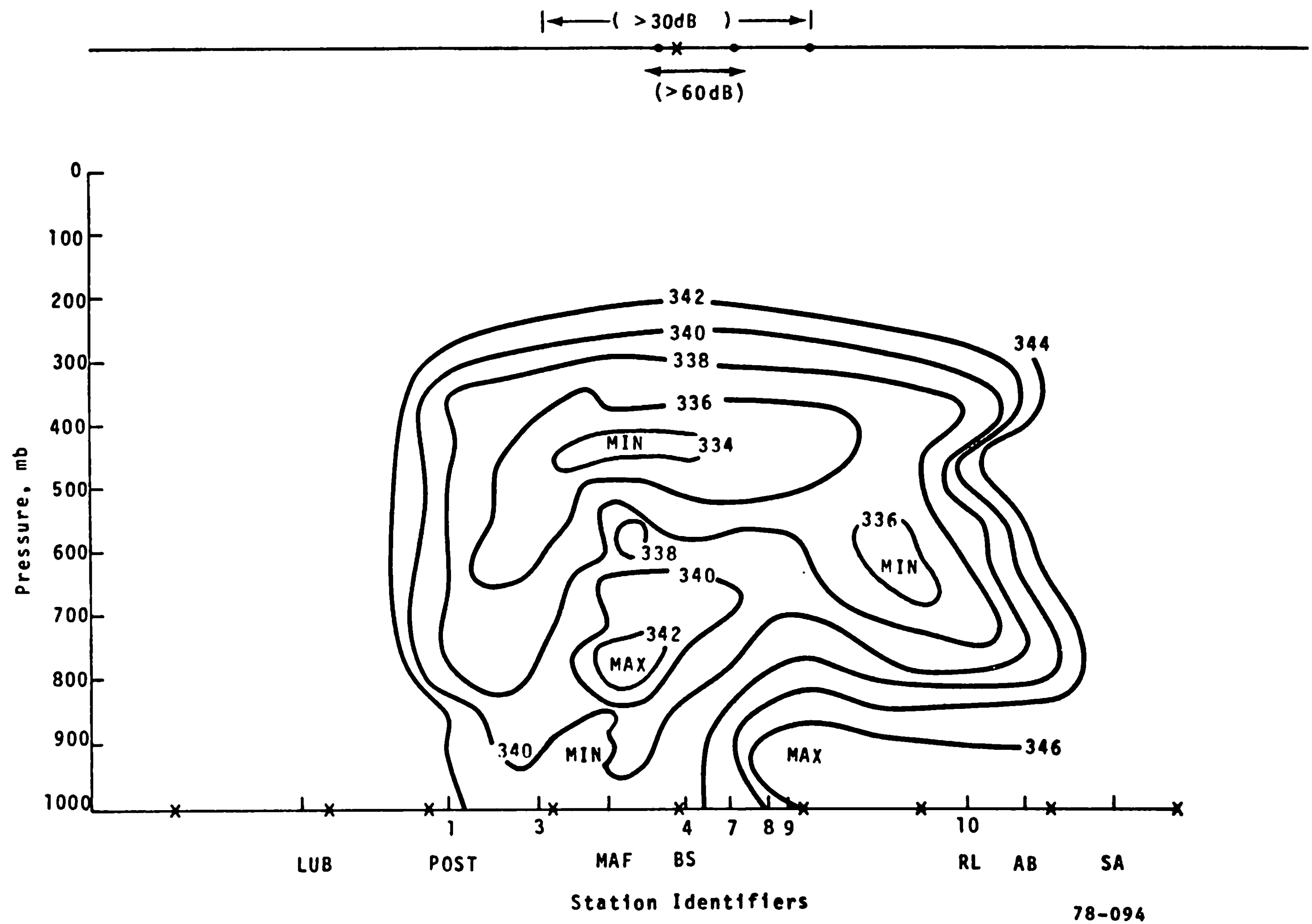

Figure 5. The Cross Sectional Analysis of θe. The Plane is Roughly Perpendicular to the Squall Line

July 10-11, 1976

In the 500 mb synoptic analysis at 1200Z (July 10) there was a low pressure system centered over the Hiplex area. The surface and upper air analyses show southerly flow in the area. There was no predominant frontal or squall-line system as in the first case study (June 22-23, 1976).

The θ-soundings in Big Spring (Figure 6) show moist instability for most of the observed hours. At 1500Z, the instability was small, but the closeness of the θe and θe*s curves show the air was moist at all levels. At 1800Z (1300 CDT), radiative heating increased the surface temperture (notice the change of θ, from 300 to 305°K), and the moist instability greatly increased. From 2100Z, the moist instability decreased continuously. The sounding data show that convective motion could be triggered by the surface heating in contrast to the June 22-23 case.

The radar PPI plot for 2152Z is shown in Figure 7. At 2152Z, some convective cells with more than 60 dbZ were located in the vicinity of Snyder and Big Spring. Roughly thirty minutes later, the cells covered a larger area, and the maximum dbZ was located to the west of Snyder. At 2331Z, the echo area had expanded, and thereafter the cells showed signs of dissipation.

The raingage network data of CRMWD, analyzed by the Bureau of Reclamation, show good agreement between the maximum dbZ area and the major precipitation area near Snyder and Big Spring.

From the rainfall analysis and PPI echoes the cloud active period was defined as 2100 to 2400Z in the Snyder-Big Spring area. The sounding characteristics show that the maximum instability occurred around 1800Z, but the high dbZ echoes appeared roughly three hours later.

Figure 8 shows the vertical profile of horizontal winds in the Big Spring area. The wind speeds below 500 mb level for three time periods were lower than 10 m/sec^{-1}. Wind direction veered continuously from 135° at the surface to about 270° at 300 mb. The shears calculated by the absolute value of winds at the surface and 800 mb are listed in Table 1. From 1800Z to 0000Z, the magnitude of downshear increases with time. This may have contributed to the downdraft development associated with the dissipation of clouds in the area.

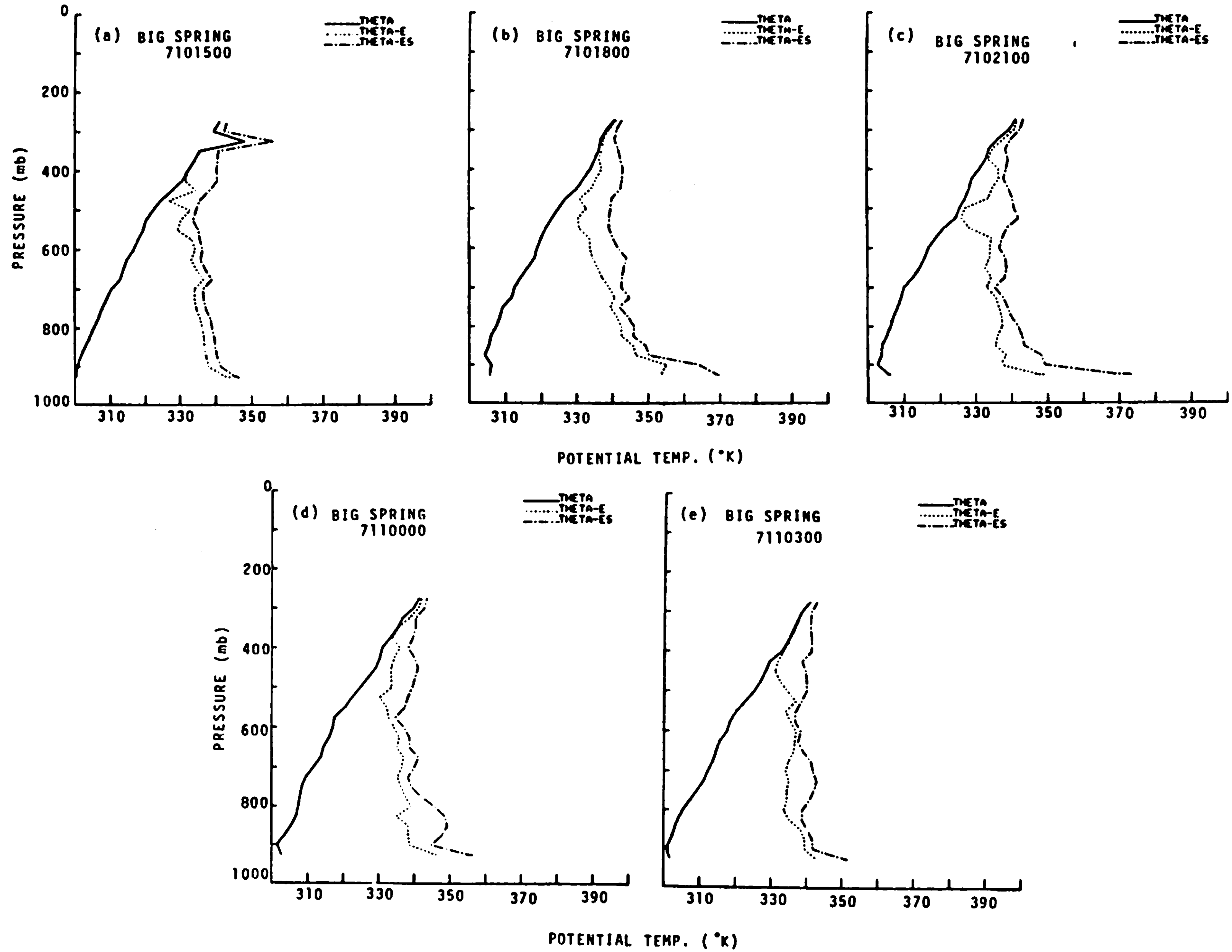

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Figure 6. The Time Display of θ's Soundings at Big Spring (July 10-11)
(a) 1500Z (b) 1800Z (c) 2100Z (d) 0000Z (e) 0300Z

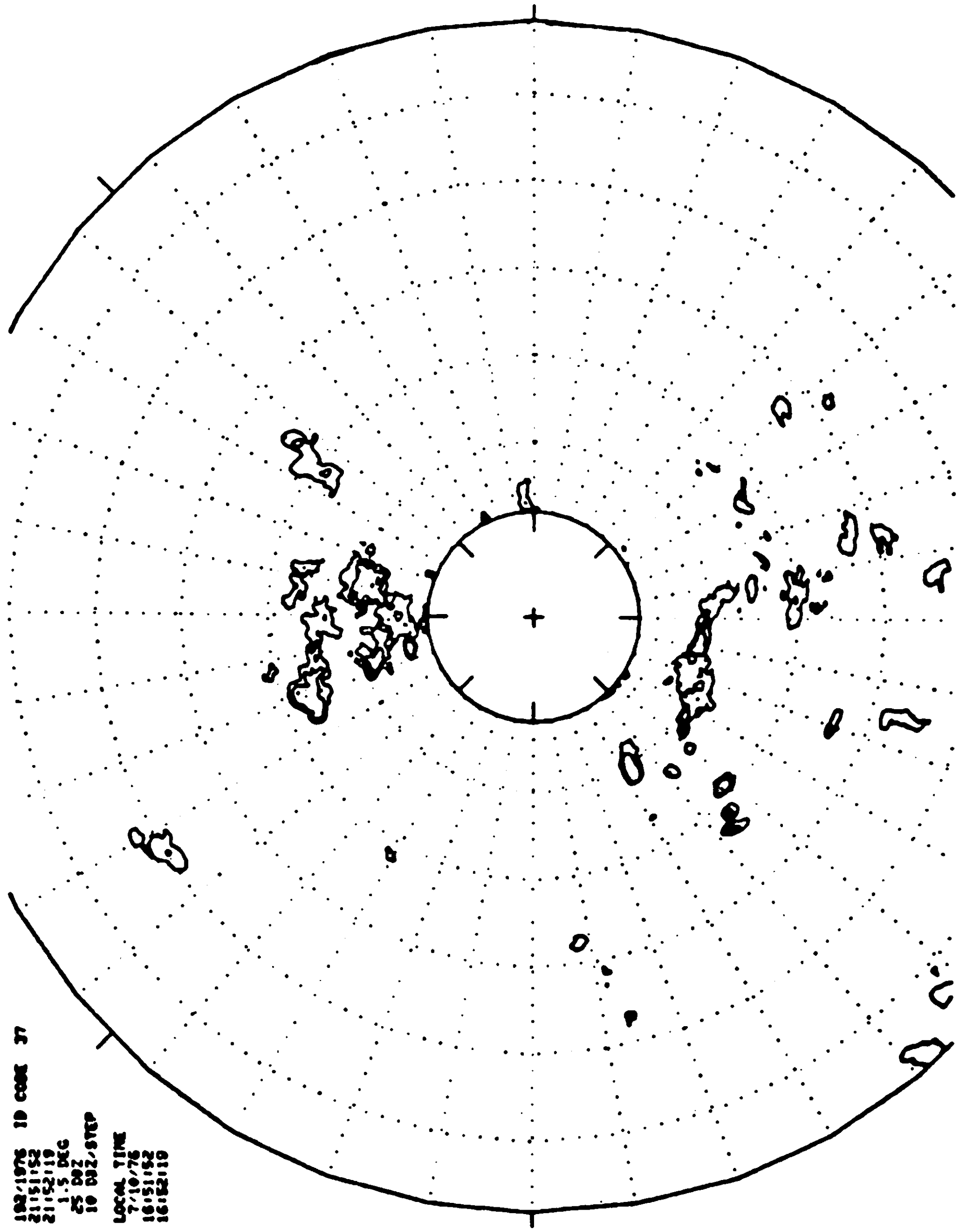

Figure 7. PPI Radar Plot for 2152Z

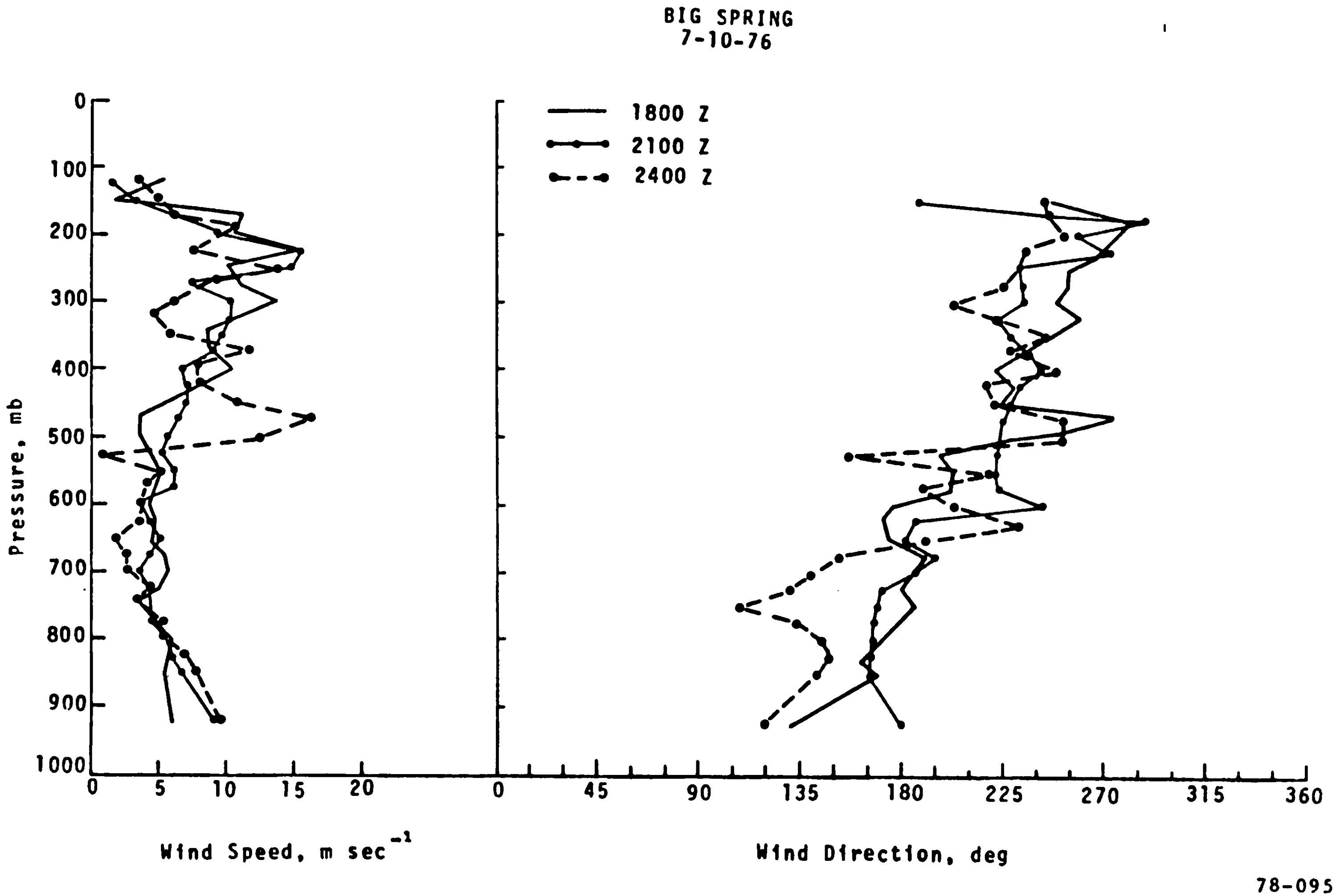

Figure 8. Vertical Wind Profiles

Table 1. Wind Shear Between Surface and 800 mb at Big Spring (July 10, 1976)

Time (GMT)	Units ($m\ sec^{-1}/km$)
1800	-0.31
2100	-2.68
2400	-2.78

1977 Climatology

The synoptic conditions for all of the 1977 operational days have been reviewed. Deep convective motions are generally associated with upper air troughs and fronts. The occurrence of air mass convective showers without the support of some type of trough condition is very infrequent. The present direction of the study is to categorize the types of trough support and to generate a catalog which will identify these periods of occurrence and frequencies.

TEXAS A&M UNIVERSITY

"MESOSCALE DATA ANALYSIS"

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LIST OF FIGURES

1. PREPARATIONS FOR SUMMER 1978 FIELD PROGRAM

A draft of the Operations Plan for the Texas HIPLEX Field Program for the summer of 1978 was completed. This draft has undergone several revisions and is nearing final form. The preparation of the Operations Plan constituted a major task during this report period.

In addition to the Operations Plan, plans were made for the mesoscale experiment to be conducted as part of the 1978 Field Program. Contacts were made with the U. S. Army at White Sands Missile Range regarding the loan of a rawinsonde unit, the National Weather Service regarding the purchase of soundings for Midland, the Bureau of Mines regarding the purchase of helium, and Texas Tech University and NASA regarding the loan of microbarographs. Five additional hygrothermographs were ordered and paid for from Texas A&M University funds, and numerous other aspects handled. The principal task remaining before leaving for the field is that of building five instrument shelters. This task will be undertaken as soon as authorization has been received from TDWR.

2. DEVELOPMENT OF A CUMULUS ENTRAINMENT MODEL

Considerable progress was made on this task although a model has not yet been formulated. The approach has been to consider the environment as representing conditions in the triangle formed by Midland, Post, and Robert Lee, determine kinematic parameters for this environmental volume, and make certain assumptions relating these conditions to those associated with convective clouds which occupy a smaller volume within the large volume. Mass continuity equations have been written for the larger and smaller volume and these combined to specify entrainment into the convective clouds as a function of altitude. The primary assumptions in the model is that environmental divergence extends up to the boundary of the cloud, the only significant vertical motion within the larger volume occurs in the convective clouds, and the only loss of water vapor is due to precipitation. The concept of the model is to determine horizontal divergence at the boundary of the clouds, integrate this divergence to determine the vertical motion profile within the clouds, and from these two quantities compute entrainment. Aircraft measurements within clouds during the summer of 1978 will be used as the basis for specifying the vertical motion profile within the cloud and for verifying model results. It is hoped that the model can be formulated and initial results available by the end of August.

3. RELATIONSHIPS BETWEEN SYNOPTIC CONDITIONS AND CONVECTIVE ACTIVITY

A study was initiated to determine the relationships between synoptic conditions and convective activity in the Texas HIPLEX area. Synoptic conditions are being analyzed and interpreted through the use of vertical cross sections, constant pressure charts, and thermodynamic diagrams. Synoptic conditions will be related to mesoscale conditions observed in the HIPLEX area. This study was begun recently and significant results are not yet available.

4. ANALYSIS OF 1977 TEXAS HIPLEX DATA

The analysis of the 1977 Texas HIPLEX data is underway. Computer programs have been altered to improve efficiency and reduce costs and the programs checked out. This task has been delayed somewhat due to a delay in receiving data from the National Climatic Center in Asheville. It is expected that rapid progress will be made on this task during the next report period.

5. ENVIRONMENTAL MODELS ACCOMPANYING CONVECTIVE ACTIVITY

The successful modification of cumulus clouds to enhance rainfall or to suppress hail is a very practical goal in meteorology today. Before one can begin to modify a complex convective cloud system a complete description of its natural state and variability must be accomplished in order to determine if changes in the system are a result of natural events or are artificially induced.

Many studies have attempted to describe the synoptic, or large scale, environment that is favorable to convective development. Much research also has been conducted to establish interactions between the individual clouds and their immediate environment. The problem becomes one of adequately describing the mesoscale environment conducive to development, maturation, and dissipation of convective elements. In addition, the specification of interactions between these elements and their original environment is also necessary.

The primary objective of this research is to determine from 3-h rawinsonde data the upper-air characteristics that exist prior to, during, and after convective activity in the Texas HIPLEX region.

