PRECIPITATION CLIMATOLOGY FOR THE HIPLEX SOUTHERN REGION

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PRECIPITATION CLIMATOGRAPHY FOR THE HIPLEX SOUTHERN REGION

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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.

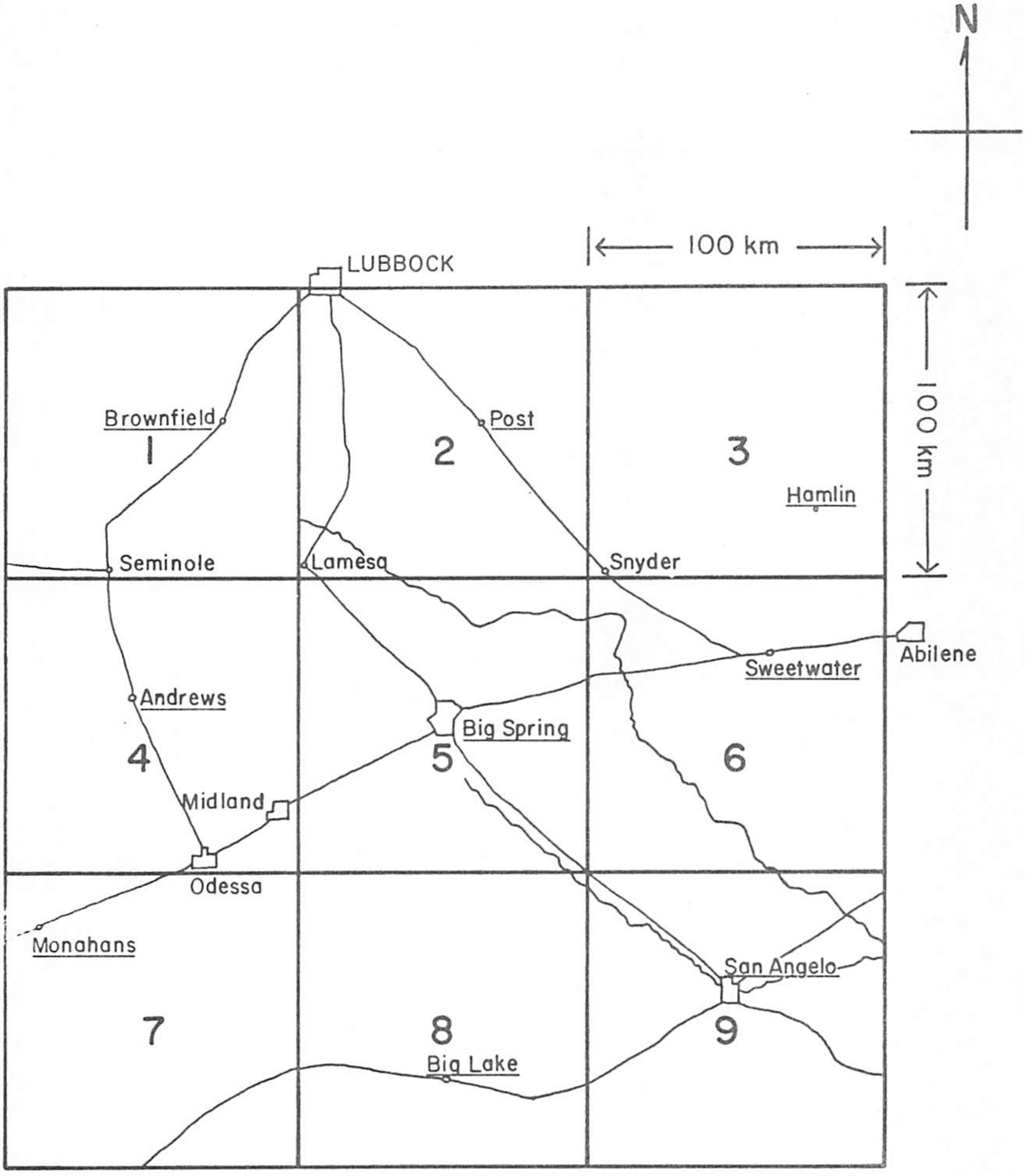

Figure 1. The area of study. Each region is denoted by number as well as by a city name.

