HYDROMETEOROLOGICAL REPORT NO.53

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Seasonal Variation of 10-Square-Mile Probable Maximum Precipitation Estimates, United States East of the 105th Meridian

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TABLE OF CONTENTS

Page

FIGURES

TABLES

SEASONAL VARIATION OF 10-SQUARE-MILE PROBABLE MAXIMUM PRECIPITATION ESTIMATES UNITED STATES EAST OF THE 105th MERIDIAN

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ABSTRACT. Estimates of the upper limit to rainfall that the atmosphere can produce (probable maximum precipitation) are given in this study for durations from 6 to 72 hours for each month of the year for 10 mi^2 areas. The results are in a generalized form, that is, on maps allowing use for planning and design of any present or proposed hydrologic structure for the United States east of the 105th meridian. The probable maximum precipitation estimates show a smooth variation with duration, season, and location.

1. INTRODUCTION

1.1 Authorization

This study was authorized and funded through Interagency Agreement No. NRC-01-77-113 between the Nuclear Regulatory Commission (NRC) and the National Oceanic and Atmospheric Administration (NOAA) dated June 2, 1977. The Agreement was extended to October 1, 1979, by an amendment dated May 20, 1979.

1.2 Purpose

The purpose of the study is to give seasonal variation of probable maximum precipitation (PMP) estimates for 10 mi^2 areas for the United States east of the 105th meridian. PMP estimates for durations of 6 to 72 hours, by 6-hr increments are required.

1.3 Scope

PMP estimates for 6, 24, and 72 hours are given on generalized maps for each midmonth for 10 mi^2 areas. While smaller sized areas have greater PMP values, especially for the warm season, they will not be defined in this study. For the winter season, PMP for smaller areas are not appreciably different from the 10-mi^2 values in this study.

All-season estimates of PMP, Hydrometeorological Report (HMR) No. 51, *Probable Maximum Precipitation Estimates, United States East of the 105th Meridian,* (Schreiner and Riedel 1978) set the greatest values that can be reached at some time during the year. They are accepted as upper bounds for the present study.

1.4 Definitions

Probable maximum precipitation (PMP) means *the theoretically greatest depth of precipitation for a given duration that is physically possible over a particular drainage basin at a certain time of year.* (American Meteorological Society 1959). Realizing there are yet unknowns in the physical processes responsible for extreme rainfall, we refer to PMP values as estimates.

Generalized PMP estimates are estimates determined for large regions that are now required or one would expect will be needed in the future. These are frequently presented as a series of isolines on a map for a given area size and duration.

All-season PMP is the greatest PMP regardless of season. For the region of this study one can generally say that for all durations, the all-season PMP will fall sometime between June and September for every point. Our problem is to determine the variation from this all-season estimate for each month of the year.

1.5 Previous Study

The only other study covering seasional variation of PMP for the entire region is HMR No. 33 (Riedel et al. 1956). Because the all-season values of HMR No. 51 differ from those of HMR No. 33, it follows that the estimates for each month in HMR No. 33 also need revision. All facets of PMP for the region were restudied and therefore the seasonal values differ from those in HMR No. 33.

2. BASIC DATA

2.1 Background

As in all PMP studies, basic data are the extreme record storm rainfalls. *Storm Rainfall in the United States, Depth-Area-Duration Data* (Corps of Engineers 1945-) is a kept-up-to-date catalog of many of the most extreme areal rainfalls. The data are maximum areal depths for standard area sizes and durations. Data for more than 600 storms have been published in this catalog. Additional data come from unofficial sources developed by the Hydrometeorological Branch (Shipe and Riedel 1976).

Most of the storms include data from surveys after the storm or resulting flood, sometimes called *bucket surveys*, in which additional rainfall measurements are found. Some of these values are measured in regular rain gages, privately owned or owned by local agencies or companies but not included in usual published records. Other values are measured in small *test tube* type gages, oil cans, or buckets. Such unofficial catches are accepted after checks against other observations and weather patterns, discussions with observers, and more recently, against radar echoes and satellite pictures. It turns out that the most extreme point rainfalls of record are almost entirely from unofficial sources. This should be expected since there is practically no chance that the most extreme rainfall of a storm would occur over a preselected gage site. A shortcoming is that only very limited surveys and studies have been made for "out of season" (that is out of the season giving most intense rainfalls of the year) storms. Thus, we must augment our sample with extremes from regularly reporting precipitation stations and recognize that these values may not include the most extreme falls.

2.2 Available Station Rainfall Data

Table 1 lists several data sets that were surveyed for obtaining the greatest rainfalls for each month.

2.2.1 Storm Rainfall

This means *Storm Rainfall in the United States, Depth-Area-Duration Data* (Corps of Engineers 1945-) and the augmented computer file of storm data (Shipe and Riedel 1976). The greatest value for 6, 12, 24, 48, and 72 hours for each month were used from these sources.

2.2.2 Maximum 1-Day or 24-Hr Values, Each Month

These values (Jennings 1952) are for regularly reporting stations for the period of record through 1949. Because nonrecording stations are more numerous than recording stations and have longer records, the maximum values generally are from nonrecording stations.

2.2.3 Maximum 6-, 12- and 24-Hr Values, Each Month

For 28 of the 37 states involved in this study, there are published (U.S. Weather Bureau 1951-61) maximum observed depths at recording stations for these durations for the period beginning, in most cases, in the 1940's and ending in 1950. Exceptions are the few recorders going back many years at "first-order" Weather Bureau (now National Weather Service) stations.

2.2.4 Maximum Recorded Rainfall at First-Order Stations

A paper (Jennings 1963) published the greatest depths at first-order stations for durations from 5 minutes to 24 hours for about 200 stations in the study region. This is for the period of record through 1961.

2.2.5 Data Tapes, Selected Stations

For about 50 stations in our study region, daily rainfall records have been put on magnetic tapes for the period 1912-61. From these tapes we can extract 1-, 2-, and 3-day maxima for each of the 12 months.

Table 1.--Data sources for determining maximum station precipitation of record

Item	Type of Data	Period of record	Remarks
United States Data			
Storm Rainfall	Primarily maximum known areal depths	For greatest known storms - kept up to to date.	Mainly for warm season
Technical Paper No. 16	Maximum 1-day or 24-hr values, each month for regular reporting stations	Through 1949	
Technical Paper No. 15	Maximum 1-, 2-, 3-, 6-, 12- & 24-hr values for each month	Through 1950	Available for 28 of the 37 states in study region
Technical Paper No. 2	Maximum recorded rainfall 5 min to 24 hr for 296 1st order stations	Through 1961	
Data tapes	Daily precipitation	1912-1961	Available for stations in study region
Data tapes	a. daily & b. hourly precipitation for reguular reporting stations	1948-73	More than 6500 stations
Canadian Data			
Storm Rainfall	Similar to U.S. storm rainfall		
Station Maxima	Daily Observation	1941-1970	See section 2.2.7

2.2.6 Data Tapes, 1948-73

These tapes include all observed hourly and daily rainfalls for the period measured both at recording and nonrecording stations, updating to 1973 the published data of pars. 2.2.2 to 2.2.5 for the durations we are interested in.

2.2.7 Canadian Data

The Canadians have summarized maximum rainfall depths in much the same way we have in the United States. They maintain a catalog *Storm Rainfall in Canada* of greatest areal rainfall depths (Atmospheric Environment Service 1961-). Another publication (Atmospheric Environment Canada 1973) gives the greatest single observed value for one day at each observing station for the period 1941-70. Yet another source (Department of Transport) lists the greatest single observed value for a day in the period 1931-58. A list of station locations (Department of Transport, Meteorological Branch 1970) was helpful in locating extremes near the northern bound of our study region.

3. APPROACH TO PMP

3.1 Summary

Central to this study, as already mentioned, is HMR No. 51. For at least one midmonth the values of the present study reach the all-season PMP of HMR No. 51 for every geographical point. The basic approach used in HMR No. 51 is the approach adopted here. We will not repeat the various techniques, steps, and tests fully detailed in that report. More generally, a manual of PMP (World Meteorological Organization 1973) which summarizes PMP procedures that have been used in the United States is recommended for any reader who wishes to pursue the topic further.

Development of PMP for each month consisted of the following operations on selected major record storm rainfalls.

a. Moisture maximization

b. Transposition

c. Envelopment

Brief discussions of these items follow. At times we extract liberally from HMR No. 51.