The description of the meso-environment accompanying convective activity in this research is accomplished in four steps. The steps include the selection of appropriate atmospheric parameters, the analysis of time profiles of these parameters in specific case-study situations, the construction of model time profiles relative to the time of occurrence of convective activity for each type of convective regime, and the examination of average profiles for days with and without convective activity.

The parameters chosen in this research include mixing ratio, moisture divergence, vertical motion, temperature, and lapse rates of both potential and equivalent potential temperature. Mixing ratio was selected because it gives an adequate measure of moisture content while eliminating the interpretation problems that both dew point and relative humidity have with height. Moisture divergence is important in concentrating and supplying the moisture needed for convection, and vertical motion is important in transporting moisture upward and triggering the release of its latent heat. Thus, these parameters are also included. Both of the previous values are 20-point averages near the center of a grid placed over the Texas HIPLEX area where grid points were 15 km apart. The average is an adequate representation of conditions surrounding Big Spring. Diurnal variations are incorporated by including temperature as a parameter. All of the above are presented at 850, 700, and 500 mb since these levels adequately represent the lower troposphere.

Lapse rates of potential and equivalent potential temperature were calculated for the 700-850- and 500-700-mb layers and represent measures of static and convective stability, respectively. Wind direction and wind speed were not included as parameters since neither the velocities nor the vertical shears were large enough to be significant.

The analysis of specific case-study situations was accomplished in four parts. First, convective activity was classified as to type, i.e., squall line, isolated cell, and its location, movement, and intensity identified. Secondly, time profiles of all selected parameters were constructed. Sample time profiles for mixing ratio are shown in Fig. 1.

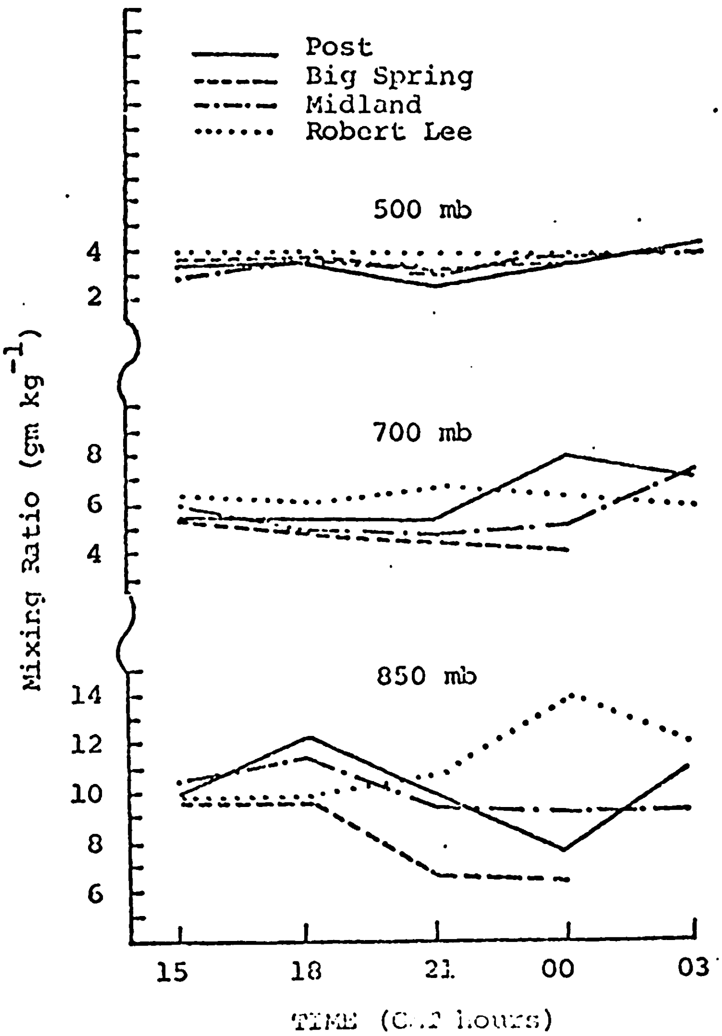

Fig. 1. Time profiles of mixing ratio (gm kg^{-1}) for 22-23 June 1976.

Profiles of mixing ratio and moisture divergence were examined to describe the initial moisture distribution and its changes with time as a result of convective activity. Vertical motion profiles are examined and any synoptic or diurnal effects noted from the temperature profiles. Finally, the influences on both static and convective stability that result from any of the above changes were documented.

Having selected appropriate parameters and analyzing each case study, model profiles were constructed to detail the complete life history of environmental changes due to convective activity for each regime. Each model contains profiles of each parameter which are a composite of portions of development, maturation, and dissipation profiles obtained from each case study. Each profile is then referenced to time of maximum activity and indicated as 00 hours. Diurnal effects are not included to insure that profiles remain as general as possible so that applicability is not restricted. A typical model profile for mixing ratio is given in Fig. 2.

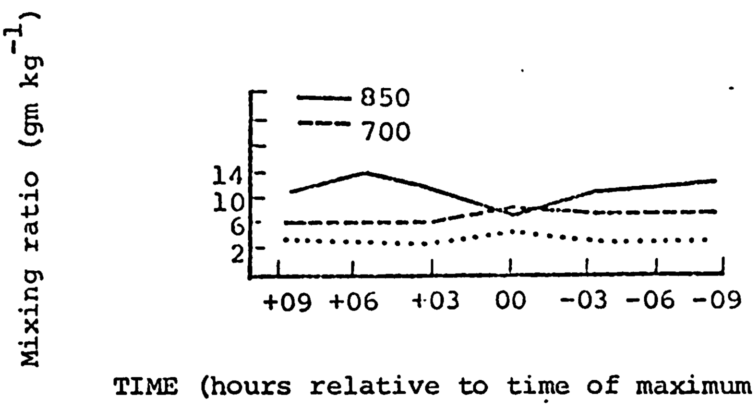

Fig. 2. Model time profiles of mixing ratio ($gm\ kg^{-1}$) for days that experienced isolated cells.

Finally, all days on which soundings were available were separated into two groups; those that experienced convection at some time during the day and those that did not. Average time profiles of the selected parameters were computed for each group and were analyzed to identify those features unique to each particular regime.

Conclusions about environmental changes for both moisture and stability were made as a result of this research and are outlined below.

Moisture: Significant low-level (850 mb) moisture increases were observed 3-6 h prior to convective development. Moisture decreases at the time of activity because vertical transport exceeds the horizontal supply. Mid-level (700 mb) moisture remains constant until the time of activity and then increases as a result of the vertical transport of moisture from below. Extremely low values of moisture at upper levels on days without convective activity suggest that entrainment may be a key factor in inhibiting convection. Also lacking on days without activity is an adequate low-level moisture supply.

Stability: Low-level static stability decreases during days with sufficient surface heating while upper-level static stability remains constant during all days. Low-level convective stability decreases significantly 3-6 h prior to convective development as a result of the increase of low-level moisture. Upper-level convective stability remains constant prior to activity and then decreases during convection; this is a result of the addition of moisture to that layer. On days without convective activity low-level convective stability increases and upper-level convective stability decreases.

The complete results of this study will appear in a comprehensive technical report now in preparation and expected to be completed by the end of April.

6. MOISTURE BUDGET ANALYSIS

The primary purpose of this analysis is to examine moisture sources, and therefore energy sources for convective activity. The distribution of water vapor with height is determined from various moisture-related processes.

A triangle was formed over the Texas HIPLEX area by the vertices of three rawinsonde stations (Robert Lee, Post, Midland), encompassing an area of 8.31×10^9 m^2. The effect of balloon drift was determined to be negligible; the area was assumed to remain constant with height. The volume for which the analysis was performed is this area times the vertical distance between 850 and 300 mb. Sounding data taken at 3-h intervals from 1500 GMT to 0300 GMT for 9 days during the summer of 1976 were used in the analysis.

The Water Vapor Budget

The equations for the water vapor budget have been derived and will appear in a technical report to be submitted soon. The final form of the water vapor budget terms can be expressed as the following moisture-related processes:

$\int_s (q\rho_a \vec{V}_2)_n dA$: The horizontal transport of water vapor through lateral boundaries of the volume.

$\int_s (q\rho_a W) dA$: The vertical transport of water vapor through boundaries of the volume.

$\int_v (q\rho_a \vec{V}_3) dV$: The combined net horizontal and vertical transport of water vapor through boundaries of the volume.

$\int_v (q\rho_a) dV$: The total mass of water vapor present, defined as the total precipitable water within the volume.

$\int_V \frac{\partial(q\rho_a)}{dt} dV$: The local rate of change in the total mass of water vapor within the volume.

These terms were all evaluated for 50-mb layers from 850 to 300 mb. Results and time profiles of all these terms will appear in the technical report that is under preparation.

From the various moisture-related processes previously described, a complete evaluation of the water vapor budget was made for 9 days from 1976 Texas HIPLEX mesoscale data. Terms involving the continuity of water substance were used in the evaluation of the total water budget. A summary of results appear in this section. Complete results will appear in the technical report under preparation.

Times when convective activity occurred were determined from hourly radar maps. Conditions concerning convective activity were divided into four categories: (1) times when convective activity approaches the Texas HIPLEX area; (2) times when convective activity occurs within or develops over the Texas HIPLEX area; (3) dissipation or movement of convective activity out of the Texas HIPLEX area; and (4) times when no activity is reported near or within the Texas HIPLEX area.

As convective activity approaches the Texas HIPLEX area, a large increase in the horizontal transport of water vapor is observed for most 3-h intervals preceding activity. Upward vertical transport indicates moisture convergence in upper layers at these times. This is shown by the local-rate-of-change of water vapor with a net gain in layers above 700 mb and a net loss in lower layers. Although the vertical transport tends to "store" water vapor in the upper layers, the horizontal moisture convergence into the Texas HIPLEX area is responsible as the moisture source prior to convective activity. This was found to be true for both cases of line and isolated cell movement. Hudson[1] (1971) arrived at similar results concerning the horizontal moisture convergence being a primary moisture source.

Times when convective activity occurred over the Texas HIPLEX network reflects a substantial increase in the total mass of water vapor at all times. However, the local-rate-of-change term continues to show a net loss in lower layers, which may be attributed to condensation and precipitation. Vertical transport of water vapor remains upward during activity, and increases in magnitude during convective activity. During development and especially when convection reaches the mature stage, the contribution of

[1]Hudson, H. R., 1971: On the relationship between horizontal moisture convergence and convective cloud formation. J. Appl. Meteorol., 10, 755-762.

horizontal moisture transport extends from the surface to greater heights and is the principle moisture source. This can be seen in the case of July 3-4 from 1500 to 1800 GMT, when an isolated cell formed directly over the network. At 1800 GMT the horizontal moisture convergence extended from the surface to 500 mb. This result agrees with that obtained on a synoptic scale by Fritsch *et al.*[2] (1976).

During dissipation, or times when convective activity moves out of the Texas HIPLEX area, the total mass of water vapor decreases accordingly. The local rate-of-change in water vapor for a 3-h interval following activity shows a large decrease in upper layers above 700 mb. The increase in water vapor in lower layers may be attributed to evaporation of clouds and precipitation during dissipation. In many cases, the vertical transport of water vapor becomes downward, which would also tend to accumulate water vapor in lower layers. However, times when vertical transport remains upward, the magnitude of this term decreases considerably. Once convective activity has moved out of the network, vertical profiles of moisture begin to resemble those prior to the activity.

At times when no activity was observed near the Texas HIPLEX area, the effect of moisture related processes existed. On several cases analyzed, when no activity occurred, moisture was stratified in several layers. This stratification was reflected in HIPLEX soundings. Moisture stratification leads to increased moisture gradients, and to increased turbulent mixing of moisture in adjacent layers. This mixing is observed in profiles of local rate-of-change in water vapor throughout the day. Little change is observed in layers above 450 mb, due to the decreased amounts of water vapor present in these layers at all times when no activity occurred. Profiles of the total mass of water vapor show an intense dry layer which develops around 450 mb on all days which convective activity was absent. In each case studied such a development at one or more times during the day became a characteristic of "no activity", and may be an important factor in cloud development when determining whether or not convective activity will occur. Vertical motions, and therefore vertical transport of water vapor through constant-pressure surfaces, remained upward and nearly constant throughout the day. This may be attributed to free convection produced by surface heating during the day. Although no intense convective activity occurred due to the lack of water vapor present, surface observations report light

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[2] Fritsch, J. M., C. F. Chappell, and L. R. Hoxit, 1976: The use of large-scale budgets for convective parameterization. Mon. Wea. Rev., 104, 1408-1418.

and numerous scattered to broken cumulus during the afternoon. This was observed to occur mainly on days when a moisture stratification existed. These clouds form in a moist layer, and their growth appears limited by the rate of mixing and the entrainment of dryer air below and aloft. Winds aloft remain fairly strong; these clouds may form within the volume and be advected out.

Figures 1 and 2 show the total mass of water vapor present in the entire volume obtained from profile data. The nine days analyzed were divided into 2 groups: (1) days when no activity occurred within the network at any time, shown by Fig. 1, and (2) days when activity occurred within the network, shown by Fig. 2. Specific times with convective activity were observed and are denoted on these figures. Average values for total mass of water vapor were obtained from these figures. The results indicate that a "threshold" value of water vapor of about 2.0×10^{14} gm is needed over the Texas HIPLEX area for convective activity with precipitation to occur.

From the hourly totals of precipitation provided by the Bureau of Reclamation and presented in the February progress report, a definite correlation between periods of maximum precipitation and maximum amounts of water vapor was found. The magnitude of the average amount of water vapor was found to be proportional to the duration of convective activity which occurred on a given day.

The Total Water Budget

The equation for the continuity of water substance can be expressed as:

$$\underset{(1)}{\int_V \frac{\partial(q\rho_a)}{\partial t}\,dV} + \underset{(2)}{\int_s (q\rho_a\vec{V}_2)_n\,dA} + \underset{(3)}{\int_s (q\rho_a w)\,dA} = \underset{(4)}{R}$$

where q = mixing ratio

ρ_a = density of the air

$\vec{V}_2$ = horizontal wind velocity

w = vertical velocity

n = normal component

V = volume

s = surface integral

This equation represents a balance of the total water budget at any particular time expressed in units of (gm/sec). The terms in this equation

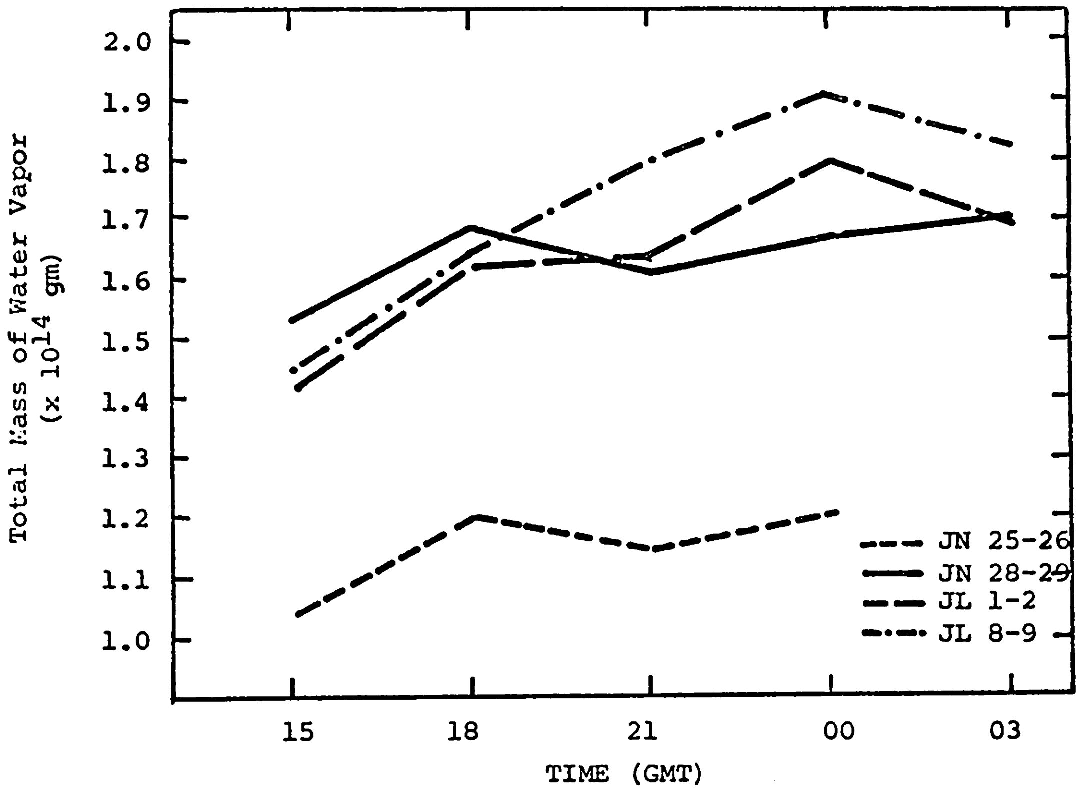

Fig. 1. Total mass of water vapor over the Texas HIPLEX area for days during summer 1976 containing no activity.

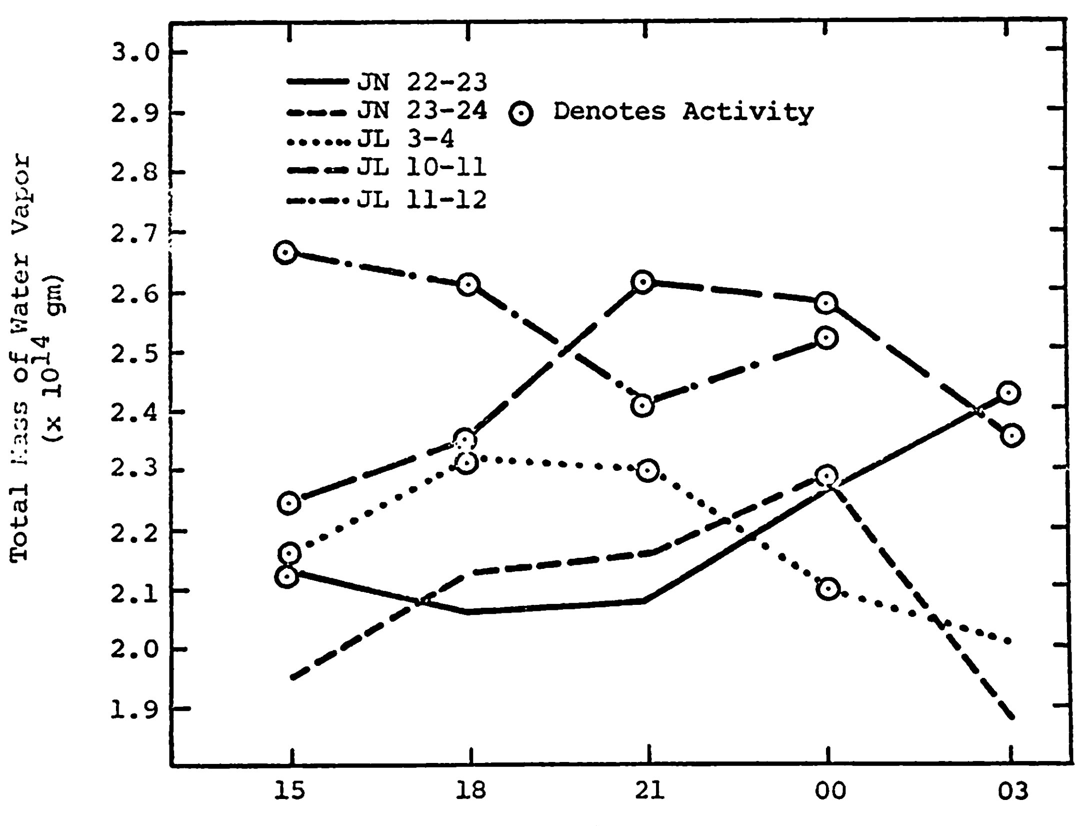

Fig. 2. Total Mass of Water Vapor over the Texas HIPLEX area for "activity days".

have the following meaning: (1) the local rate of change or the net gain or loss of water vapor within the volume; (2) transport of water vapor through the lateral boundaries; (3) transport of water vapor through the vertical boundaries; and (4) the sources and sinks of moisture (evaporation, condensation, precipitation, and turbulent flux of moisture through the boundaries).

The total water budget was evaluated for 9 days during the summer of 1976 over the Texas HIPLEX area. Hourly totals of precipitation were obtained from the Bureau of Reclamation for two of these days. A comparison of these data to the above equation was made, and the results appeared in a progress report for February 1978, along with time profiles of the terms in the water budget equation.

Results for two days analyzed for the summer of 1976 appear in the progress report for February 1978. In summary, a comparison of the residual term of the total water budget to the actual precipitation amounts was made. The area for which these precipitation analyses were available was approximately half the size of the triangular area used in the total water budget equation. The residual term was reduced in magnitude (normalized) by a ratio of these areas. For comparison, a ratio of the normalized residual term to the total measured precipitation was computed.

Results indicate a good correlation between the residual term and the observed precipitation for both cases studied. In principle, as the integration period increases, the limit of the ratio should approach unity. This suggests that over a long enough time period, the contributions by condensation and evaporation to the residual term tend to cancel thus making precipitation the dominant factor in the residual term. Turbulent boundary fluxes were assumed to remain unchanged or insignificant. Results show that during periods of intense precipitation, and over longer time periods, this ratio decreases substantially.