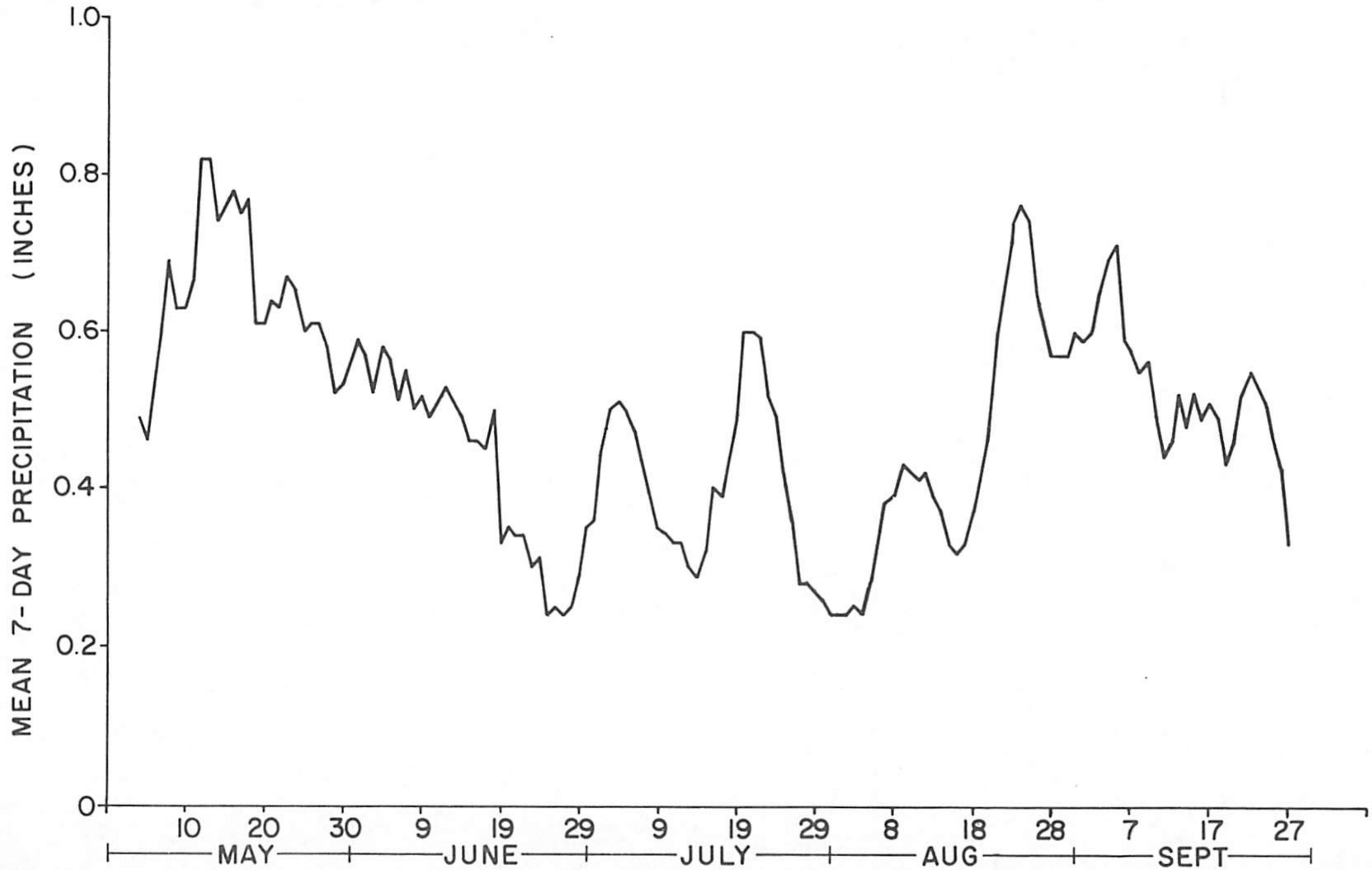

FIG. 2. DAILY PRECIPITATION 7-DAY RUNNING MEANS
BIG SPRING

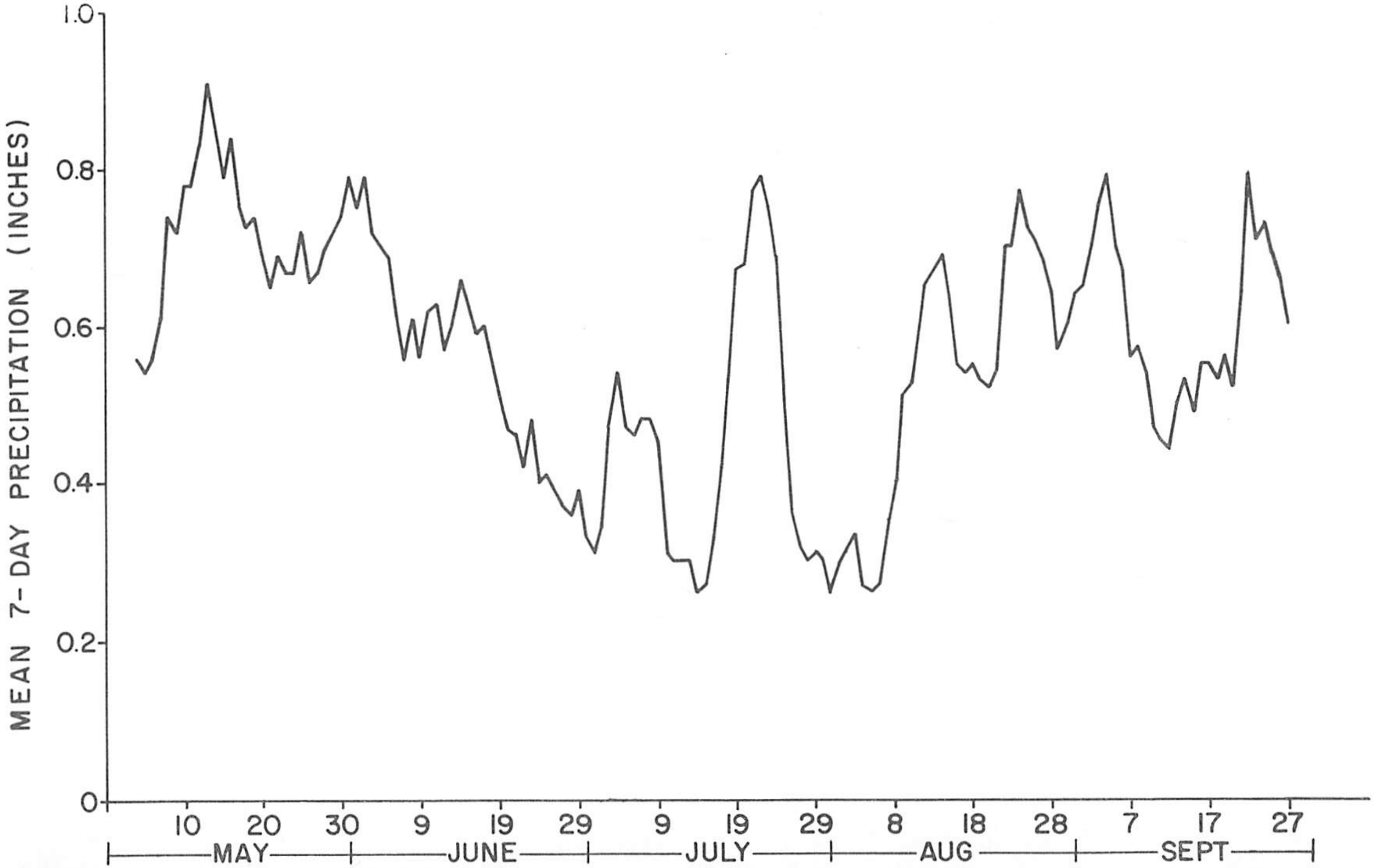

FIG. 3. DAILY PRECIPITATION 7-DAY RUNNING MEANS
SNYDER

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

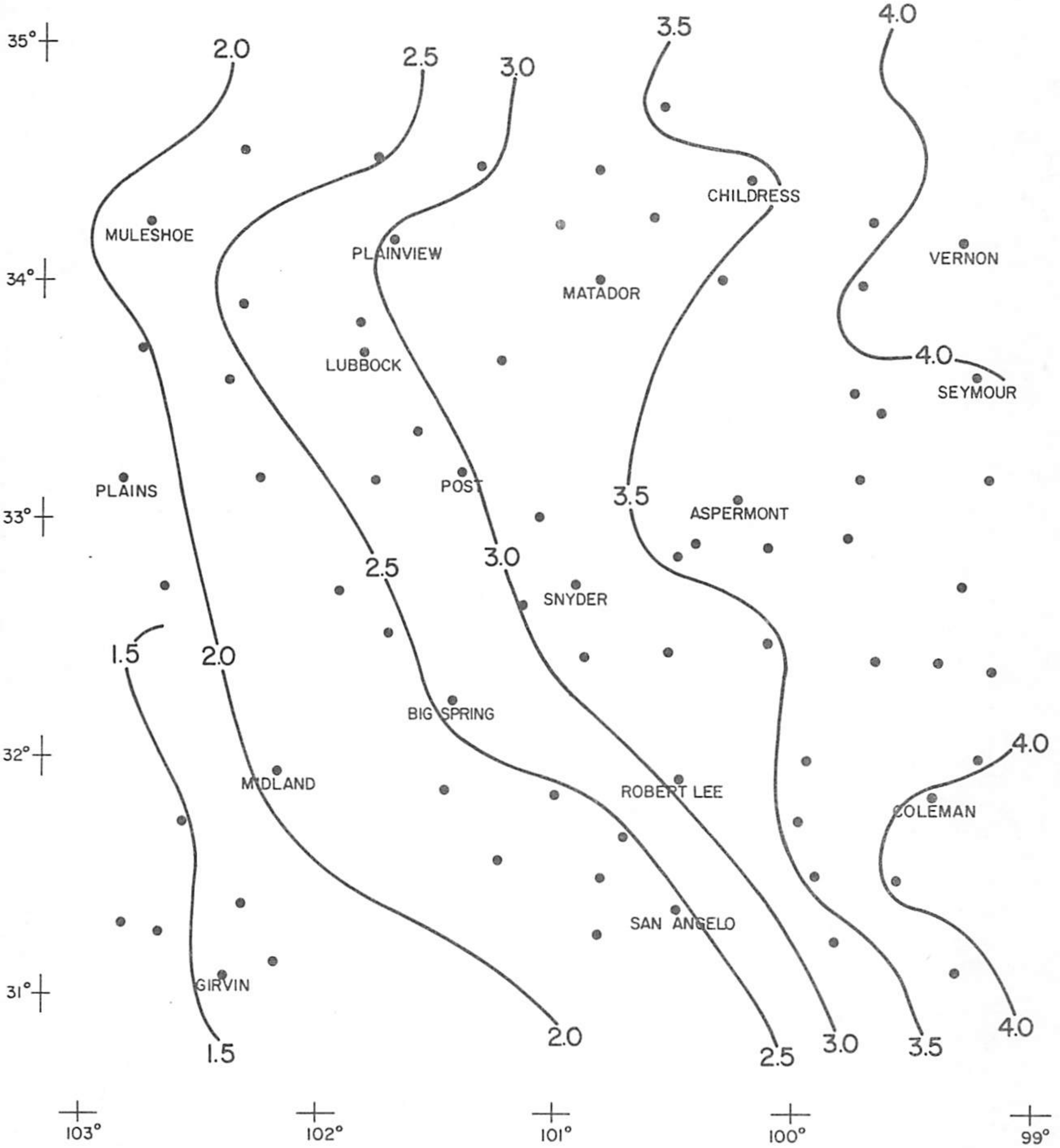

FIG. 4. MEAN MONTHLY PRECIPITATION - MAY

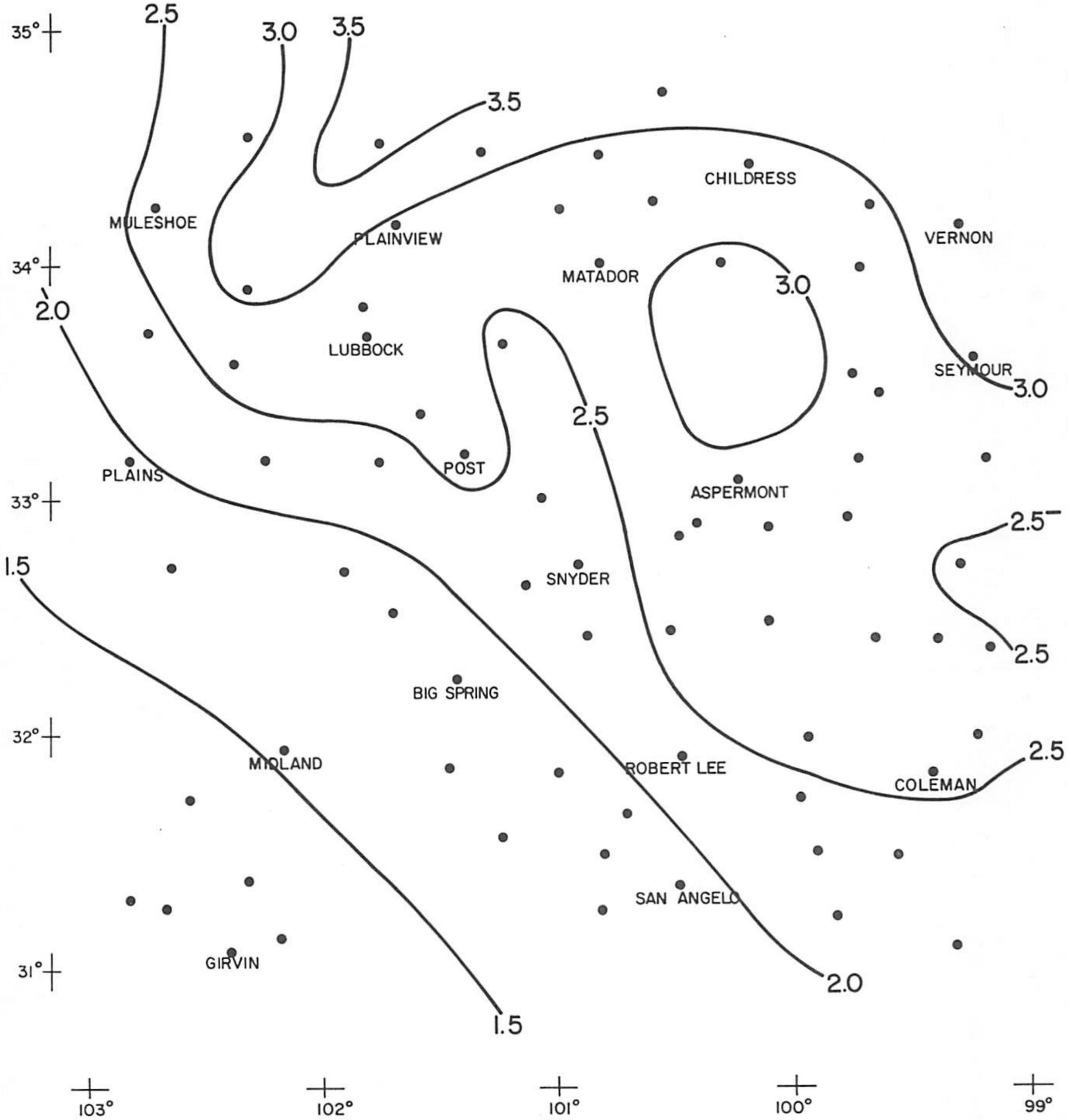

FIG. 5. MEAN MONTHLY PRECIPITATION - JUNE