3.2 Selected Major Storm Values

From the data sources listed we extracted those values that could significantly influence the level of PMP after they are moisture maximized (par. 3.3) and transposed (par. 3.4), for September through June and any portion of the study region. This was done by first plotting the most extreme depths for a given duration from *Storm Rainfall in the United States* on 12 maps, one for each month. We then extracted the greatest station values from the other data sources and added them to the plotted maps if they were of the same general level or greater than those already on the maps. Such maps were plotted for extreme values for durations of 6, 12, 24, 48 and 72 hours. On these maps we also plotted the most extreme rainfall values for the region adjoining the United States from the Canadian data sources.

Table 2 lists the storms selected chronologically by month. We show the storm location by latitude, longitude, town, and State. The storm number we used is given, as well as the Corps of Engineers' assignment number (if there is one) from *Storm Rainfall in the United States* (Corps of Engineers 1945-) and the source of the data. The observed depth for the most critical duration is given. Other information in table 2 is explained in par. 3.5.

Figures 1a, 1b, and 1c show the locations of these most important storms together with the observed rainfall depths for 6-, 24-, and 72-hr durations respectively. The month of occurrence is also given.

Table 3 lists the more important storms selected from the Canadian data. These have a bearing on the magnitude of PMP near the U.S. border.

3.3 Moisture Maximization

3.3.1 The Concept

Moisture maximization is increasing storm rainfall depths for the storm location and season, for higher atmospheric moisture than was available in the actual storm.

Signficant precipitation results from lifting moist air. Processes causing this lifting, associated with horizontal convergence, have been described in numerous texts. Various attempts at developing a model that will reproduce extreme rainfalls are hampered by the lack of sufficient data within storms to adequately check the magnitudes of horizontal convergence, vertical motion, and other parameters. Since measurements of these parameters during severe storms are not readily obtainable, the solution has been to use extreme record storm rainfalls as an indirect measure of parameters, other than moisture, that are important to such events.

We thus adjust storm rainfalls of record to the equivalent that would have occurred with maximum moisture and make the following assumption: The sample of extreme storms is sufficiently large so that near optimum "mechanism" (or efficiency) has occurred. By "mechanism" is meant a combined measure of all the important parameters to rainfall production, except moisture. The assumption thus circumvents a quantitative evaluation of "mechanism" and results in increasing the observed storm rainfall, assumed to occur with near optimum "mechanism", by an adjustment for moisture.

This assumption is probably most realistic when considering all-season PMP. Having to spread the storm sample throughout the 12 months weakens the assumption and we compensate by more liberal envelopment (par. 3.6).

3.3.2 Atmospheric Moisture

The best measure of atmospheric moisture through depth can be obtained from radiosonde observations. Specifically for the present study we have

Table 2.--Major storms selected for moisture maximization and transposition

Date	Storm Number	Location				CoE[1] Assignment Number	Source*	Gridpoint(s) transposed to ∇	Critical Duration(s) (hrs)	Obs. Depth (in.)	Controlling for grid point(s)	Total storm adjustment (%)
		City	State	Lat.	Long.							
1/18-21,1935	2	Hernando	MS	34°50	90°00	LMV1-19	STR	6,7,10,11,13	72	13.4	6	70
1/1-2,1941	3	Pigeon River	MI	48°00	89°42		T.P.16	9,10	24	4.7	9,10	150
1/4,1949	4	Coleraine	MN	93°28	47°16		DTD	1,5,9				
1/22-27,1949	5	Timbo	AR	35°52	92°19	SW3-10	STR	6,7,8,10	6	7.5	6,13	70
								11,12,13	24	11.7	10	74
1/31-2/2,1920	6	St.Augustine	FL	29°51	81°21		STR	12,15				
2/14-19,1938	8	Calvin	OK	34°56	96°15	SW2-17	STR	6,7,10,11	6	4.8	6	78
2/6,1955	9	Oberlin	LA	30°36	92°47		DTD	12,15,17				
2/22,1961	10	Bessemer	AL	33°22	87°01		DTD	12,15,17	72	13.5	17	150
2/10,1966	11	Leesville	LA	31°09	93°16		T.P.16	7,8,11,12,15				
2/26,1969	12	Mt.Washington	NH	44°16	71°18		DTD	a	72	14.1		
2/10-11,1970	13	Mt.Washington	NH	44°16	71°18		DTH	a	24	10.2		
2/1,1973	14	Spearsville	LA	32°56	92°36		DTH	7,8,11,12	6	10.6	8,12	141
											7,11	116
2/23-25,1875	15	Clingman Dome	NC	35°33	83°30		STR	14,16	6	5.8	16	90
3/26-4/1,1886	16	Pinkbeds	NC	35°22	82°47		STR	14				
3/23-27,1913	17	Bellefontaine	OH	40°22	83°46	OR1-15	STR	6,7,10,11,13	24	7.3	13	116
									72	10.4		
3/24-28,1914	18	Merryville	LA	30°46	93°32	LMV3-19	STR	8,12,15				
3/11-16,1929	19	Elba	AL	31°25	86°04	LMV2-20	STR	8,12,15	6	14.0	8,12,15	134
									24	20.0		
									72	29.6		
3/28-4/2,1945	20	Van (nr)	TX	32°20	95°42	SW3-5	STR	8,12				
3/25,1964	21	Spruce Mt.	NC	35°37	83°12		DTH	14				
3/16-17,1965	22	Bayfield	WI	46°53	90°49		DTD	9,10,13				
											1	110
3/2-5,1966	23	Courtenay	ND	47°14	98°35		STR	1,5,9	24	4.7	5	116
3/14,1973	24	Lead	SD	44°21	103°46		DTD	1,2,5,6,9,10	24	5.7	1,5,9	105
											2	135
4/22-24,1932	25	Ellendale	ND	46°29	99°45		STR	1,5,6,9,10	6	3.0	5,9	149
											1	135

See last page for notes.

Table 2.--Major storms selected for moisture maximization and transposition (continued)

Date	Storm Number	Location City	State	Lat.	Long.	CoE[1] Assignment Number	Source*	Gridpoint(s) transposed to ∇	Critical Duration(s) (hrs)	Obs. Depth (in.)	Controlling for grid point(s)	Total storm adjustment (%)
4/11-14,1933	26	Durham	NH	43°08	70°56	NA1-23	STR	17,18,20	6	4.9	18	150
											20	142
4/3-4,1934	27	Cheyenne	OK	35°37	99°40	SW2-11	STR	7,8	6	17.3	7	148
									24	21.3	8	150
4/24-28, 1937	28	Clear Spring	MD	39°40	77°54	SA5-13	STR	16,17,18				
4/26, 1954	29	Morris	MN	45°35	95°55		T.P.16	5,6,9,10,13	24	6.9	9	148
4/23-24,1960	30	Gurney	WI	46°28	90°30		P.P.16	5,6,9,10,13				
4/28, 1970	31	Hazelton	ND	46°29	100°17		DTH	1,2,5,6,9,10	6	3.8	9	110
4/20-22, 1973	32	Moberly	MO	39°28	92°25		DTH	9,10,11,13	24	8.3	13	122
4/12-14, 1974	33	Magee	MS	31°55	89°42		STR	8,12,15				
5/30-31, 1935	34	Hale	CO	39°36	102°08	MR3-28a	STR	3	6	16.5	3	128
									24	22.2		
5/6-12,1943	35	Warner	OK	35°29	95°18	SW2-20	STR	7,10,11	6	9.9	10	116
									24	17.2	11	134
									72	24.9	10,11	
5/30, 1949	36	Thief Rvr Flls	MN	48°07	96°11		DTD	1,5,9				
5/28, 1961	37	Bar Harbor	ME	44°23	68°12		DTD	18,20				
6/13-18, 1886	38**	Alexandria	LA	31°19	92°33	LMV4-27	STR	8,12				
6/17-21, 1921	39	Springbrook	MT	47°18	105°35	MR4-21	STR	1,2				
6/14-15, 1942	40	Warren 1SE	NH	43°55	71°53		T.P.15	16,17,18,20				
6/10-13, 1944	41	Stanton	NE	41°52	97°03	MR6-15	STR	5,6,7,9,10	6	13.4	5,9	128
								11,13			6,10	141
											11	148
											13	122
6/23-24, 1948	42	Del Rio	TX	29°22	100°37		STR	4,8	24	26.2	4	121
6/23-28, 1954	43**	Vic Pierce	TX	30°12	101°35	SW3-22	STR	4,8	6	16.0	4	116
									24	26.7	8	150
									72	34.6	4,8	
6/30, 1962	44	Cedar Is	NC	34°57	76°17		DTD	17				
6/23-24, 1963	45	David City	NE	41°14	97°05		STR	5,6,7,9,10,11	6	14.6	5	128
											6,9	134
											10,11	141

See last page for notes.

