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CLOUDS AND PRECIPITATION IN THE SOUTHERN HIPLEX REGION

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ABSTRACT

Climatological analyses of the space and time distribution of clouds and precipitation were 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.

INTRODUCTION

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.

HIPLEX is an acronym for the High Plains Cooperative Experiment, a weather modification research effort sponsored by the Bureau of Reclamation. The goal of HIPLEX is to develop a practical, scientifically sound, and socially acceptable precipitation management technology applicable to summer convective cloud systems in the High Plains region of the United States. Achieving this goal requires reduction of crucial scientific uncertainties concerning cloud and precipitation processes.

In 1974, the Bureau of Reclamation's Division (now Office) of Atmospheric Water Resources Management entered into cooperative agreements with interested High Plains states and selected three experimental sites representative of the northern, central and southern sections of the Great Plains. These sites are located in Montana, Kansas, and Texas, with Big Spring, Texas being selected as the focal point of activities in the southern region. The analyses presented here provide a data base for evaluating the natural occurrence and variability of clouds and precipitation in this area.

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. Approximately two-thirds of the average rainfall in this area 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 (1916-1970) of daily precipitation records at the two stations. Both curves show a maximum in mid-May decreasing to a minimum in late June. In each case 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 standpont of seeding opportunities, the period from mid-May to mid-June is probably the most desirable time in which to conduct a rainfall augmentation experiment, even though the efficiency of natural rain-producing mechanisms is high during this period.

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 1944-1970. 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.

The sequence of meteorological events leading to precipitation in one season of the year is 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 20-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 with distance out to approximately 10 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, result 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 (1944-1970) 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.

ANALYSIS OF PRECIPITATION DAYS

Results of a North Dakota experiment to increase precipitation by cloud seeding revealed a greater number of rainfall events during the 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 (to 1970) at each station. A rainfall period refers to a sequence of days each 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. Some months had no rainfall periods, whereas others had more than seven. The rainfall periods tabulated in Table 1 brought widely differing amounts of rain, shown in Table 3. 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. 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 no significant difference between the two stations.

MESO-SYNOPTIC PATTERNS RESPONSIBLE FOR PRECIPITATION EVENTS

Rainfall events during the months of May through September were studied for the six-year period, 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.

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. It should be emphasized that these results are for a 6-year period only and may not reflect average conditions for a longer time period.

CONVECTIVE CLOUD SUMMARY

A summary of convective cloud occurrences during the 10-day period 1963-1972 was prepared for the HIPLEX region (Haragan, 1978). Hourly cloud occurrences were tabulated for Midland (MAF), Lubbock (LBB) and Abilene (ABI) in order to provide a convective cloud census for the area. Figures 12 through 17 present a geographical 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 15 that the cumulonimbus maximum occurs much later in the day, between 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 months 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:

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.

SUMMARY AND APPLICATION

The proper design and subsequent evaluation of weather modification experiments are dependent ultimately on a knowledge of the natural variation of clouds and precipitation within the experimental or operational area. This investigation has provided a quantitative cloud and precipitation climatography for the HIPLEX southern region in order to establish a "natural variability" for this region. The study has provided some answers to the following questions:

(1) What is the frequency of occurrence of convective clouds?
(2) When does it rain?
(3) Where does it rain?
(4) Why does it rain?
(5) How often does it rain?
(6) How much rain occurs during a rainfall period?
(7) What is the duration of rainfall periods?

In addition to providing essential data for planning and implementation of the experiment, answers to these questions can be extremely valuable when evaluating results of seeding. The following information can be derived:

(1) The percentage of expected (based on climatology)precipitation which falls during seeded periods.
(2) The effect of seeding on inter-station correlation patterns.
(3) The effect of seeding on the frequency of occurrence of rainfall periods.
(4) The effect of seeding on the average amount of rainfall during a rainfall period.

ACKNOWLEDGEMENTS

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TABLE 1

PERCENT FREQUENCY OF RAINFALL PERIODS

STATION	RAINFALL PERIODS PER MONTH	MAY	JUNE	JULY	AUGUST	SEPTEMBER
Big Spring	0	0	3	5	2	8
(1914-1970)	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	0	2	2	0	3	2
(1910-1970)	1	14	10	13	14	19
	2	13	24	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	0	0	2	5	5	10
(1914-1970)	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 (1914-1970)	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 (1910-1970)	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 (1914-1970)	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

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 (73%)	15 (7%)

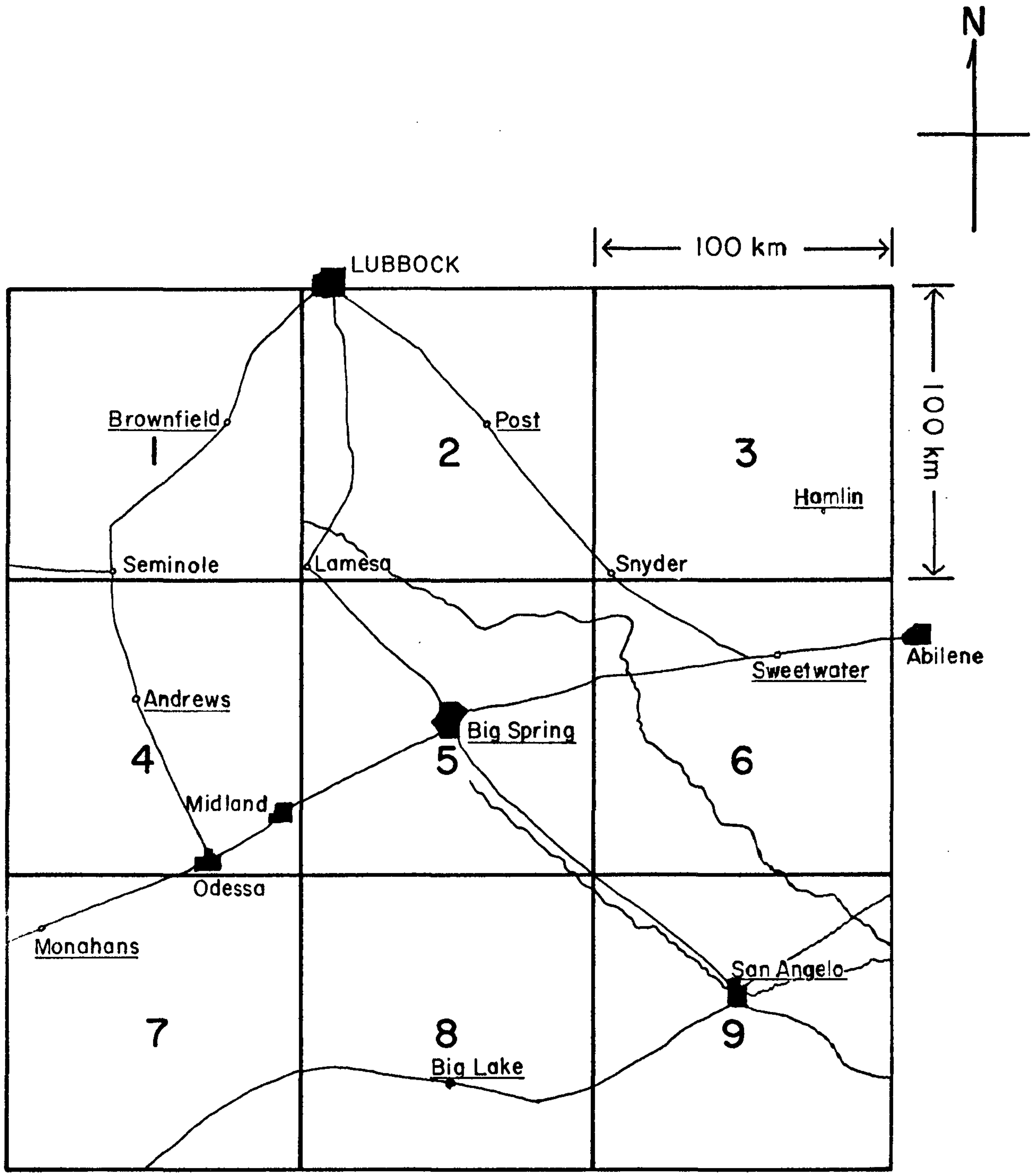

Figure 1. The area of study. Each region is denoted by number as well as by a city name.