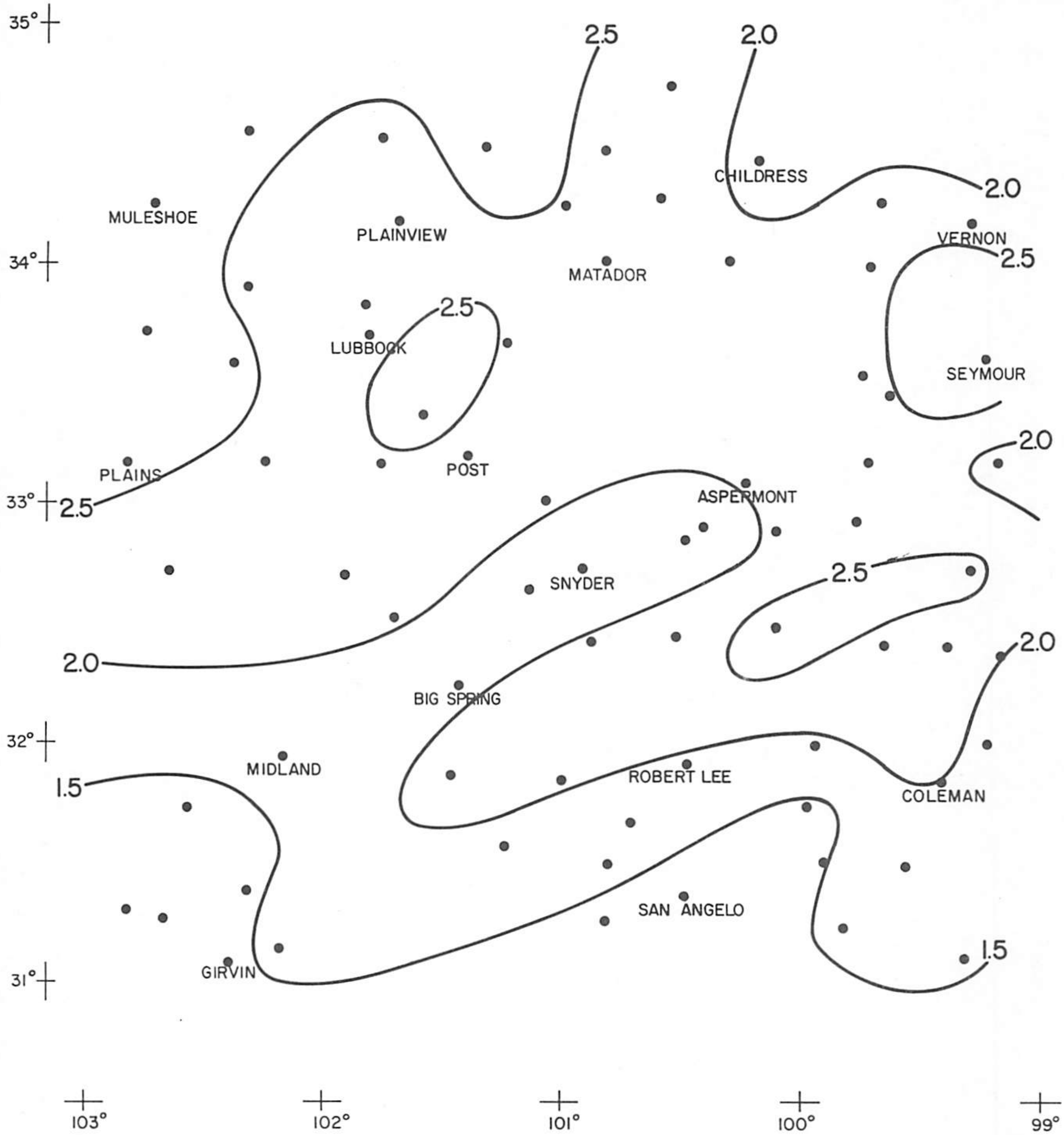

FIG. 6. MEAN MONTHLY PRECIPITATION - JULY

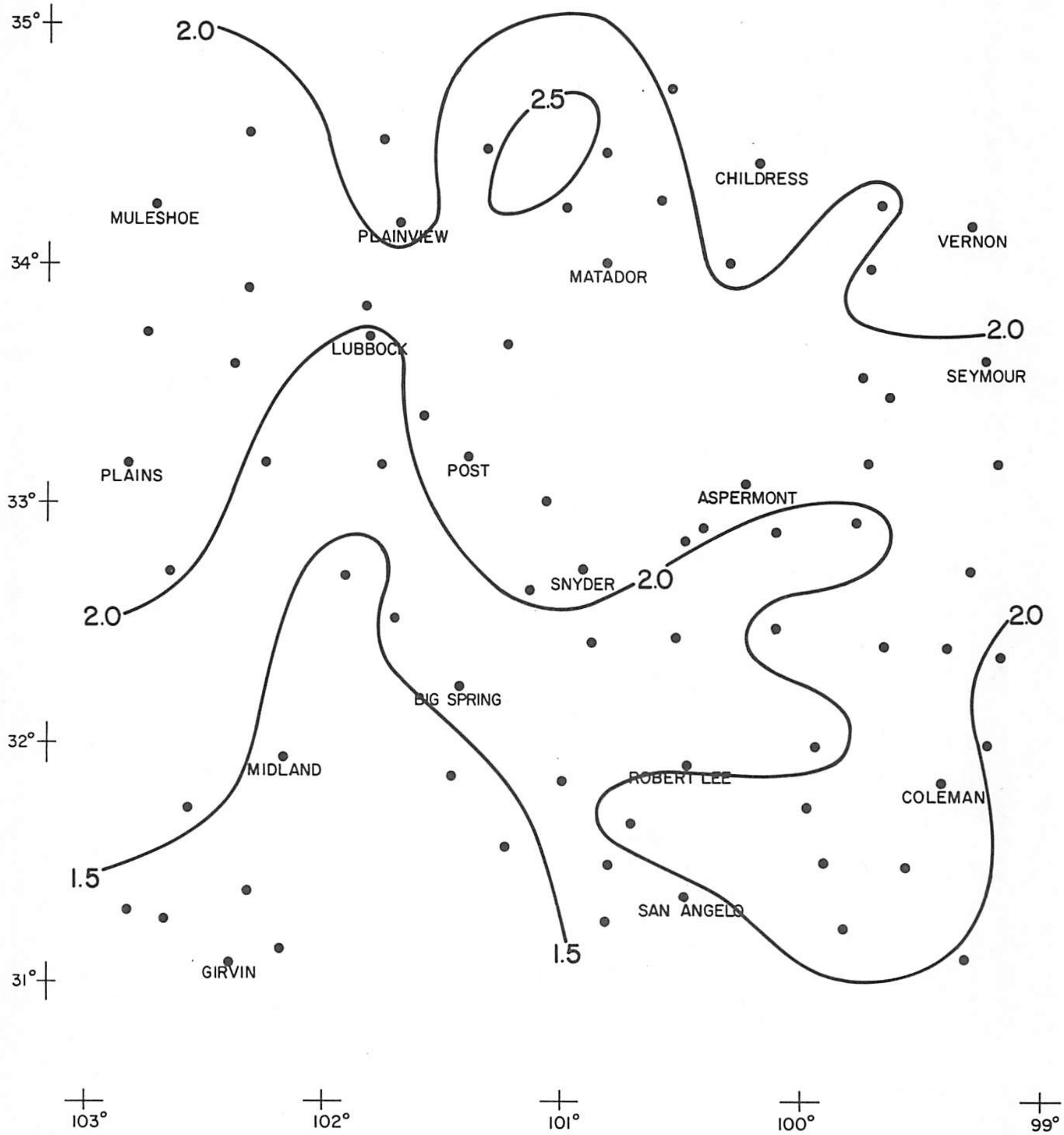

FIG. 7. MEAN MONTHLY PRECIPITATION - AUGUST

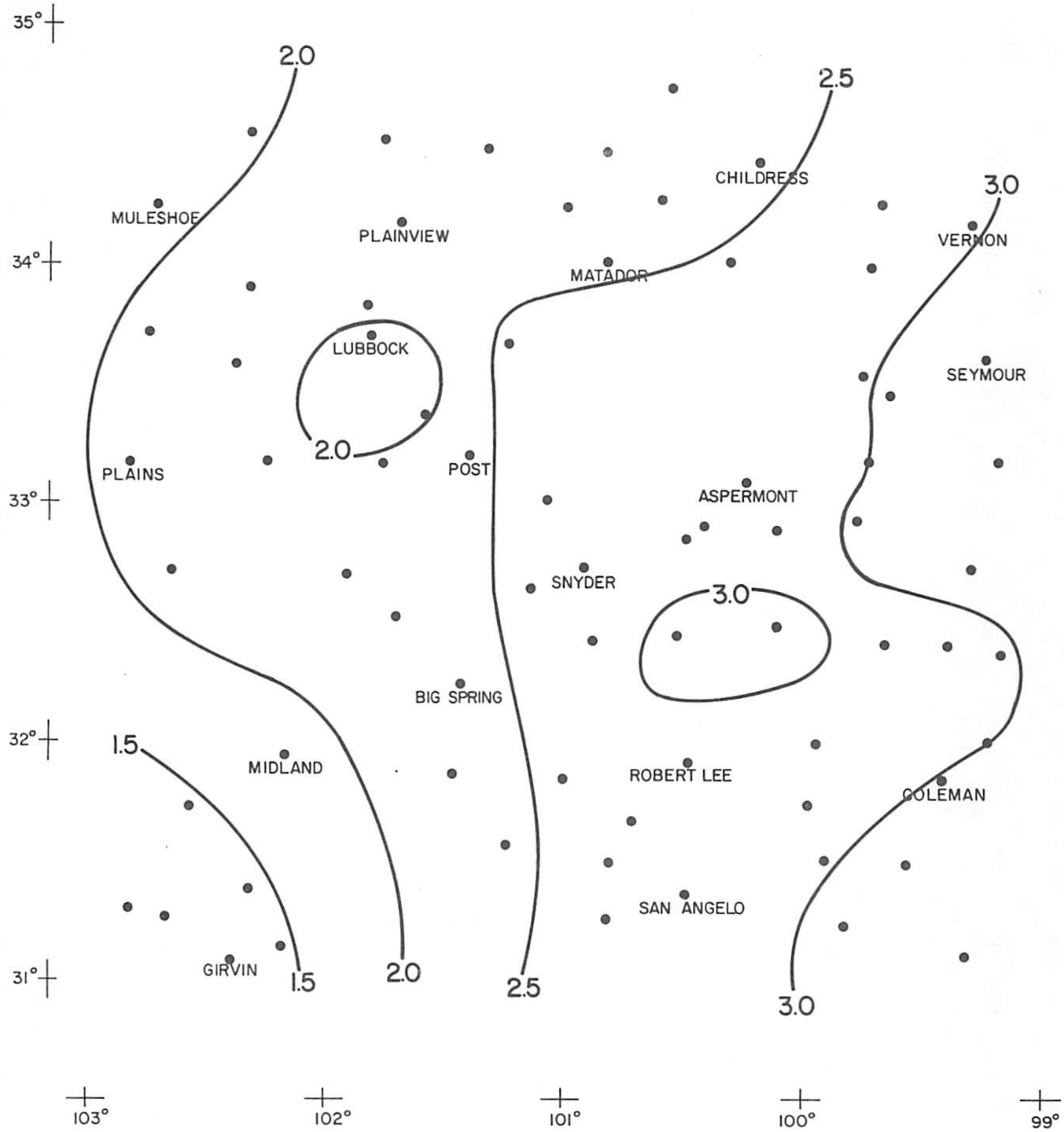

FIG. 8. MEAN MONTHLY PRECIPITATION - SEPTEMBER

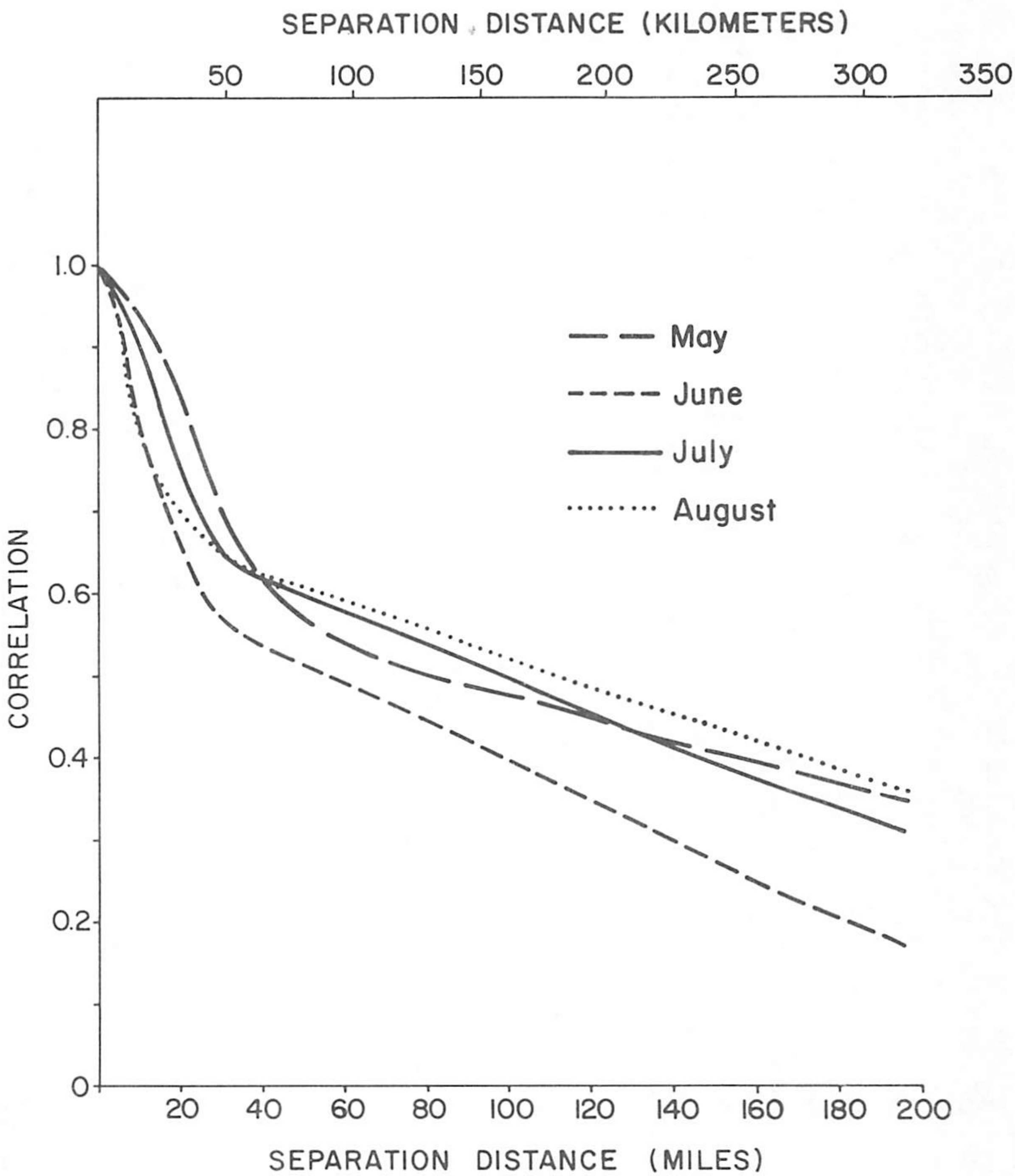

FIG. 9. MEAN MONTHLY PRECIPITATION CORRELATION (MAY - AUGUST)

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.