Table 2.--Major storms selected for moisture maximization and transposition (continued)

		Location										
Date	Storm Number	City	State	Lat.	Long.	CoE[1] Assignment Number	Source	Gridpoint(s) transposed to ∇	Critical Duration(s) (hrs	Obs. Depth (in.)	Controlling for grid point(s)	Total storm adjustment (%)
6/24, 1966	46	Mellen Dam	ND	47°21	101°19		STR	1,2,5,6,9	6	11.1	1	148
6/9,1972	47	Rapid City	SD	44°12	103°31	MR10-12	STR	2				
6/20-22, 1972	48	Bolivar	NY	42°05	78°10		STR	16,17,18,20	24	14.3	20	121
									72	18.5		
9/8-10, 1921	49**	Thrall	TX	30°35	97°18	GM4-12	STR	4,8,12,15	24	36.5	8,12	114
9/17-19,1926	50	Boyden	IA	43°12	96°00	MR4-24	STR	5,6,7,9,10,11	6	15.1	5,9	122
								13	24	21.7	6,10	134
											7,11	141
											13	128
6/16-17,1932	51	Westerly	RI	41°22	71°50	NA1-20	STR	16,17,18,20				
9/1, 1940	52**	Ewan	NJ	39°42	75°12	NA2-4	STR	17,18	6	20.1	17	128
											18	122
9/2-6,1940	53	Hallet	OK	36°15	96°36	SW2-18	STR	7,8,11,12	6	18.4	7,8,11,12	141
									24	23.6		
9/3-7,1950	54**	Yankeetown	FL	29°03	82°42	SA5-8	STR	8,12,15,17	24	38.7	8	100
											12,15	98
10/27-30,1900	55	Bedford	IA	40°53	94°34	UMV1-7A		6,9,10	6	5.0	9	122
10/7-11,1903	56	Petersburg	NJ	40°55	74°10	GL4-9	STR	16,17,18				
10/17-22,1941	57**	Trenton	FL	29°48	82°57	SA5-6	STR	8,12,15,17	24	30.0	8,12,15	116
									72	35.0	17	110
10/11-18,1942	58	Big Meadows	VA	38°31	78°26	SA1-28A	STR	16,17,18	24	13.4	18	150
									72	18.7		
10/9-10,1954	59	Aurora	IL	41°45	88°20		STR	10,13	24	11.7	10	150
10/25,1959	60	Pinkham Notch	NH	44°16	71°15		DTD	16,18,20				
10/3-4,1969	61	Hartford	CT	41°50	72°54		STR	15,16,17,18				
10/4, 1971	62	Mt. Weather	VA	39°04	77°53		DTH	16,17,18				
10/10-11,1973	63	Enid	OK	36°25	97°52		STR	6,7,10,11	6	16.9	11	116
									24	18.6	6,10	100
											7	110
11/1, 1909	64	Ironwood	MI	46°27	90°11		T.P.16	5,6,9,10				
11/7, 1915	65	Crosby	ND	48°54	103°18		T.P.16	1,2,5,6				
11/12-15,1922	66	Lakeside	LA	30°02	92°30	LMV3-29	STR	8,12,15				

See last page for notes.

Table 2.--Major storms selected for moisture maximization and transposition (continued)

		Location				CoE[1] Assignment		Gridpoint(s) transposed	Critical Duration(s)	Obs. Depth	Controlling for grid	Total storm adjustment
Date	Number	City	State	Lat.	Long.	Number	Source*	to ∇	(hrs)	(in.)	point(s)	(%)
11/2-4,1927	67	Kinsman Notch	NH	44°03	71°45	NA1-17	STR	16,17,18	6	7.8	16,18	141
									24	12.0		
									72	14.0		
11/15-17,1928	68	Iola	KS	37°55	95°26	MR3-20	STR	6,7,10,11,15	24	9.0	6	111
											10	122
11/22-25,1940	69	Hempstead	TX	30°08	96°08	GM5-13	STR	7,8,11,12	24	18.6	7	100
									72	21.1		
11/1, 1969	70	Fernandina Bch	FL	30°41	81°28		DTD	15,17				
12/5-8, 1935	72	Satsuma	TX	29°54	95°37	GM5-4	STR	8,12,15	24	18.6	8,12,15	150
									72	20.8		
12/29-1/1/49	73	Berlin	NY	42°40	73°19		STR	18	6	3.5	18	150
									24	8.1		
									72	12.6		
12/27, 1969	74	Mt.Washington	NH	44°16	71°18		DTD	a				
12/10, 1971	75	Vallient	OK	34°00	95°06		DTD	7,11				

NOTES:

1. CoE: Corps of Engineers

* Source (refer to table 1)

STR: Storm Rainfall

T.P. 16: Technical Paper No. 16

DTH: Data tape; hourly precipitation

DTD: Data tape, daily precipitation

**: Distance-from coast adjustment used.

∇ See figure 1 for grid point locations

a: not transposed (see par. 7.2)

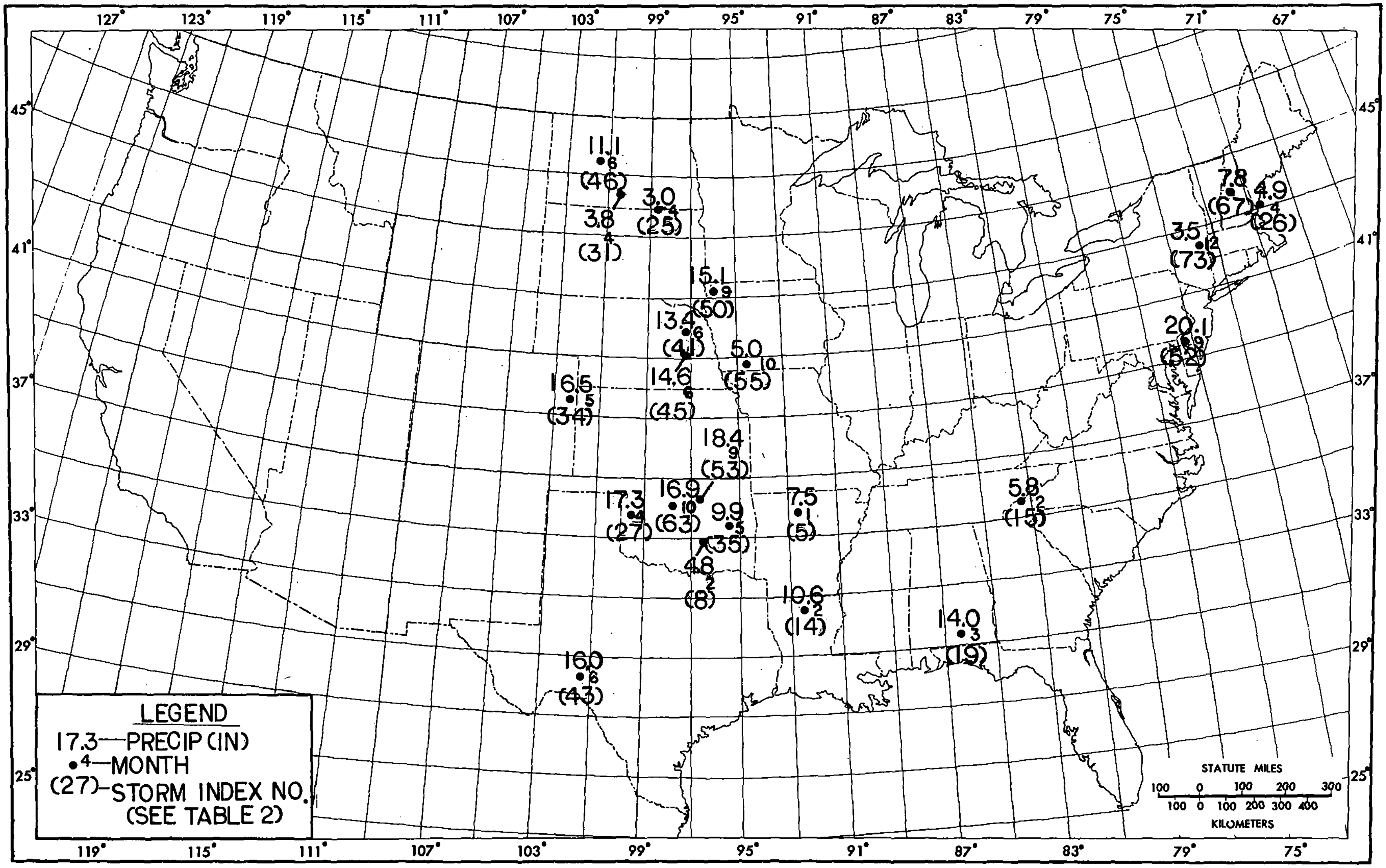


Figure 1a.--Storms controlling PMP (September through June) for 6 hours.