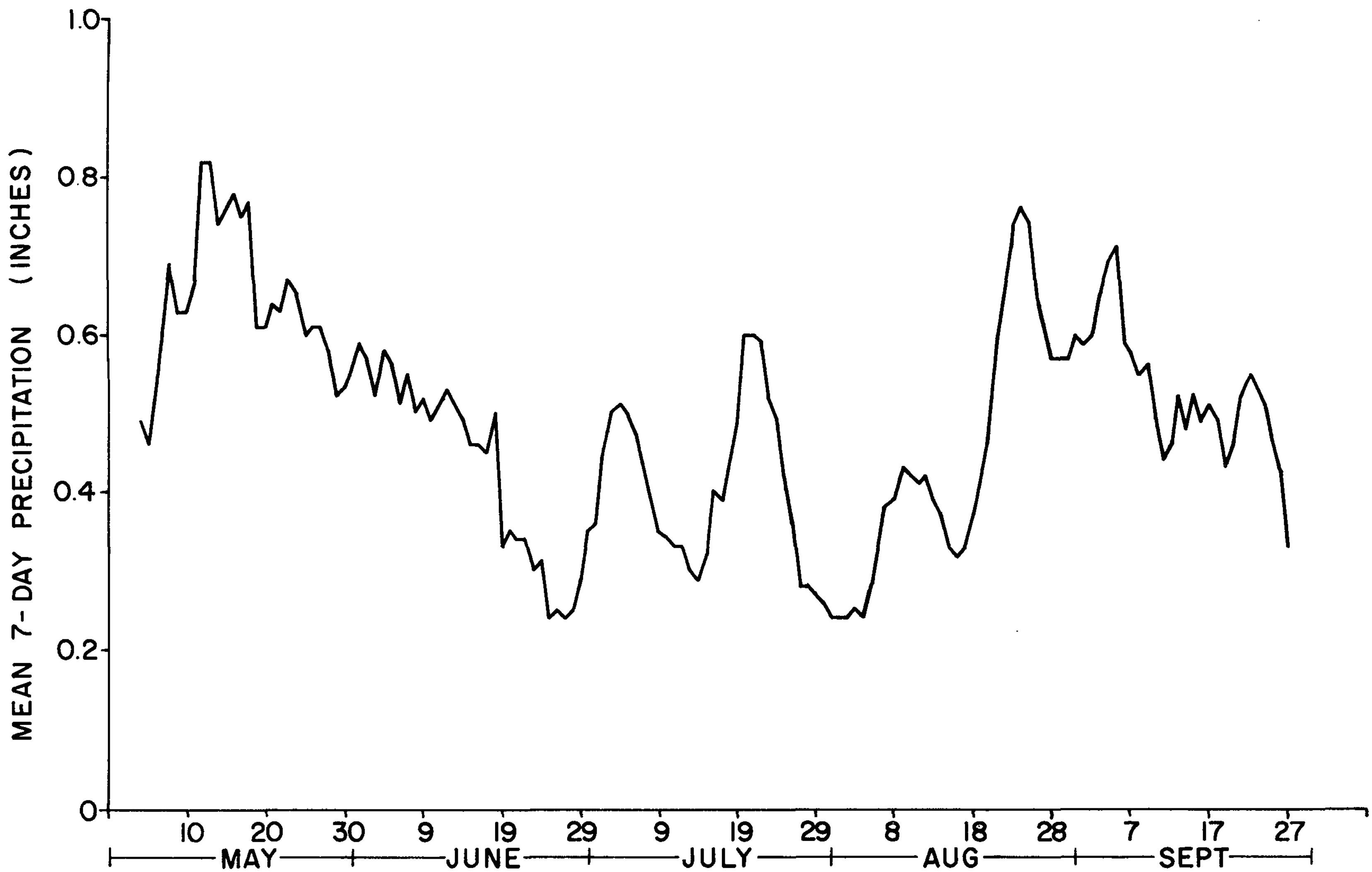

FIG. 2. DAILY PRECIPITATION 7-DAY RUNNING MEANS
BIG SPRING

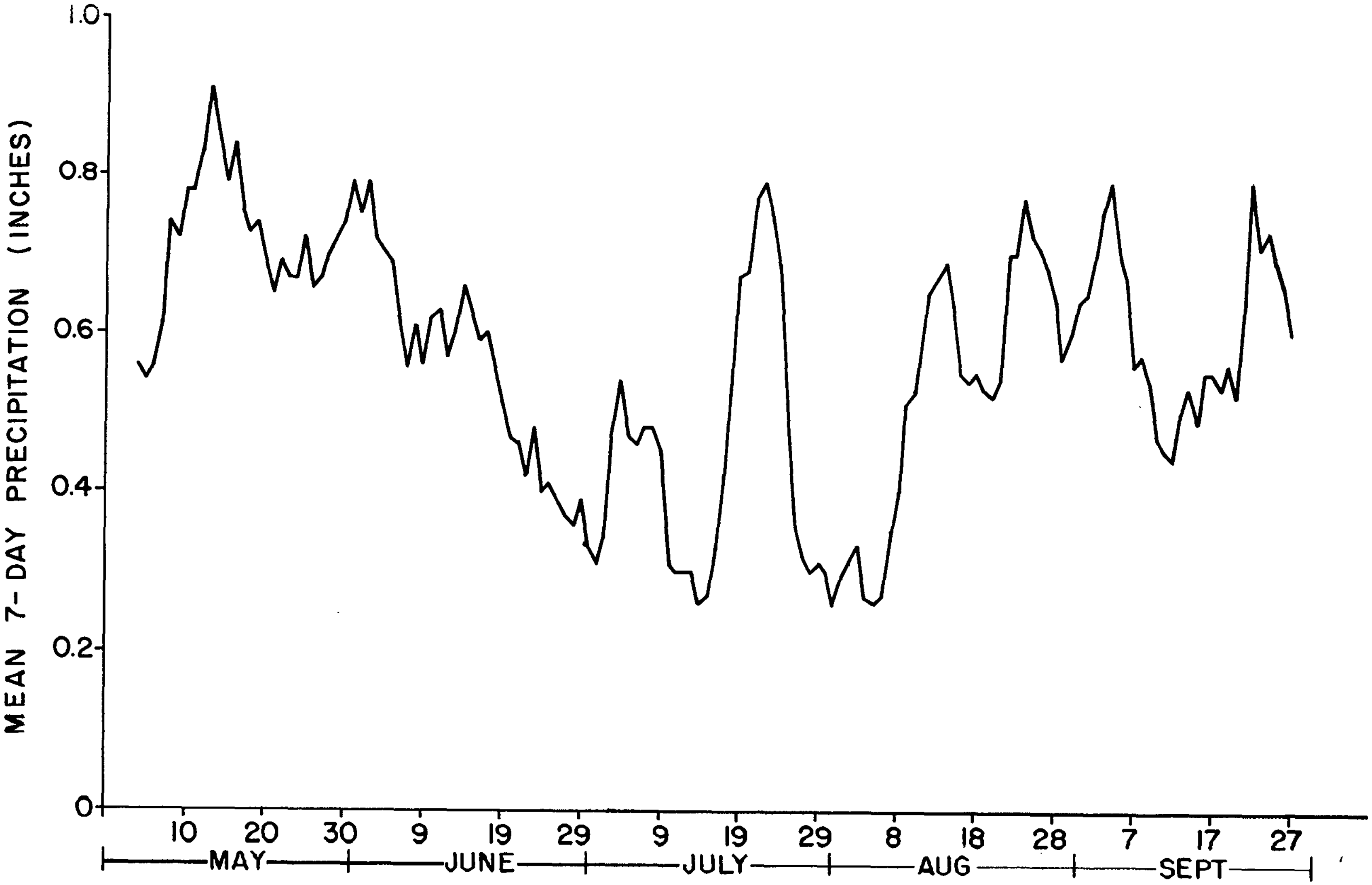

FIG. 3. DAILY PRECIPITATION 7-DAY RUNNING MEANS
SNYDER

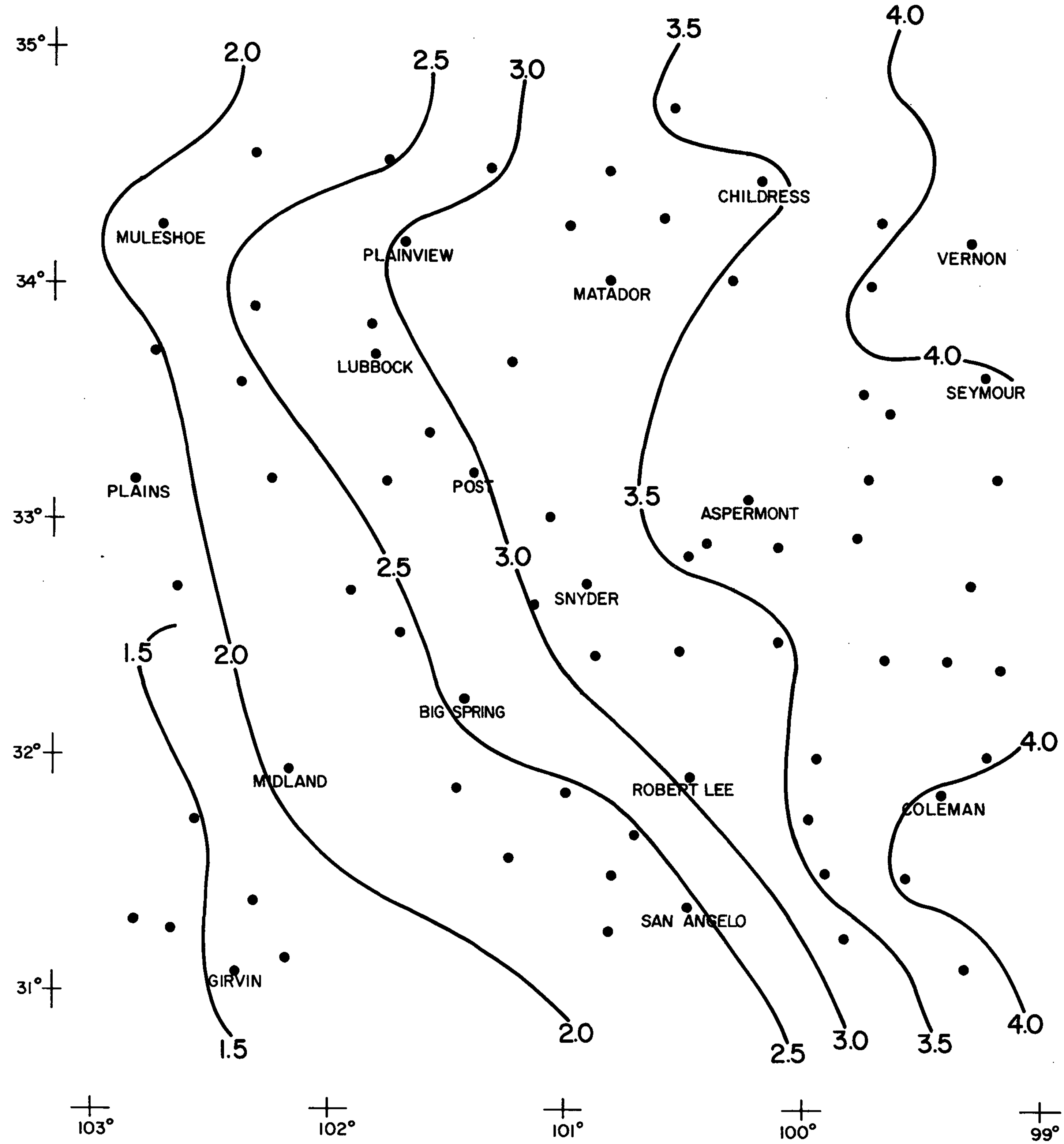