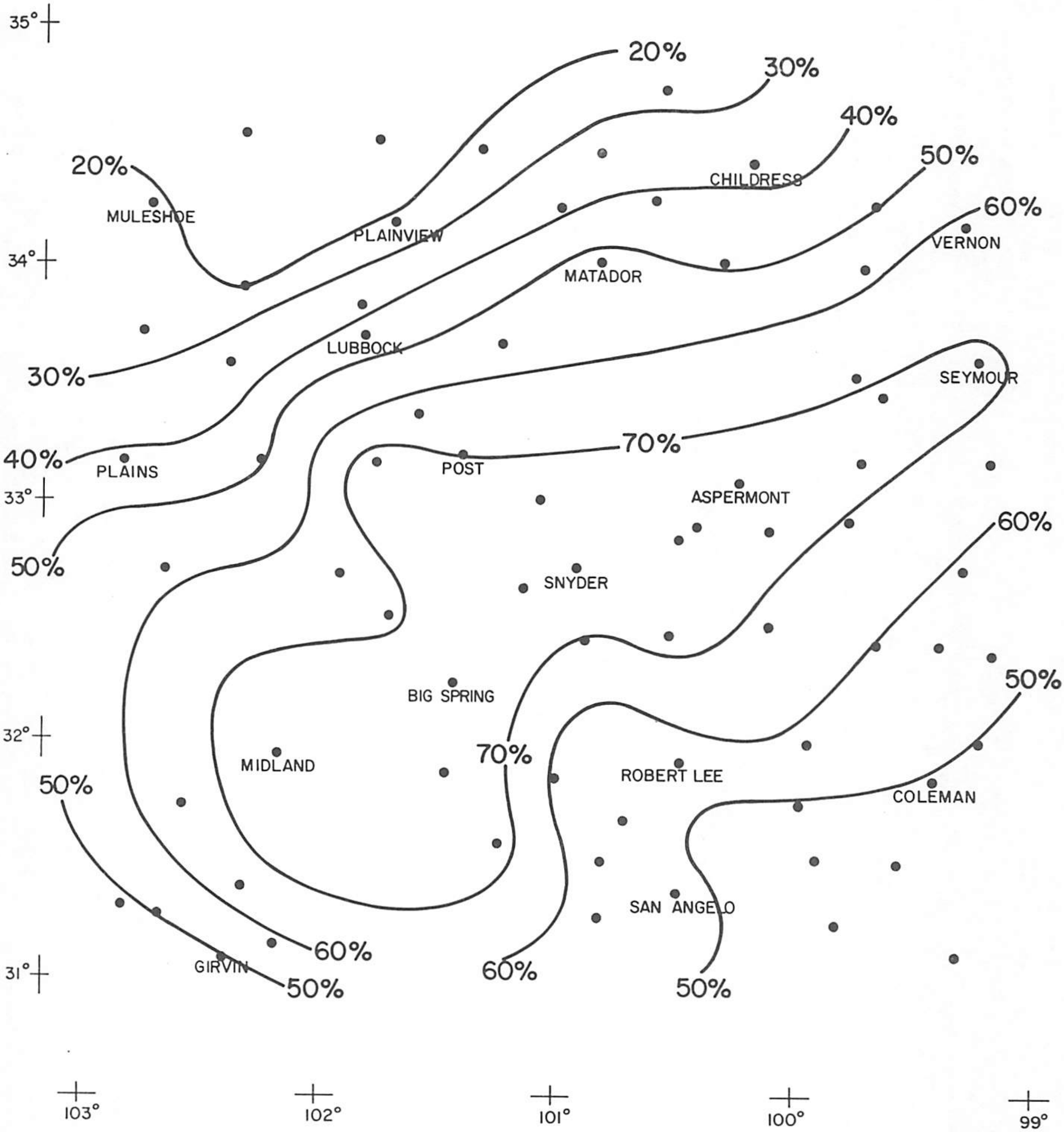

FIG. 10. PRECIPITATION CORRELATION WITH BIG SPRING - MAY

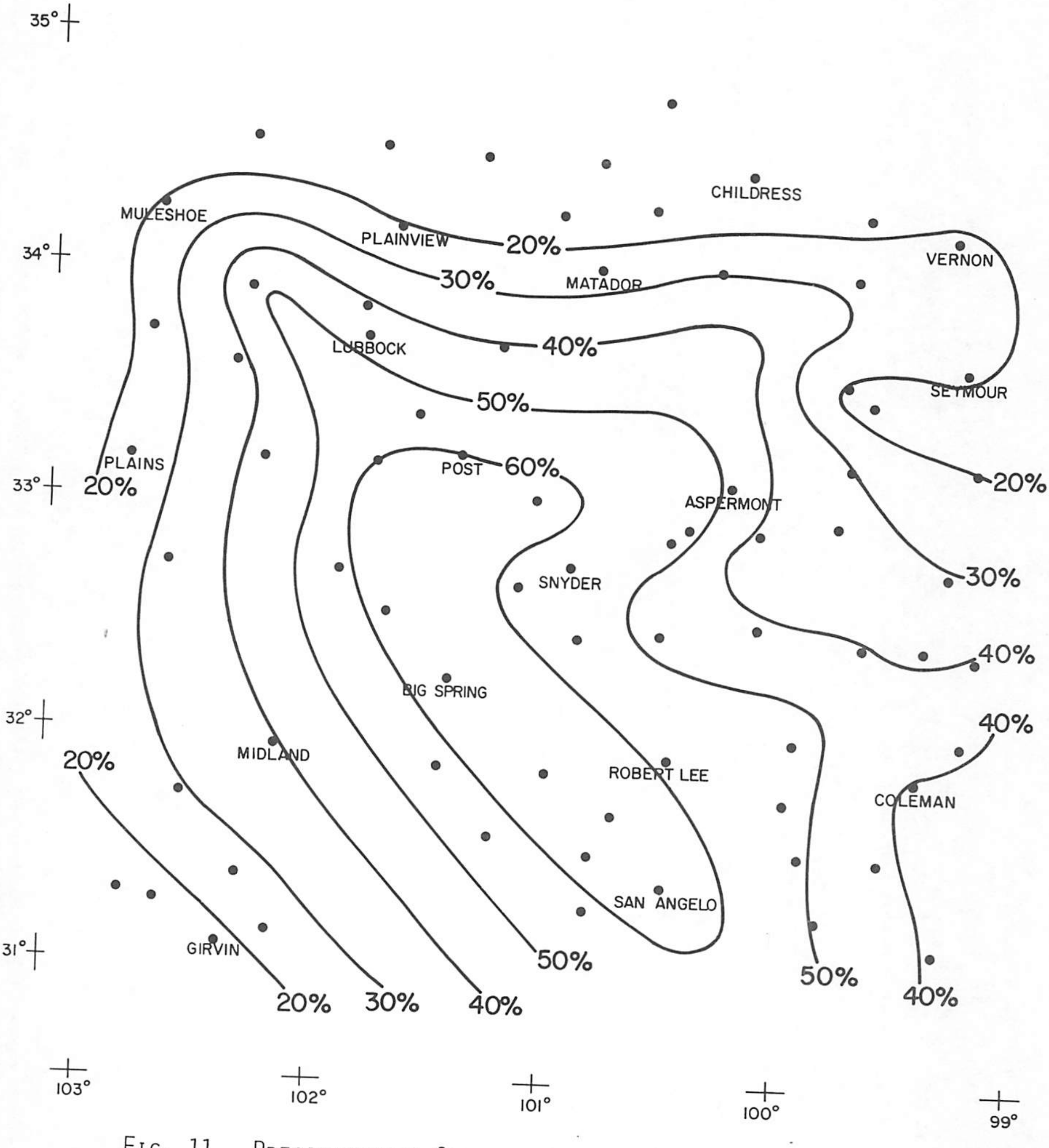

FIG. 11. PRECIPITATION CORRELATION WITH BIG SPRING - JUNE

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:

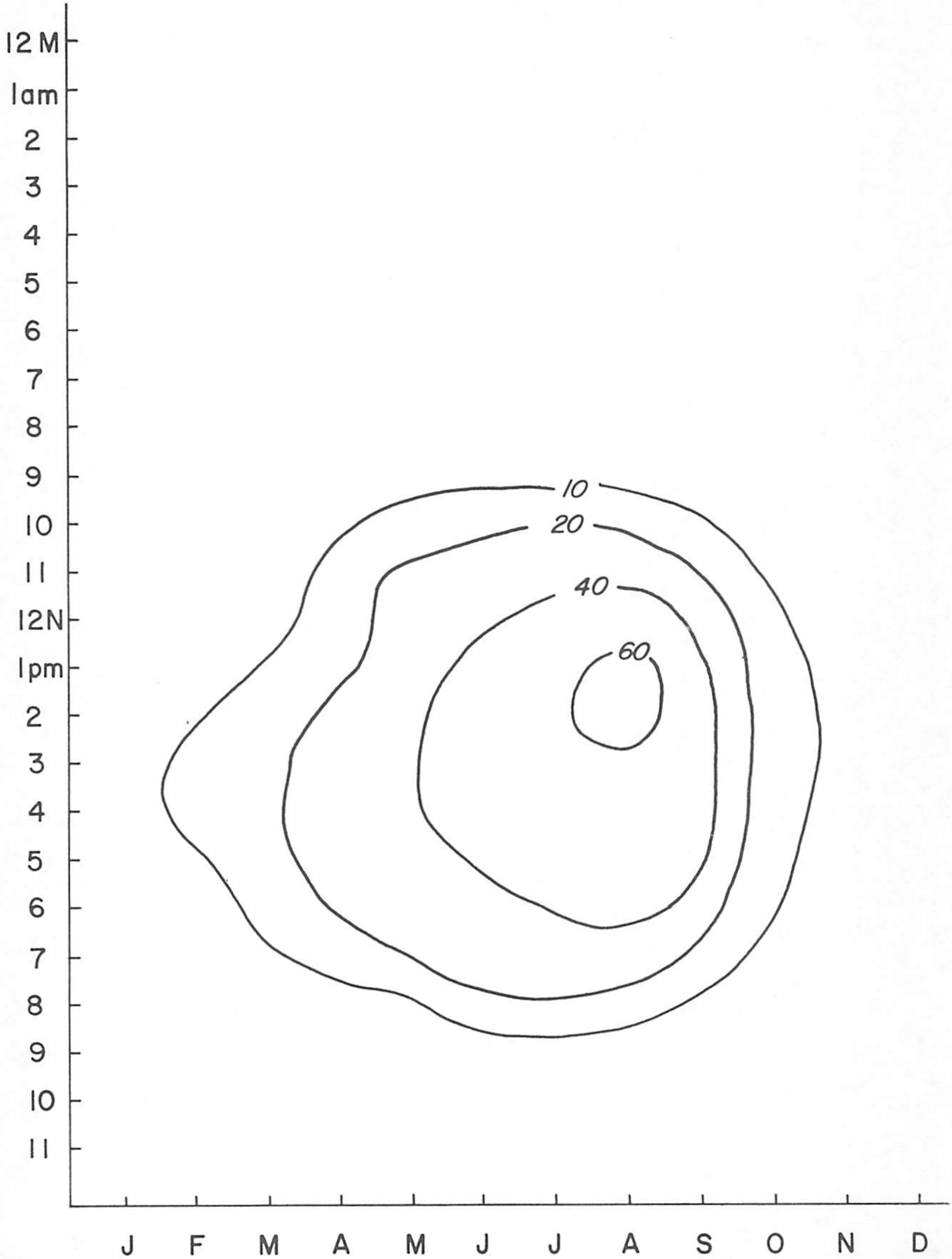

FIG. 12. Percentage Occurrence of Cumulus
Midland, Texas

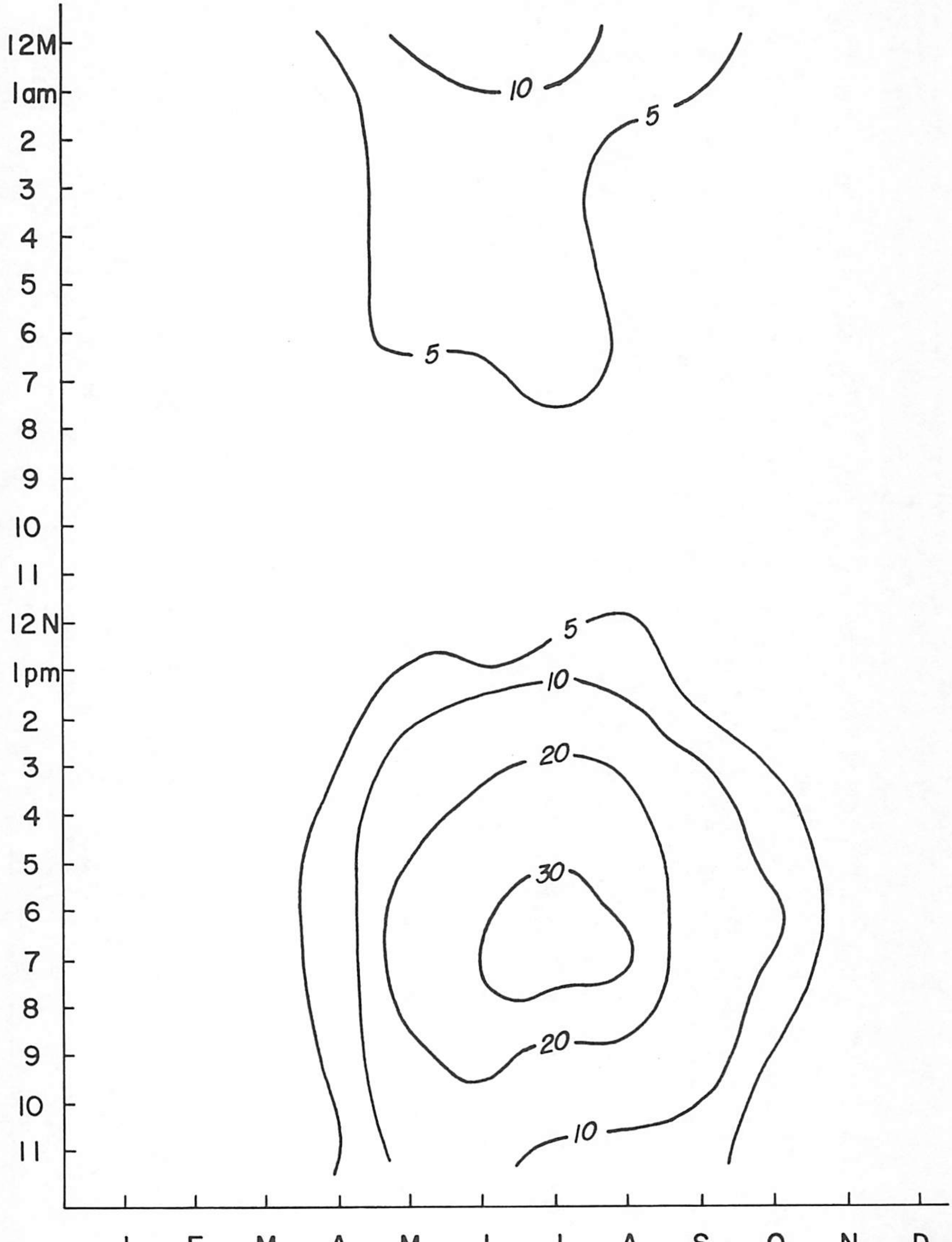

FIG. 13. Percentage Occurrence of Cumulonimbus
Midland, Texas

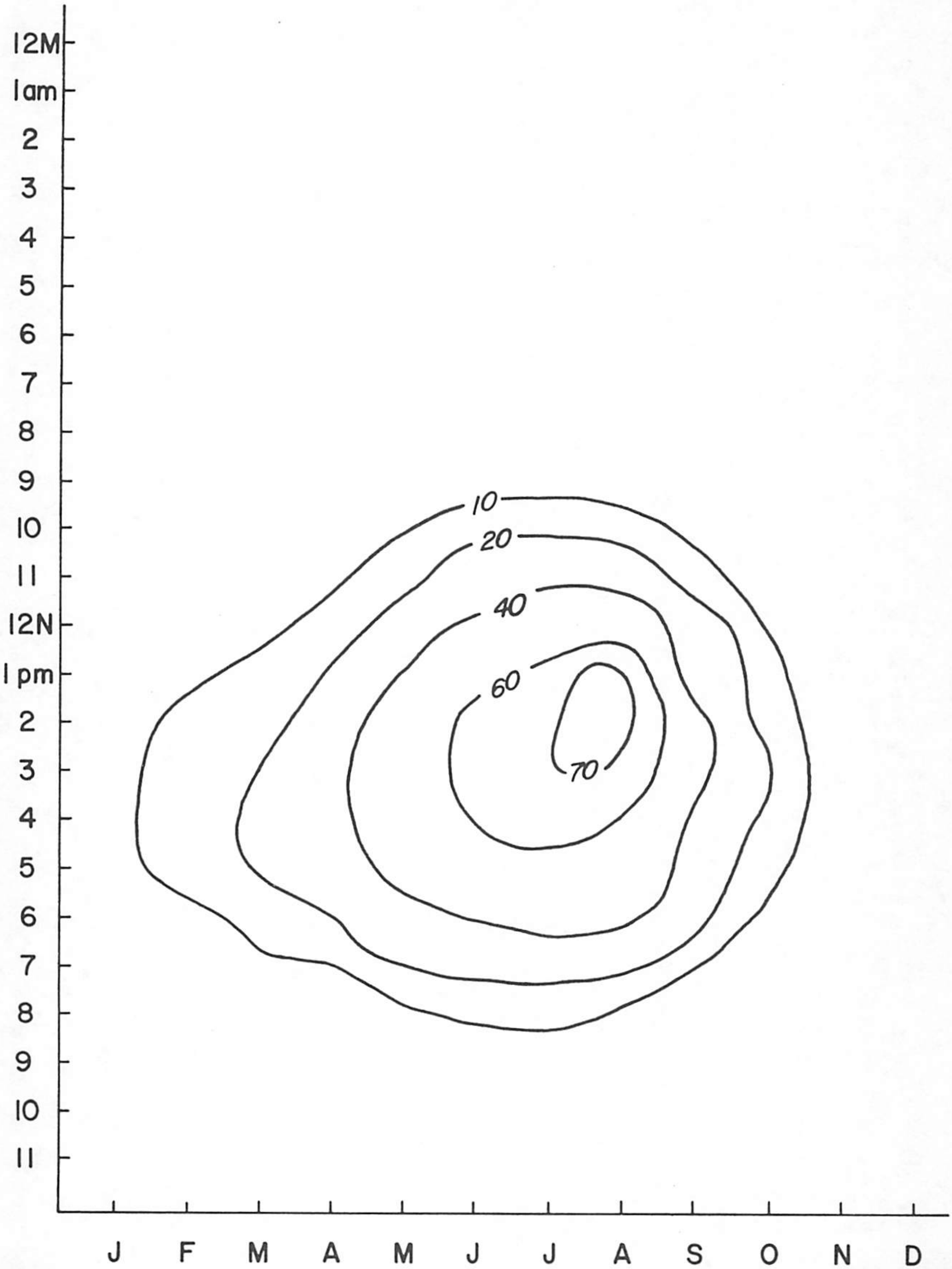

FIG. 14. Percentage Occurrence of Cumulus
Lubbock, Texas

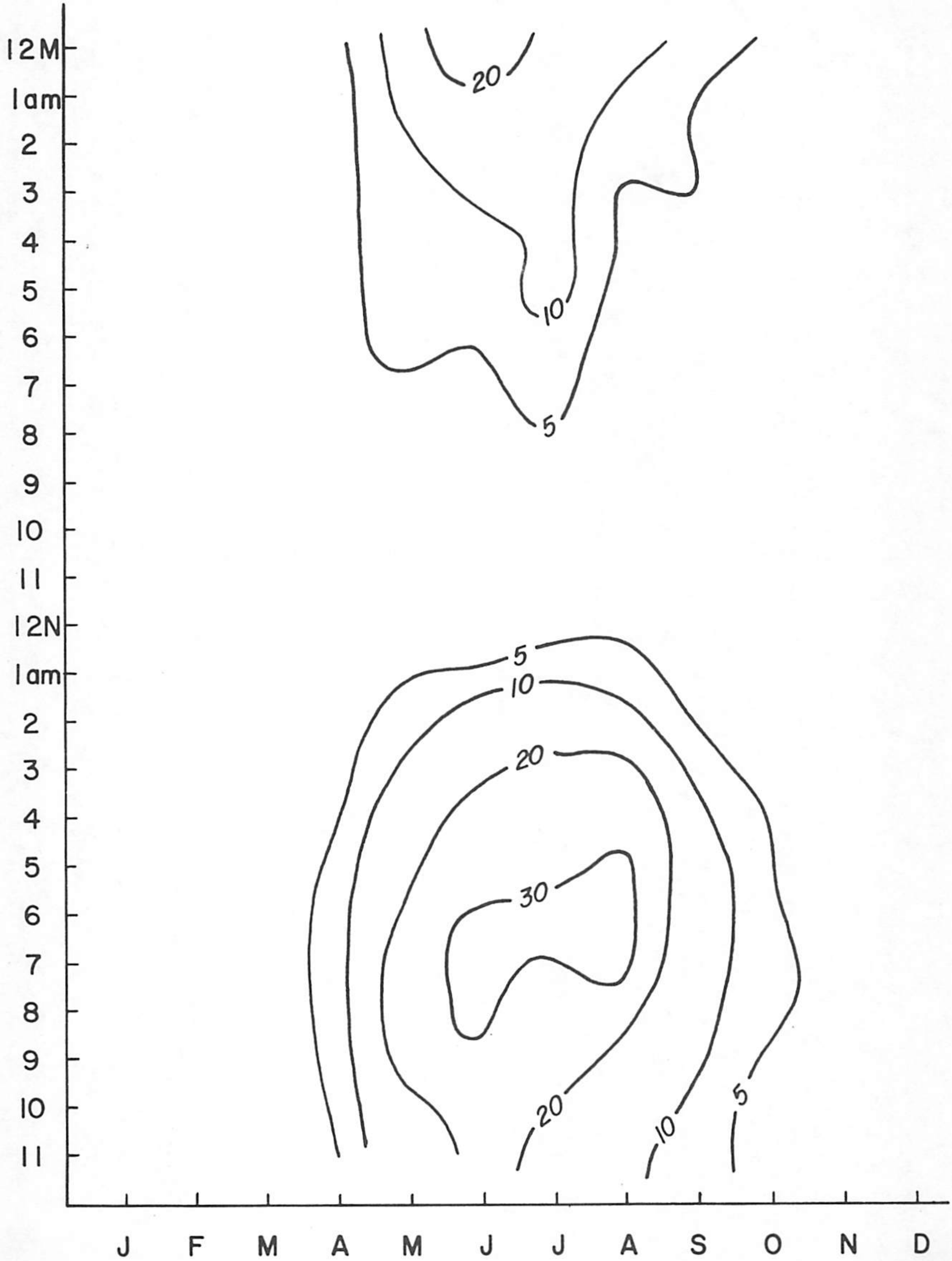

FIG. 15. Percentage Occurrence of Cumulonimbus
Lubbock, Texas

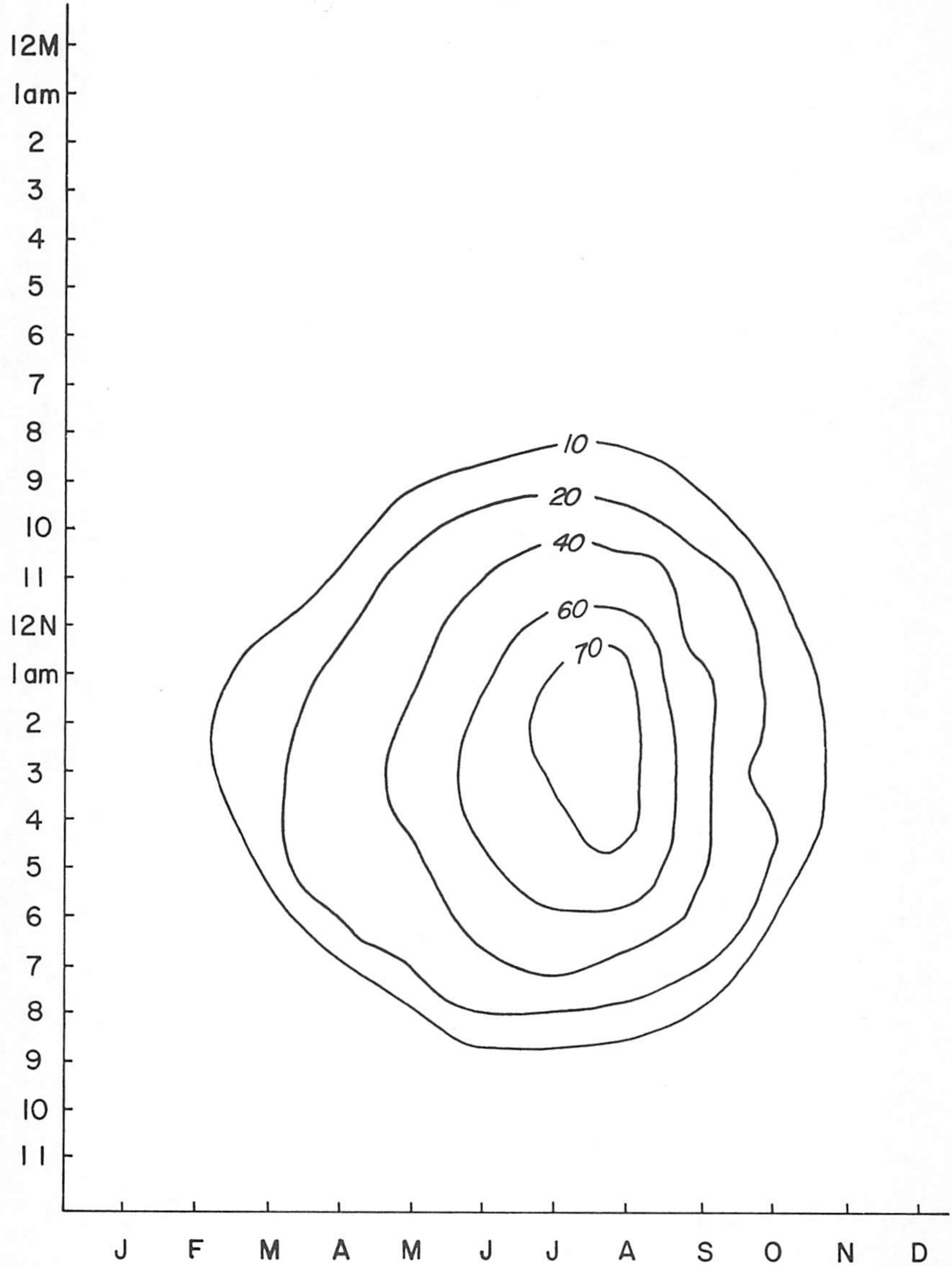

FIG. 16. **Percentage Occurrence of Cumulus Abilene, Texas**