A comparison of the terms in the total water budget equation during precipitation should reveal the source of moisture for the precipitation. Results show a significant increase in the horizontal moisture transport (horizontal moisture convergence) into an area of convective activity during precipitation periods. These results agree with the water vapor budget study, indicating that the horizontal moisture convergence term may be the primary moisture source for convective activity.

It has been established that precipitation becomes the dominant factor in the residual term, thus a profile of the residual term with height may indicate a source level for precipitation. Figures 3 and 4 represent time profiles of the residual term with height for two days previously studied in the February 1978 progress report. For the case of June 22-23, Fig. 3 shows a net loss in lower layers to approximately 700 mb, with maximum amounts occurring in the lowest layers. Above 700 mb, the residual shows a net gain at all times except at 0300 GMT when a line of convective activity moved into the Texas HIPLEX area. At 0300 GMT, the profile shows a net loss in the residual at most levels above 600 mb. In the case of July 10-11, radar maps show large amounts of convective activity present at all times over the Texas HIPLEX area. This can be seen in Fig. 4 where profiles of the residual term show a net loss at all levels for most times throughout the day. Hourly totals of precipitation indicate a maximum value at 2200 GMT. Figure 4 shows a maximum in the residual term at 2100 GMT at all levels. Thus, when precipitation is observed, the residual term increases in proportion to the amount of precipitation.

Figures 3 and 4 indicate that when precipitation amounts are large, the magnitude of the residual term does not vary much with height. This shows that during well developed convective activity each layer tends to contribute equally to the residual term. However, during moderate and light periods of precipitation, the magnitude of the residual is greatest in lower layers, and generally decreases with height. This may be attributed to lighter amounts of precipitation falling from stratus-type clouds, which are not well developed vertically. In this case, precipitation formation is confined to a smaller layer. A comparison of Figs. 3 and 4 shows that although greater amounts of precipitation were observed on July 10-11, the magnitude of the residual term remained nearly equal in lowest layers at all times. This indicates that the increased amounts of precipitation are due to increased contributions from each layer above approximately 750 mb. Therefore, the contributions from upper layers becomes a function of the depth of the convection, and the heights to which convective activity extends. These results agree with the water vapor budget study, indicating a "storage" of water vapor in upper layers prior to convective activity.

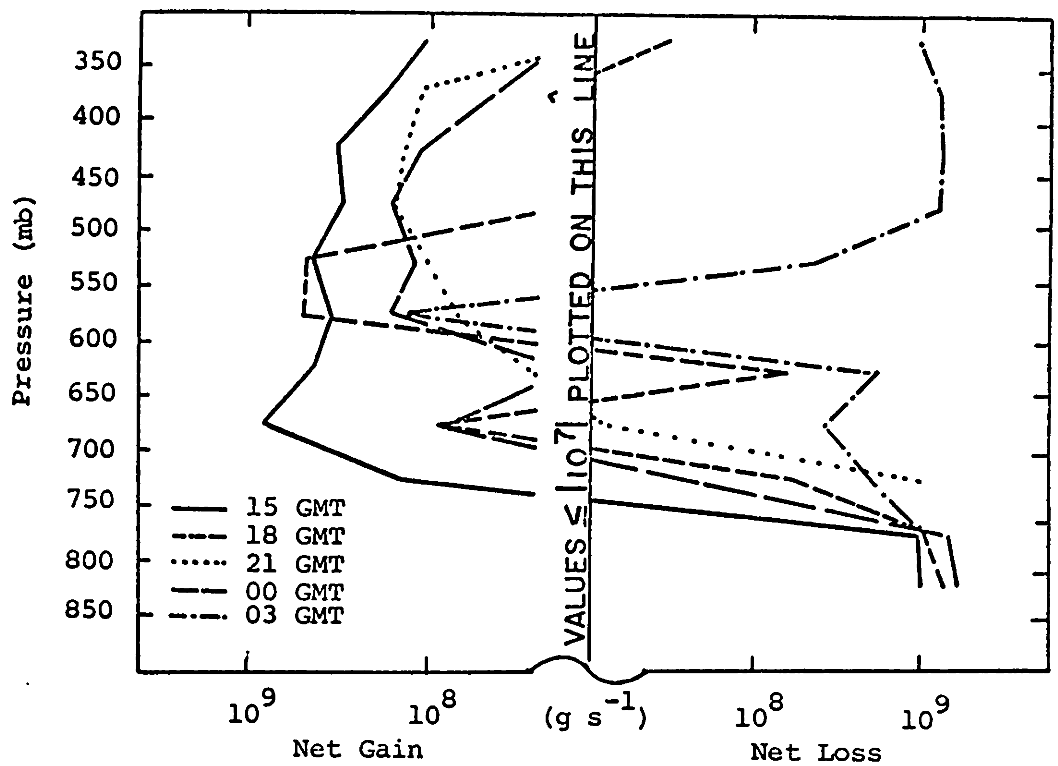

Fig. 3. Residual term in total water budget equation for 22-23 June 1976.

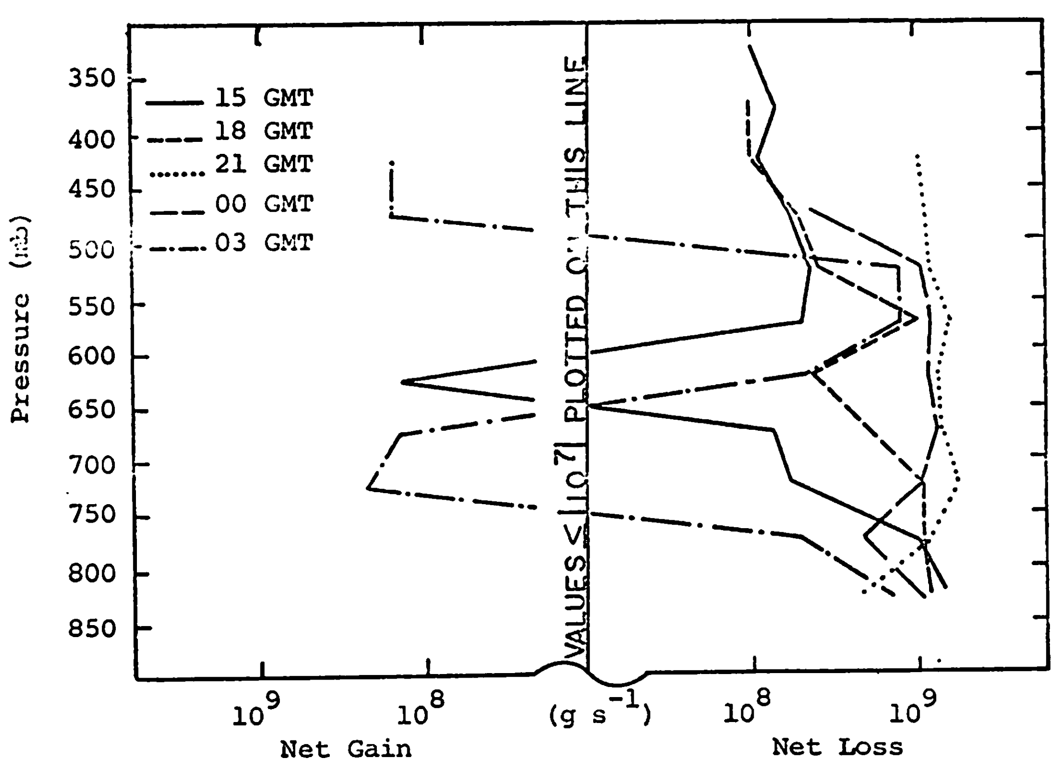

Fig. 4. Residual term in total water budget equation for 10-11 July 1976.

Comments and Future Plans Regarding the Analysis of Moisture

The results obtained to date are encouraging and support the validity of the various moisture-related processes described. These preliminary results indicate the importance of horizontal moisture convergence as a source term for the formation and maintenance of convective activity. This is also shown by the relationship between the horizontal moisture convergence term and the residual term of the total water budget at all levels. Work is currently underway to determine the level at which this source term is most important in producing the large residuals. It is planned to evaluate the water budget for three layers (850-700, 700-500, and 500-300 mb), and determine the relative importance of each of these layers during various stages of convective activity. It is also hoped that this analysis will determine the levels at which precipitation originates, which will lead to a better understanding of the factors producing precipitation.

It has been shown that the magnitude of each term in the total water budget equation affects the magnitude of the residual term. A comparison of each term to the residual term will be studied to determine the relative importance of each term in relation to various stages of convective activity. A ratio of each term to the residual term will provide a relative percent of that term comprising the residual term. This ratio will vary depending upon development, maintenance, dissipation, or no convective activity present. It is hoped that from such a study, an interaction of these total water budget terms can explain the energy source of convective activity.

Results have indicated that although the horizontal moisture convergence is the primary moisture source, the vertical transport tends to flux this moisture upward into regions of convective activity. A similar type study involving the comparison of the total water budget terms will involve a ratio of the net horizontal transport of moisture to the net vertical transport of water vapor to determine if any relationships exist to produce convective activity.

Both the water vapor budget and the total water budget will be computed for data obtained during the summer of 1977 for the Texas HIPLEX area. It is hoped that these results will reinforce the results obtained previously, especially with the introduction of 1 1/2-hour rawinsonde sounding data. Also it is clear that more precipitation analyses are needed to adequately evaluate the validity of the preliminary results obtained in this report.

7. COMPOSITE SURFACE AND UPPER-AIR ANALYSIS

Much uncertainty exists as to the atmospheric conditions which lead to the development, maintenance, and dissipation of convective activity. The goal of this research is to reduce the amount of uncertainty in the Texas HIPLEX area by combining various surface and upper-air fields in a manner which would best reveal the basic physical processes taking place in the atmosphere during convective activity.

Exactly what diagrams, tables, and figures will be needed has yet to be established. Shortage of data and problems encountered in combining surface and upper-air data have made this task anything but simple. A tedious trial-and-error procedure has been initiated in order to attack the problem.

Only preliminary results are available for this study. The first step taken toward an effective analysis of the data was to classify the radar data into categories which represented the basic stages of convective activity. Originally, only the days were classified in this manner for the purpose of performing case studies where each day represented a different case. Recently, however, it was determined that more conclusive results could be obtained if the radar data were classified for each hour into one of four categories--nonconvective, development, maintenance, and dissipation--and that the data included within each category be studied collectively and compared to that of the other categories. These four categories were classified according to the following subjective criteria:

1. Nonconvective: Radar echoes did not appear during the hour within the HIPLEX region, and if so not within 40 km of a surface or upper-air station used in the analysis.
2. Development:
    a. Development was considered to have occurred during the hour in which an echo first appeared, as well as during the hour prior to echo formation. If echoes were present initially, then an increase in areal coverage by the echoes of 15% or more (without a decrease in intensity) was also included under this category.

b. Intensification of a pre-existing echo by a minimum increase in vertical extent of 5000 feet, even if other echoes present during the same hour showed no such increase was considered as development, but only at the hour prior to the observed increase. If a further increase was observed during the following hour, as was the case in part (a), both the hour prior to and during the initial increase were considered as hours of development.

For example, the following table lists typical echo tops which might exist to give a classification of development for hours 17-20:

Hours (CDT)	17	18	19	20
Echo tops (feet)	--	20,000	27,000	29,000
Echo formation	Dev.	Dev.	--	--
Intensification	--	Dev.	Dev.	--

If the echo top reported at hour 20 in the above example had been 26,000 feet, then only hours 17 and 18 would be considered as hours of development.

3. Maintenance: Activity was considered to be maintained at a certain hour if the following two conditions were satisfied:

   a. The amount of area covered by the echo during the subsequent hour was within ±15% of the area covered at the given hour.

   b. Echo tops reported during the subsequent hour were within 5000 feet of those reported at the given hour.

   If a situation existed where only one or none of these conditions was satisfied, then the hours involved would necessarily be classified under the development or dissipation category.

4. Dissipation: Activity was classified as dissipating for a given hour if either of the following two conditions were met:

   a. The amount of area covered by the echoes during the following hour had decreased by at least 15% of that covered during the given hour.

   b. One or more of the echo tops during the subsequent hour had decreased in vertical extent by at least 5000 feet from the respective echo tops reported at the given hour.

Each hour during the 1976 and 1977 operational periods has been classified accordingly.

This classification scheme admittedly combines into a single category criteria which do not necessarily represent the same atmospheric process; for example, echo formation and intensification. However, such a broad scheme was required due to the shortage of available data, particularly during the 1976 field project. Other problems which arose in using such a classification scheme stemmed from the possibility of both development and dissipation occurring during the same hour in different areas of the HIPLEX region. The frequency of occurrence of this situation, however, was quite small. The few such cases that existed were examined carefully to determine which of these categories would be most appropriate.

In addition to the radar classification, several other results have been obtained. A computer program has been written to calculate various quantities from the desired gridded surface fields. For a parameter such as moisture divergence, these quantities include grid average, percent of the negative area, maximum intensity of moisture convergence, and maximum intensity of moisture divergence for each hour. The calculations from this program are being analyzed, and as yet, only a few conclusions were drawn from them. During nonconvective hours the cells of moisture divergence and convergence are generally weak and of similar intensities. During hours of development, although the amount of area covered by moisture divergence and convergence is about the same, the intensity of the moisture convergence cells is quite large and exceeds that of moisture divergence. During hours of dissipation the reverse is seen, with moisture divergence dominating over moisture convergence.

Several scatter diagrams have been prepared with average surface values versus upper-level values for several levels and for each radar category. For instance, moisture divergence at the surface was plotted against 700-mb moisture divergence for the nonconvective cases collectively and for each of the other radar categories. Unfortunately, only the 1976 data is included in these diagrams, and so any conclusions concerning these will be deferred pending the analysis of 1977 data.

TEXAS A&M UNIVERSITY

"RADAR-ECHO CLIMATOLOGY FOR THE

SOUTHERN HIPLEX REGION"

From WSR-57 radar film of the Midland and National Weather Service for the period April-September 1973-1976, data on various echo characteristics were analyzed during the reporting period as part of the development of a radar-echo climatology of the Texas HIPLEX project area. Those climatological characteristics examined by the study are tabulated below.

(a) Time variation of initial and transient echoes

1. Interannual
2. Intermonthly
3. Diurnal
4. Running means of daily echo frequency
5. Frequency distributions: echoes vs. days

(b) Geographic aspects

1. Interannual comparisons
2. Intermonthly comparisons

(c) Duration of echo existence

1. To 8 km, stratified by size of initial echo
2. To maximum size, stratified by size of initial echo

(d) Speed and direction of echo movement

In addition, work centered on the determination of what effects cloud-seeding activities may have had on the occurrence and behavior of radar-echo populations. Two approaches were used in investigating the geographic aspects of seeded and non-seeding echo populations: (1) seed vs. no-seed echo frequency after empirical correction was made for radar bias; and, (2) seed vs. no-seed echo frequency by paired squares. The durations of life cycles of both seed and no-seed echo populations were also examined.

Furthermore, planning was done for associating various characteristics of radar echoes with surface and upper-atmospheric synoptic conditions. This phase of the work had not been completed as the report period ended.

A final report describing all results obtained from the study is due to be submitted by the Principal Investigator to the Department no later than May 15, 1978.

COLORADO RIVER MUNICIPAL WATER DISTRICT

"HIPLEX RAIN-GAGE AND RAWINSONDE SUPPORT PROGRAMS"

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LIST OF FIGURES

RAIN-GAGE NETWORKS

All of the Belfort recording rain gages remained on location in the HIPLEX study area during the report period. District personnel constructed a newly-designed base for each of the 81 gages to allow easier levelling and calibration of the gages at their respective field locations. These bases were positioned in the field preparatory to the calibration of the gages by Department technicians in April 1978.

RAWINSONDE OPERATIONS

As support for the analysis of mesoscale data being conducted at Texas A&M University, the District's rawinsonde technician obtained 1976 and 1977 rawinsonde data from the three HIPLEX sites and prepared scatter diagrams of numerous upper-atmospheric parmaters. The mean and standard deviation of such parameters as temperature, millibar height variation, dew point depression, potential temperature, equivalent potential temperature, wind speed and direction were calculated.

CLOUD-SEEDING ACTIVITIES

The District relocated its base of operations from Howard County Airport near Big Spring to the vacated facilities known formerly as Webb Air Force Base. Most of the equipment to be used during the 1978 Texas HIPLEX Program was transferred from Howard County Airport to the new base of operations. The following tabulation gives the location and operational status of Texas HIPLEX project equipment as of March 31, 1978:

Equipment	Transferred	Operational Status
RD-65 Rawinsonde unit	Yes	No
Anemometer system	Yes	Yes
Bureau's trailer	Yes	Yes
700-ASR data terminal	Yes	Yes
7202-A Graphic plotter	Yes	Yes
GE terminet	Yes	Yes
3-cm radar console	Yes	Yes
3-cm remote scope	Yes	No

In addition, two VHF radios operating on FCC-assigned frequencies of 122.9-122.925 and 158.19 were installed near the main operating console of the FPS-77 radar system at the new operations base. A license was obtained from the FCC for operating the FPS-77 radar at frequencies below 5590 MHz.

A summary and analysis of all cloud-seeding activities conducted by the Colorado River Municipal Water District was prepared by the District's radar meteorologist during the reporting period. The report, entitled "1977 Weather Modification Program: Precipitation Enhancement Conducted by the Colorado River Municipal Water District," describes the purpose and operational design of the program, equipment used, as well as analyses of rainfall and cotton yield data for the District's "target" area. Excerpts of the summary report are provided below.

"When individual isohyetal maps (Figures 1-7) representing the seven cloud-seeding years are considered, an axis of maximum precipitation (is seen to be) generally associated with the eastern side of the seeded area.

In each of the seven years, a closed center of maximum rainfall occurs within the operational area. This is not typical of the historical precipitation pattern for the area, for the unseeded period was characterized by a gradual and uniform increase in precipitation from west to east (i.e., no closed center or precipitation).

"Only in 1976 does the area of maximum precipitation (18" closed contour) appear not to be directly associated with the seeded area. However, the axis associated with the area of maximum rainfall observed during 1976 extends from Lubbock southward through the northwest portion of the target area to a point immediately south of the Cope Ranch.

When rainfall totals for the seven years of cloud seeding are compared with the "historical normal" ... the location of the greatest percent of normal is (seen to be) essentially synonymous with the seeded area (Figure 8).

"When the seven years of cloud-seeding are combined (Figure 10) the isohyetal pattern is in close agreement with that observed in several of the yearly isohyetal patterns--an elongated precipitation center (hatched area) meandering across the eastern half of the target area in a northwest to southeast direction.

"When the period of the seven cloud-seeding years is compared to the non-seeded historical record, differences in isohyetal patterns become evident. Whereas rainfall totals generally increase from west to east in the historical period (Figure 9), peak amounts of rainfall occurred within and adjacent to the target area, with lesser rainfall totals observed both to the east and west of the seeded area. Another noteworthy feature is the displacement of the precipitation regime westward. Particularly important is the fact that the alignment of the isohyetal pattern remains north-northwest to south-southeast. In addition, rainfall totals along the eastern edge of the operational area appear to be unchanged (note the relative positions of the 13-inch isohyets in Figure 8 and 9). Consequently, it may be assumed that the cloud populations developed within the operational area during both the seeded and non-seeded periods. That is to say, the same amounts of moisture existed in cloud form in both periods. However, the precipitation efficiency of the clouds developing during the seeded period may have been enhanced through the aerial application of silver iodide.

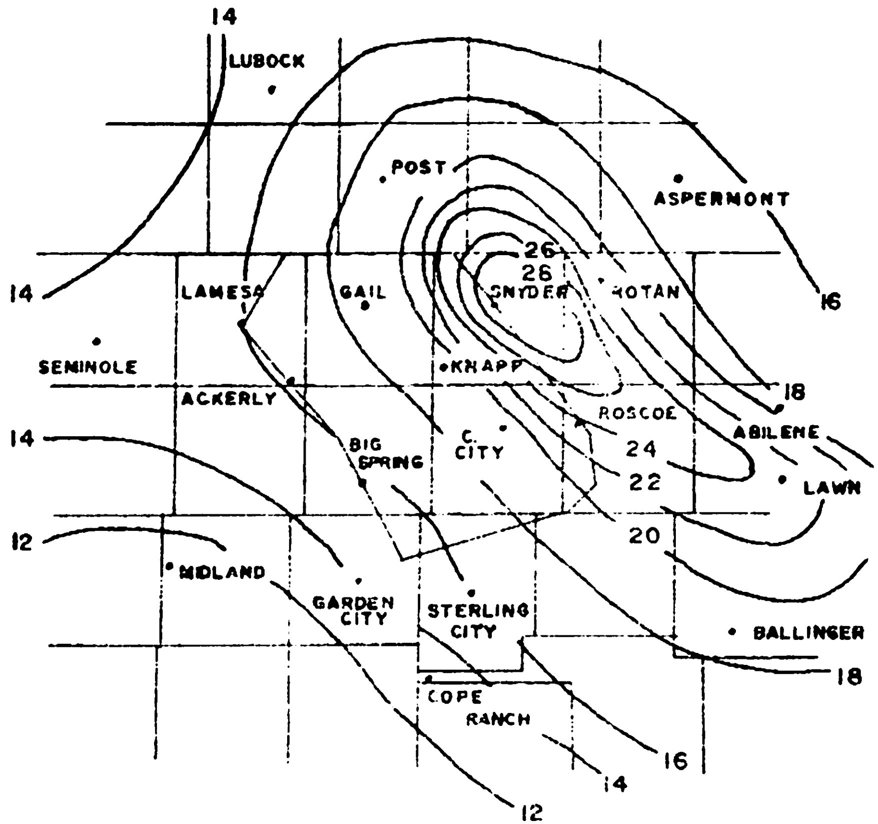

Figure 1. Isohyetal Pattern (in inches) for the period May-September 1971.