FIG. 4. MEAN MONTHLY PRECIPITATION - MAY

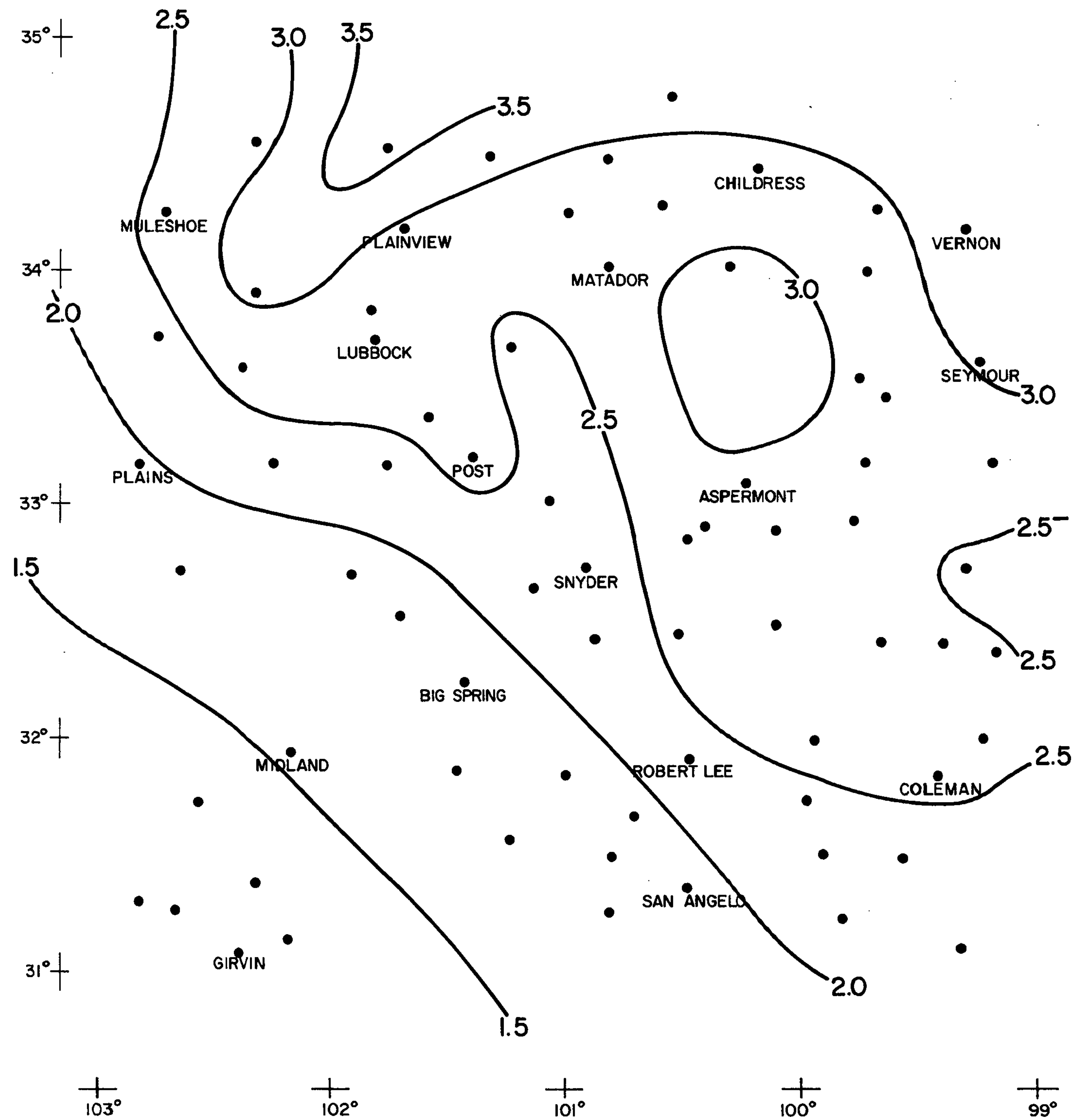

FIG. 5. MEAN MONTHLY PRECIPITATION - JUNE

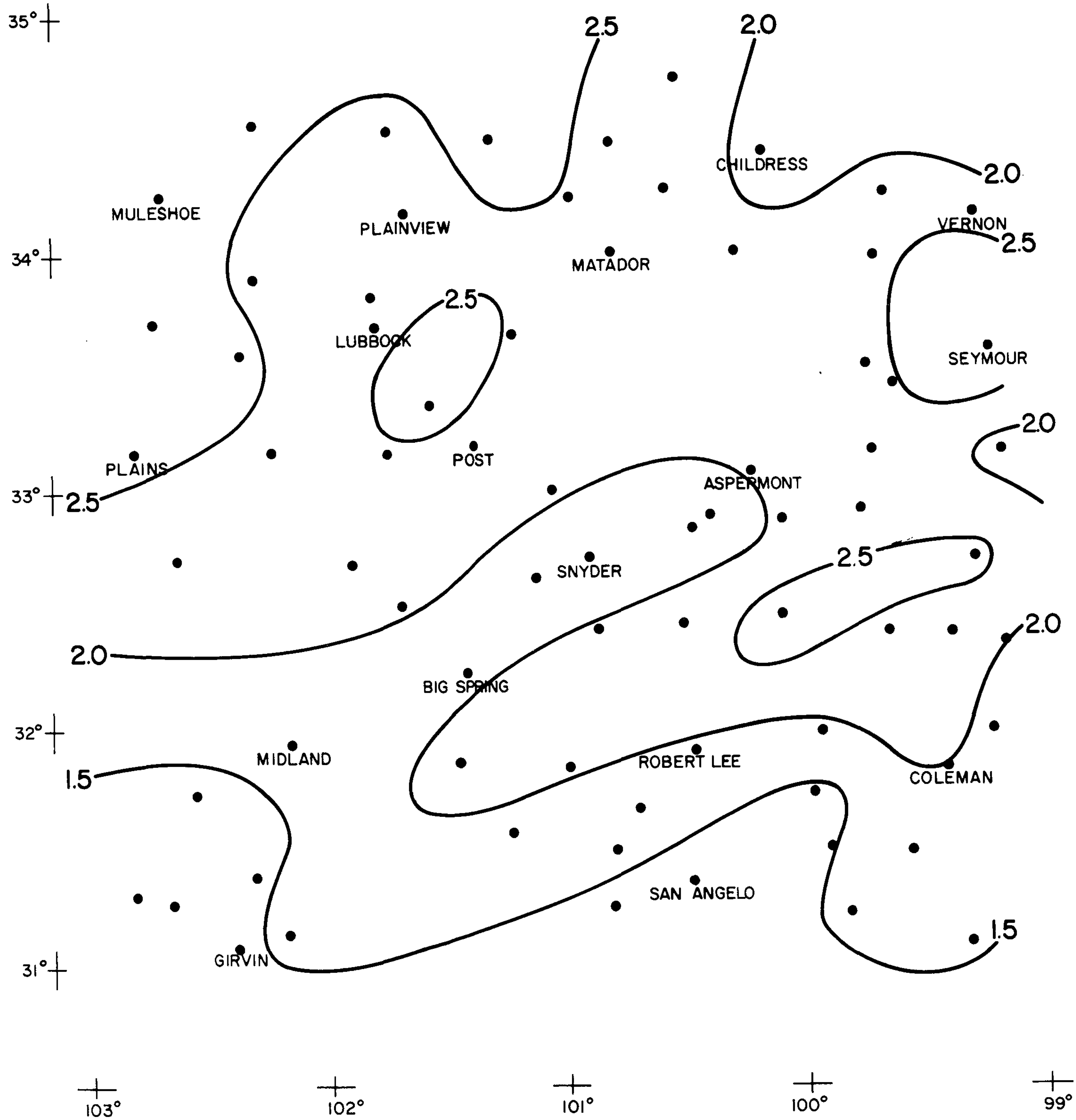

FIG. 6. MEAN MONTHLY PRECIPITATION - JULY

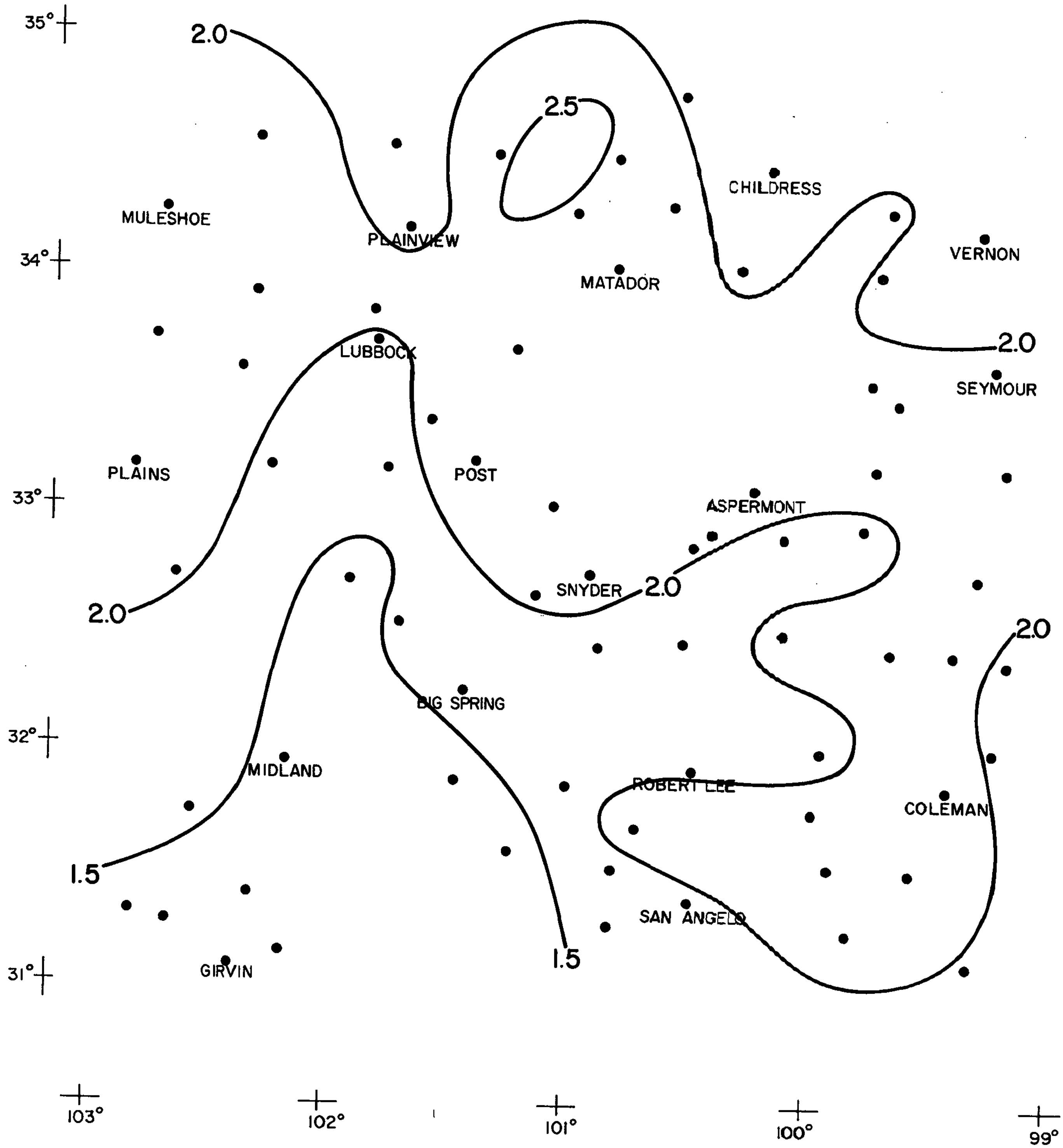

FIG. 7. MEAN MONTHLY PRECIPITATION - AUGUST