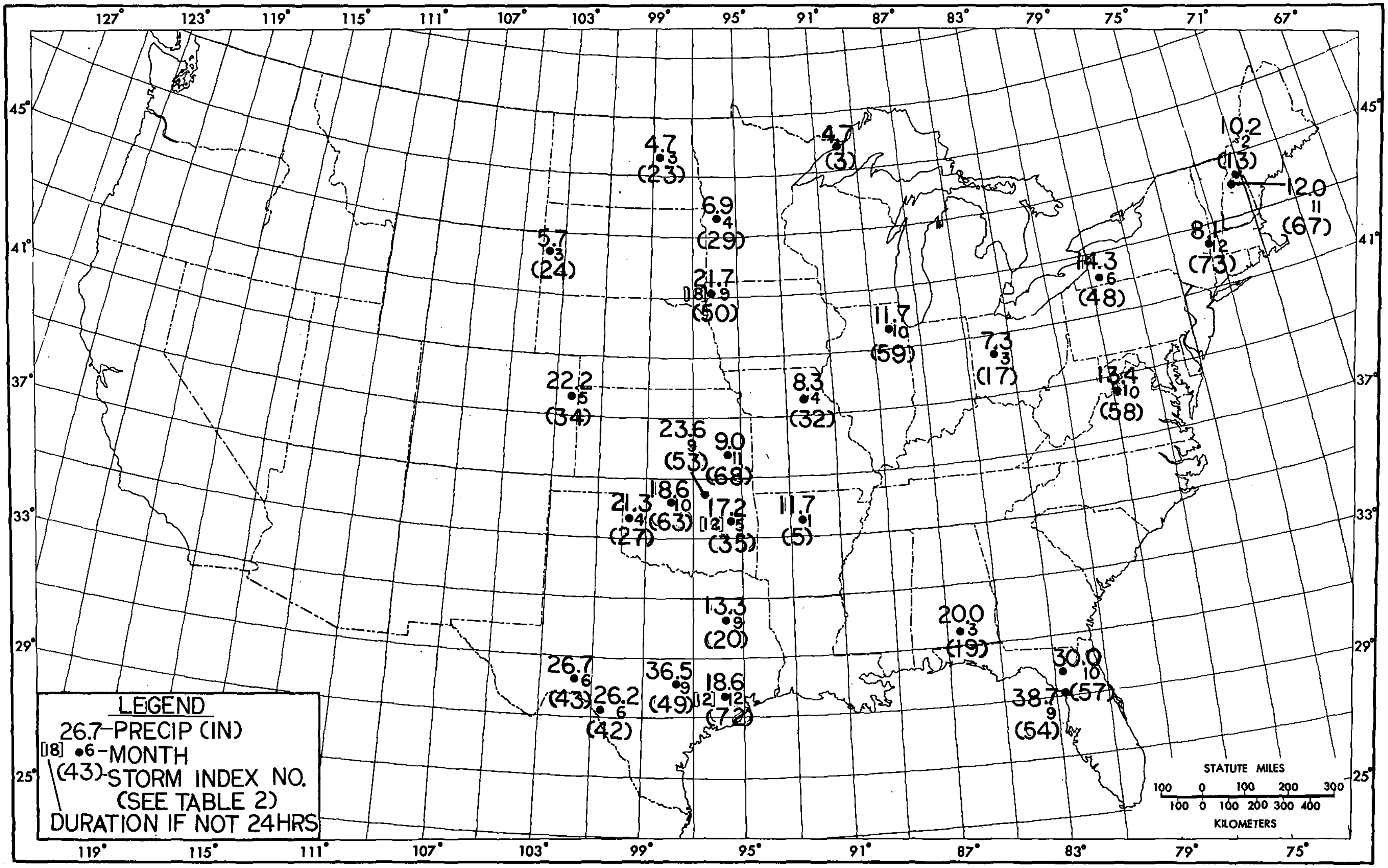


Figure 1b.--Storms controlling PMP (September through June) for 24 hours.

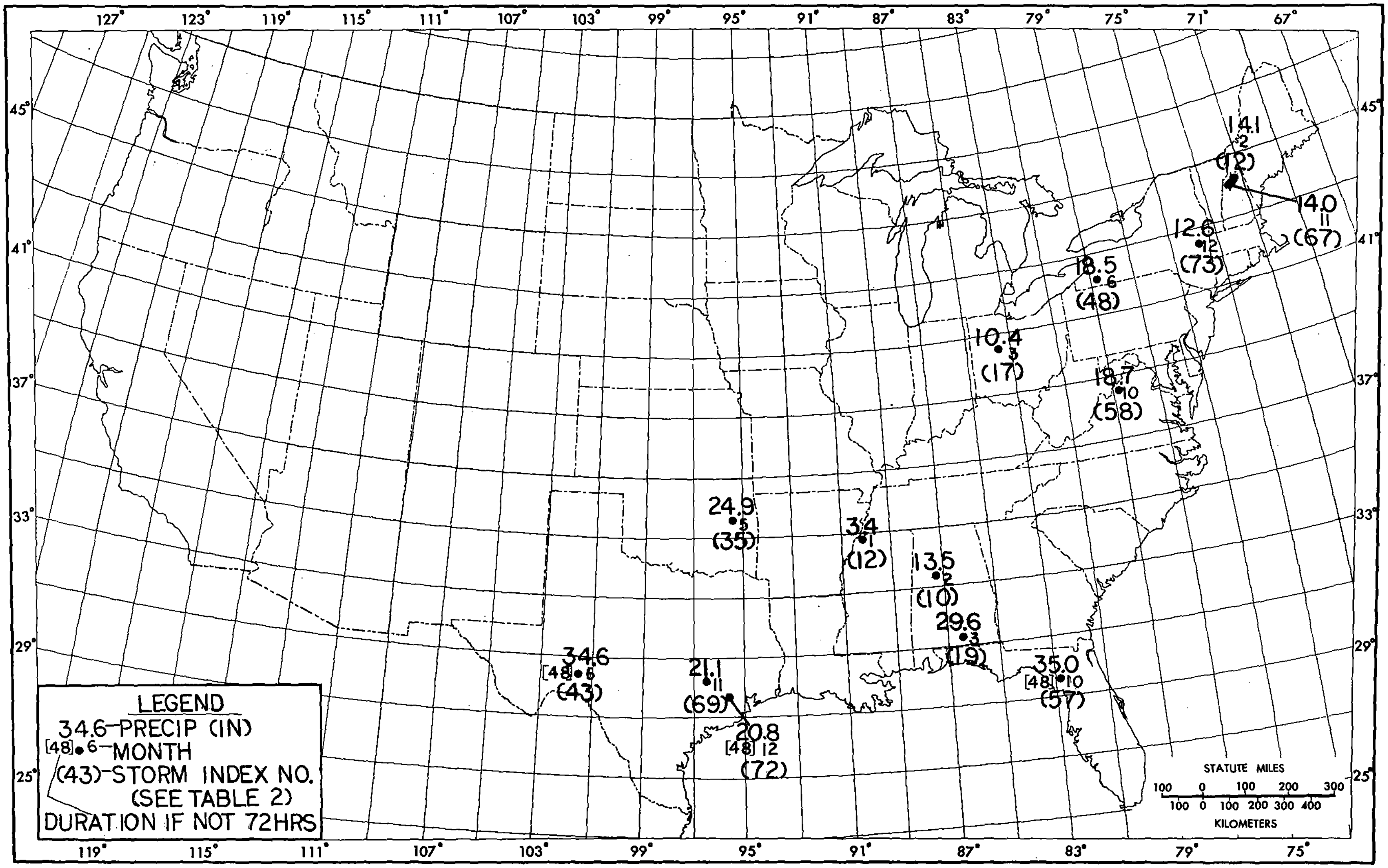


Figure 1c.--Storms controlling PMP (September through June) for 72 hours.