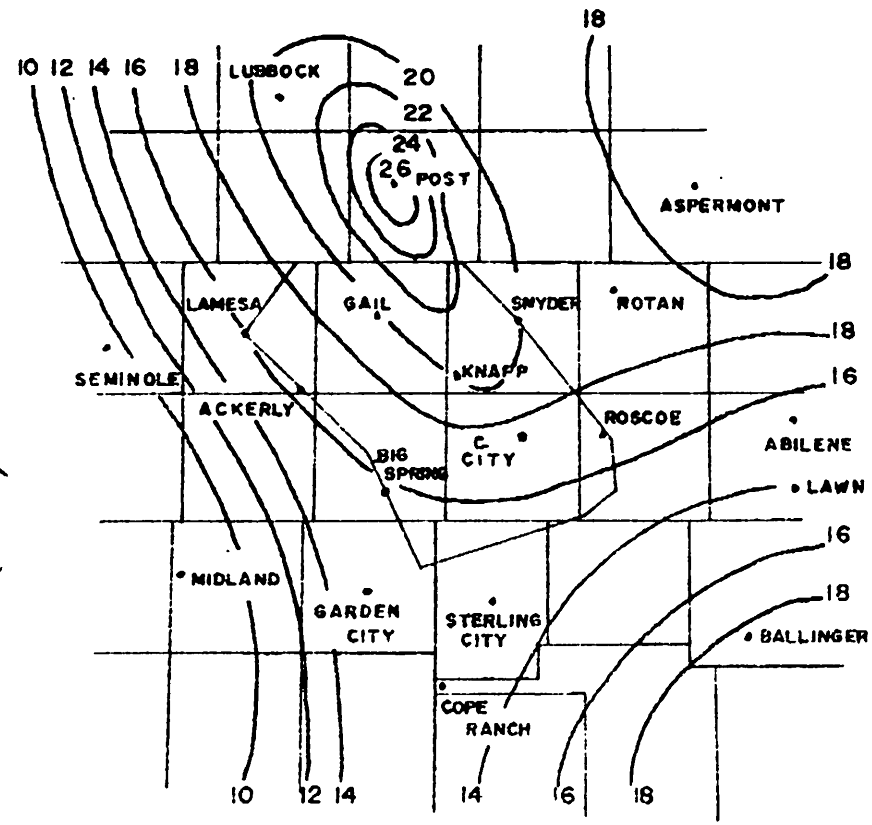

Figure 2. Isohyetal Pattern (in inches) for the period May-September 1972.

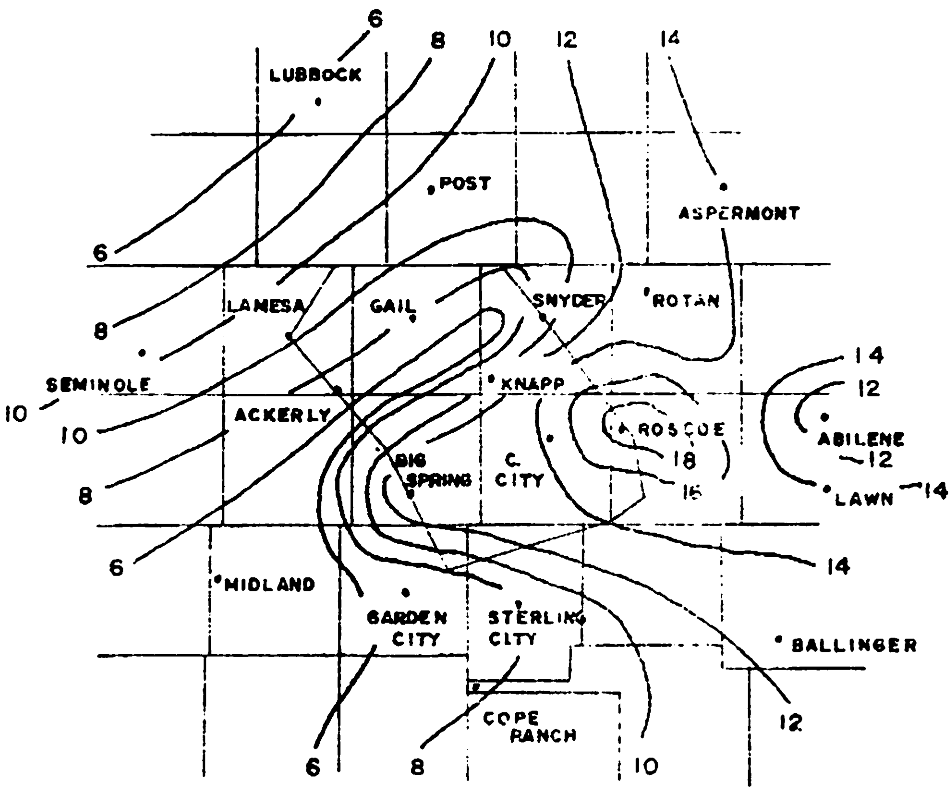

Figure 3. Isohyetal Pattern (in inches) for the period May-September 1973.

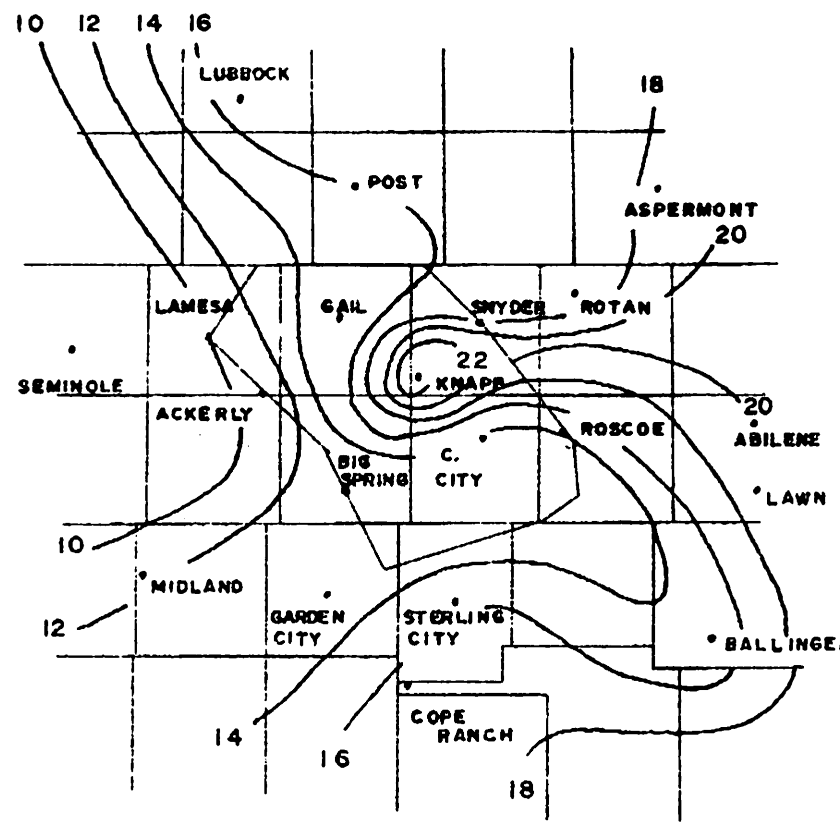

Figure 4. Isohyetal Pattern (in inches) for the period May-September 1974.

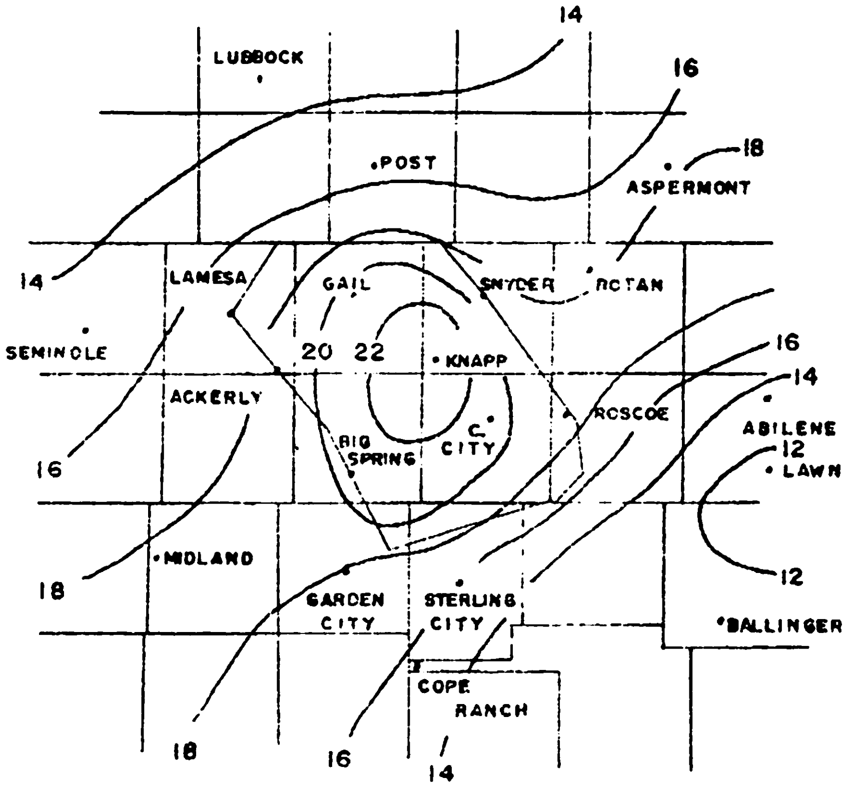

Figure 5. Isohyetal Pattern (in inches) for the period May-September 1975.

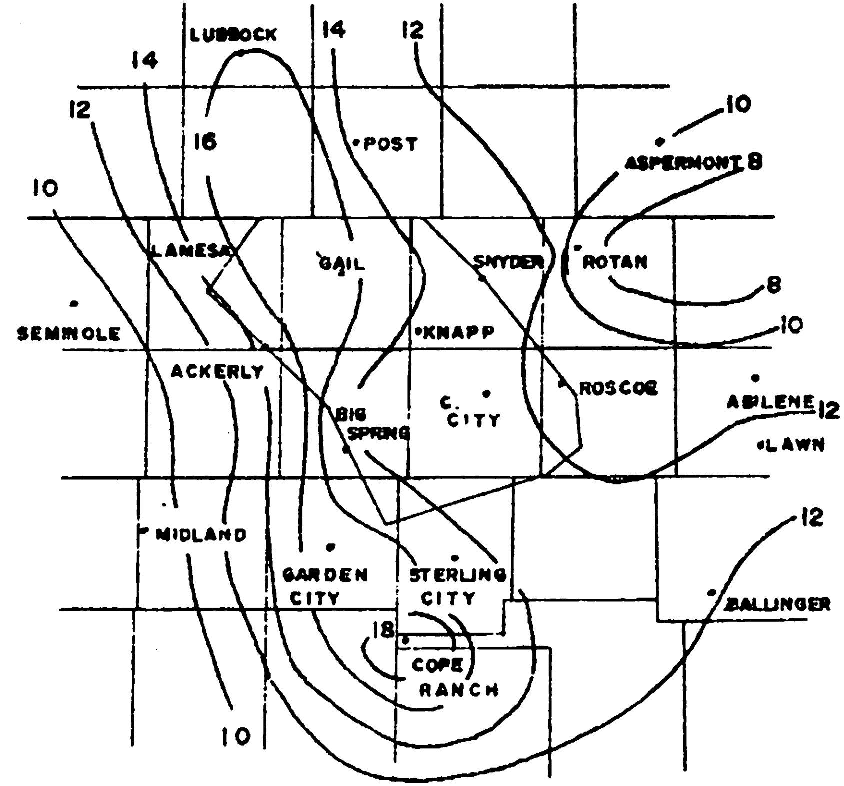

Figure 6. Isohyetal Pattern (in inches) for the period May-September 1976.

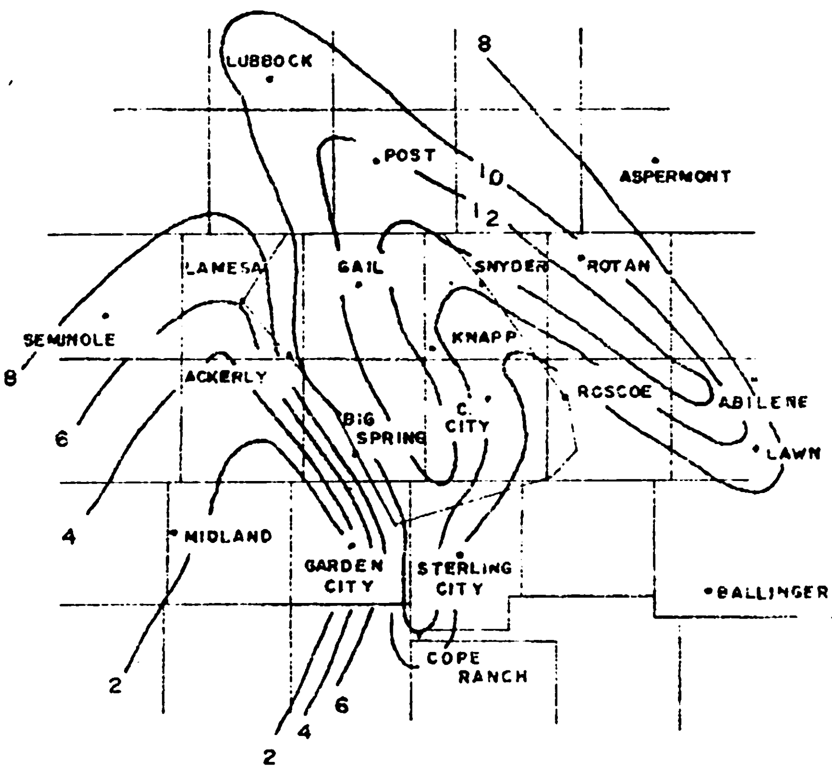

Figure 7. Isohyetal Pattern (in inches) for the period May-September 1977.

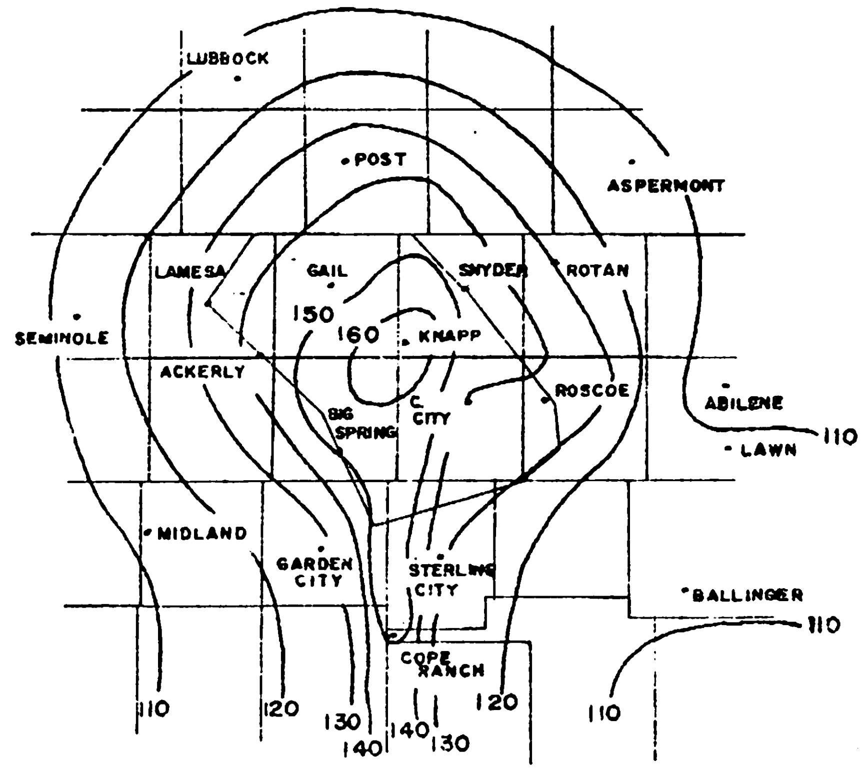

Figure 8. Ratio (expressed as a percent) of mean rainfall totals for the period May-September 1971-77 to those for the period May-September 1936-70.

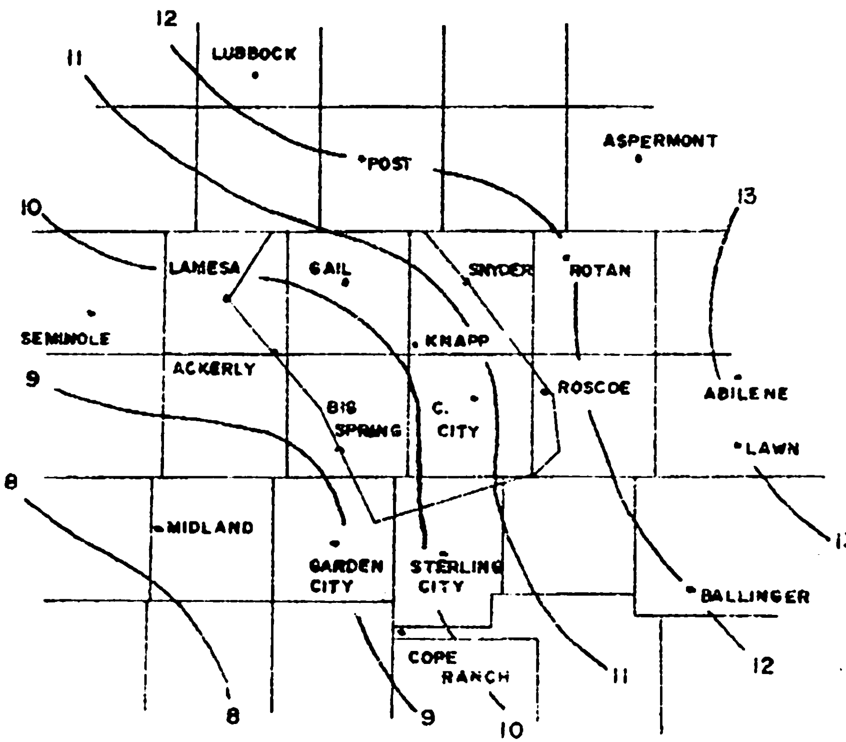

Figure 9. Isohyetal Pattern (in inches) for the period May-September 1936-70.

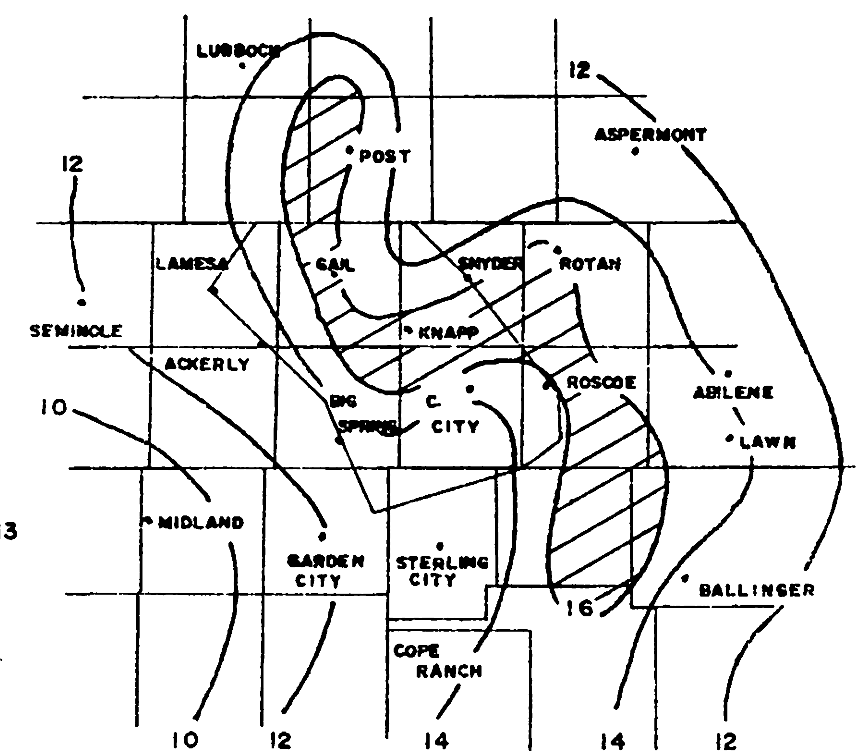

Figure 10. Isohyetal Pattern (in inches) for the period May-September 1971-77.

"Cotton yield percent departures from normal ranged from 46% to 61% above normal (in the seeded counties) (Figure 11).

"The seeded counties located within the 14-inch contour (Figure 10) showed an average departure from normal of 55 percent while the unseeded areas to the west of that contour reflected cotton yields were up an average of only 17 percent. Additionally, cotton production was fifty percent above normal for those counties immediately east and northeast of the seeded area and located within the 14-inch contour.