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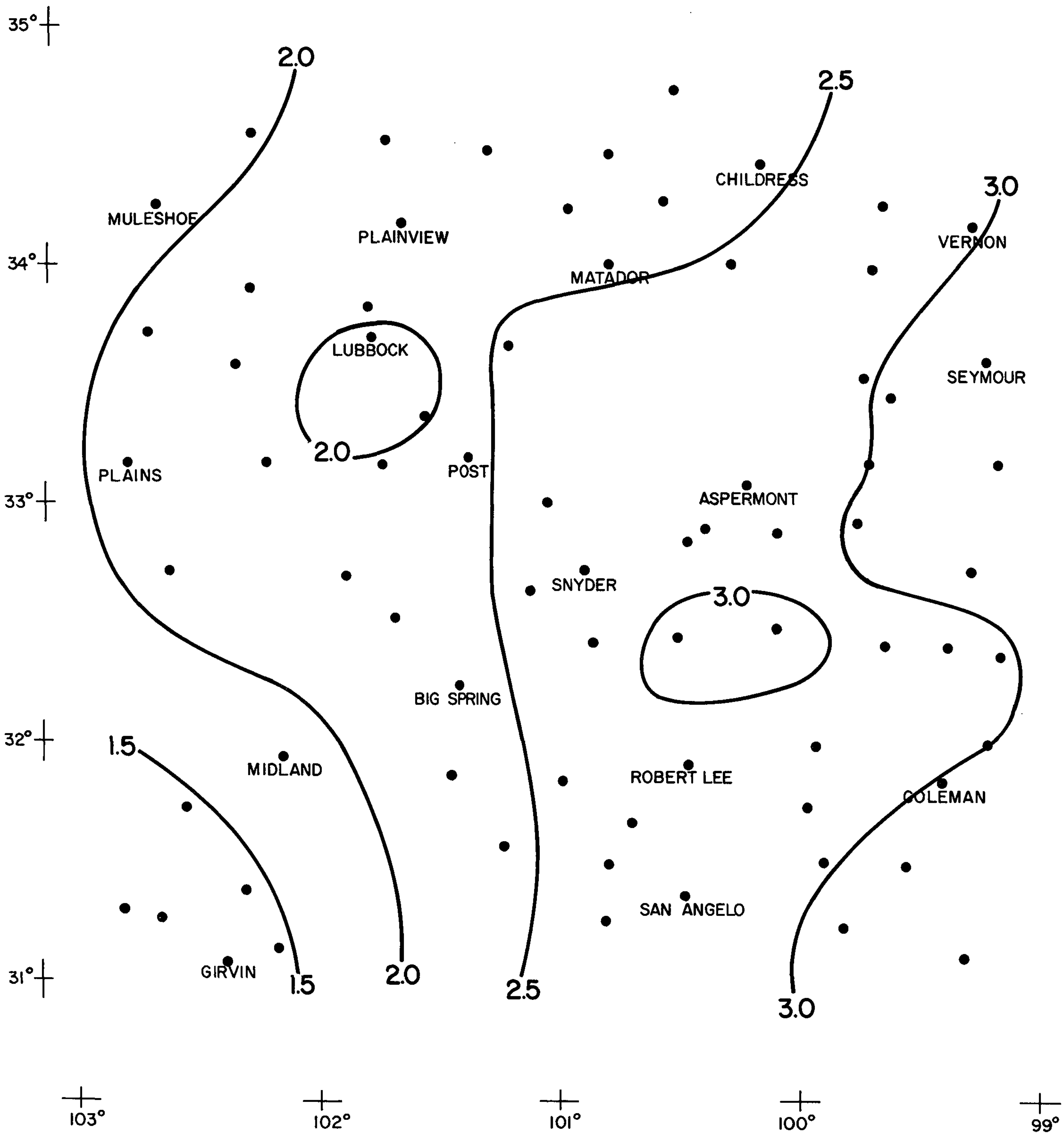

FIG. 8. MEAN MONTHLY PRECIPITATION - SEPTEMBER

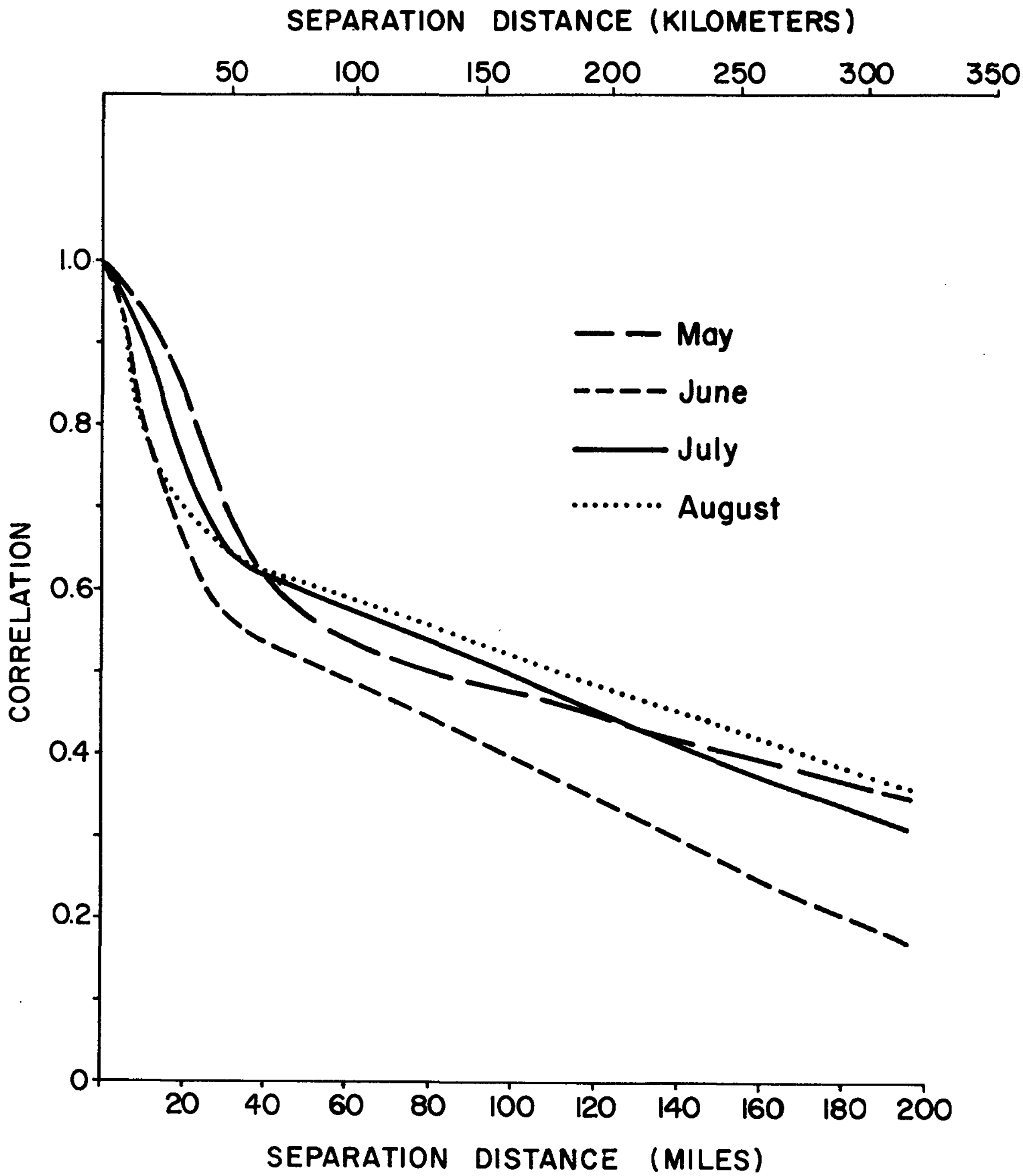

FIG. 9. MEAN MONTHLY PRECIPITATION CORRELATION (MAY - AUGUST)