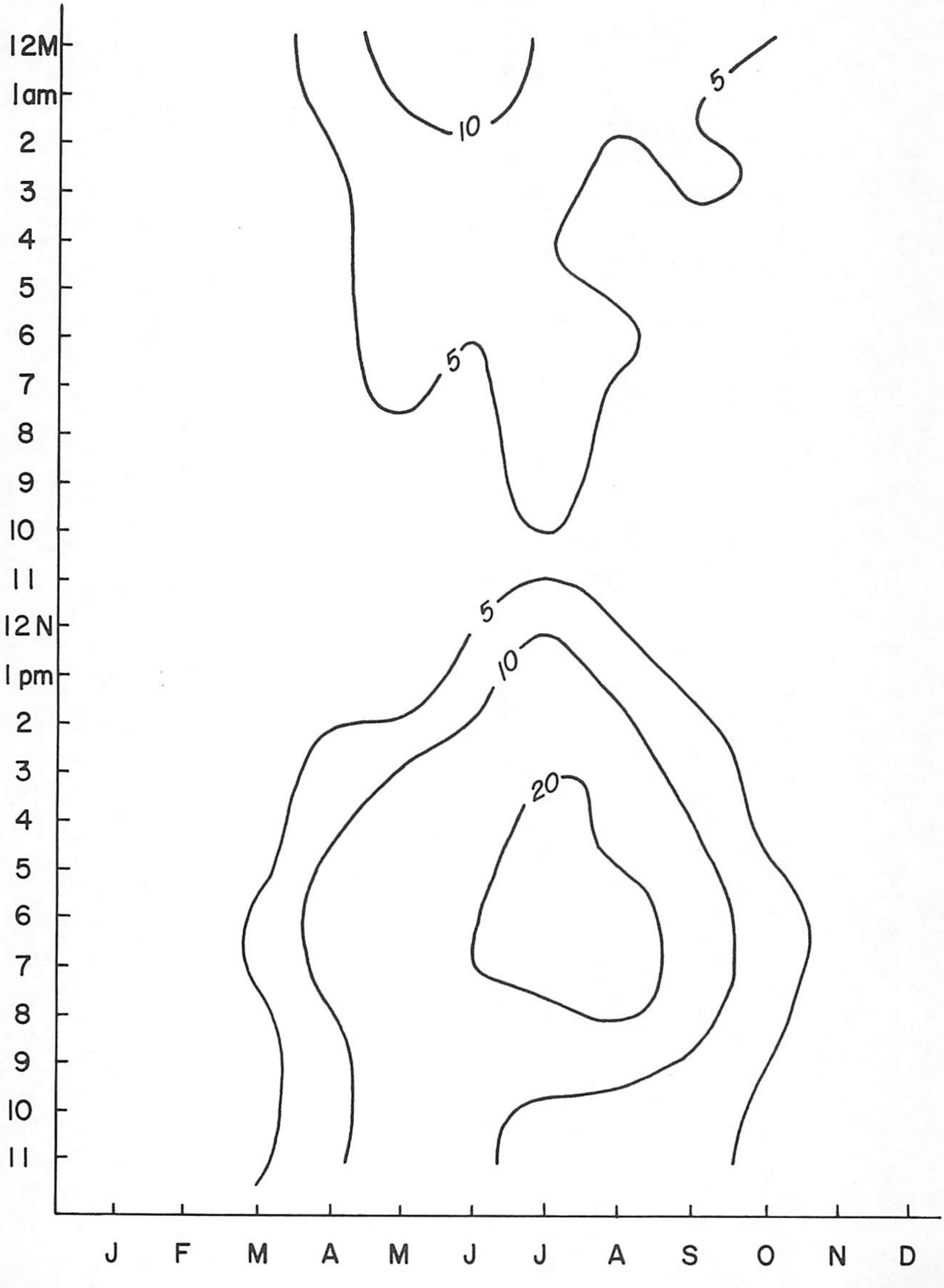

FIG. 17 Percentage Occurrence of Cumulonimbus
Abilene, Texas

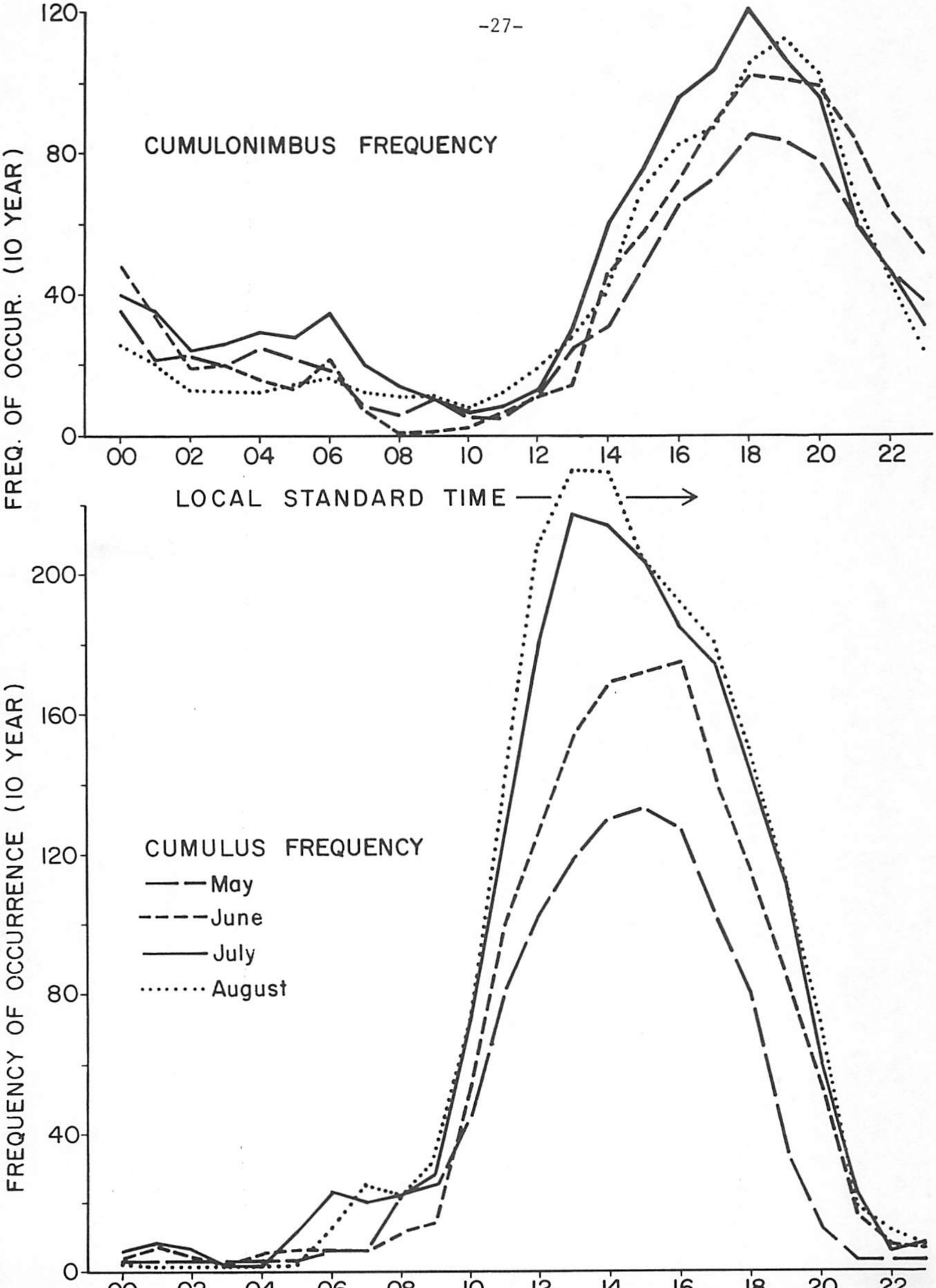

FIG. 18. FREQUENCY OF OCCURRENCE OF CUMULUS AND CUMULONIMBUS - MIDLAND

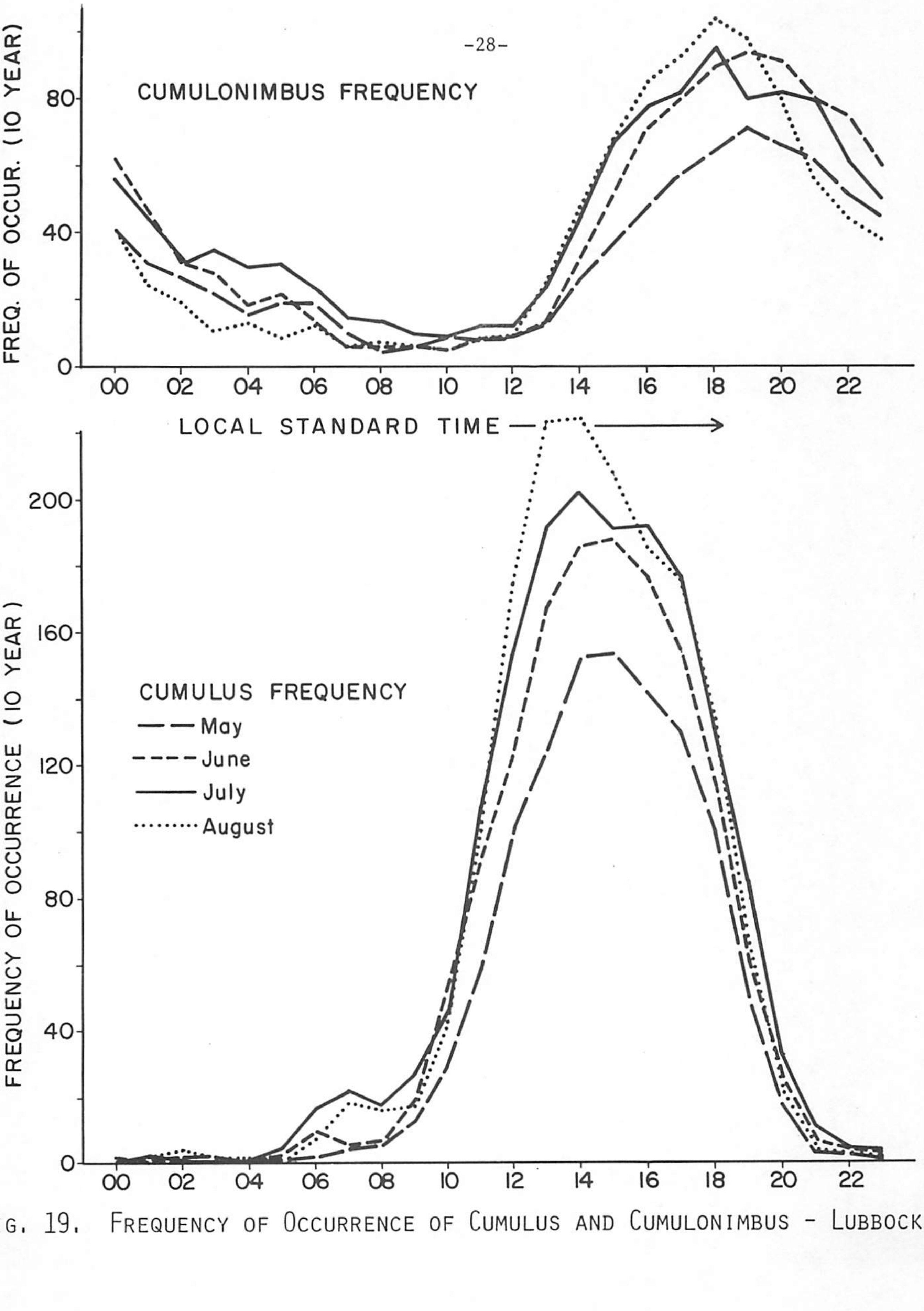

Fig. 19. Frequency of Occurrence of Cumulus and Cumulonimbus - Lubbock

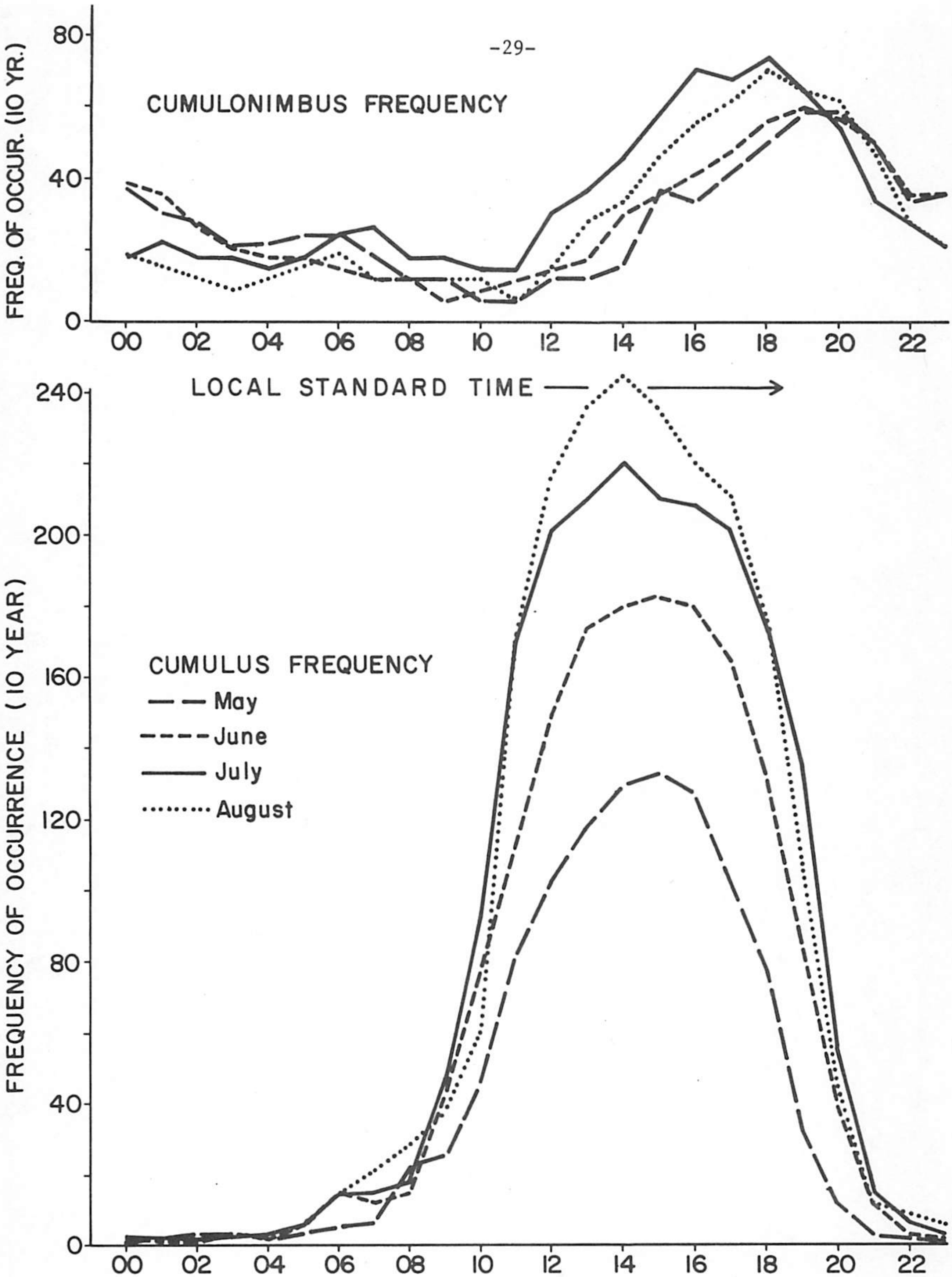

FIG. 20. FREQUENCY OF OCCURRENCE OF CUMULUS AND CUMULONIMBUS - ABILENE

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).