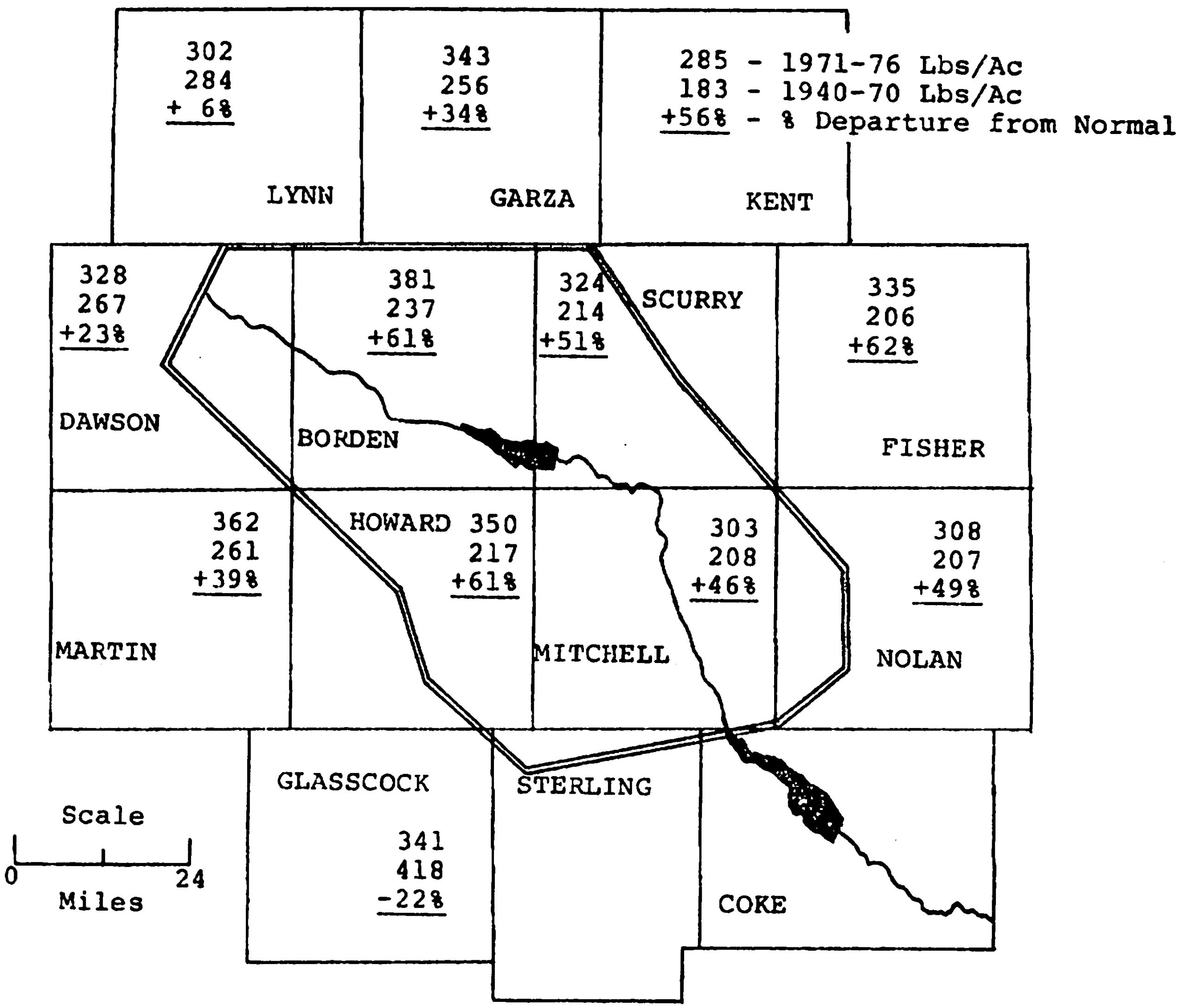

Figure 11. The CRMWD Operational Area with values representing the observed changes in cotton yield production for seeded and unseeded periods.

SECTION II

WORK PLANNED FOR THE PERIOD

APRIL 1 - SEPTEMBER 30, 1978

Much of the work to be performed during the period April 1 through September 30, 1978 will consist of preparations for and the conduct of the field portion of the 1978 Texas HIPLEX Program in the vicinity of Big Spring. This phase of the program is described in depth in the "Operations Plan for the 1978 Texas HIPLEX Program." An initial draft of the Operations Plan was written during the reporting period of October 1, 1977 - March 31, 1978. Once the final version of the Plan has been written and published, copies will be made available to all Texas HIPLEX participants. The following is an overview of the work and services to be provided by each organization participating in the Texas HIPLEX Program during the six months ending September 30, 1978.

Management of the Texas-HIPLEX Program and Support Studies (TDWR)

Among the activities of the Department staff in conjunction with the 1978 Texas HIPLEX Program are:

Continued administration of the 1974 contractual agreement between the Bureau and the Department and the various interagency, consultant, and cost-reimbursable performance contracts between the Department and other institutions and organizations participating in the 1978 Program;

The work and services to be provided by the contracted institutions are described in the "Operations Plan for the 1978 Texas HIPLEX Program" and in subsequent parts of this section of the interim progress report;

Funds to be used to support these various endeavors include the appropriation in the amount of $685.5 thousand in Federal monies to the Department by the Bureau and the $100 thousand appropriation by the 65th Texas Legislature for the Texas HIPLEX Program;

Oversight in executing all segments of the Operations Plan;

Direction and management of the field program during July by Department meteorologists serving as Project Director and Alternate Project Director, and assistance to the Chief Scientist during June;

Forecasting of weather conditions by the Department's resident meteorologist at the Big Spring Meteorological Facility in support of cloud-seeding operations, including utilization of the Forecast Decision Tree and products from the Thunderstorm Prediction Model;

Maintenance and servicing of the Texas HIPLEX recording rain-gage network throughout the operational period; and,

Collection of photographic data of equipment, facilities, and personnel associated with all phases of the field program for use in making information available on the Texas HIPLEX Program (including the dissemination of a brochure describing and illustrating the various elements of the Program).

Satellite-Derived Cloud Climatology for the Southern HIPLEX Region (TTU)

A description of the work to be performed under the direction of Dr. Gerald Jurica during the 6-month period beginning April 1, 1978 begins on page 39 of this report. In addition, personnel associated with this aspect of the Texas HIPLEX Program will collect and archive visual and infrared satellite data during the field portion of the program for subsequent analysis.

Precipitation Climatology for the Southern HIPLEX Region (TTU)

Contingent upon the award of a contract by the Department to TTU for further development of a precipitation climatology for the Texas HIPLEX study region, work will focus on the development of a detailed climatology of storm systems migrating across the study region using data from the Texas HIPLEX recording rain-gage network. The rain-cell climatology will include information on the size, intensity, frequency, and duration of these storm events. In addition, more work will be devoted to the analysis of case-study events in conjunction with investigations being conducted by other HIPLEX participants utilizing radar, satellite, and meso-network data.

Snyder Radar-Data-Collection Program and Data Analysis (MRI)

Radar Data Processing

The aim of the present program is to convert all of the available 1976-77 data tapes to Bureau format by May 15. Barring unforeseen digital processor problems that have not yet been recognized, this goal appears to be fairly reasonable although the opportunities for rerunning any of the data, if necessary, within the time limitations are small.

There are two factors which suggest that the 1978 data may be more easily processed than the 1976-77 data sample:

1. The digital processor has had time to burn in to a more reliable mode of operation. More experience has been gained in trouble-shooting the unit and a varied assortment of space components has been supplied for the 1978 season.

2. A quicker turn-around will be available for quality control in 1978. An on-site computer will be used to quality check the radar data each day so that any errors can be more quickly identified.

Based on diligent efforts to maintain the digital processor in good working order and the existence of the error-correcting computer program, it is expected that the 1978 tapes can be processed into Bureau format within a few months after completion of the field season.

Mesoscale Analyses

1. Three case studies of mesoscale events are being prepared. These events are June 22-23 and July 10-11 in 1976 and June 22-23, 1977. The June 1976 case is nearly complete while the other events, together, comprise a representative variety of precipitation situations in the Big Spring area.

2. A description of precipitation organizational patterns in the Big Spring area is being prepared. The 1976 and 1977 seasons will be covered in detail and as much information as possible developed for 1974 and 1975. This study will show the characteristic types of organization (lines, clusters, isolated cells, etc.) as observed by the Snyder radar, their frequency of occurrence and their relation to their synoptic environment.

Radar and Precipitation Analyses

1. A summary of radar echo characteristics will be prepared from processed data provided from Bureau programs.

2. A study of radar-raingage relations will be undertaken as soon as the radar data processing schedule permits.

Mesoscale Field Program and Initial Data Analysis (TAMU)

Various studies utilizing mesoscale data collected in previous summer seasons at the Big Spring HIPLEX site will continue during the next reporting period. More progress is anticipated in the development of a cumulus entrainment model, and further work is planned to determine relationships between synoptic conditions and convective activity in the study region using vertical cross sections, constant pressure charts, and thermodynamic diagrams. Details of plans for further analyses of the moisutre budget are provided in Section I beginning on page 142.

The Chief Scientist will coordinate field and analysis efforts in Texas with those in the other HIPLEX states and will participate as the Project Director at the Big Spring site during June. He will coordinate and integrate the results of analytical work done by all of the Texas HIPLEX participants during the period.

Surface and upper-air weather data using a meso-observing network similar to that employed in 1976 and 1977 will be collected during the field program.

HIPLEX Cloud-Seeding Rain-Gage, and Rawinsonde Support Programs (CRMWD)

An on-top seeding aircraft and crew of experienced personnel will be provided as part of the experimental cloud-seeding effort of the 1978 Texas HIPLEX Program. As in 1977, District personnel will monitor a rain-gage system for the collection of rainfall data and will operate a RD-65 rawinsonde unit for the collection of atmospheric profile data. The District will also furnish the services of a radar meteorologist to operate the FPS-77 radar, collect data, and give direction to the cloud-seeeding aircraft.

SECTION III

PERSONNEL

Management of the Texas-HIPLEX Program and Support Studies (TDWR)

John T. Carr, Jr.	Head, TDWR Weather Modification and Technology Section
Robert Riggio	Meteorologist
George Bomar	Meteorologist
William Alexander	Resident Forecaster at Big Spring
Thomas Larkin	Meteorologist
William Hanshaw	Rain-gage Technician
Keith Topham	Computer Program Analyst
Mike Kengla	Economist

Snyder Radar-Data Analysis (MRI)

T. B. Smith	Superviser
Don Takeuchi	Principal Investigator
Robert Anderson	Project Manager at Snyder
Robert Schaff	Radar Technician
Dean House	Radar Technician
Ed Huber	Radar Technician

Mesoscale Data Analysis (TAMU)

James R. Scoggins	Principal Investigator, Director of Project
James E. Arnold	Instrumentation and Planning
Gregory S. Wilson	Computer Programmer and Analyst
Mark E. Humbert	TAMU Field Program Manager, Data Specialist, and Analyst
Gordon Grant	Data Specialist
John Rod	Data Specialist
Pete Reynolds	Rawinsonde Operator, Data Specialist, and Analyst
Jack Hinson	Rawinsonde Operator and Data Specialist
Steven Bishkin	Rawinsonde Operator and Data Specialist
Terry Allison	Electronics Technician, Rawinsonde Operator, and Data Specialist
Myron Gerhard	Data Specialist
Henry E. Fuelberg	Analyst
Jackie Wilson	Keypunch Operator
Doreen Westwood	Data Specialist and Draftsman
Karen Cobbs	Typist, Keypunch Operator, and Data Specialist

Radar-Echo Climatology for the Southern HIPLEX Region (TAMU)

Dennis M. Driscoll	Principal Investigator, Director of Project
Judson W. Ladd	Graduate Research Assistant

Satellite-Derived Cloud Climatology for the Southern HIPLEX Region (TTU)

Gerald M. Jurica	Principal Investigator, Director of Project
Schwe-Yi Chi	Graduate Research Assistant, Cloud Characteristic Study
Shih-Cheng Chao	Graduate Research Assistant, Analysis of Radiance Data
Vicki Thrasher	Research Associate, Computer Programming
Don Williams	Research Associate, Computer Programming
Russell Pfost	Graduate Research Assistant, Acquisition and Analysis of Satellite Imagery
Robert Suddarth	Student Assistant, Graphics
Debrajean Kerr	Secretary, Documentation and Reporting

Precipitation Climatology for the Southern HIPLEX Region (TTU)

Donald R. Haragan	Principal Investigator, Director of Project
Joe Falkner	Research Assistant
Libby Patterson	Keypunch Operator
James Holman	Student Assistant, Computer Programming

HIPLEX Rain-Gage and Rawinsonde Support Programs (CRMWD)

Owen H. Ivie	General Manager, Colorado River Municipal Water District
R. A. Schooling	Coordinator and Supervisor
John Girdzus	Radar Meteorologist
Alan Giacomelli	Cloud-Seeding Aircraft Pilot
Harold Hancock	Rawinsonde Technician
Humberto Padillo	Rain-gage Technician

APPENDICES

APPENDIX A

"Using Discriminant Analysis to Predict Rainshower Occurrence in the Texas HIPLEX Area"

USING DISCRIMINANT ANALYSIS TO PREDICT RAINSHOWER OCCURRENCE IN THE TEXAS HIPLEX AREA

by:

Robert F. Riggio

and

Keith L. Topham, Jr.

Texas Department of Water Resources
Austin, Texas

May, 1978

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INTRODUCTION

The Texas HIPLEX program is entering into its fourth season of experimental studies. The goal of the experiment is to develop a viable technology whereby certain summertime shower-producing clouds that commonly develop over the Texas High Plains may be treated to produce additional rainfall on the ground. The experiment is jointly supported by the Bureau of Reclamation and the Texas Department of Water Resources. The participants of the program to date include the Bureau of Reclamation, Texas Department of Water Resources, the Colorado River Municipal Water District, Texas A&M University, Texas Tech University and Meteorology Research, Incorporated.

The work of the Texas HIPLEX program during the last three years falls into the realm of exploratory studies. The purpose of these studies was to learn as much about the development, maintenance, and life history of shower-producing cumulus clouds that develop over the Texas High Plains as time and funds would allow. This knowledge is considered essential before the program can move ahead into the experimental and proof-of-concept stage, because only from a basic understanding of the clouds and atmosphere over the Texas High Plains can an appropriate hypothesis be developed and a sound statistical design to test the hypothesis evolve.

A review of the literature c.f. Huff (1969) emphasizes the problem of natural rainfall distribution, as it relates to weather modification experiments and project evaluations, is by far the most difficult obstacle to hurdle before any seeding effects can be determined within a reasonable number of years. Recent weather modification experiments in Florida reported by Biondini et al. (1977), South Dakota reported by Dennis et al. (1975) and in North Dakota reported by Dennis et al. (1975) have suggested that with a minimum number of cases statistically significant cloud-seeding effects can be determined by reducing the effects of natural rainfall variability through stratification techniques with the use of meteorological predictors. Olsen and Woodley (1975) examined the effects of natural rainfall variability on the Florida Area Cumulus Experiment and concluded that "...it is absolutely critical that seedability or suitability criteria for a day of experimentation be followed to reduce variability. Seeding on all days without a physical model or predictors to diminish the importance of natural rain variability would be a serious mistake."

To avoid this type of mistake, the Texas Department of Water Resources initiated a preliminary exploratory study to identify predictor variables for the Texas HIPLEX program that can be used in a decision-making process to objectively prestratify the occurrence of the shower-producing cumulus clouds, and thus, reduce the effects of natural rain variability.

Inasmuch as the goal of HIPLEX is to increase rainfall from summertime cumulus clouds, the experimental unit will involve shower-producing cumulus clouds. Therefore, this paper will examine the problem of minimizing the effects of natural rainfall variability in the Texas HIPLEX program by prestratifying summertime seeding opportunities using predictor variables of summertime shower-producing cumulus clouds.

FORECAST STUDY AREA

The forecast study area used in this analysis (Figure 1) is located in the Permian Basin region of West Texas. The terrain is nearly level to rolling, sloping from northwest to southeast.

The climate is sub-tropical with dry winters and warm humid summers. Annual rainfall averages from nearly 15 inches in the western portion to 23 inches in the eastern portion. Most of the precipitation is from few relatively large summertime convective cloud systems.

A study by Haragan (1978) of the meso-synoptic patterns responsible for summertime rainshower development in the forecast study area reveals that 92% of rainshower occurrences were initiated by some sort of forcing function, e.g., upper-wave, front or dry line, and only 7% of the rainshower occurrences were initiated by surface heating. These findings suggest that the presence of a forcing function is highly significant when predicting rainshower occurrences and needs to be addressed in the prediction model.

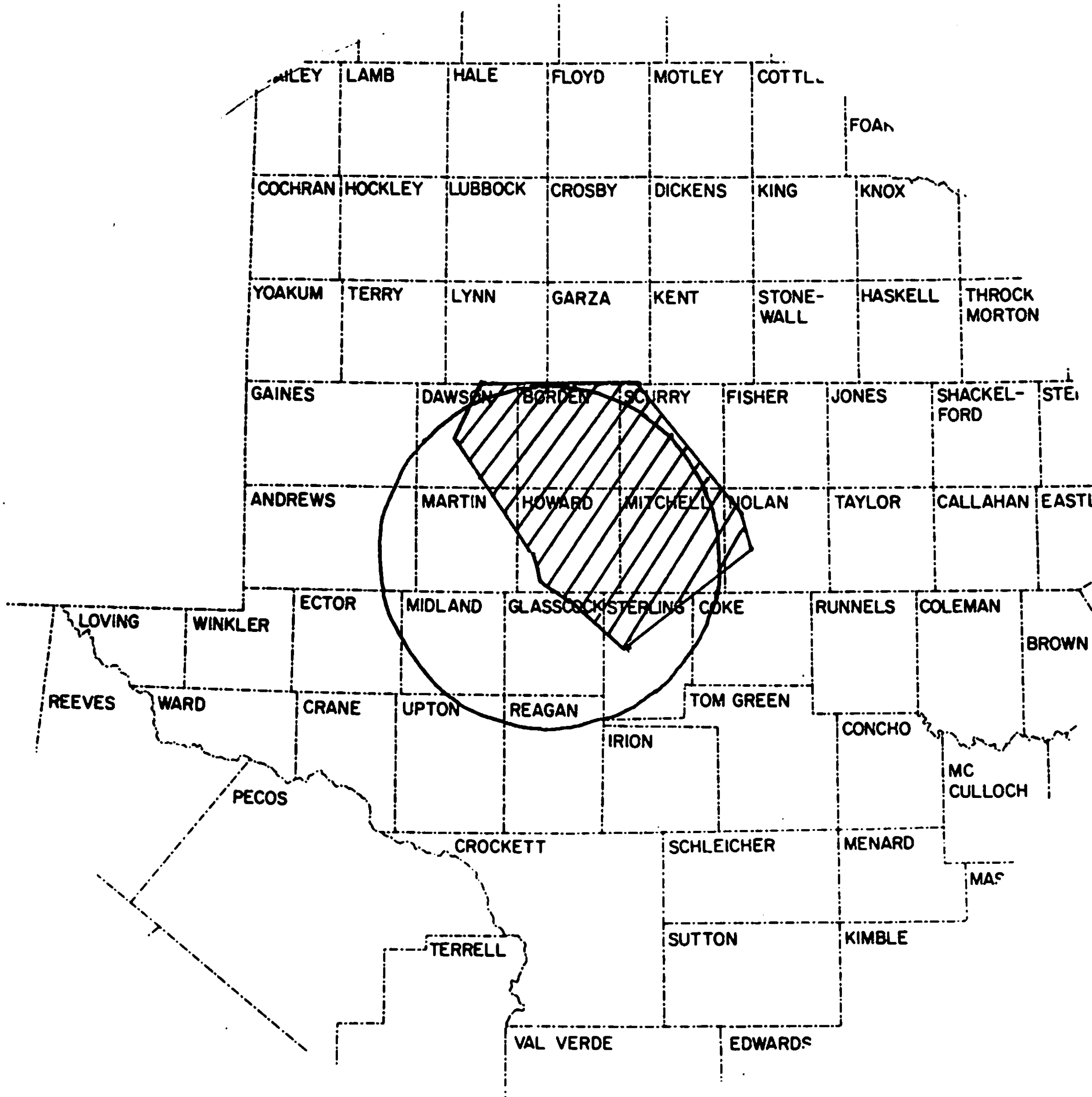

FIGURE 1. The forecast study area encompasses a 50 mile radius area centered on Webb AFB. The Texas HIPLEX target area is the shaded area.

APPROACH

The objective of this phase of the study was two-fold. First, this study identified the best predictor variables for forecasting the occurrence of shower-producing clouds. Secondly, a method was developed to utilize these predictor variables in a forecast technique.

The approach was to classify individuals into three pre-defined populations or groups. Each individual was a vector made up of certain 1200 GMT* meteorological data collected for a single day. The three groups defined the occurrence or non-occurrence of shower-producing clouds.

The Statistical Package for the Social Sciences (SPSS) DISCRIMINANT Subprogram was used to implement the above approach. The procedure of this Subprogram is summarized below:

(i) An optimal subset of all the meteorological variables introduced was selected using a step-wise linear regression procedure to serve as predictor variables. The predictand for the regression was determined by the group number 1, 2, or 3 .

(ii) Two orthogonal linear discriminant functions of the predictor variables were developed which best discriminate among the three groups.