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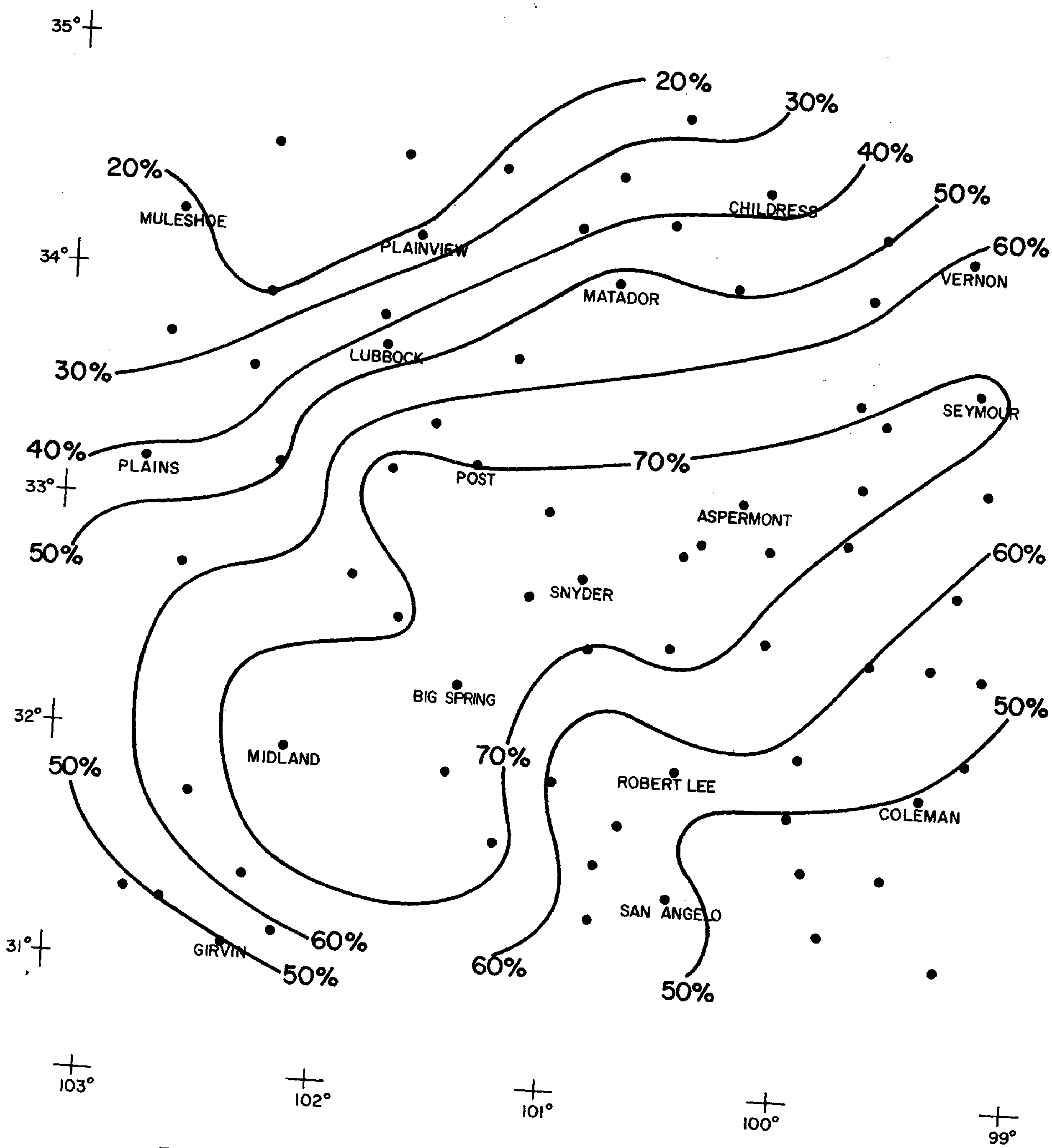

FIG. 10. PRECIPITATION CORRELATION WITH BIG SPRING - MAY

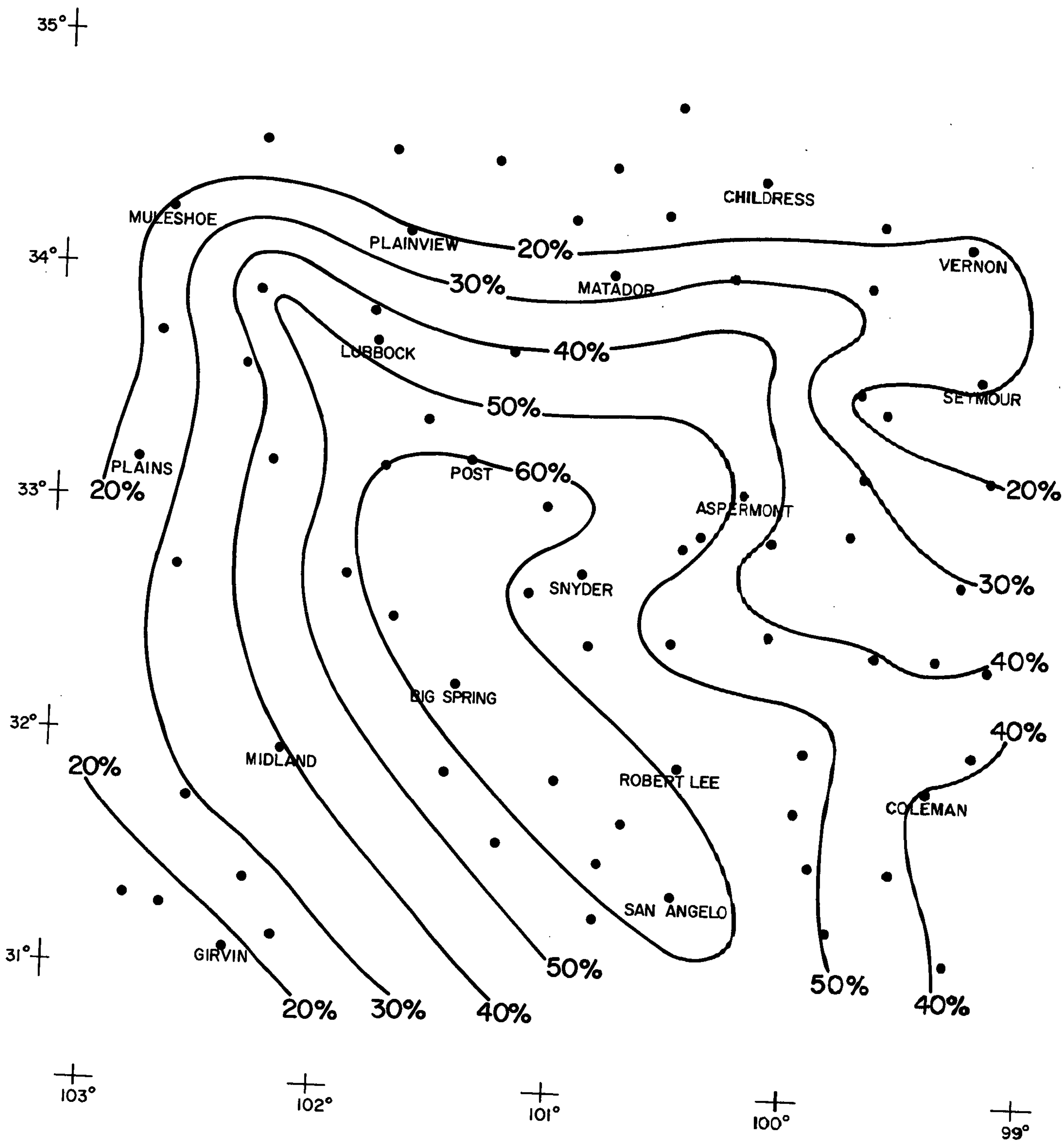

FIG. 11. PRECIPITATION CORRELATION WITH BIG SPRING - JUNE

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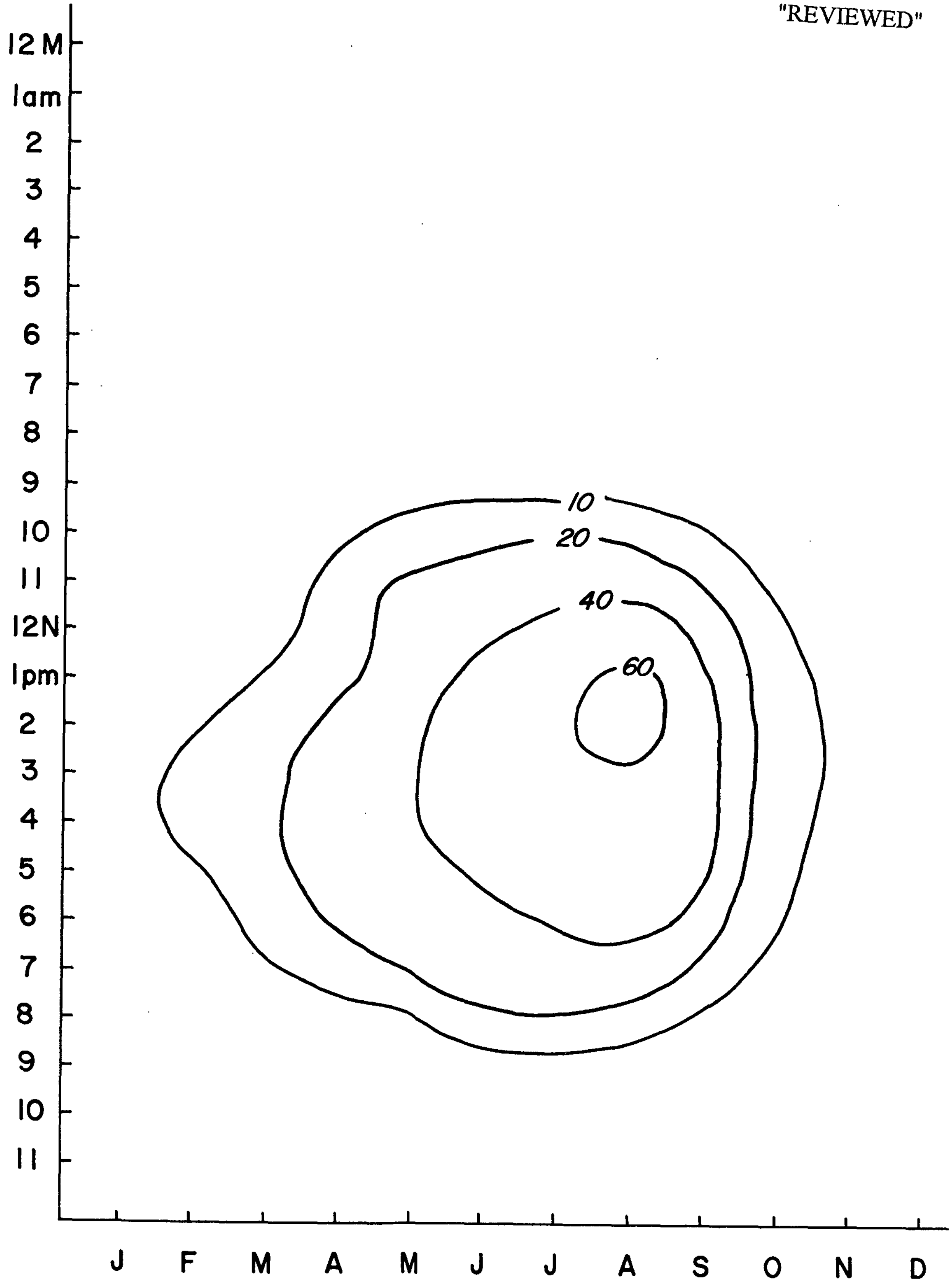