Table 3.--Important storms centered in Canada near the U.S. border

Date	Storm no.	Location				Critical duration(s) (hr)	Rainfall depth (in.)
		City	Province	Lat.	Long.		
1/15-17,1958	76	Liverpool	NS	44°08	64°56	24	5.8
						60	10.0
3/31-4/2,1962	77	Alma	NB	45°36	64°57	24	9.3
5/25-28,1961	78	--	--	45°47	66°45	6	4.0
						24	9.5
						72	11.8
5/30,1961	79	Buffalo Gap	Sask.	49°07	105°17	6	10.5
6/29-7/1,1935	80	Tilson	Man.	49°22	101°18	60	13.0
9/20-23,1942	81	Stellarton	NS	45°34	62°39	72	13.4

therefore published (Ho and Riedel 1979) the maximum observed semimonthly precipitable water (w_p or depth of liquid equivalent of the water in a column of air) for more than 100 stations for the period of record. This information was useful guidance. However, radiosonde data alone cannot be used for moisture maximization for several reasons. First, many extreme storms occurred before the radiosonde network was established. Second, the radiosonde network is too sparse to detect narrow tongues of moisture that are important to many storms. The solution was to use surface dew points, which are observed by many stations, as indices to atmospheric moisture. A saturated pseudo-adiabatic atmosphere is assumed, tied to surface dew points, which fixes the moisture and its distribution with height in the atmosphere. Tests have shown that the moisture thus computed is generally an adequate approximation to atmospheric moisture in major storms or for high dew point situations (Miller 1963). For a saturated pseudo-adiabatic atmosphere, tables have been prepared (U.S. Weather Bureau 1951) giving w_p values based on 1000-mb dew points.

Two dew points are required for moisture maximization. One is the dew point representative of moisture inflow during the storm. The other is the maximum dew point for the same location and time of year as the storm. Both storm and maximum dew points are reduced pseudo-adiabatically to 1000 mb to normalize for differences in station elevations.

Both storm and maximum dew points are usually taken as the highest value persisting for 12 hours. Instantaneous extreme dew point measurements may not be representative of inflow moisture over a significant time period. Also, taken over a duration, the effect of possible erroneous instantaneous dew point values is reduced.

3.3.3 Representative Storm Dew Point

Dew points are selected in the warm moist airflow into the storm. Both distance and direction of the dew points from the rainfall center are recorded. An average dew point value from several stations is considered to give the best estimate. Care must be used to insure that dew point observations are taken within the moist tongue involved in the heavy precipitation. The time sequence of dew points from each station is reduced to 1000 mb before averaging. After averaging, the highest persisting 12-hr value is selected.

3.3.4 Maximum Dew Point

Maximum dew points are generally the highest dew points observed for a given location and time of year. These dew points are based on seasonal and regional envelopes of maximum observed surface dew points that have persisted for 12 hours, reduced to 1000 mb, at many stations (Environmental Data Service 1968).

We adjust the storm to the maximum dew point 15 days from the storm date into the warmer season except for one case, the Hale, Colo., storm of 1935 which was accompanied by unusually cold air judged to be dynamically significant to the rainfall. Moisture maximization adjustments are increased by up to 10 percent by the 15-day seasonal transposition into the warm season. In the cool season (December-February), the 15-day leeway usually does not change the moisture adjustment.

3.3.5 Moisture Adjustment

Moisture maximization is accomplished by multiplying observed rainfall by the moisture adjustment, which is the ratio of w_p for the maximum 1000-mb 12-hr persisting dew point to the w_p for the storm 1000-mb 12-hr persisting dew point. Theoretical justification for this adjustment is found in HMR No. 23 (U.S.W.B. 1947). This maximization expressed mathematically is:

$$P \times \frac{w_p \text{ (maximum)}}{w_p \text{ (storm)}} = \text{moisture adjusted rainfall}$$

where

P = observed rainfall

w_p = precipitable water. (Maximum) refers to enveloping highest observed w_p and (storm) refers to the storm w_p. (Both dew points are for the same location.)

3.3.6 Elevation and Barrier Considerations

Where there is a significant mountain barrier between the moisture source and rain location, or the rain occurs at high elevations, a refinement is sometimes applied to the moisture adjustment. In such cases, mean elevation of the barrier ridge, or elevation of the rainfall rather than the 1000-mb surface, is used as the base of the column of moisture. For the region of our study, location of representative storm dew points (usually toward a coast and at lower elevations) and restrictions to storm transposition (par. 3.4.2) generally eliminated the need for using elevation in the moisture adjustment.

3.4 Transposition

3.4.1 Definition

Transposition means relocating storm precipitation within a region that is homogeneous relative to pertinent terrain and meteorological features.

3.4.2 Transposition Limits

Topography is one of the more important controls on limits to how far storms can be transposed. If observed rainfall patterns show correspondence with underlying terrain features, or indicate triggering of rainfall by slopes, transposition should be limited to areas of similar terrain. Identification of broadscale meteorological features is important, e.g., surface and upper air high- and low-pressure centers that are associated with the storm, and how they interact to produce the rainfall. Thus, useful guidance to determining transposition limits are storm isohyetal charts, weather maps, storm tracks, rainfalls of record for the type of storm under consideration, and topographic charts.

The more important limits to storm transposition for this study were:

a. Transposition was not permitted across the generalized Appalachian Mountain ridge.

b. Tropical storm rainfalls were not transposed farther away from nor closer to the coast without an additional adjustment (par. 3.4.4) in cases where the maximum dew point charts showed no variation.

c. In regions of large elevation differences, transpositions were restricted to a narrow elevation band (usually within 1000 feet of the elevation of the storm center).

d. Eastward limits of transposition of storms located in the Central United States were the first major western upslopes of the Appalachians.

e. Westward transposition limits of storms located in Central United States were related to elevation. This varied from storm to storm but in most cases the 3000- or 4000-ft contour was used to set the limit.

f. Southward limits to transposition were generally not defined since other storms located farther south usually provided higher rainfall values.

g. Northward limits were not defined if they extended beyond the Canadian border (the limit of the study region).

We used a simplification in transposing by making decisions for each critical storm on whether or not to transpose to each of 20 grid points covering the study region. These points are shown on figure 2. A similar set of points was used as a test in the all-season study (HMR No. 51) for transposition rather than setting outer bounds. After regional smoothing, thus extending the influence of major storms, the results of the two techniques are similar for the area size of this study.

3.4.3 Transposition Adjustment

The transposition adjustment applied to relocated rainfall values is the ratio of w_p for the maximum 12-hr persisting dew point for the transposed location to that of the storm in place. The maximum dew point is for the same distance and direction from the transposed location as the storm representative dew point is from the storm location (par. 3.3.3).

3.4.4 Distance-From-Coast Adjustment for Tropical Storm Rainfall

The general decrease in tropical storm rainfall with distance inland is well known. It is attributed to the difficulty of maintaining the same rainfall intensity as distance from the moisture source increases, and to the deterioration of the tropical storm circulation with increasing distance inland.

A study (Schwarz 1965) developed a relation showing the distance in tropical rainfall with distance up to 300 n.mi. inland. The relation was based on both observed and moisture-maximized tropical rainfall data for several area sizes and durations. Figure 3 shows this variation along with its extension for distance farther inland. It shows no decrease in rainfall for the first 50 n.mi. inland from the gulf coast, a smooth decrease to 80 percent at 205 n.mi. inland, and 55 percent at 400 n.mi. inland.

We applied the adjustment for distance-from-coast to tropical storm rainfall (all durations) transposed within the region where the maximum 12-hr persisting dew point charts (Environmental Data Service 1968) indicate no variation. When transposing tropical storm rainfalls farther from the coast, the values are decreased. In the same way, they are increased when transposed nearer to the coast.

Of the major rains shown in table 2 we applied the distance-from-coast adjustment to six storms. These storms are identified with a double asterisk by the storm number.

3.5 Total Storm Adjustment

Table 2 includes the grid points to which the selected major storm rainfalls were transposed, the grid point where the storm was most important, and the total adjustment to the rainfall for those grid points. This total adjustment is the product of the adjustments for maximum moisture and for storm transposition; the latter was determined either from maximum dew points or from the distance-from-coast relation.