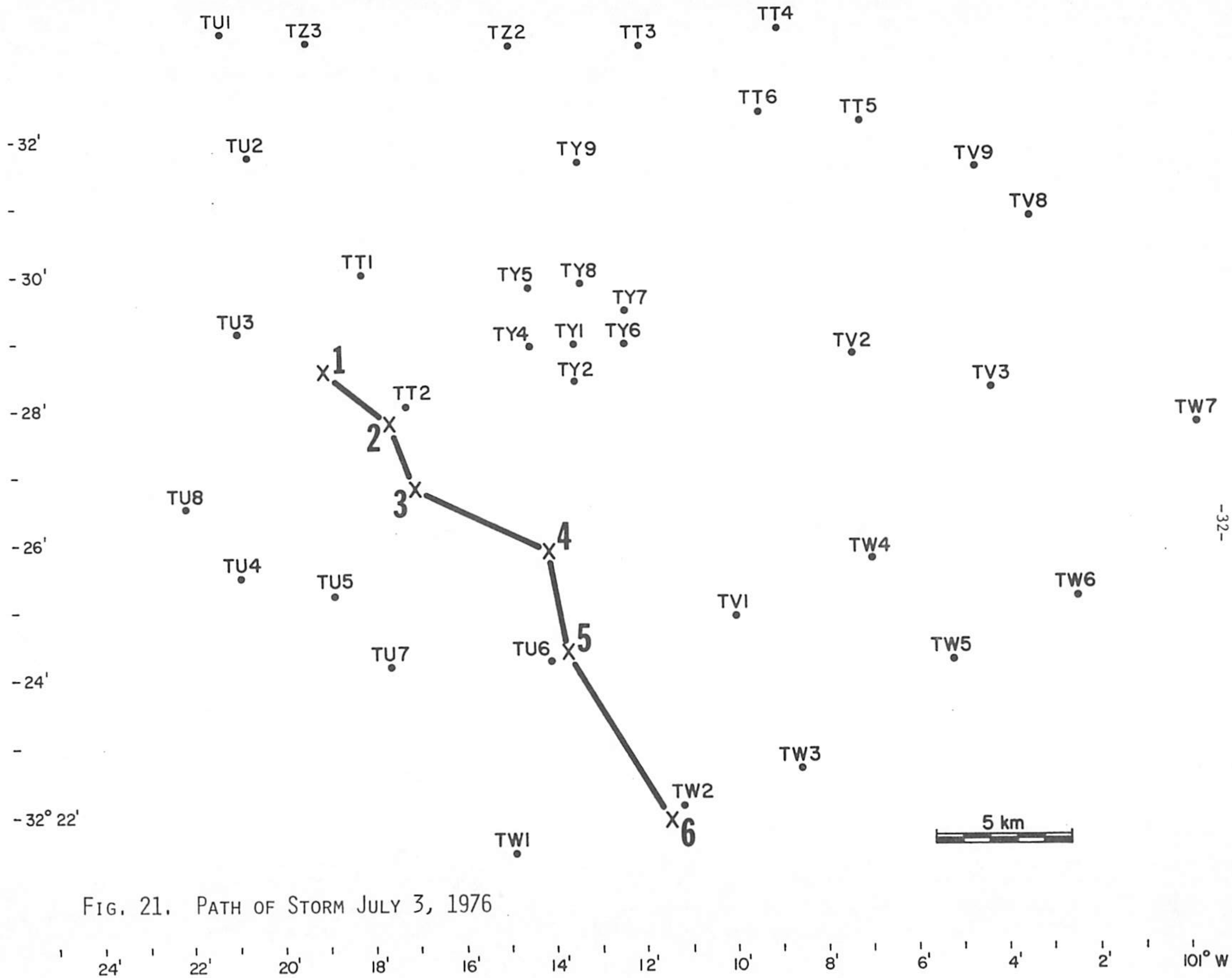

Fig. 21. Path of Storm July 3, 1976

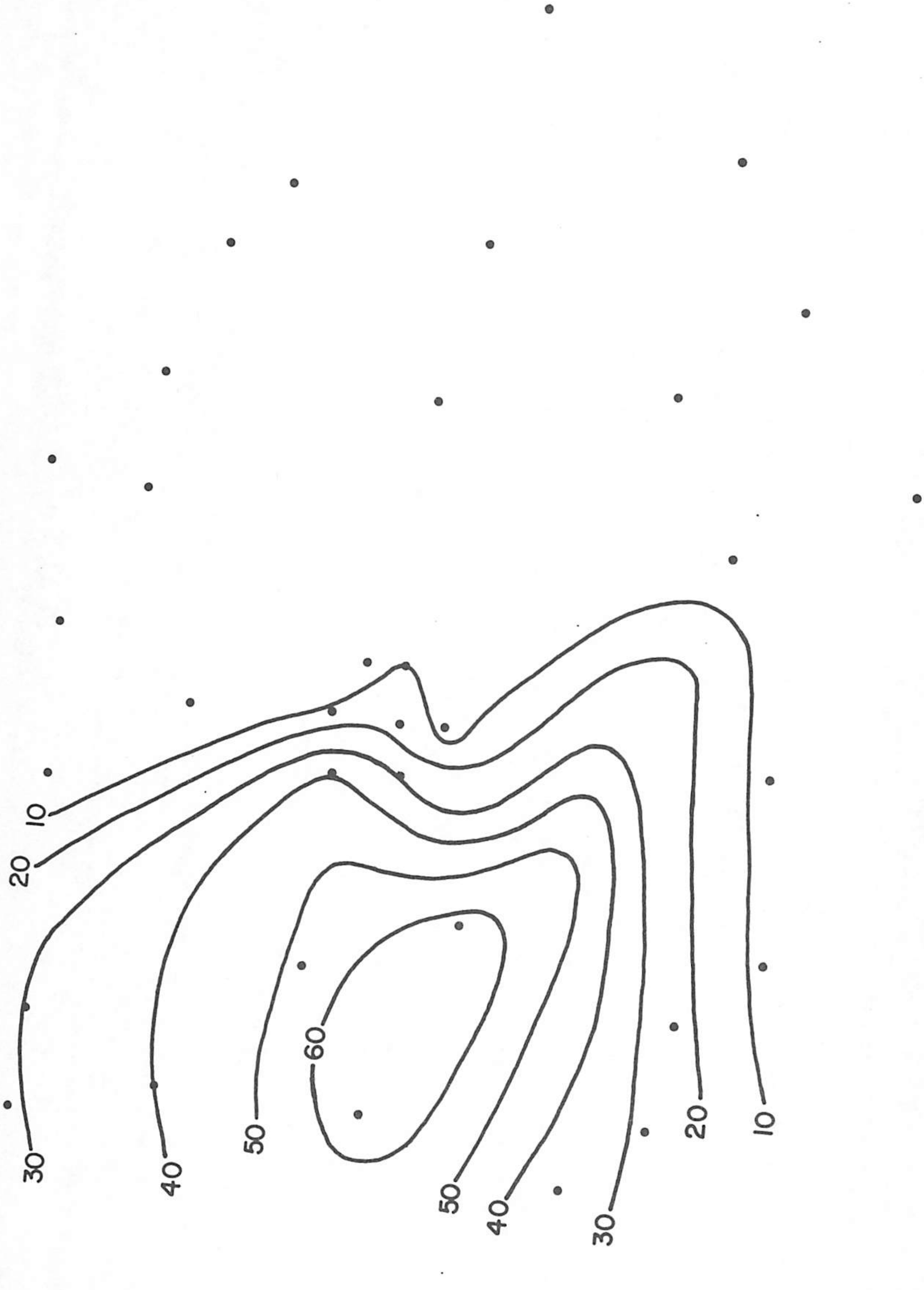

Fig. 22. Storm Precipitation 10:45 AM CDT

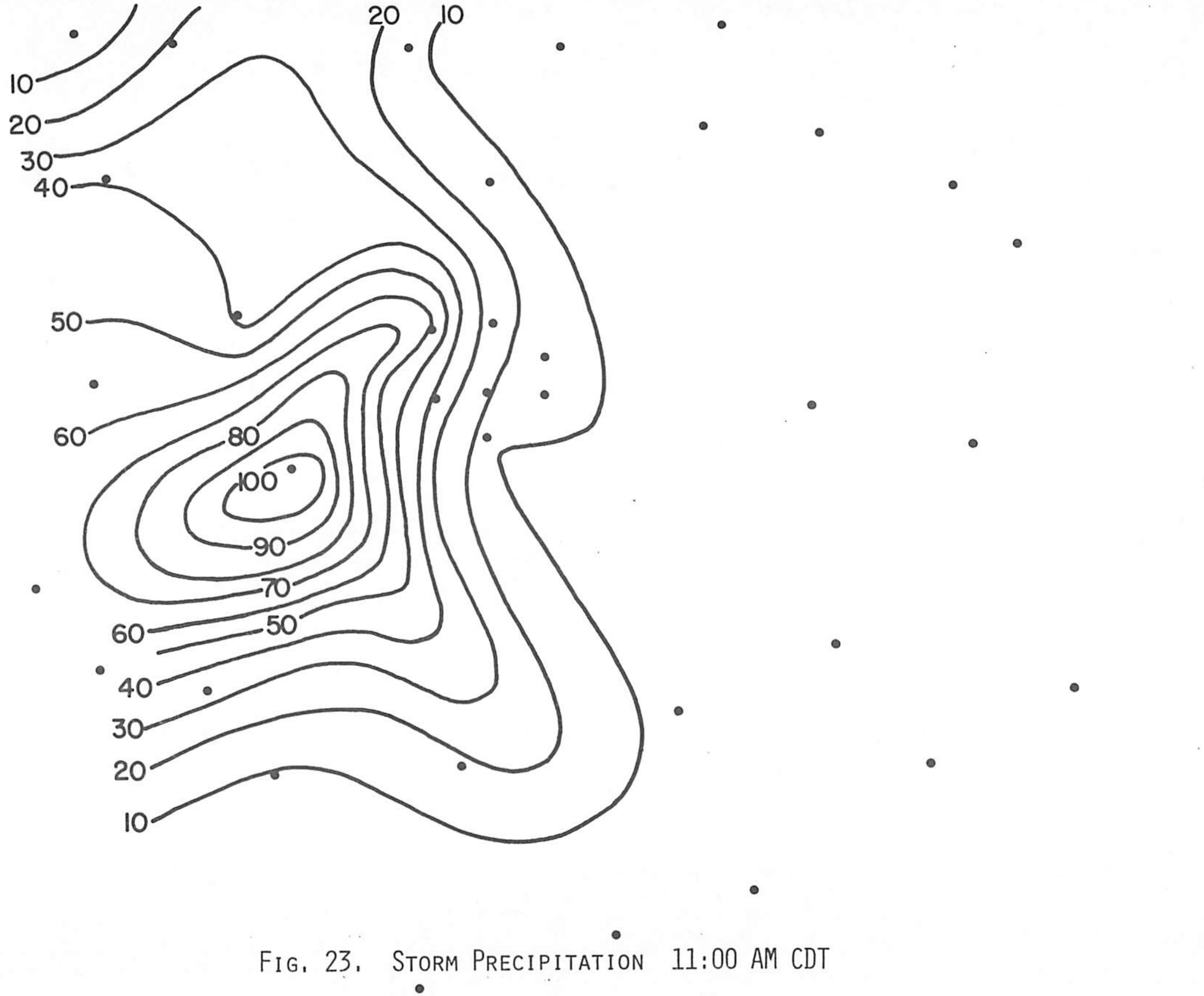

Fig. 23. Storm Precipitation 11:00 AM CDT

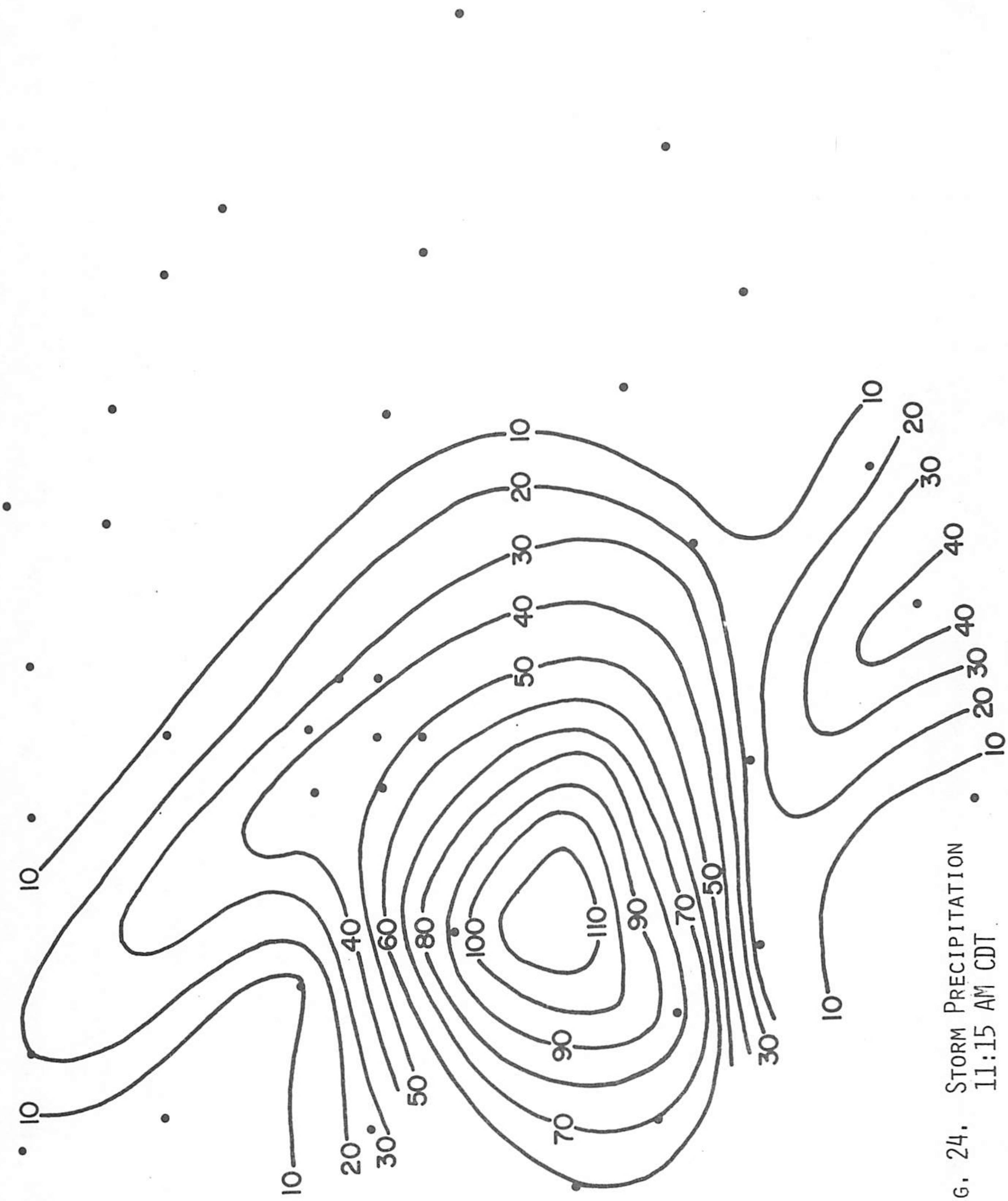

Fig. 24. Storm Precipitation
11:15 AM CDT

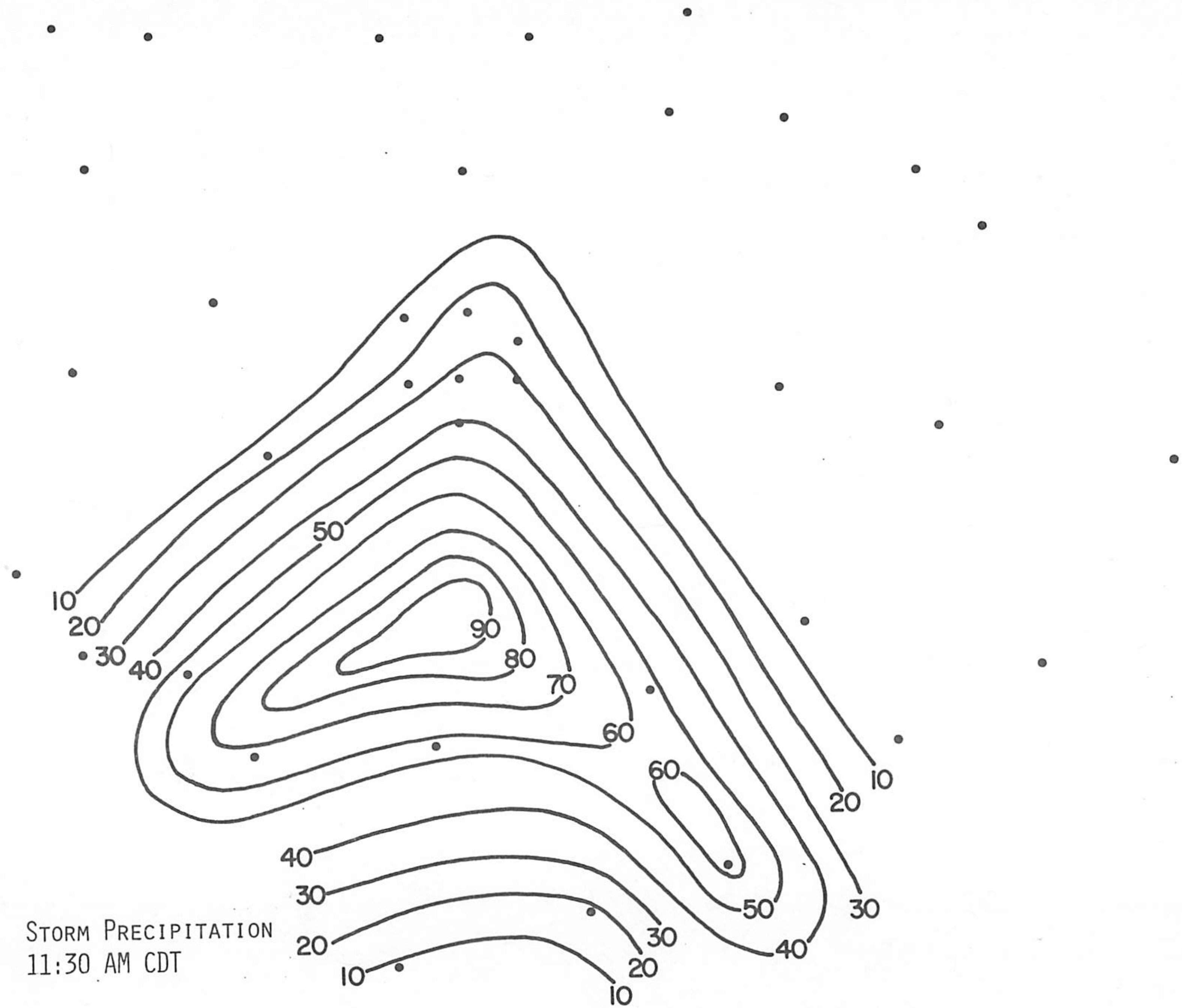