FIG. 12. Percentage Occurrence of Cumulus
Midland, Texas

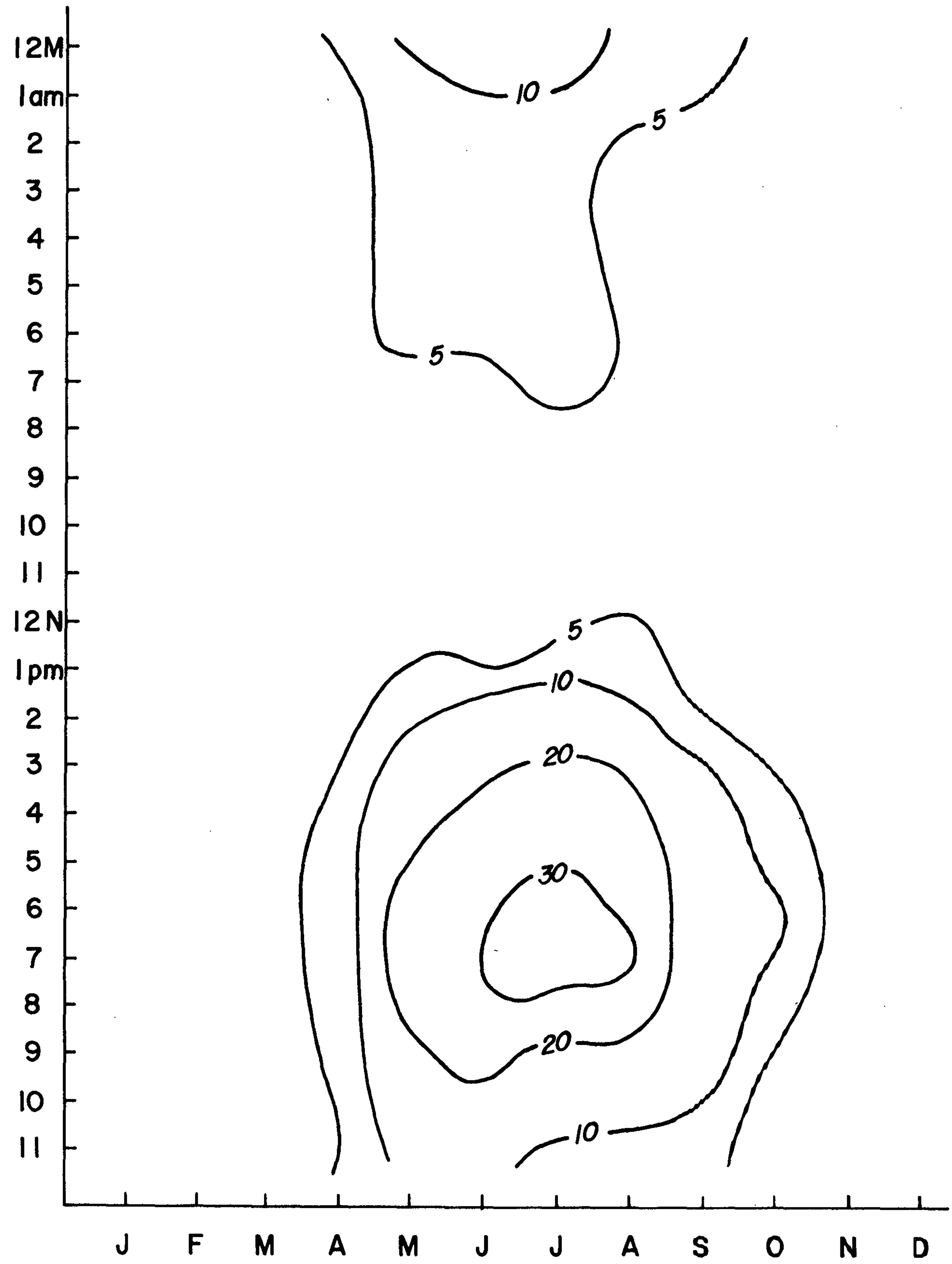

FIG. 13. Percentage Occurrence of Cumulonimbus Midland, Texas

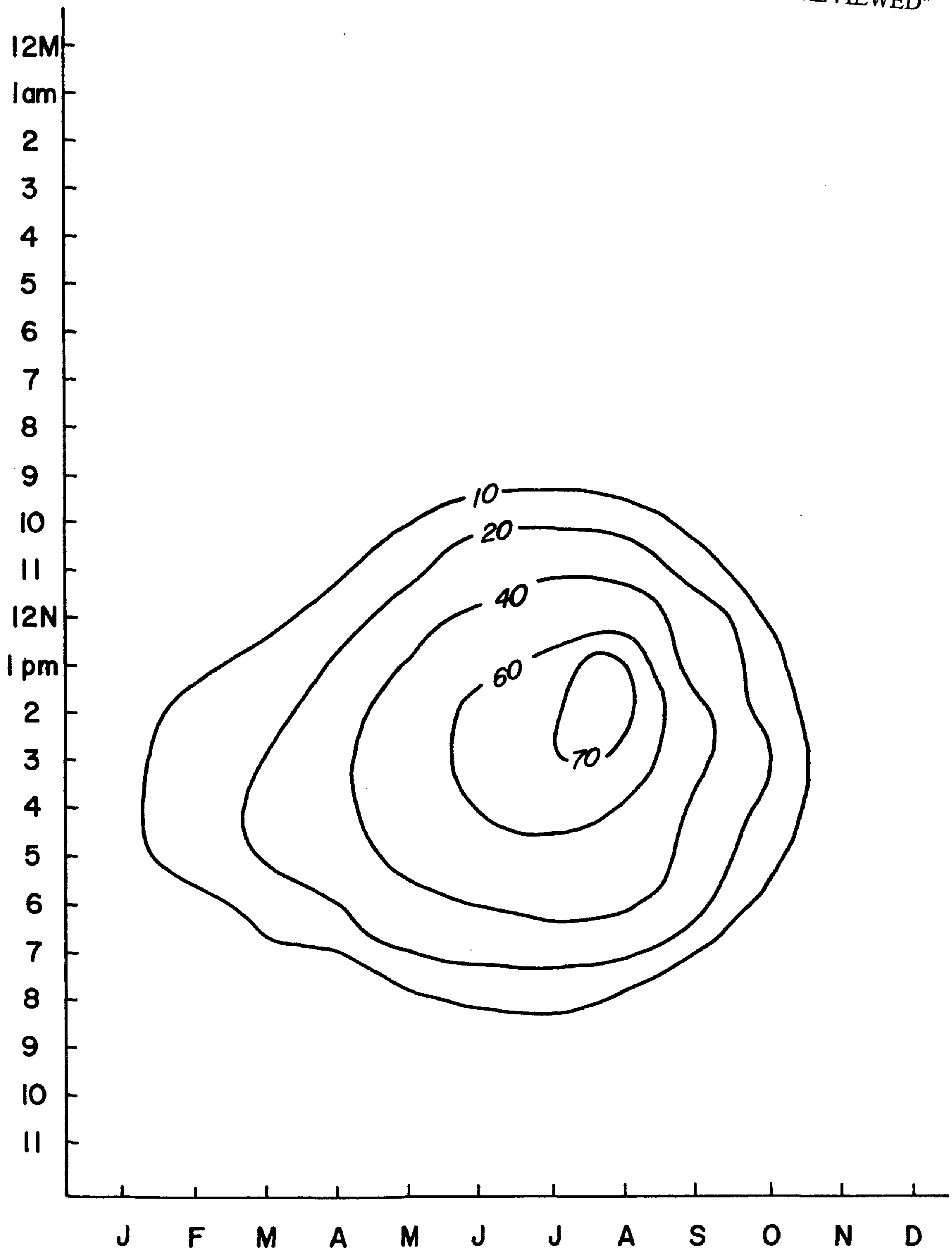

FIG. 14. Percentage Occurrence of Cumulus
Lubbock, Texas

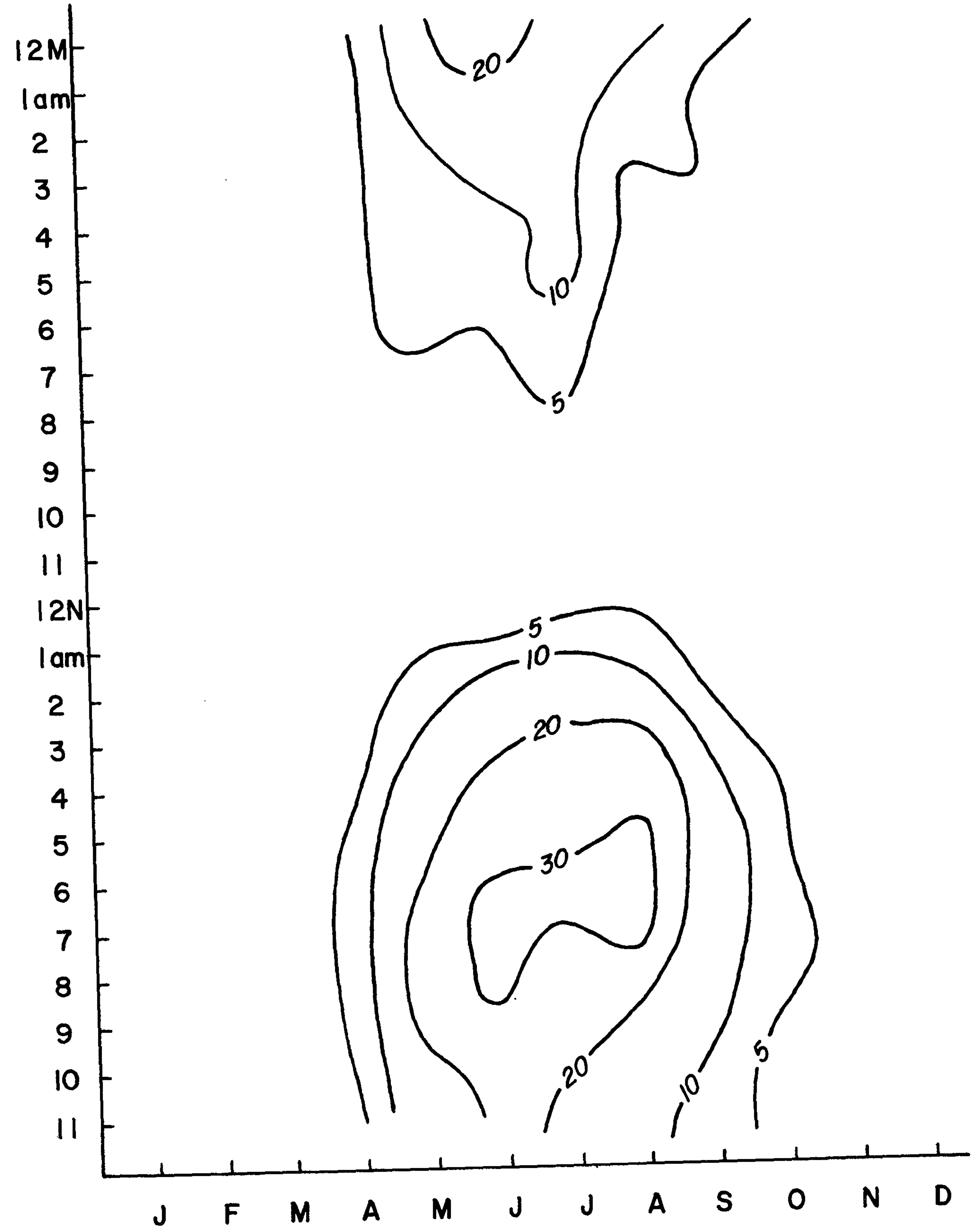

FIG. 15. Percentage Occurrence of Cumulonimbus
Lubbock, Texas

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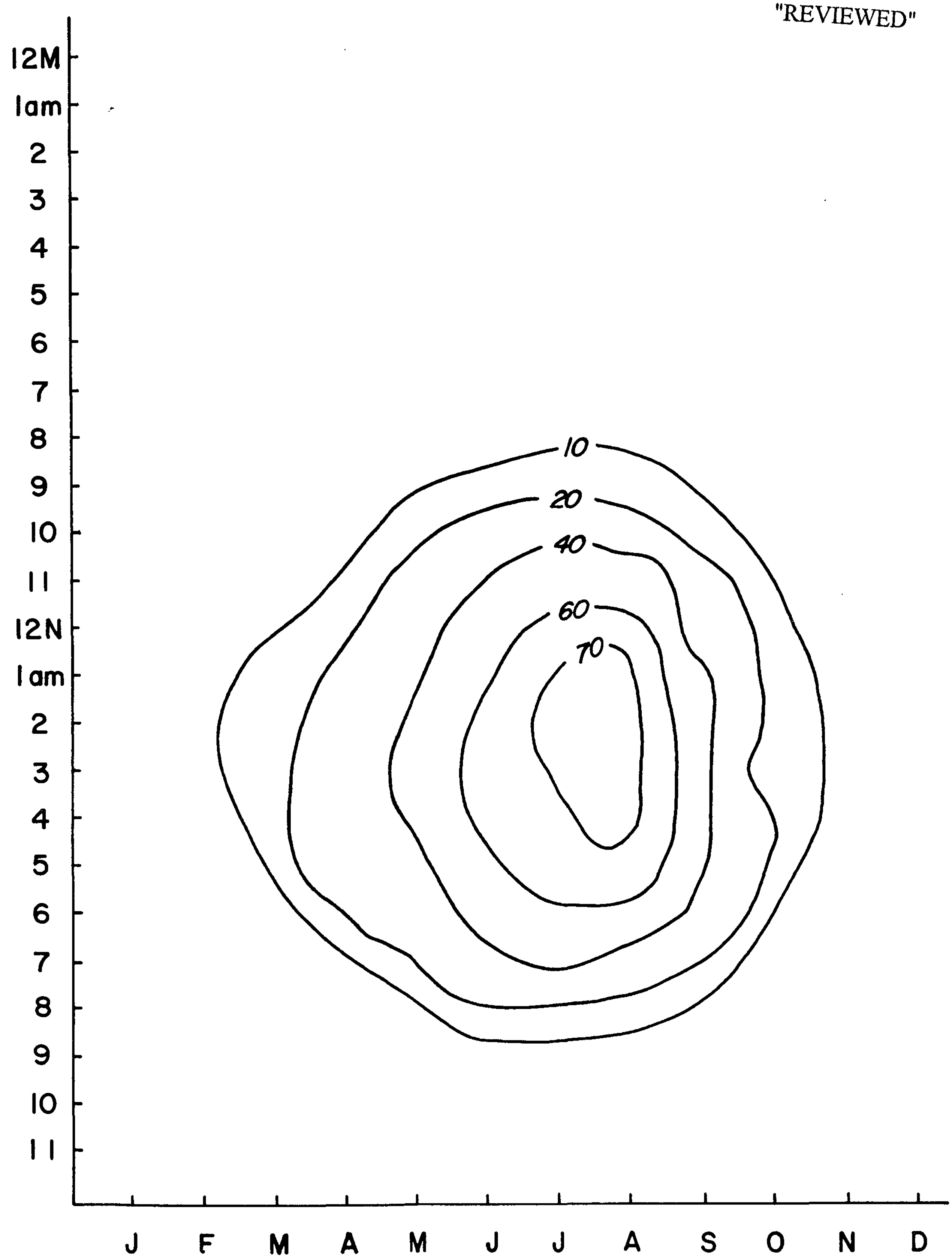