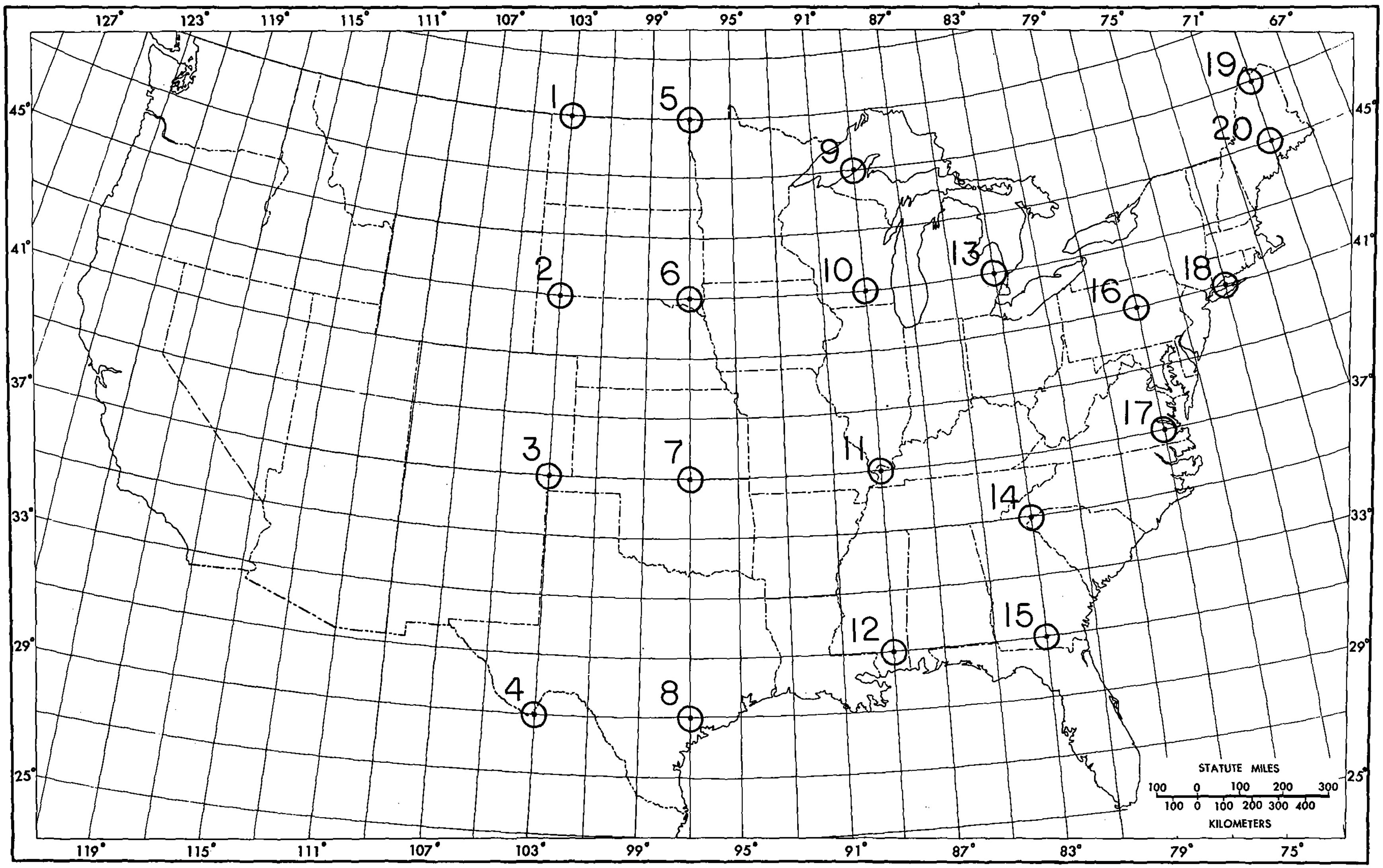


Figure 2.--Grid points used for transposition.

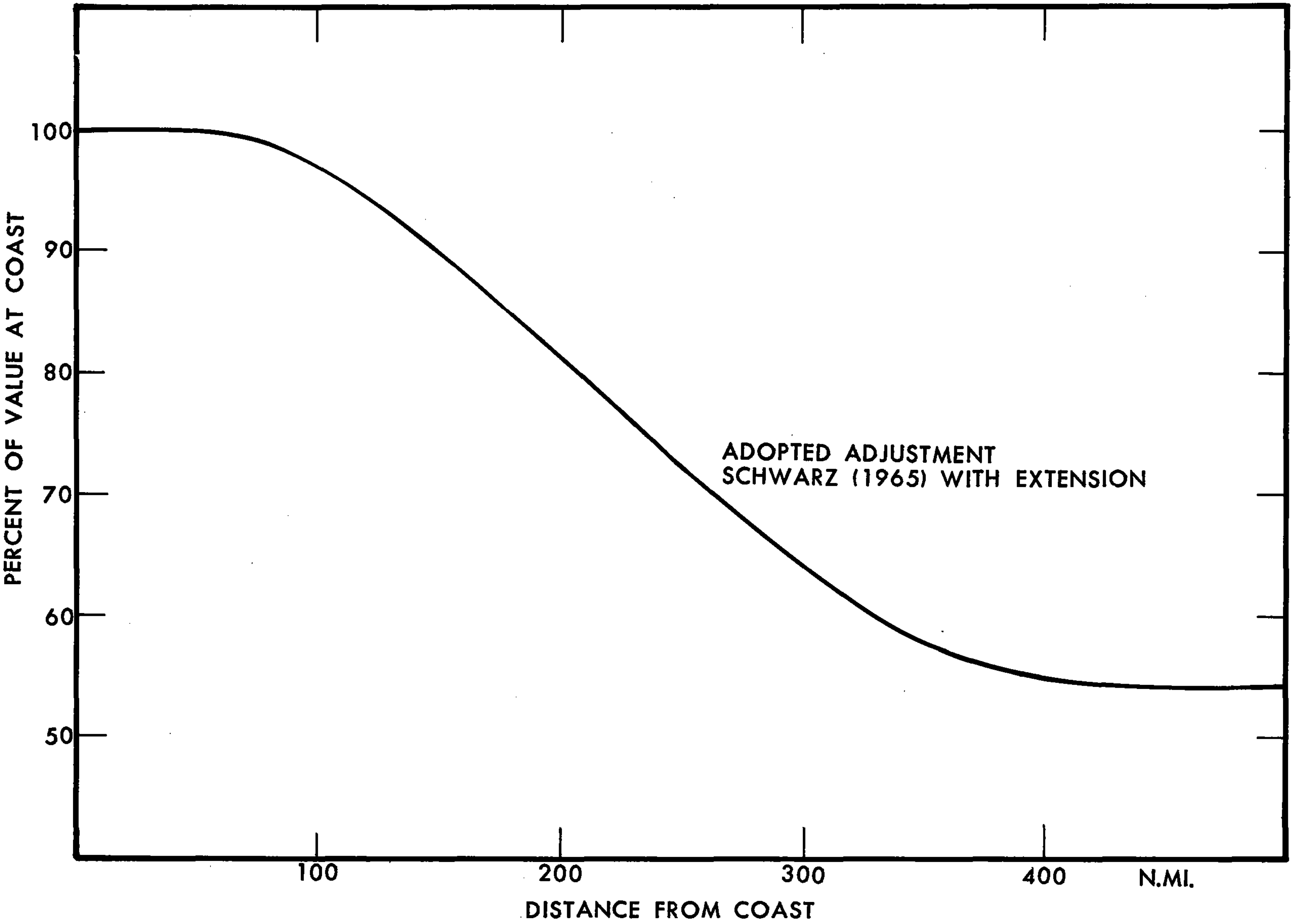


Figure 3.--Distance-from-coast adjustment for transposing tropical storm rainfall (from HMR No. 51.).

3.6 Envelopment

Moisture maximization and transposition of major storms to the 20 grid points set the very lowest value of PMP for each month at these points. How much to envelop these values and give consistent PMP from place-to-place, month-to-month and duration-to-duration is the major portion of this study.

3.6.1 Durationally

By this we mean smooth curves of rainfall depths extending from one duration to another. Such smooth curves imply that the storm record has given more extreme depths for certain selected durations than for others.

3.6.2 Seasonally

Seasonal envelopment, in much the same context as in durational envelopment, assumes the storm record does not provide equally extreme depths for all months. We thus draw smooth seasonal curves for a selected grid point, enveloping all of the data for some months.