(iii) Considering the two linear discriminant functions to be a two-dimensional random vector, this random vector has a probability density function $f_j(\vec{x})$ for each group $j = 1,2,3$. The Subprogram outputs classification function coefficients for each group from which the densities $f_j(\vec{x})$ can be computed.

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*Greenwich Mean Time

The classification of an individual vector $\vec{x}$ into one of the three groups involves computing the posterior probability of group membership $P\ (G_j \mid \vec{x})$ for each group and then assigning the individual vector to the group for which $P\ (G_j \mid \vec{x})$ is a maximum. $P\ (G_j \mid \vec{x})$ is computed according to the formula

$$P\ (G_j \mid \vec{x}) = \frac{p_j\ f_j\ (\vec{x})}{\sum_{\ell=1}^{3} p_\ell\ f_\ell\ (\vec{x})}$$

The p_j above are prior probabilities of group membership and were determined by historical group size.

DATA

Data used in this study were examined for the years 1972, 1973, and 1974. The forecast period was confined to June and July which was the normal operating period of the Texas HIPLEX field program during the past three years.

The predictand for the step-wise linear regression was determined according to the following group definitions:

Group (1) shower-producing clouds observed at or within 50 miles of Webb Air Force Base;

Group (2) shower-producing clouds observed beyond 50 miles of Webb AFB;

Group (3) no shower-producing clouds observed.

The predictand data were taken from Webb AFB's official Federal Meteorological Form 1-10 entitled, "Surface Weather Observations." This form was used by trained Air Force weather observers to record hourly and special surface weather observations.

A day was classified as Group 1 when during the period 1200 GMT and 0000 GMT a thunderstorm or rainshower was observed at the station or by radar to be 50 miles or less from Webb AFB. A day was classified as Group 2 when during the period 1200 GMT and 0000 GMT a thunderstorm or rainshower was observed, visually or by radar, but did not meet the requirements of a Group 1 day. If no thunderstorms or rainshowers were observed during the period 1200 GMT and 0000 GMT the day was classified as a Group 3 day. Surface observations during the period 0000 GMT and 1200 GMT were not considered in this analysis.

The candidate predictor variables used to develop the linear discriminant functions were basic meteorological parameters that are easily accessible to the forecaster from standard National Weather Service Facsimile maps. Because the predictands were limited to the 1200 GMT to 0000 GMT observations the candidate predictor variables were limited to only the 1200 GMT data. No transformations of the basic data were considered during this phase of the analysis such as stability indices, potential temperature, etc.

The candidate predictor variables considered were temperature, dew point depression and wind speed and direction at 850- and 500-millibar (mb) levels, temperature and dew point depressions at the 700-mb level, the height of the 500-mb pressure level, and the 500-mb level synoptic feature which in the forecaster's opinion would have an influence on the occurrence of shower-producing clouds during the forecast period.

The 500-mb synoptic feature was the only candidate predictor variable that required a subjective decision by the forecaster. The 500-mb synoptic feature was considered as a candidate predictor variable because previous observations suggest that initial development of rainshowers in the Big Spring area often requires a forcing function. The 500-mb synoptic features were classified as follows: closed lows, troughs, short waves, zonal flows, easterly waves, ridges, and closed high pressure systems. In the analysis each synoptic feature was considered as a binary variable.

The candidate predictor variables were recorded from each of three first-order stations located generally upwind of the forecast HIPLEX study area. These stations were Amarillo, Del Rio and Midland.

RESULTS

Discriminant functions were developed for both June and July. Tables 1 and 2 identify the predictor variables that best discriminate between the three groups for the respective months.

As rainshower predictor variables, dew point depression, winds and synoptic feature are invariant with respect to time for the June-July period, whereas temperature stands out as having marked time association. In June the occurrence of shower-producing clouds is, in part, dependent upon temperature, whereas during July practically all the temperature dependence is missing.

It is interesting to note, too, that all but two of the temperature and dew point depression predictor variables picked by the step-wise linear regression process were chosen from the 850- and 500-mb level. The synoptic feature term was also chosen as a best predictor variable for both June and July.

The skill of the predictor variables to forecast the occurrence of rainshower development was examined using an independent data source. The probabilities of rainshower occurrence were computed for each day during the period June 1, 1977 through July 15, 1977, which was the 1977 Texas HIPLEX field experiment season. The group for which the probability was a maximum was then compared with the observed group. Three of the days had missing 1200 GMT upper-air data and were not included in the analysis.

The results (Table 3) show that during the forecast period Webb AFB weather observers recorded nine Group 1 days, seven Group 2 days, and 26 Group 3 days. It should be emphasized at this point that in the

Table 1. Predictor variables used in the June discriminant functions.

Station	Pressure	Temp	Dew Point Depression	Winds	Height	Synoptic Feature
Amarillo	850	X		X /E-W/		
	700	X				
	500	X*	X*	X /E-W/		X
Del Rio	850	X	X*	X /N-S,E-W/		
	700					
	500	X	X*	X /N-S/	X	X
Midland	850	X	X	X /N-S/		
	700					
	500		X	X /N-S[1], E-W/		X

* Most Significant

Table 2. Predictor variables used in the July discriminant functions.

Station	Pressure	Temp	Dew Point Depression	Winds	Height	Synoptic Feature
Amarillo	850		X	X /E-W7 *		
	700					
	500		X	X /E-W7		
Del Rio	850	X	X	X /E-W7		
	700					
	500		X	X /E-W7		X*
Midland	850					
	700		X*			
	500			X /E-W7*		X*

* Most Significant

TABLE 3. Prediction Results Using Independent 1977 Data

		Predicted Group Membership			
		1	2	3	Total
Actual Group Membership	1	4	4	1	9
	2	1	2	4	7
	3	2	2	22	26
	Total	7	8	27	42

strictest sense, the Group 1 day can be more clearly defined as an occurrence day (shower-producing clouds less than or equal to 50 miles of Webb AFB) and a Group 3 day can be clearly defined as a non-occurrence day, whereas the Group 2 days are "maybe" days and would be difficult to define from an operational standpoint. From the onset of this analysis it was believed that the Group 2 days would be the most difficult to forecast because by definition a high spacial variation of rainshower activity is allowed.

The posterior probability technique forecasted correctly 28 times out of 42 (Table 3). It is gratifying to note that this technique did well when forecasting the Group 1 and Group 3 days (the two most clearly quantified groups). However, the technique did predict one Group 3 day when a Group 1 day was observed and two Group 1 days when a Group 3 day was observed. As expected, the technique had difficulty in discriminating the Group 2 days.

A simple test of these prediction results was made using the "Chi Square" (χ^2) test (Table 4). Because of the limited number of observations in the Group 1 and 2 categories, it was decided to combine the two Groups in order to make the χ^2 test more meaningful. Operationally, combining Groups 1 and 2 is acceptable, because if the model forecasts a Group 1 or a Group 2 day the project director would probably declare the day an operational day anticipating shower-producing cumulus development in or near the study area.

What we wish to learn from the χ^2 test is whether the prediction results had some skill or instead resulted by chance. A test of the hypothesis that the predictor variable forecast had no skill was

TABLE 4. Model Forecast Verification Using the Chi Square Test

MODEL FORECAST

	Operational	Non-Operational	Total
Operational	11	5	16
Non-Operational	4	22	26
Total	15	27	42

NO-SKILL FORECAST

	Operational	Non-Operational	Total
Operational	6	10	16
Non-Operational	9	17	26
Total	15	27	42

$\chi^2 = 8.84$ (computed using continuity correction)

$\chi^2_{1,.01} = 6.64$

Because the observed value of Chi Square is within the critical region, it can be said that the probability is less than one percent (1%) that a no-skill forecast would have led to the model predicted forecast table.

performed because even forecasts that are made without any skill may produce results that appear to be good. We shall then make the assumption that the posterior probability forecast belongs to a "no-skill" population.

The expected no-skill forecast was developed through probability theory; i.e., the probability of getting into any one box would be the probability of getting into the given column multiplied by the probability of getting into the given row. On the basis of the χ^2 test, we can reject the assumption that the observed predictor variable forecast belongs to the no-skill population, with at most a one percent (1%) probability of error.

DISCUSSION

Because this analysis only examines three years of data no conclusions were drawn. However, the results warrant some discussion.

In an analysis of this type the selected predictor variables should make physical sense in order for the user of the forecast model to have confidence in the forecast results.

The predictor variables chosen by the step-wise linear regression make some physical sense. The 1200 GMT meteorological parameters chosen to be the predictor variables were mainly from the 850-mb and 500-mb level. This leads one to believe that the energy source needed to initiate rainshower development over the forecast study area is taken from the 850-mb level or low level moisture. As the cumulus begin to grow it entrains ambient air, and whether or not the ambient air at 500-mb or mid-level is moist or dry will oftentimes dictate the life expectancy of the growing cumulus cloud.

Another reason why only two predictor variables were chosen from the 700-mb level may be inherent in the DISCRIMINANT Subprogram. The step-wise linear regression process may not accept highly correlated parameters into the discriminant function. It is not unreasonable to believe that a high correlation exists between the 700-mb level parameters and either the 850-mb level parameters or the 500-mb level parameters. Consequently, the DISCRIMINANT Subprogram may have accepted only the 850- and 500-mb level parameters and not the correlated 700-mb level parameters.

The components of wind speed and direction at both 850- and 500-mb levels seem to be important to the forecast of the occurrence (or non-occurrence) of summertime shower-producing clouds in the Texas

HIPLEX program. The literature points out that the development and maintenance of convective clouds depend not only upon the thermodynamic processes in a convective cloud but also upon the interactions with the environmental wind field. Conclusions from the Thunderstorm Project reported by Byers and Braham (1945) suggest that strong wind shear provided a negative effect to convective development. However, later studies by Newton (1963) and Fankhouser (1971) conclude that vertical shear of winds provides kinetic energy to the developing convective clouds that were set off or increase vigor of convection. They propose that wind shear: tilts the updraft region allowing the precipitation to fall outside the updraft region thus increasing the life of the updraft region and the convective storm; enhances mid-level entrainment providing a more dynamic release of potential energy; and induces hydrodynamic pressure fields providing vertical accelerations mutually exclusive with vertical accelerations due to buoyancy forces. Marwitz (1972) reports that the super cell storms he observed commonly exist in strong vertical wind shears.

The results also support what has been observed by Haragan which is a forcing function seems to be a significant meteorological parameter to initiate rainshower development.

From an operational standpoint the model performed quite well with the 1977 data. If the project leader defines a Group 2 day as a day when operations must be on standby because the development of thunderstorm will occur in or near the target area, the model verified 11 out of 15 cases for operational days and for non-operational days the model verified 22 out of 27 cases.

The results also indicate that the forecast model using the posterior probability technique to separate operational and non-operational days may have some skill. We can say that the probability of the model forecast results being accidental is very low, less than 1 percent.

LIMITATIONS AND RECOMMENDATIONS

The classical model utilized in this study classifies an individual, characterized by a vector of response data belonging to a population of all possible data vectors, into one of three pre-defined sub-populations. The applicability of this model as a tool for forecasting the occurrence of shower-producing cumulus clouds derives from the sub-population definitions of Groups 1, 2, and 3 and its relative ease of on-site implementation. However, the limitations of the model must be acknowledged.

Meteorological data observations are continuous vectors dependent upon geographic location and time. The non-stochastic model used in this analysis was unable to account for any changes in meteorological data with time. The distribution of meteorological data evidences strong seasonal dependence. The bias brought about by this dependence may have been reduced by developing a separate classification model for each month. However, further refining of the model will require identification and classification of these seasonal changes of the meteorological data.

Since the upper-air synoptic features over a region can act as a mechanical trigger to initiate rainshower development and possibly overshadow objective predictor variable data, it is important to incorporate the 500-mb synoptic feature information into the forecast model. The daily synoptic feature for each station was categorized as one of seven possible qualitative types on the basis of a subjective determination by the forecaster. Each of these seven types was represented as a binary variate for input to SPSS. Even this crude introduction of the discrete synoptic feature information into the model demonstrated its significance. A better method for incorporating synoptic feature data is either to use this data for determining prior probabilities of group membership or to develop two models corresponding to the presence or absence of a synoptic forcing function.

Inherent in the classification model lie other limitations. The three arbitrarily defined sub-populations are not truly distinct and independent, but are an approximation to a continuum of sub-populations of days ranging from intense thunderstorm activity in the center of the study area, to days when rainshowers of different intensities are observed at various distances from the center of the study area, to absolutely clear days. Hence, a continuous index of the occurrence of thunderstorms may be preferred.

Implementation of the classification model entails additional restrictions. First the selection of an optimal subset of predictor variables from the set of all variables considered is open to criticism and is especially suspect when the selection process is accomplished by step-wise linear regression. It turns out that the variables selected as predictors do not in fact belie plausible meteorological interpretation. Secondly, the step-wise regression process must not be allowed to fit the data too closely relative to the number of data cases observed for each of the three sub-populations: otherwise, the discriminant functions derived will have little value as a predictive device. Thirdly, the mathematical assumptions necessary for the derivation of the discriminant functions may not be satisfied by the data. Classically, these assumptions dictate that each variable have a normal distribution for each sub-population and that there be a common covariance matrix for the three sub-populations. The data considered here does not meet the above requirements, but the effect of this failure is unclear. Recent work by Dr. G. A. Shea, University of Texas, (personal conversation) suggests that considerable weakening of the classical assumptions is possible. Finally, it should be noted that the classification scheme ensuing from orthogonally derived linear discriminant functions is not optimal for several sub-populations.

It is hoped that a theoretical model will evolve which is better suited to forecasting the occurrence of shower-producing cumulus clouds. Criteria for the development of such a model should consider:

(i) that the requirements of the model regarding the assumed nature of the meteorological data be met;

(ii) that the predictor variables be available to the forecaster;

(iii) that as much information as possible be output by the model concerning shower-producing cumulus cloud development;

(iv) the practical limitations imposed by data collection resources.

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APPENDIX B

"A Census of the Number of Severe Storm Days
In the Texas HIPLEX Project Area"

A CENSUS OF THE NUMBER OF SEVERE STORM DAYS IN THE TEXAS HIPLEX PROJECT AREA

by

George W. Bomar

Texas Department of Water Resources
Austin, Texas

May 1978

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INTRODUCTION

General

Severe local storms--defined herein as tornadoes or severe thunderstorms accompanied by very strong winds and/or hail--are one of the most important and more difficult of all weather phenomena to forecast. Consequently, the National Weather Service has had in operation for more than 25 years a system for preparing and disseminating specific forecasts and warnings of impending severe weather.

The responsibility for developing and issuing severe weather watches for the Texas HIPLEX project site rests with the National Severe Storms Forecast Center at Kansas City. A watch is merely an indication of where and when the probabilities for severe local storms are highest. It is usually issued for a time interval of 4-8 hours and for a rectangular area having dimensions of 225 km (140 mi) by 322 km (200 mi) (U.S. Department of Commerce, 1977).

The issuance of severe weather warnings is the responsibility of the National Weather Service Forecast Office (WSFO) (National Oceanic and Atmospheric Administration (NOAA), 1977). The Texas HIPLEX project site is situated within the domains of responsibility of the WSFO's at Midland, Lubbock, San Angelo, and Abilene (Figure 1).

Whereas a watch is an indication that severe storms are possible, a warning is a notice that a severe local storm has either been sighted by a spotter or indicated by weather radar. The warning describes the area downwind of the identified storm that is likely to be affected by movement of the storm. In Texas, the area specifically covered by a warning is usually the county within which the severe local storm was sighted, and a warning is typically valid for 1-2 hours after issuance. Obviously, the

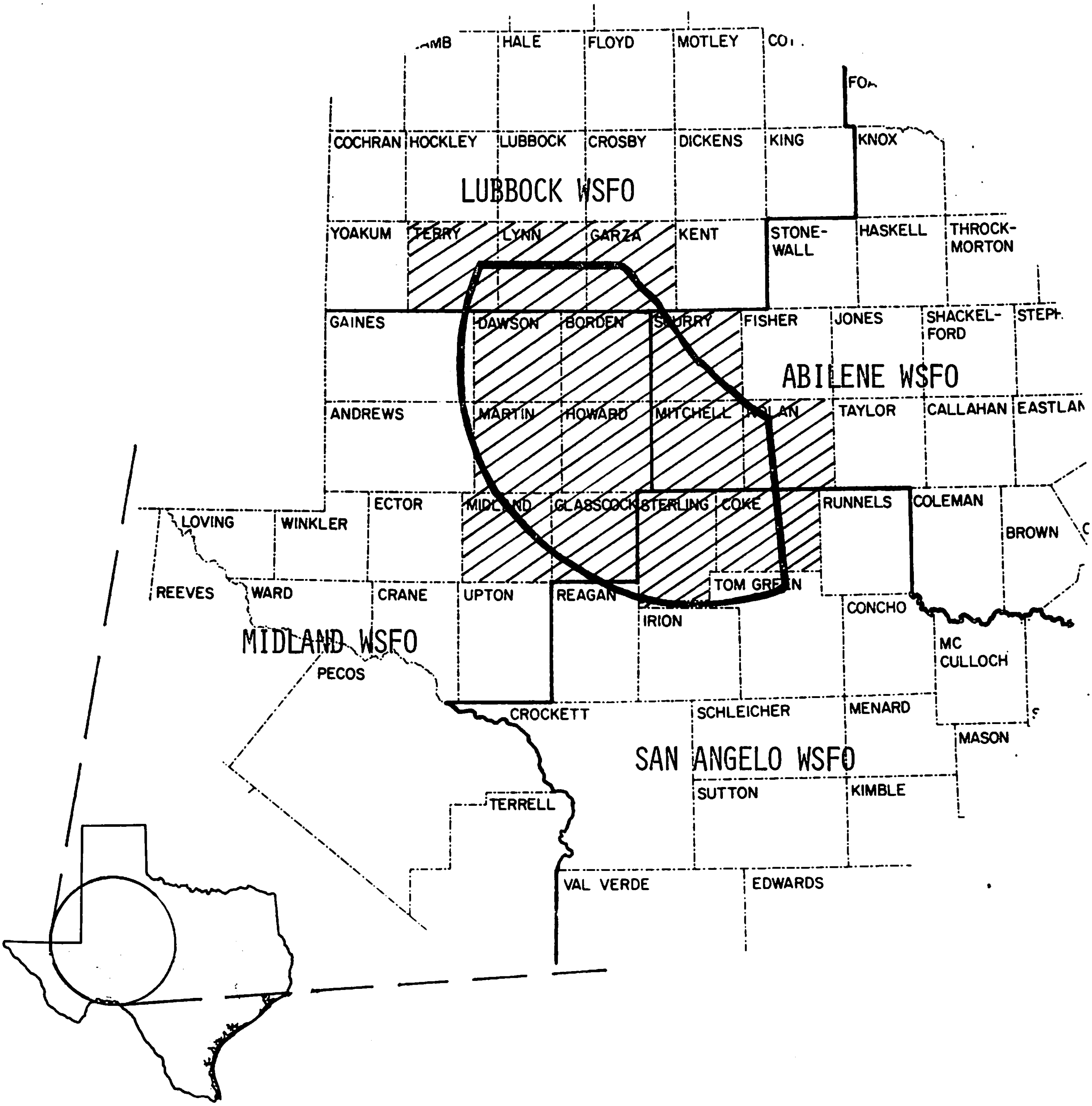

Figure 1. The portion (shaded) of the Texas High Plains for which the census of severe storm occurrence was performed. Also shown are the boundaries of the Texas HIPLEX project site and the regions for which the National Weather Service Forecast Offices has responsibility for issuing severe storm advisories.

absence of a warning is no assurance that severe storms do not exist, since the issuance of a warning is contingent upon actual detection of these storms.

The watches and warnings most frequently issued for the Texas HIPLEX project area are for severe thunderstorms and tornadoes. Events which require the issuance of a severe thunderstorm warning are surface winds (sustained or gusts) of 50 knots or greater and/or surface hail having a diameter of 3/4 of an inch or greater (NOAA, 1977). The term "hail" in a warning implies hail observed at the ground and aloft, unless a qualifying phrase such as "hail aloft" is used. Torndao warnings are based upon the visual observance of either a tornado or funnel cloud or the suspicion that a tornado or funnel cloud exists (as may be indicated by radar).

Objective of the Study

According to the Operations Plan for the 1978 Texas HIPLEX Program, cloud-seeding activities in conjunction with the HIPLEX Program will not be conducted "within a National Weather Service severe weather area, either forecasted or existing ..." (Texas Department of Water Resources, 1978). The issuance of a severe weather watch or warning by the NWS for any portion of the Texas HIPLEX project site will, therefore, result in either the cancellation or termination of all experimental cloud-seeding planned or in progress in the affected portions.

The design of the field portion of the 1978 Texas HIPLEX Program encourages the most efficient use of each available opportunity for conducting cloud-seeding experiments. Previous Texas HIPLEX field exercises in the Big Spring area, as well as a recently-developed rain-fall climatology for the region, have shown that as many as 20 "operational" days for cloud-seeding may be expected to occur during the 6 days in the months of June and July (Texas Department of Water Resources, 1977; Haragan, 1978). Since candidate days for experimentation are only about one-third of the total number of days during the period, it is needful that some sort of estimate be made of the number of candidate days which may be lost to the cloud-seeding effort because of the likelihood or presence of severe weather phenomena. This study was undertaken to provide some insight to the probability that severe weather alerts will significantly affect HIPLEX operations during 1978.