FIG. 16. **Percentage Occurrence of Cumulus Abilene, Texas**

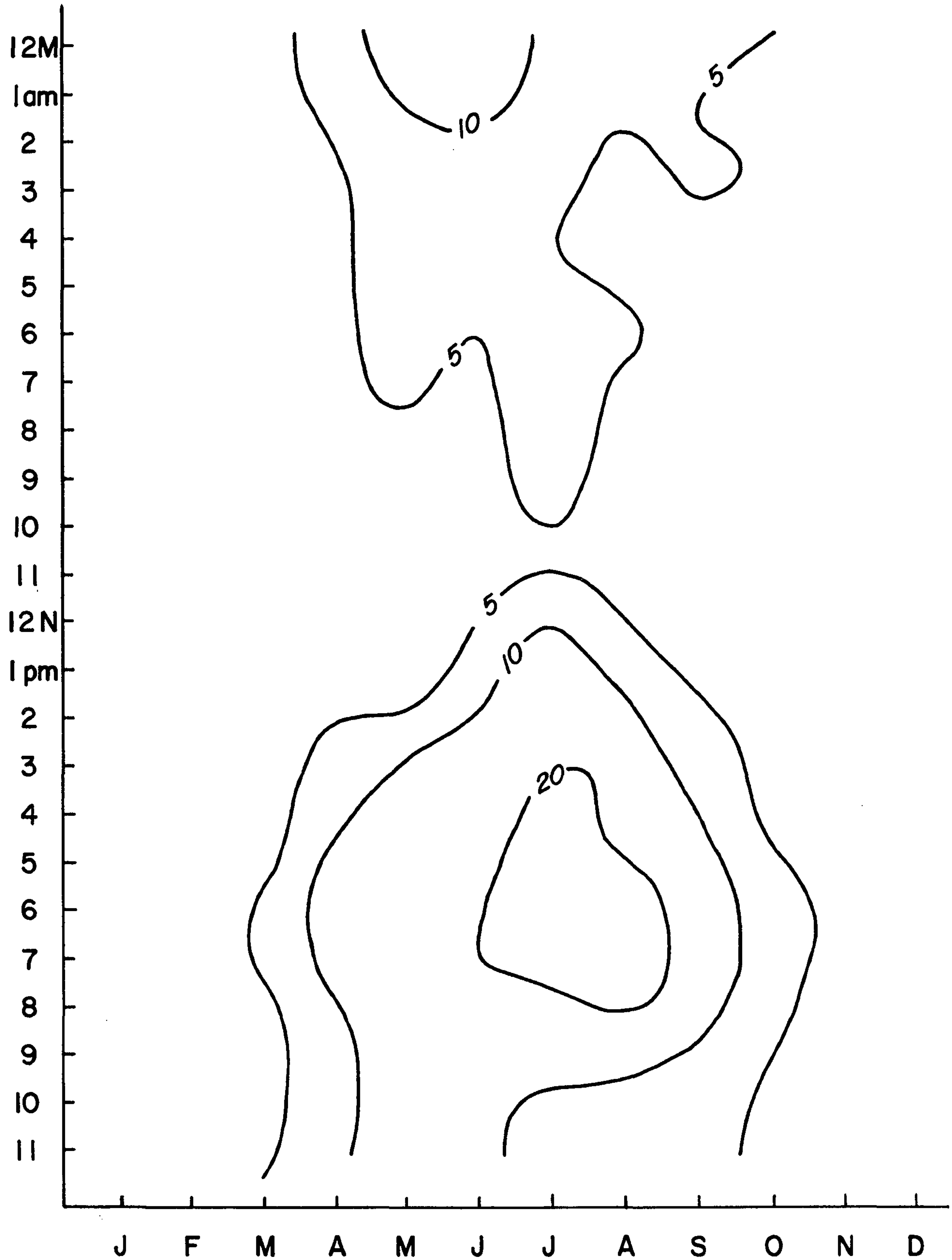

FIG. 17 **Percentage Occurrence of Cumulonimbus Abilene, Texas**

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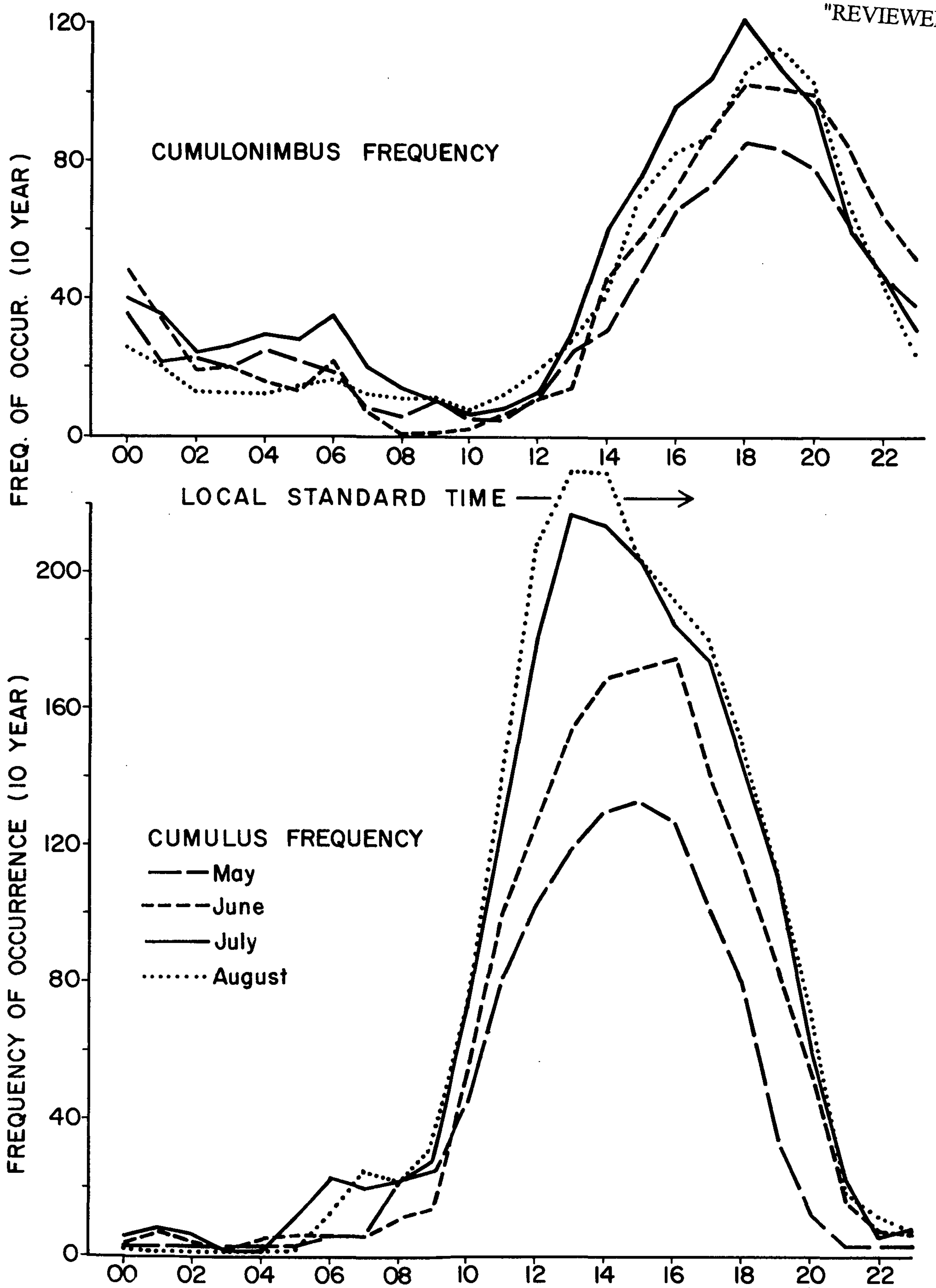

FIG. 18. FREQUENCY OF OCCURRENCE OF CUMULUS AND CUMULONIMBUS - MIDLAND