3.6.3 Regionally

We assume that except for topographic and coastal influences we should have a smooth regional pattern of PMP.

4. ANALYSES

4.1 Introduction

We have set the stage by describing the available data and the basic concepts that bear on the results and on how these results will be reached. We now give details of the data analyses leading to our goal.

One additional consideration entering into our procedures is how to show results concisely but fully, that is, how to show PMP for durations for 6 to 72 hours for 10 mi^2 for each month for the study region. Tests have shown that for a point east of the 105th meridian when PMP values for 6, 24, and 72 hours are plotted on linear graph paper (duration vs. depth) and joined by a smooth curve through the point of origin (0,0) the curve adequately defines PMP by 6-hr increments to 72 hours. We decided to present maps covering the region for each month showing PMP depths at midmonth in inches, for 6, 24, and 72 hours. (For July and August, the mapped values turn out to be identical to the all-season PMP of HMR No. 51 and to each other for the entire study region. Similarly, the PMP values for January and February are the same).

In our approach, we need to take care that the smoothing procedures give PMP values that are not unrealistically extreme: each smoothing step, if not done with care, could give a cumulative envelopment that results in an unreasonably large final product. This concern must be balanced with the basic need -- that at the least, all known observed rainfall depths maximized for moisture should be enveloped. Further, our results should, to the best of our capability, give extremes that will not be exceeded by future storms.

4.2 Minimum PMP at 20 Grid Points

Seasonal plots were made for each of the 20 grid points (fig. 2) of the greatest moisture maximized and transposed from depths for 6, 12, 24, 48, and 72 hours. We then drew tentative smooth enveloping curves for these data for 6, 24 and 72 hours on each plot. An example of these plots and in this case the final smooth enveloping curve is shown in figure 4. The storms on the figure (identified by a number near the X axis) can be identified by storm number in table 2.

The remainder of chapter 4 gives analysis of various rainfall data that was helpful in decisions on how to obtain a consistent set of PMP values for all durations, months, and locations.

4.3 Statistical Computations of Taped Rainfall Data (1948-73)

Using computer programs we determined a variety of products that could influence or give guidance to our study. The first simple product, of course, is a tabulation of the greatest observed depths for a specified duration for each month of observation. Such maxima lend themselves to statistical analysis.

From the rainfall for each station recorded on tape with 20 or more years of record, the maximum values for each month for a duration of interest were put into series of all January maxima, all February maxima, etc. To each series we fitted the Fisher-Tippett type I distribution by the Gumbel fitting procedure. This statistical distribution is used almost exclusively by the National Weather Service, for precipitation frequency analysis (Hershfield 1961 and Frederick et al. 1977).

From the fits, the rainfall amounts with 0.04 and 0.01 chance of being equalled or exceeded for each month at each station were abstracted (hereafter referred to as 4 percent and 1 percent probability level rainfalls). These rainfall amounts for all stations located with each 2° latitude and longitude quadrangle were then averaged. This was done for quadrangles overlapping (both in the north-south and east-west direction) by 1° latitude and longitude, respectively. This averaging was a smoothing step.

Table 4 summarizes the statistical analyses for 6, 24, and 72 hours. The sets of 4 percent and 1 percent probability level and maximum values which were computed and plotted on maps using a computer program are indicated in table 4, part 1. Figure 5a is an example of the 6-hr 4 percent probability level values for November and their analyses.

Part 2 of table 4 refers to maps of the ratios of monthly values to the maximum value for any one of the 12 months. These ratios are guides to the corresponding ratio of monthly PMP to all-season PMP. Figure 5b is an analyzed example of these ratio maps for the 4 percent probability level amounts for 6 hours for November. The values shown in this figure came from combining the ratios in each quadrangle for the months of November and December. The highest ratio of the two months was selected and plotted.

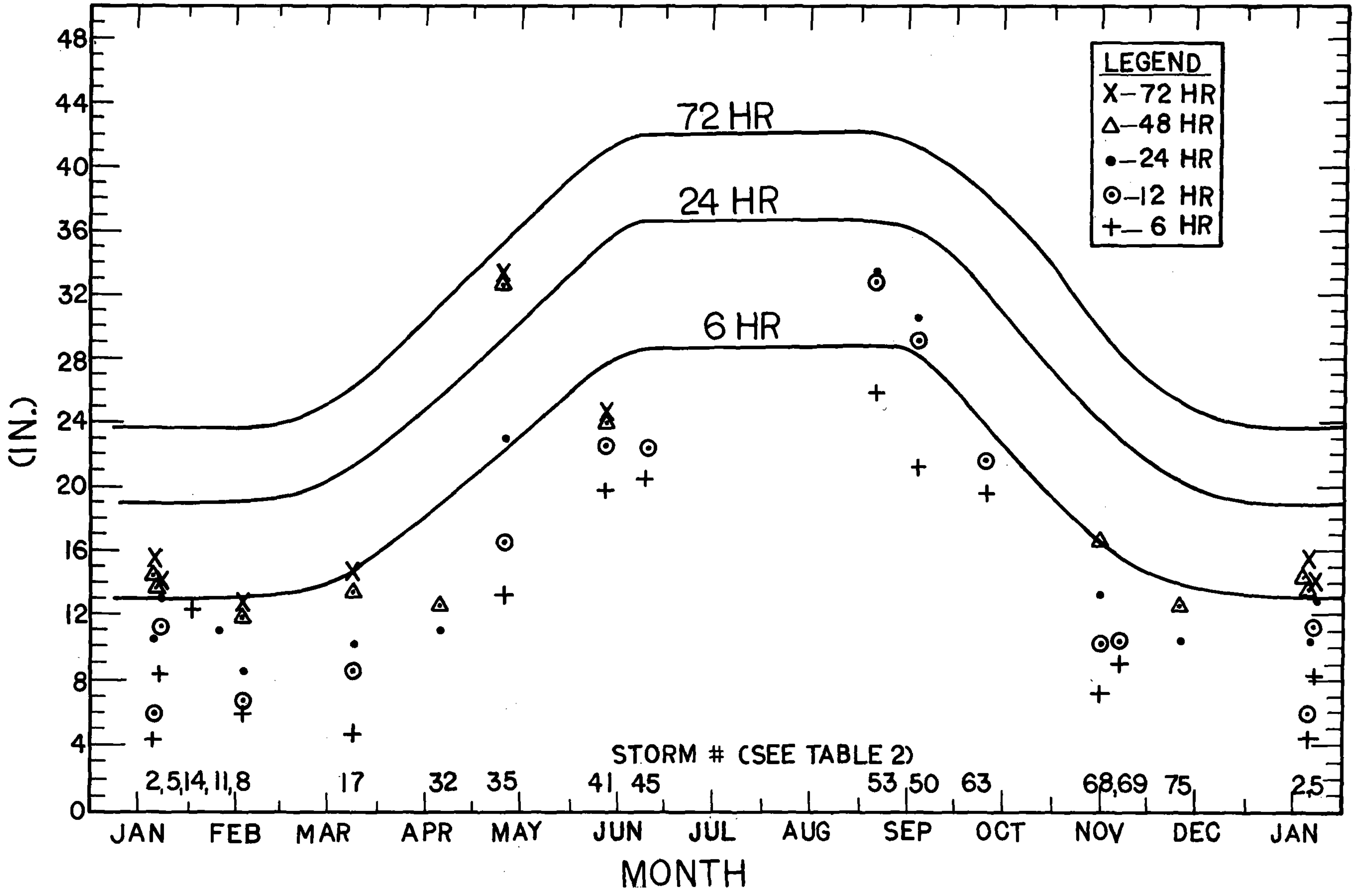


Figure 4.--6-, 24-, and 72-hr PMP for grid point 11, (37°N, 89°W) Data are moisture maximized and transposed storm rainfall depths.

Table 4.--Statistical analyses for 1948-73 station precipitation on magnetic tapes

		*4%	*1%	maximum
<u>Part 1</u>				
12 maps, each duration, in inches	6 hr	X	X	X
	12 hr	X	X	X
	24 hr	X	X	X
	1 day	X	X	X
	2 day	X	X	X
	3 day	X	X	X
<u>Part 2</u>				
12 maps, each duration, % of highest month	6 hr	X	X	X
	12 hr	X	X	X
	24 hr	X	X	X
	1 day	X	X	X
	2 day	X	X	X
	3 day	X	X	X
<u>Part 3</u>				
2 maps, each duration of month of maximum and and minimum	6 hr	X	X	X
	12 hr	X	X	X
	24 hr	X	X	X
	1 day	X	X	X
	2 day	X	X	X
	3 day	X	X	X
<u>Part 4</u>				
12 maps, each rain ratio	6/24	X	X	X
	12/24	X	X	X
	72/24	X	X	X

*4% and 1% probability values based on Fisher-Tippett Type I distribution fitted by the Gumbel procedure.