SOURCE AND LIMITATIONS OF DATA USED

Source

Records containing information on the number, type, and time of each watch and warning, as well as the areas covered by them, are maintained by the WSFO from which the advisories are issued. These records are usually retained by the WSFO for 3-4 years, after which time they are transferred to appropriate Federal archives and the National Weather Records Center at Asheville, North Carolina.

Since all of the Texas HIPLEX area is covered by watches and warnings issued by the WSFO's at Midland, San Angelo, Abilene, and Lubbock, the weather archives at these four stations were searched to obtain relevant data on severe weather watches and warnings issued by them in the past. Only data for the period 1974-1977 were available from these four WSFO stations. All pertinent information for the preparation of this census was logged for later analysis.

Limitations

Any interpretation of the findings of this census must take into consideration the fact that a total of only four years of data were evaluated in the calculations used to yield the results reported herein. To obtain a highly reliable measure of the frequency with which severe storm watches and warnings are issued for the Texas HIPLEX area, data for a considerably longer time period are needed.

This census should not be regarded as a substitute for a severe weather climatology which could be developed for the area with data obtained from other sources. Nevertheless, it is the author's belief that this census, though limited in scope, will give the reader and the HIPLEX participants some awareness of the number of days during the experimental season when severe weather advisories are likely to be issued.

Of course, the frequency with which watches and warnings are issued during the 1978 experimental season is highly dependent upon the synoptic and mesoscale weather conditions which prevail during that time. These conditions may be considerably dissimilar to those which occurred in any of the years 1974-1977. Nevertheless, in spite of this unknown influence, it is believed that this census can serve as a useful tool to the personnel at Big Spring who plan daily activities in support of the HIPLEX program.

Numerous instances of hail, tornadoes, strong winds, and torrential rains likely occurred but were not recorded in the publication "Storm Data." According to its publisher, the periodical "contains our best information on storms but, due to the difficulties inherent in collection of the type of data, it is not all-inclusive." (U.S. Department of Commerce, 1959-1977). The number of actual occurrences of severe weather phenomena in the study area can probably best be estimated from radar-echo data. A climatology of such occurrences is being developed as a part of the 1978 Texas HIPLEX Program.

PRESENTATION OF RESULTS

Severe Storm Watches

Nineteen severe local-storm watches were issued by the National Weather Service for portions of the Texas HIPLEX area during the period 1974-1977 (Table 1); of this number, 14 were issued during 1974 and 1975. Furthermore, all but five of the nineteen storm watches were posted during June. It is obvious that the dominant weather pattern in the region during the latter two years of the study period was less contributive to the formation of severe weather phenomena than that of the earlier two years. As suggested by Haragan (1978) and evident in Table 1, a climatic regime less conducive to the occurrence of severe weather phenomena usually prevails during July.

In more than half of the instances in which a tornado/severe thunderstorm watch was issued, no severe weather was reported to have occurred in the affected portion of the Texas HIPLEX area. This observation is not meant to infer that the margin of error in many storm watches is inordinately great. As stated previously, watches are invariably issued for areas of up to 30,000 square miles, and only a small portion of the watch area may intercept the study area. Even though weather within the study area may have been relatively tranquil, other areas covered by the advisory may have sustained considerable severe-storm activity, the magnitude and frequency of which could be the subject of a separate study.

The census suggests that, when a watch covering a segment of the study area is issued, there is a good likelihood (more than a 50-50 chance) that local storms of severe proportions will not be observed in the study area. Continuous monitoring by the HIPLEX 5 and 10-cm radars, rather than mandatory termination of all experimental operations, may be action enough to

Table 1. Severe local-storm watches issued for portions of the study area for June-July, 1974-1977.

Type of Watch	Period of Effectiveness: Date	Period of Effectiveness: Time	Counties Affected	Verification Reports
TORNADO & SEVERE THUNDERSTORM	June 3, 1974	4:30-9:30 pm	all of the project area	tornado observed at 10:10 pm 10 NE Sweetwater
	June 3-4, 1974	9:30 pm-1:30 am	Terry, Lynn, and Garza	no reports of severe storms filed
	June 8, 1974	2-8 pm	Fisher and Nolan	no reports of severe storms filed
	June 7, 1975	5-11 pm	Lynn, Garza, Terry, Scurry, and Fisher	no reports of severe storms filed
	June 8, 1975	2-8 pm	Coke and Nolan	no reports of severe storms filed
	June 9, 1975	7-11 pm	most of the project area	hail as large as 1 3/4" and strong winds occurred in Dawson and Borden Counties in the evening
	June 22, 1975	6-11 pm	most of the project area	hail up to 1 3/4" and wind gusts to 50 mph occurred in Lynn County in the early evening
	June 23-24, 1976	9 pm-3 am	Scurry, Garza, Fisher, Nolan, and Mitchell	winds of 60 mph caused $100K in damages in Snyder (Scurry Co.); high thunderstorm winds caused $45K in damages to homes 8 E Big Spring (Howard County)
SEVERE THUNDERSTORM	June 11, 1974	4:30-9 pm	Garza	no reports of severe storms filed
	June 8, 1975	2-8 pm	Coke	no reports of severe storms filed
	June 9, 1975	2-8 pm	Nolan, Scurry, and Fisher	hail up to 1 3/4" and strong winds occurred in Dawson and Borden Counties

(continued)

Table 1. Severe local-storm watches issued for portions of the study area for June-July, 1974-1977. (continued)

Type of Watch	Period of Effectiveness: Date	Time	Counties Affected	Verification Reports
	June 30, 1976	5-11 pm	southeastern half of project area	no reports of severe storms filed
	June 13, 1977	5:30-11 pm	Lynn and Garza	no reports of severe storms filed
FLASH FLOOD	June 9-10, 1975	eve/night	Scurry, Fisher, Mitchell and Nolan	less than 1/2" of rain fell in the affected region
	July 17-18, 1975	5:30 am-next day	Coke and Sterling	3-4" rains fell in Coke County
	July 20-21, 1975	9:25 pm-early am	northeastern half of project area	2-7" rains were common in the region affected
	July 25, 1975	2 pm-next am	Garza, Scurry, Nolan and Mitchell	1/2" or less fell in most of the region covered
	July 11, 1976	4 pm-next day	Borden, Dawson, and Scurry	1-2" rains occurred in the affected region
	July 8, 1977	6 pm-9 pm	most area of the project	1/4-1/2" rains fell in most of the region

take when severe weather watches are announced, with termination to take effect upon receipt of a severe weather warning.

Severe Storm Warnings

When severe storm warnings are issued, HIPLEX project personnel are already cognizant of the presence of the storms in the area and are likely to have taken appropriate steps to insure the safety of all aircraft and personnel. Too, as inferred from the Operations Plan, it is not the purpose of the Texas HIPLEX Program to modify the physical processes of a storm that has attained the capability for producing hail, tornadoes, strong winds, and flash-flooding rains. Issuance of the weather warning by the WSFO may serve to substantiate the observation by project personnel that severe weather exists and to provide additional information as to the expected effects of the storms.

On the average, issuance of severe thunderstorm warnings for some part of the Texas HIPLEX region can by expected on about seven days during June (Table 2). An appreciably lesser number (2) can be anticipated in

Table 2. Number of days in June and July, 1974-1977 on which a severe weather warning was issued for some portion of the Texas HIPLEX project area.

Type of Warning	Year				4-year mean
	1974	1975	1976	1977	
		June			
Severe Thunderstorm	6	8	7	8	7.2
Tornado	4	0	0	0	1.0
Flash Flood	0	0	0	1	0.5
		July			
Severe Thunderstorm	2	4	3	0	2.2
Tornado	0	4	5	0	2.2
Flash Flood	0	1	0	1	0.5

July. The number of issuances of tornado warnings in the study area totals no more than two. No more than one flash-flood warning is likely to be issued during the program's 1978 experimental period.

Severe storm warnings are most likely to be issued for the study area from mid-afternoon through the early nighttime hours (Table 3). This is due to the fact that cumulinimbi capable of producing severe local phenomena usually do not attain severe-storm potential until the mid-afternoon (Haragan, 1978). The issuance of warnings at times other than the late afternoon and evening is probably attributable to the presence in the region of a synoptic triggering mechanism such as a cold front or short-wave disturbance. These "triggers" provide a lifting force that may be absent on days when severe thunderstorms primarily erupt as a result of intense surface heating and air-mass instability.

In June of the years 1974-1977, severe weather warnings were issued most frequently for the extreme westernmost portion of the study area. Although the frequency of issuance is substantially reduced, the areal distribution is about the same for July.

Severe Weather Occurrences

Since a severe weather warning consists of both an observation of the existence of a severe weather event and an advisory statement identifying the areas likely to be affected by the storm, no verification of warnings was attempted in this study. However, an examination of the "Storm Data" series yielded data that imply that the past few years in all of the Texas HIPLEX area have been characterized by only a modicum of severe weather activity (Table 4). Reports of hail, tornadoes, and strong winds in all of the Texas HIPLEX project area during the 3-year life of the Texas

Table 3. Number of issuances of severe thunderstorm (TSM) and tornado (TOR) warnings by interval of time during June and July, 1974-1977 within the Texas HIPLEX project area.

Time Internal (LDT)	1974		1975		1976		1977	
	TSM	TOR	TSM	TOR	TSM	TOR	TSM	TOR
				--June--				
0 - 3AM	4	2	0	0	0	0	3	-
3 - 6AM	1	-	-	-	-	-	2	-
6 - 12N	-	-	-	-	-	-	-	-
12N - 3PM	-	-	-	-	-	-	-	-
3 - 6PM	2	-	2	-	-	-	2	-
6 - 9PM	1	1	8	-	5	-	2	-
9 - 12MN	9	1	4	-	1	-	6	-
				--July--				
0 - 3AM	-	-	1	-	2	1	-	-
3 - 6AM	-	-	-	-	-	-	-	-
6 - 12N	-	-	-	-	1	-	-	-
12N - 3PM	-	-	-	1	-	1	-	-
3 - 6PM	-	-	2	2	-	2	-	-
6 - 9PM	2	-	3	-	4	-	-	-
9 - 12MN	2	-	3	1	-	1	-	-

Table 4. Number of days on which occurrences of severe local weather phenomena were reported in the Texas HIPLEX project area during June-July, 1959-77 (Source: "Storm Data").

Time Interval	Type of Occurrences			
	Hail on the Ground	Strong Winds (>60 mph)	Tornadoes	Funnel Clouds
	--June--			
1974-77	1	2	0	1
1970-73	2	1	1	1
1966-69	7	2	2	4
1962-65	8	7	7	4
1959-61	7	7	3	4
	--July--			
1974-77	0	0	1	0
1970-73	0	0	0	2
1966-69	0	0	0	2
1962-65	3	3	5	3
1959-61	6	3	1	2

HIPLEX Program (1975-77) have been comparatively few (Table 4). The number of days on which severe local storms were reported to the NWS is considerably greater in June than in July.

With improvements in the density of the NWS observational network, one would expect an increase in the reported number of occurrences of local storms in the more recent years. Just as the number of "severe" storm days was considerably fewer in earlier decades than in the 1970's (Table 4), the decline in the number of severe storm days during July relative to June is also noteworthy.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Based upon records of severe storms for the period 1974-77, issuance of a tornado and/or severe thunderstorm watch for some portion of the Texas HIPLEX project area is likely on no more than three days during the 2-month experimental phase of the 1978 Texas HIPLEX Program. On each of these three "watch" days, the chances are better than 50-50 that no thunderstorm activity of severe proportions will be reported.

The issuance of a tornado or severe thunderstorm warning for some portion of the Texas HIPLEX project area can be expected to occur on about seven days during the month of June. Warnings are likely to be announced by the National Weather Service on no more than two days in July. Severe thunderstorm warnings are most often (80% of the time) issued in June and July for the time interval 1800 to 0000 LDT.

Recommendations

Since tornado/severe thunderstorm watches for the study area have been observed to be verified only about 50% of the time, it is suggested that the cessation of all cloud-seeding experiments not be based solely on the receipt of a severe storm watch. Having monitored weather conditions on a continual basis prior to his making decisions relative to the status of the day's operations, the project forecaster will doubtlessly be aware of the fact that conditions exist in the atmosphere which are highly conducive to the generation of severe storms. The watch, which is often issued several hours in advance of initiation of convective activity, should serve to accentuate the need for thorough and continual monitoring of conditions in the region with particular emphasis on the detection of severe storm phenomena. The watch can provide the project manager with input necessary for making adjustments in the scheduled activities of the day, should severe weather conditions so warrant.

If cloud-seeding and observational measurement activities have not been terminated prior to receipt of a tornado/severe thunderstorm warning for any portion of the project site, those activities should be terminated immediately upon receipt of one. It may not be necessary to cease experimental activities within all of the project site, however, as warnings most often are issued for only a small portion--several counties--of an area equivalent in size to the project site.

For this census to yield a more accurate representation of the actual likelihood of severe local storm activity in the project area, data for a longer time period are essential. Because the WSFO's maintain files on severe storm watches and warnings for only the most recent four years, less recent data should be obtained from the National Climatic Center and incorporated into the census.

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APPENDIX C

"An Analysis of the 1977 Texas HIPLEX Ice Nuclei Counts"

AN ANALYSIS OF THE 1977 TEXAS HIPLEX ICE NUCLEI COUNTS:

A Determination of the Effect of Silver Iodide Released by Surrounding Weather Modification Programs on the Texas HIPLEX Operational Area

William O. Alexander
Texas Department of Water Resources
Big Spring, Texas

May 1978

Abstract

During the period May through September of 1977 a network of four ice-nuclei samplers was operated in a portion of West Texas to measure the presence of silver iodide particles which were dispensed by weather modification operations conducted near the Texas HIPLEX project site. The samplers were located at Lubbock, Stanton, Big Spring, and Colorado City. They were operated daily between 1200 and 2100 local time.

Data collected from these samplers were compared with cloud-seeding data from nearby weather modification programs using linear regression analyses. The results indicated no significant relationship between the ice nuclei counts in the HIPLEX project area and the amounts of silver iodide dispensed in nearby program operations.

Streamline analyses of the study region were compared with the various ice nuclei counts. These analyses revealed that a southwesterly surface flow was observed to be commonly associated with the highest ice nuclei counts at all four sites.

Based on these observations, it is recommended that the ice-nuclei counter network not be operated during 1978 because no cloud seeding with ice nuclei is taking place within 100 miles southwest of the HIPLEX project area. Rather, it is recommended that a chemical analysis be performed on the 1977 filters used in the samplers to determine ice nuclei type in a search for their origins.

Key Words/Document Analysis

A. Descriptors--Weather modification/weather modification research/ silver iodide/cloud seeding/rain enhancement/hail suppression/ice nuclei

B. Identifiers--High Plains Cooperative Program (HIPLEX)/Big Spring, Texas

LIST OF FIGURES

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Introduction

This study was conducted in an effort to determine the inadvertent effect by other intrastate weather modification programs on the concentration of ice nuclei (IN) within the Texas HIPLEX operational area. This concentration was measured by ice-nuclei sampling equipment located at three sites near and within the Texas HIPLEX operational area: 1) Big Spring's Howard County Airport, 2) Texas Tech University in Lubbock, and 3) Stanton. These sites were believed to monitor the portions of the HIPLEX operational area to be most affected--if at all--by silver iodide (AgI) dispensed by surrounding weather modification programs. Data collected by a fourth center at Colorado City were not used in the analysis due to apparently malfunctioning equipment (see Supplemental Tables for details). Isolating the cause of IN count fluctuation is somewhat beyond the scope of this study. An examination of AgI and IN count relationships shall be studied in depth to resolve this question as completely as possible.

During the 1976 Texas HIPLEX season, a single IN sampler was used at Big Spring's Howard County Airport to detect fluctuations in IN counts. Data acquired from this site were analyzed to determine probable causes for these fluctuations (Alexander, 1977). Emphasis was placed on determining the cause of these fluctuations; it was not the objective of the study to assess the impact of nearby weather modification programs on the IN concentrations in the Texas HIPLEX operational area. However, a supplemental analysis did determine that no correlation was evident between AgI dispensed by Krick's west central Texas cloud-seeding program and the IN counts at Big Spring.

Although the analysis used data from only one source, it did reveal that during the 1976 season southeasterly surface winds correlated well with IN counts at the Big Spring site. This was attributed to the site's close proximity to an oil refinery to the southeast and several major oil fields. Their hydrocarbons and sulphur dioxides were most likely responsible for the high IN counts. This was observed to be a local effect and was not believed to be attributable to count fluctuations over the entire operational area. Thus, additional samplers were required to sample the atmosphere over all of the operational area.

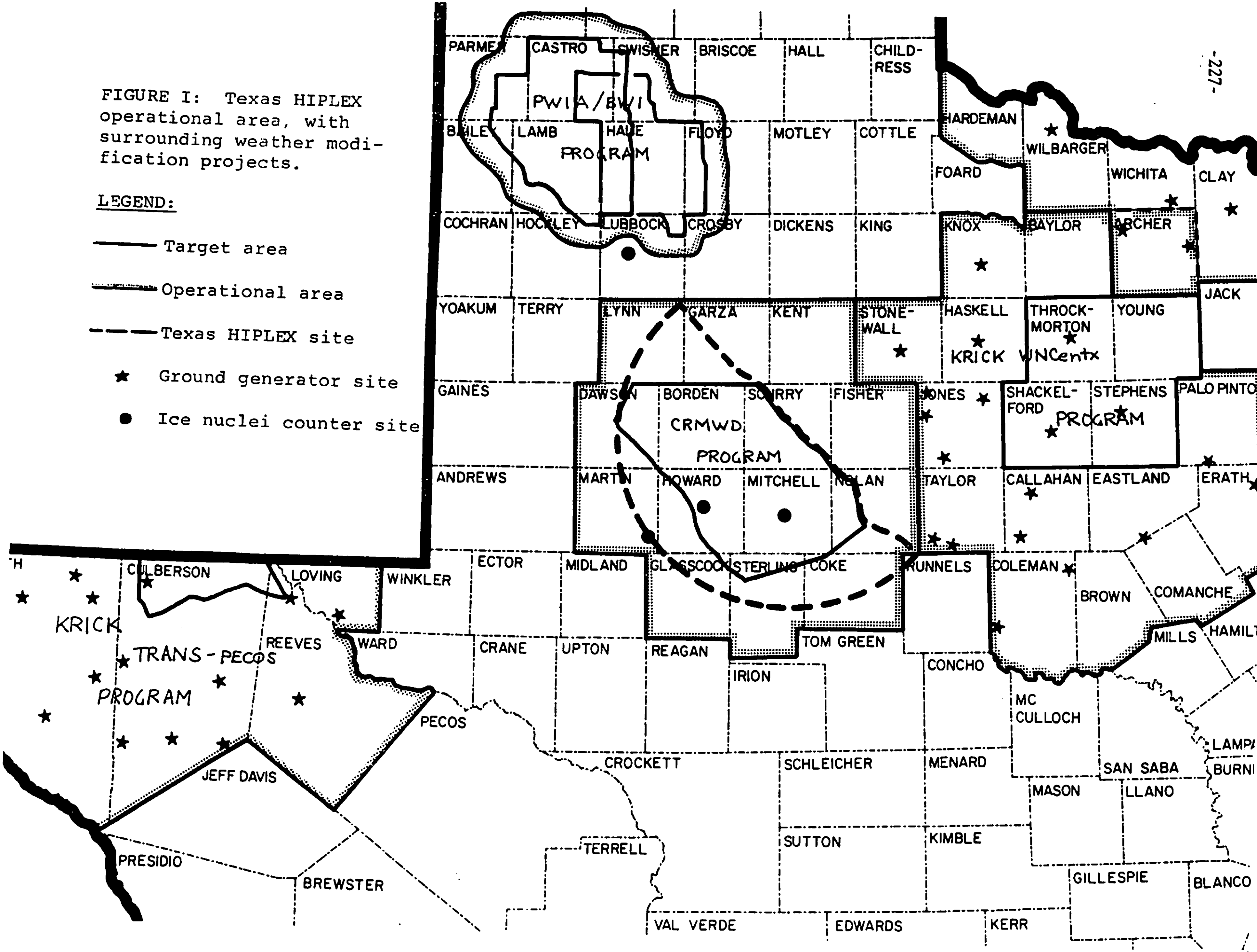
Four IN samplers were installed in easily accessible locations near the HIPLEX operational area boundary and in the direction of the four nearby commercial, weather modification project areas. This configuration was thought to be conducive to the determination of the possibility of contamination of the Texas HIPLEX operational area by AgI emissions from surrounding cloud-seeding programs.

There were five commercial weather modification programs conducted within 150 miles of the HIPLEX project site during the 1977 Texas HIPLEX IN sampling season (May through September). These included: the hail suppression programs of Better Weather, Inc. of Littlefield, Texas and Plains Weather Improvement Association, Inc. of Plainview, Texas; the Krick Trans-Pecos rainfall-enhancement program, the Krick west central Texas rainfall enhancement program; and the Colorado River Municipal Water District rain enhancement program, the target area of which is encompassed by the Texas HIPLEX operational area between Big Spring and Snyder (Figure 1).

FIGURE I: Texas HIPLEX operational area, with surrounding weather modification projects.