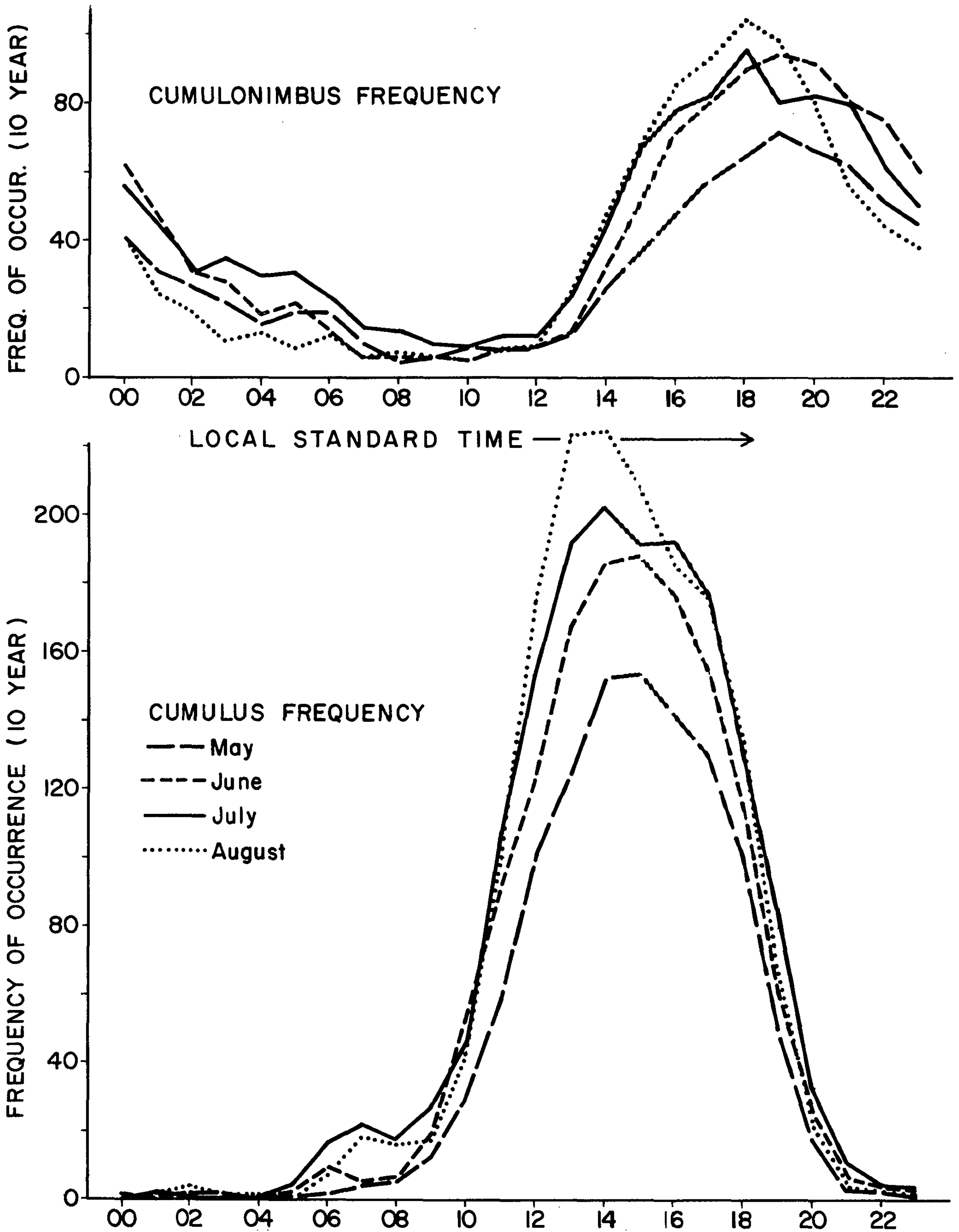

FIG. 19. FREQUENCY OF OCCURRENCE OF CUMULUS AND CUMULONIMBUS - LUBBOCK

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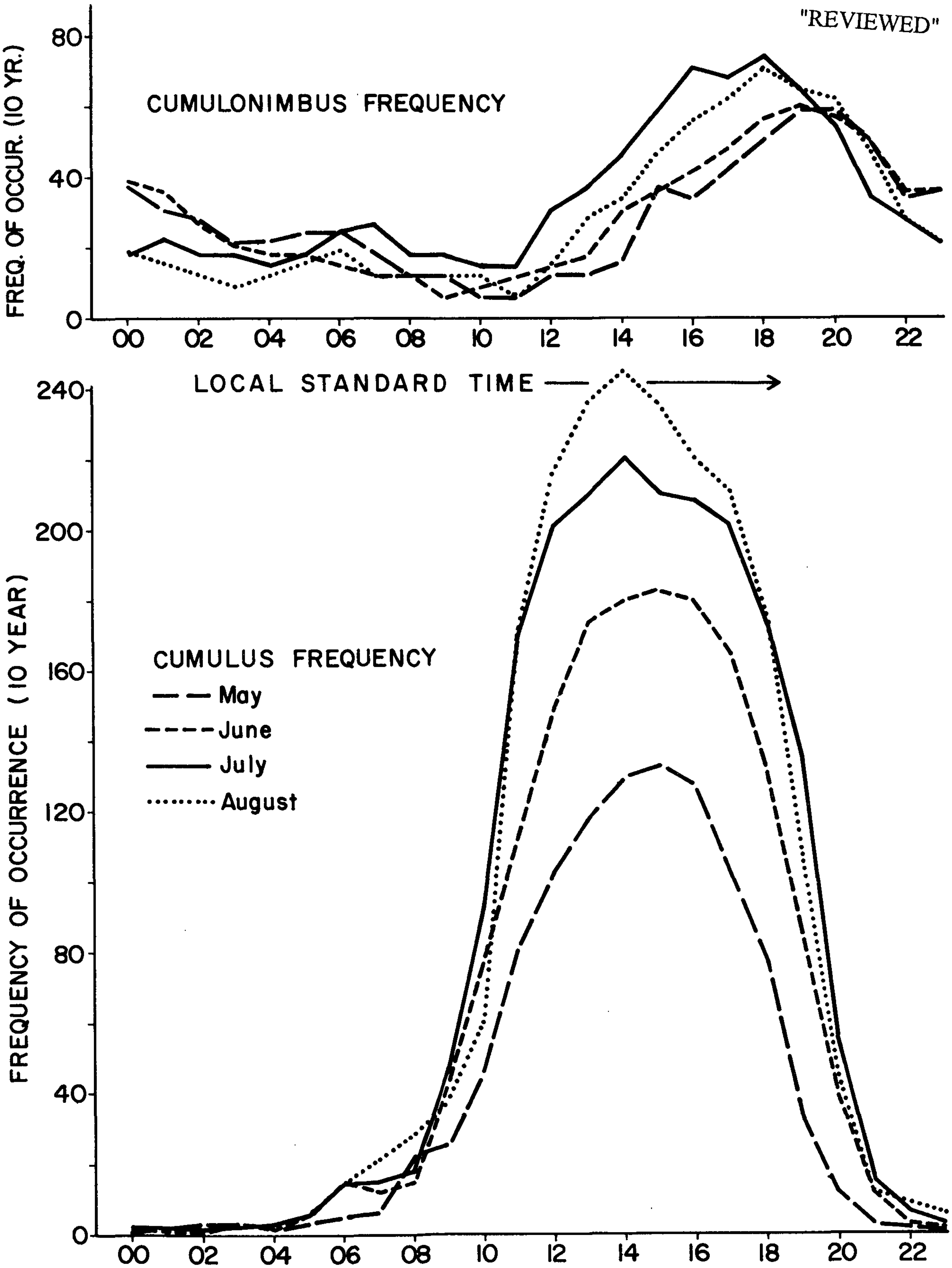

FIG. 20. FREQUENCY OF OCCURRENCE OF CUMULUS AND CUMULONIMBUS - ABILENE