FIG. 25. STORM PRECIPITATION
11:30 AM CDT

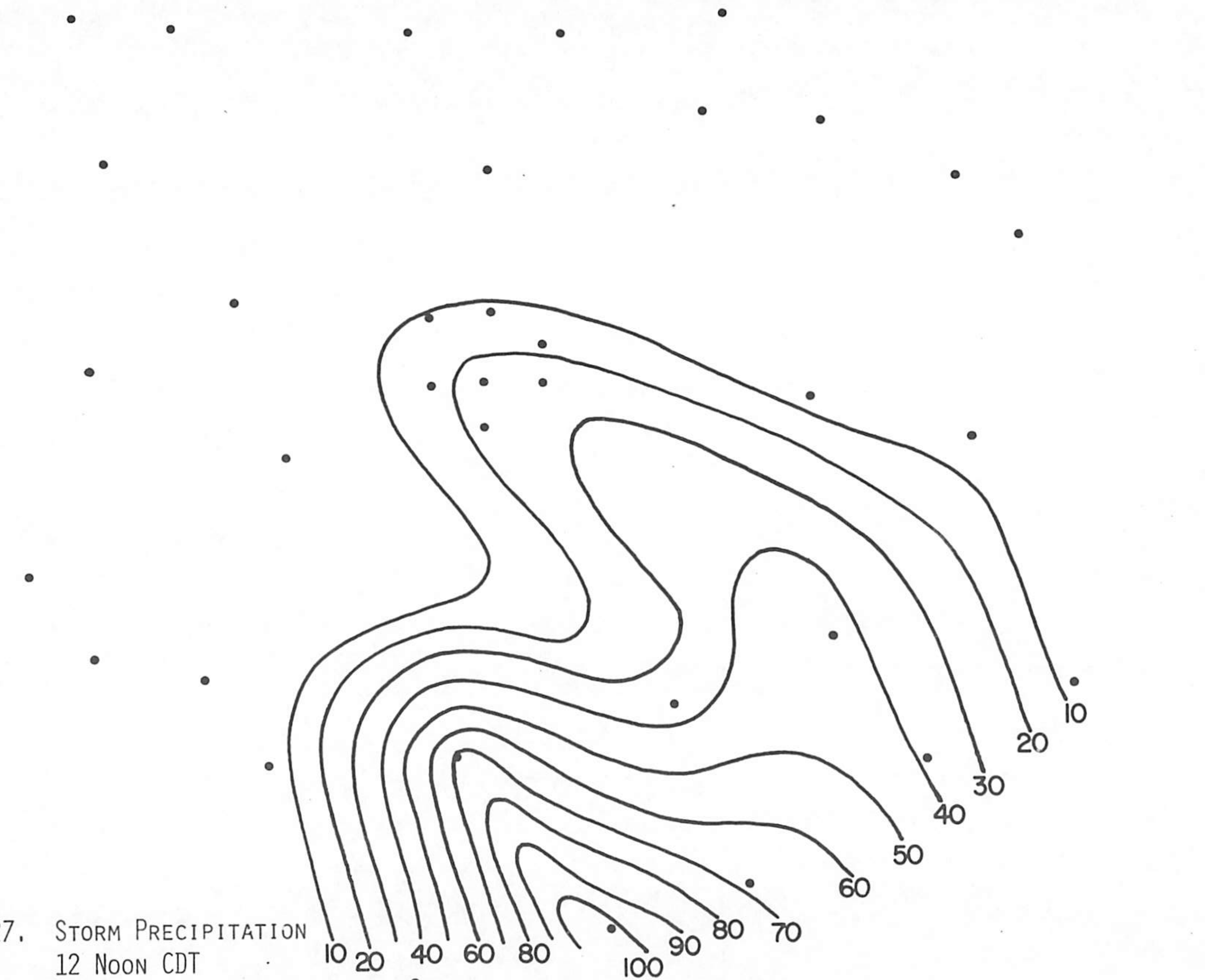

Fig. 27. Storm Precipitation
12 Noon CDT

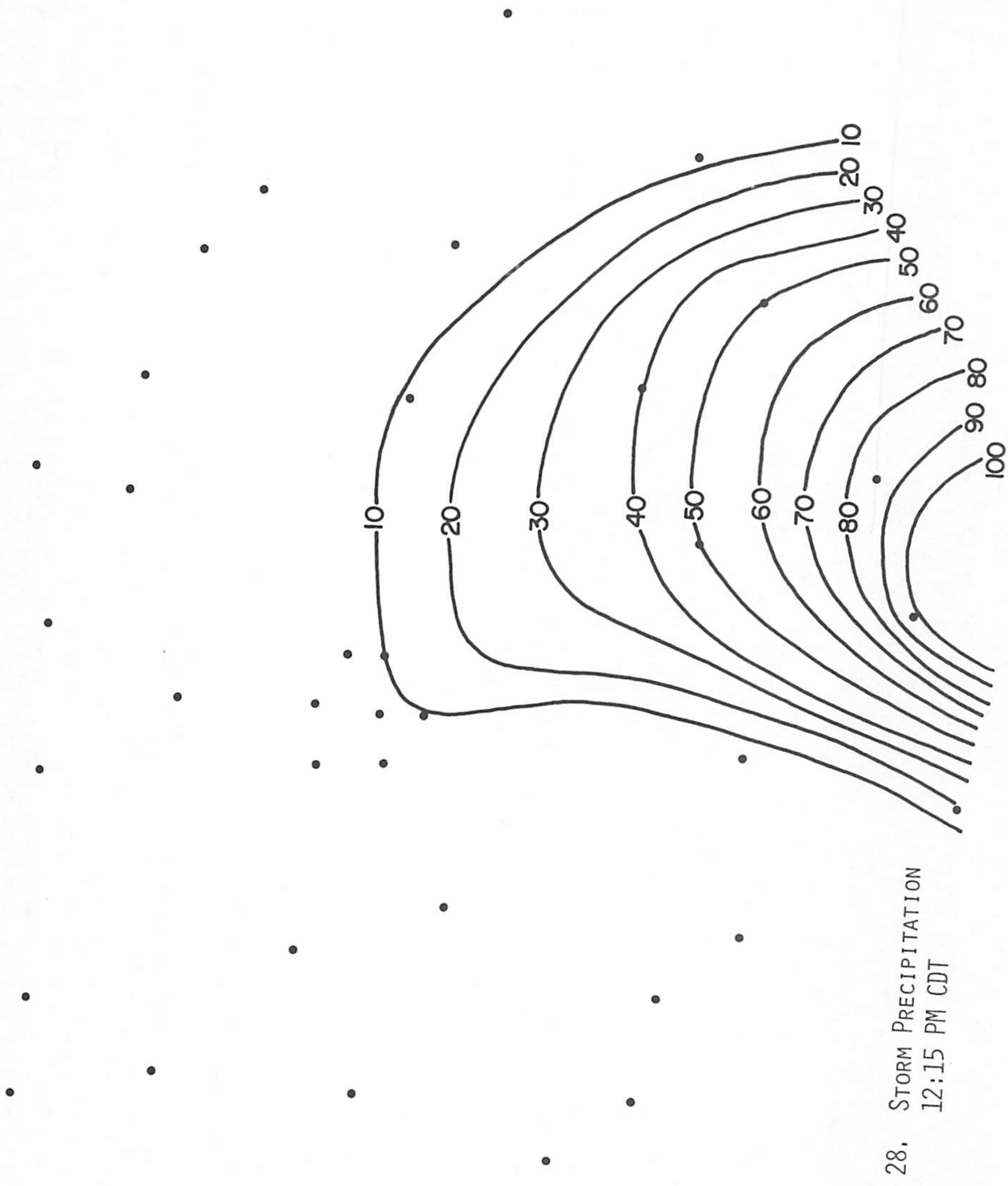

Fig. 28. Storm Precipitation
12:15 PM CDT

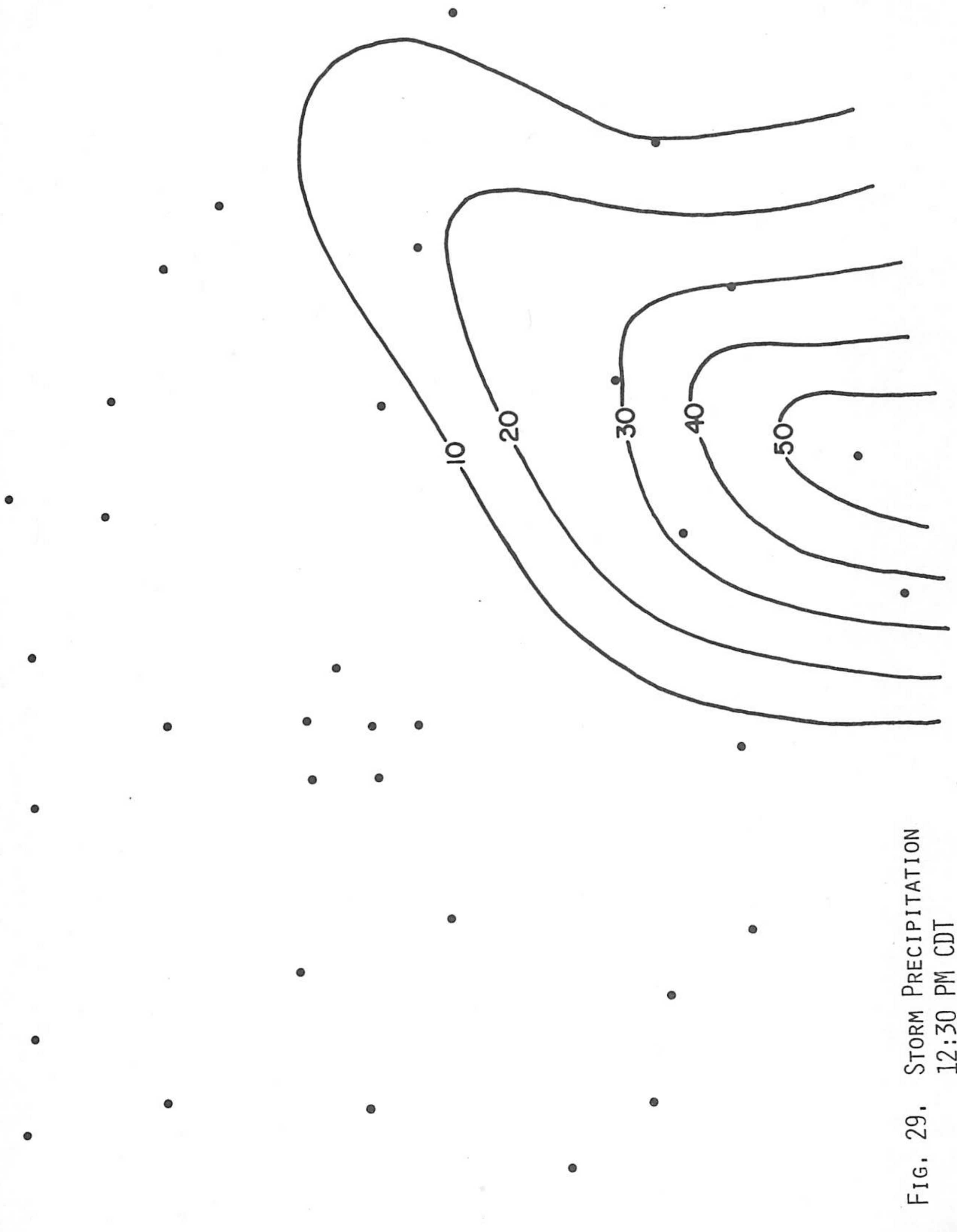

Fig. 29. Storm Precipitation
12:30 PM CDT

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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