LEGEND:

- Target area
- Operational area
- Texas HIPLEX site
- ★ Ground generator site
- ● Ice nuclei counter site



The PWIA/BWI hail-suppression programs and the CRMWD rainfall-enhancement programs both used wing-mounted pyrotechnic devices to dispense the AgI beneath cloud base. The Krick projects used a network of ground generators in conducting their rainfall-enhancement activities. In addition, the hail-suppression programs (the objective of which was also to increase precipitation over their target area) used wingtip AgI generators to supplement the pyrotechnic devices. The aircraft-dispensed AgI was released in quantities that were one to two orders of magnitude greater than that released by Krick's ground-generator networks.

SOURCE OF THE DATA

Each of the IN samplers (Figure 2) consisted of an air pump which drew outside air through a section of tubing and a "millipore filter" (on which the ice nuclei were collected). A regulator maintained flow at a constant rate of three liters per minute, and a timer automatically operated the pump, one minute on, four minutes off. The system was operated by a master timer which was set to turn on at 1200 local time and off at 2100 local time each day.

The exposed filters were shipped to Dr. Gerhard Langer at the National Center for Atmospheric Research (NCAR) for measurement of the IN concentrations. The counts were determined by exposing a quarter section of the filter membrane with to saturated, supercooled (-16°C) air and physically counting IN under a microscope. The IN-count data were then returned to Big Spring for post-analysis.

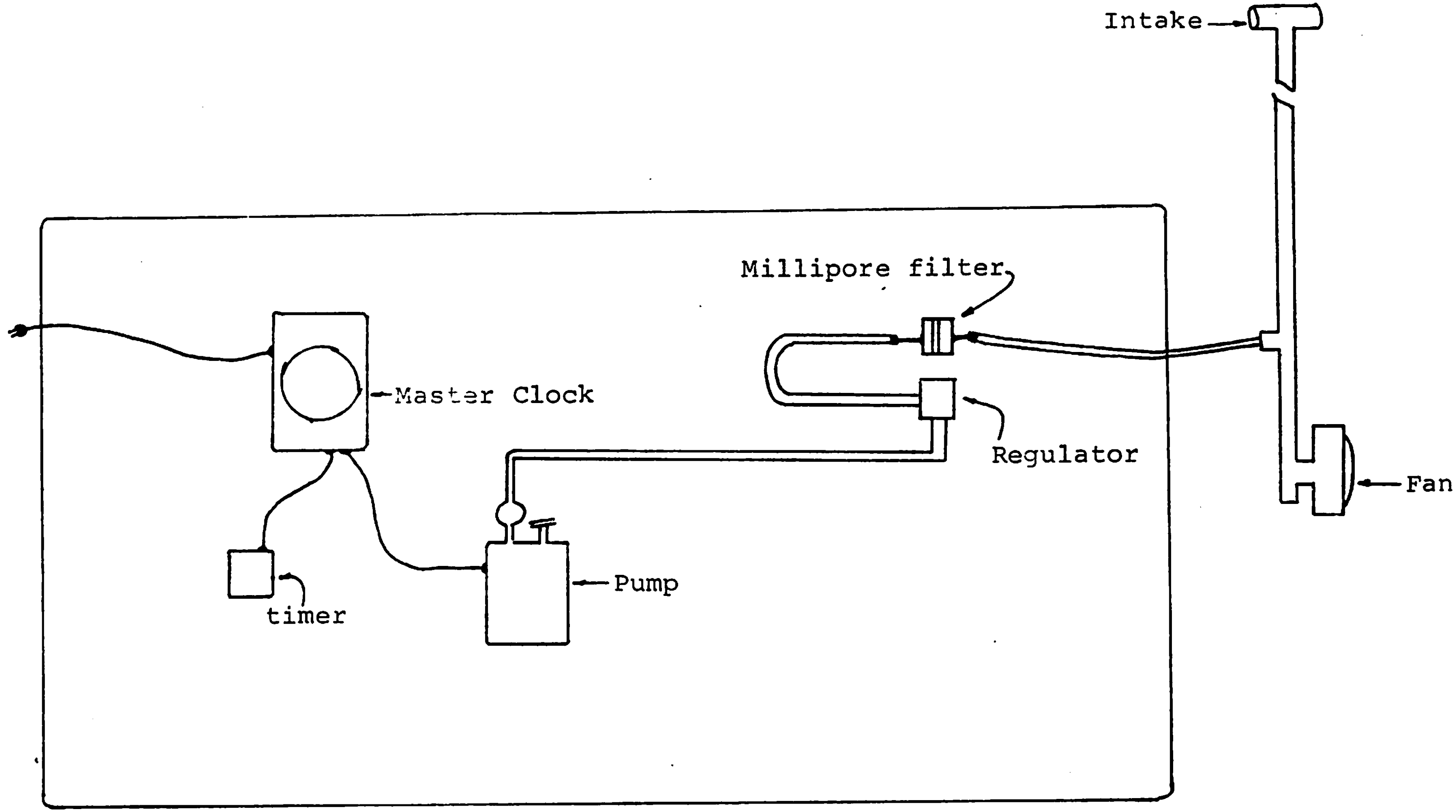


Figure 2: Ice Nuclei Sampler

Amounts of AgI used in the surrounding cloud-seeding projects were recorded by project operators and mailed on a monthly basis to the Texas Department of Water Resources. There the data were archived by Department staff and forwarded to the Big Spring Meteorological Facility.

Data used to determine mean winds were obtained from observations taken by National Weather Service (NWS) and Air Weather Service (AWS) personnel.

PRESENTATION OF RESULTS

Initial analysis of the data focused on the relationship between AgI dispensed during local seeding operations and IN counts recorded by the adjacent sampler. A daily IN count was compared to a same day amount of AgI (grams) dispensed by the neighboring or adjacent operational weather modification program. Data evaluations were performed using a linear regression analysis (Table 1).

Table 1: AgI-IN count relationships, 1977 Texas HIPLEX

Sampler site/ Wx. Mod. Pgm.	R	R^2	F†	N††	$\overline{IN}$*	Significant?
Lubbock/ PWIA-BWI	-.024	-.001	.067	115	221.8	No
Big Spring/ CRMWD	-.041	-.002	.222	137	115.8	No
Stanton/ Krick Trans-Pecos	-.219	-.048	5.381	109	84.5	Yes (5%)

* Mean Ice Nuclei count

† F-ratio = (mean square of regression/mean square of residual)

†† Number of samples evaluated

No significant correlations are evident in the Lubbock/PWIA-BWI and the Big Spring/CRMWD comparisons set. A negative correlation (R = .219)--significant at the 5% level--is indicated in the Stanton/Trans-Pecos data set. The negative correlation suggests that, on seeded days, the IN count in Stanton was lower than on unseeded days. These results suggest that factors other than neighboring cloud-seeding projects may have been responsible for the IN-count fluctuation at all three sites.

Wind Drift and the "Candidate Day"

The best situation in which AgI from an adjacent weather modification program was carried to the vicinity of an IN sampler is hypothesized to be when the winds flowed from the area where the AgI was dispensed to the IN sampler. From this hypothesis the definition of a "candidate day" is derived. A "candidate day" was defined as any Texas HIPLEX day in which both the IN sampler and the corresponding weather modification program were in operation and the mean surface to 700 millibar wind flow paralleled a line from where the AgI was released to the IN counter.

To distinguish candidate days from all other days, mean surface winds were computed from data recorded by surrounding NWS and AWS stations. Twenty-four hourly surface wind observations were averaged to provide a daily mean. Also, upper level winds (850 and 700 millibar) were averaged from 12Z and 00Z rawinsonde data at Amarillo (AMA), El Paso (ELP), Stephenville (GSW), Big Spring (BG), and Midland (MAF). The wind data values were plotted and streamlines were drawn. Each set of data (surface and upper air) was then examined to determine the candidate days. The 1977 candidate days for each site are listed in Table A-2 of the Appendix.

Recall that no positive correlation could be discerned using the linear regression analyses for IN counts and AgI data from each of the three sites during the 1977 season. By stratifying out non-candidate days from the data set, a better opportunity to detect statistically significant (at the 5% level) amounts of AgI was afforded. However, candidate days were few. Only one day was determined to be a candidate day at the Lubbock site, 14 at the Stanton site, and two at the Big Spring site. Only the Stanton candidate days were analyzed by linear regression, since other site sample sizes were prohibitively small to test by this method.

The Stanton data set for candidate days produced a negative correlation (R = -.194), indicating once again that AgI played an insignificant role in IN-count fluctuations at the Stanton site. Apparently, other IN which decreased in density and/or dispersion during days of AgI release (i.e. convectively active days), appear to have accounted for most of the count fluctuation.

<u>Wind Direction versus Ice Nuclei Counts</u>

Analysis of 1976 data acquired from the Howard County Airport IN-counter indicated that surface wind direction was the single most important factor in IN-count fluctuation (Alexander, 1977). Specifically, southeasterly flow correlated better with IN counts than did all other directions. This was explained by the fact that unburned hydrocarbons and sulphur emissions from nearby oil refineries and fields passed over the sampler site during periods of southeasterly surface flow. It was, therefore, hypothesized that local effects of this type would also play a major role in IN-count fluctuation for 1977 data.

To test this hypothesis, mean surface winds were computed for Lubbock, Big Spring, San Angelo, Abilene, and Midland NWS or AWS weather station data. These data were used to draw surface to 700-millibar streamlines, which then allowed candidate days to be determined (page 8); the Lubbock, Midland, and Big Spring data also were used to determine mean wind vectors and their variation with respect to IN count.

For this analysis Webb AFB (Big Spring) wind data were used to represent mean winds for the Howard County Airport site, Midland NWS wind data for the Stanton site, and Lubbock NWS wind data for the Texas Tech site.

These data were broken down into u and v components [$u = s\text{-}\sin(\alpha)$ and $v = s\text{-}\cos(\alpha)$], where s represents wind speed and α the angle. IN-count data for the corresponding day was sorted in descending order, such that both higher and lower IN-counts and their corresponding wind components could be examined concurrently. The results are shown in Tables A-3, A-5, and A-7 of the Supplemental Tables.

The results of these analyses do not allow solid conclusions to be drawn, but suggest a slight tendency for higher IN-counts to have been associated with southwesterly (rather than southeasterly) flow at each site. To investigate this tendency further, Tables A-4 , A-6 , and A-8 of the Supplemental Tables were constructed. These tables display two significant findings: 1) while the most common--by far--surface flow was from the southeast, 2) the highest IN-counts were recorded on days with southwesterly flow. These phenomenae occurred at all three sites.

Dust is commonly carried by southwesterly low-level flow over the Texas HIPLEX operational area, and detection of the dust by the samplers would explain why all sites recorded IN-count maxima with low-level flow from the same southwesterly direction. Local IN-emittors, such as refineries, stockyards, cotton gins, and so forth, would affect a count change at only one site. Only a mesoscale or subsynoptic scale phenomena, such as blowing dust, would consistently alter counts at all three sites. Therefore, the hypothesis that local effects produce the greatest amount of fluctuation in IN counts is rejected.

The negative correlation between AgI at the Trans-Pecos seeding site and Stanton IN counts may be attributed to the presence of dust. On days of southwesterly flow, seeding was generally not performed due to dry conditions. Coincidentally, southwesterly flow days were characterized by higher IN counts, most likely due to dust. Southeasterly flow corresponded with lower counts, probably due to lower dust concentrations. At the same time, low level moisture amounts were higher and seeding was more common on days of southeasterly flow.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

It has been shown using simple linear regression analysis that no significant positive correlation exists between AgI emitted by surrounding weather modification programs and IN counts recorded at sites along the perimeter of the Texas HIPLEX operational area. In fact, there seems to be a negative correlation between the two data sets, for IN-counts were observed to be lower on seeded days than on unseeded days.

Although very few "candidate day" were available for study, statistical analysis of the case studies indicated no identifiable correlation between AgI and IN counts.

An analysis of stratified IN-count data with respect to wind direction revealed that maximum counts coincided with southwesterly surface winds, although the most frequently observed surface flow at each site was from the southeast. Higher IN-counts appear to be due to the presence of dust particles which are detected by the sampling equipment.

Recommendations

It has been shown in two separate analyses (1976 and this study) that AgI from surrounding programs is not detectable within the Texas HIPLEX operational area. Operation of the IN samplers during 1978 would therefore be redundant, and is not recommended.

It is recommended that a chemical analysis be performed on the 1977 millipore filters for the purpose of isolating IN types, thereby explaining much of the count fluctuation and ascertaining the possibility of natural background contamination of the Texas HIPLEX operational area.

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SUPPLEMENTAL TABLES

Table A-1: 1977 Texas HIPLEX Ice Nuclei Counts

Date	Station			
May	BGS	CC	LBB	STN
16	336			
17	348			
18	276			
19	244			
20	268			
21				
22	256			
23	116			
24	132			
25	116			
26	104			
27	216		364	88
28	96			28
29	192		460	24
30	400		24	32
31	288		136	4
June				
1	76	12	220	12
2	---	16	120	12
3	176	72	56	12
4	464	0	168	12
5	68	0	48	8
6	44	12	84	4
7	68	0	76	12
8	140	0	52	20
9	4	4	56	40
10	212	0	280	28
11	228	12	144	104
12	220	0	156	44
13	36	0	80	168
14	124	0	356	32
15	192	0	608	60
16	24	0	264	120
17	32	8	372	52
18	40	16	612	16
19	32	12	192	16
20	40	8	180	4
21	36	0	292	8
22	120	8	140	28
23	44	0	100	92
24	64	0	148	16
25	48	0	704	64
26	184	0	2877	40
27	316	0	1781	48

Ice Nuclei Count

Table A-1 (con't.)

Date	Station			
June	BGS	CC	LBB	STN
28	148	0	1507	36
29	96	12	1233	40
30	256	4	360	4
July				
1	96	8	572	32
2	72	4	252	104
3	136	8	532	4
4	148	8	959	108
5	100	0	2055	68
6	60	8	344	80
7	48	0	232	36
8	92	0	216	8
9	76	0	260	32
10	120	8	336	32
11	152	4	148	52
12	96	0	36	136
13	48	0	72	52
14	32	4	80	60
15	20	0	24	180
16	52	0	---	---
17	100	8	---	---
18	88	0	---	---
19	---	0	---	---
20	116	0	---	---
21	108	0	---	---
22	44	16	---	---
23	92	4	---	---
24	88	0	---	---
25	124	0	---	---
26	92	4	---	---
27	84	4	32	---
28	100	0	40	---
29	28	84	36	---
30	100	0	52	104
31	100	0	16	100
August				
1	36	4	24	24
2	8	0	4	24
3	20	4	20	---
4	12	0	40	64
5	68	0	16	---
6	16	0	8	12
7	52	0	16	52

Table A-1 (con't.)

Date	Station			
August	BGS	CC	LBB	STN
8	112	8	100	216
9	60	0	48	96
10	16	0	20	56
11	20	0	---	---
12	60	0	12	28
13	68	0	4	68
14	60	0	28	60
15	72	0	8	56
16	28	0	72	68
17	52	0	20	64
18	92	112	72	48
19	40	44	20	40
20	60	0	4	180
21	52	0	20	52
22	68	0	60	20
23	164	0	20	400
24	108	0	20	124
25	76	8	28	16
26	60	0	20	---
27	136	4	---	228
28	12	0	20	88
29	24	0	24	28
30	72	12	108	100
31	116	---	---	72
September				
1	48	0	60	28
2	68	0	40	72
3	40	0	88	20
4	48	8	---	24
5	56	0	28	172
6	40	0	48	160
7	152	4	64	64
8	52	0	96	44
9	128	0	120	140
10	---	4	84	128
11	---	0	36	112
12	100	4	28	124
13	176	4	40	220
14	60	0	40	112
15	176	0	16	224
16	168	---	160	312
17	164	0	320	280
18	132	0	---	216
19	84	8	112	52

Table A-1 (con't.)

Date	Station			
September	BGS	CC	LBB	STN
20	484	8	396	648
21	276	0	388	224
22	200	0	284	20
23	388	24	380	204
24	152	4	---	148
25	156	4	80	64
26	92	0	192	48
27	172	0	84	84
28	336	---	296	164
29	140	4	220	96
30	404	0	404	200

Table A-2: 1977 Texas HIPLEX Candidate Days

Station	Date	Ice Nuclei Count	Silver Iodide Dispersed (gm.)
Big Spring	6/25	48	1020
	8/12	60	80
Lubbock	8/21	20	2842
Stanton	6/10	28	16
	6/22	28	76.5
	6/23	92	56
	6/25	64	8.5
	6/30	4	29
	7/10	32	28
	8/21	52	43
	8/22	20	49
	8/27	228	40
	9/3	20	34
	9/5	172	17
	9/12	124	21
	9/18	216	34.5
	9/23	204	16

Summary

Station	Sample Mean Ice Nuclei Ct.	Pop. Mean Ice Nuc. Ct.	Sample Mean AgI (gm.)	Pop. Mean AgI (gm.)
Big Spring	54	115.8	550	51.1
Lubbock	20	221.8	2842	520.8
Stanton	91.7	84.5	33.5	22.9

Table A-3: Big Spring IN/Wind Summary, May-Sept. 1977

IN Ct.%ile Increments	Numerical Range	No. of Cases	$\overline{IN}$	$\bar{u}$	$\bar{v}$	Mean Wind Velocity (M/sec)
0-10	4-50	29	29.3	-1.7426	4.4667	158.7@4.8
11-20	51-96	36	72.8	-1.7003	3.3129	152.8@3.7
21-30	97-142	22	117.3	-1.3030	4.4847	163.8@4.7
31-40	143-188	6	162.0	-0.7527	4.9849	171.4@5.0
41-50	189-234	6	210.0	-0.6781	2.9067	166.9@3.0
51-60	235-280	4	258.0	-0.6432	7.4495	175.1@7.5
61-70	281-326	2	302.0	-2.4019	3.6289	146.5@4.4
71-80	327-372	2	342.0	-0.6864	7.9461	175.1@8.0
81-90	373-418	1	400.0	1.0395	4.8907	192.0@5.0
91-100	419-464	1	464.0	1.5451	4.7553	198.0@5.0
TOTALS & MEANS		109	105.2	-1.4235	4.1964	160.3@4.5

Table A-4: Big Spring IN/Wind Summary by Directional Quadrants, May-Sept. 1977

Quadrant	No. of Cases	% of total in quad.	$\overline{IN}$ of quad.
I (0-89°)	6	5.5	97.3
II (270-359°)	1	0.9	100.0
III (180-269°)	19	17.4	120.5
IV (90-179°)	83	76.1	102.7
TOTALS & MEANS	109	100.0	105.5

Table A-5: Lubbock IN/Wind Summary, May-Sept. 1977

IN Ct. %ile Increments	Numerical Range	No. of Cases	$\overline{IN}$	$\bar{u}$	$\bar{v}$	Mean Wind Velocity (M/sec)
0-10	0-288	93	86.6	-0.8080	2.8517	164.2@3.0
11-20	289-576	13	392.9	0.5566	3.7876	188.4@3.8
21-30	577-864	3	641.3	-0.0350	4.9193	179.6@4.9
31-40	865-1152	1	959.0	-1.2156	6.8936	170.0@7.0
41-50	1153-1440	1	1233.0	-1.7535	3.5952	154.0@4.0
51-60	1441-1728	1	1507.0	-1.2202	2.7406	156.0@3.0
61-70	1729-2016	1	1781.0	0.8316	3.9126	192.0@4.0
71-80	2017-2304	1	2055.0	-0.6094	4.9627	173.0@5.0
81-90	2305-2592	0	---	---	---	---
91-100	2593-2880	1	2877.0	1.4335	3.7343	201.0@4.0
TOTALS & MEANS		115	221.7	-0.6135	3.0873	168.8@3.2

Table A-6: Lubbock IN/Wind Summary by Directional Quadrants, May-Sept. 1977

Quadrant	No. of Cases	% of total in quad.	$\overline{IN}$ of quad.
I (0-89°)	7	6.1	49.4
II (270-359°)	3	2.6	196.0
III (180-269°)	33	28.7	339.3
IV (90-179°)	72	62.6	184.8
TOTALS & MEANS	115	100.0	221.2

Table A-7: Stanton IN/Wind Summary, May-Sept. 1977

IN Ct.%ile Increments	Numerical Range	No. of Cases	$\overline{IN}$	$\bar{u}$	$\bar{v}$	Mean Wind Velocity (M/sec)
0-10	0-65	63	31.9	-2.7415	3.9612	145.3@4.8
11-20	66-130	24	96.3	-1.8738	3.9210	154.5@4.3
21-30	131-195	9	160.9	-2.8786	1.6296	119.5@3.3
31-40	196-260	8	216.5	-0.0167	3.9710	179.8@4.0
41-50	261-325	2	296.0	-0.1481	6.4826	178.7@6.5
51-60	326-390	0	---	---	---	---
61-70	391-455	1	400.0	-0.8683	4.2940	168.6@4.4
71-80	456-520	0	---	---	---	---
81-90	521-585	0	---	---	---	---
91-100	586-650	1	648.0	-1.2475	5.8689	168.0@6.0
TOTALS & MEANS		108	84.6	-2.2791	3.8261	149.2@4.5

Table A-8: Stanton IN/Wind Summary by Directional Quadrants, May-Sept. 1977

Quadrant	No. of Cases	% of total in quad.	$\overline{IN}$ of quad.
I (0-89°)	11	10.2	96.7
II (270-359°)	2	1.9	66.0
III (180-269°)	14	13.0	122.6
IV (90-179°)	81	75.0	76.9
TOTALS & MEANS	108	100.0	84.6