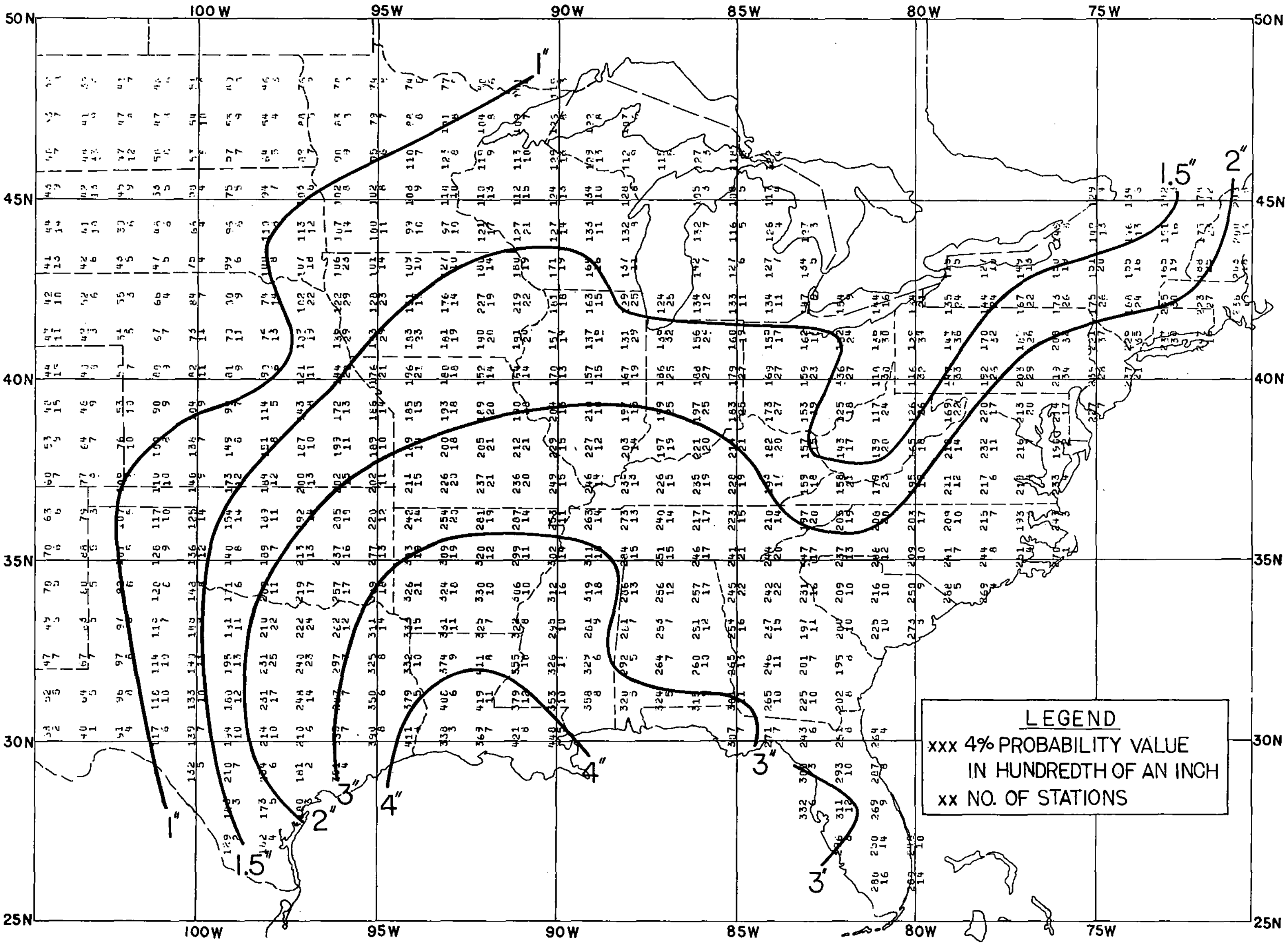


Figure 5a.--4% probability values for 6-hr duration for November.

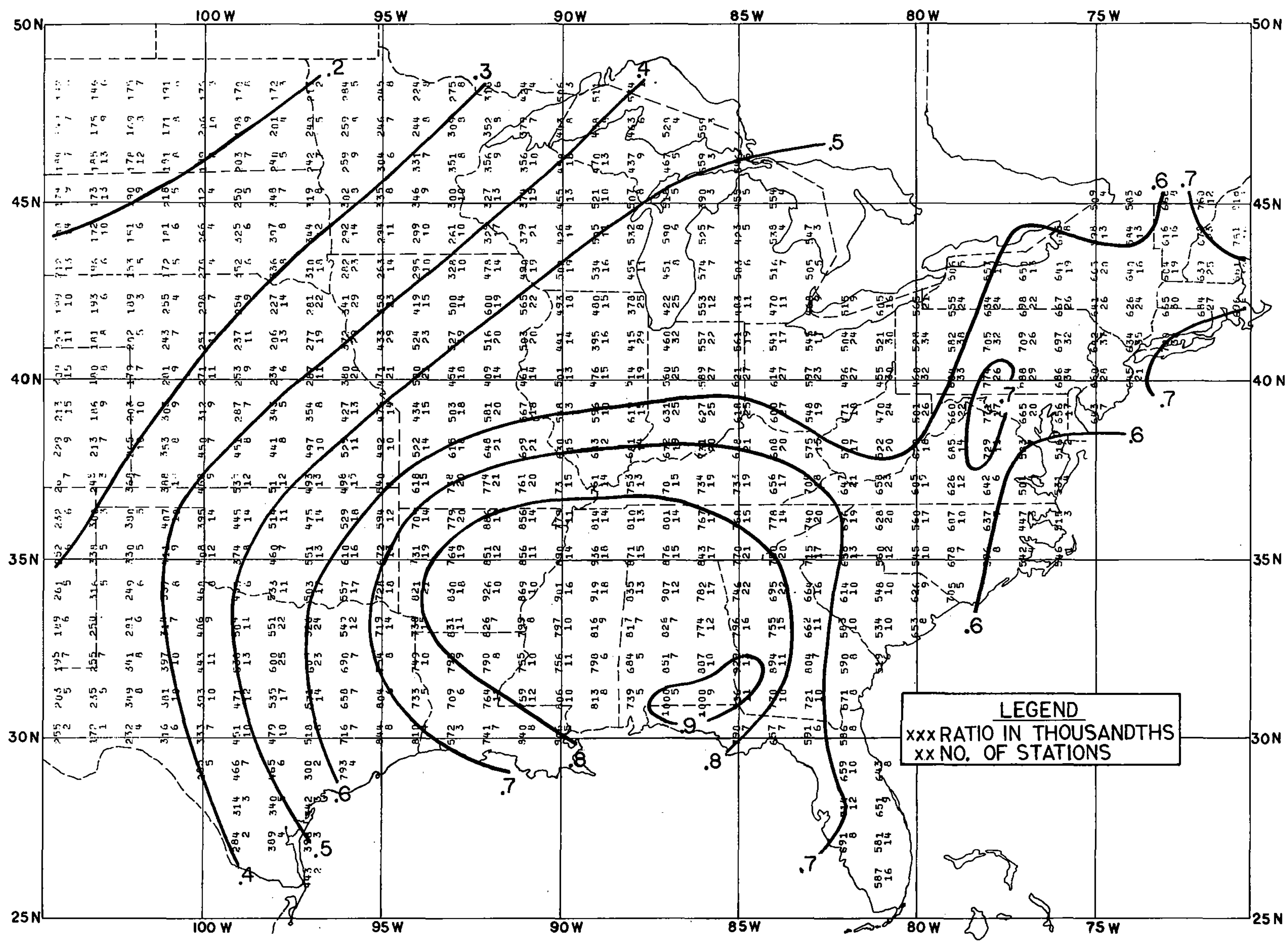


Figure 5b.--Ratios of 4% probability values for 6-hr duration for November or December to the highest of the 12 monthly values.

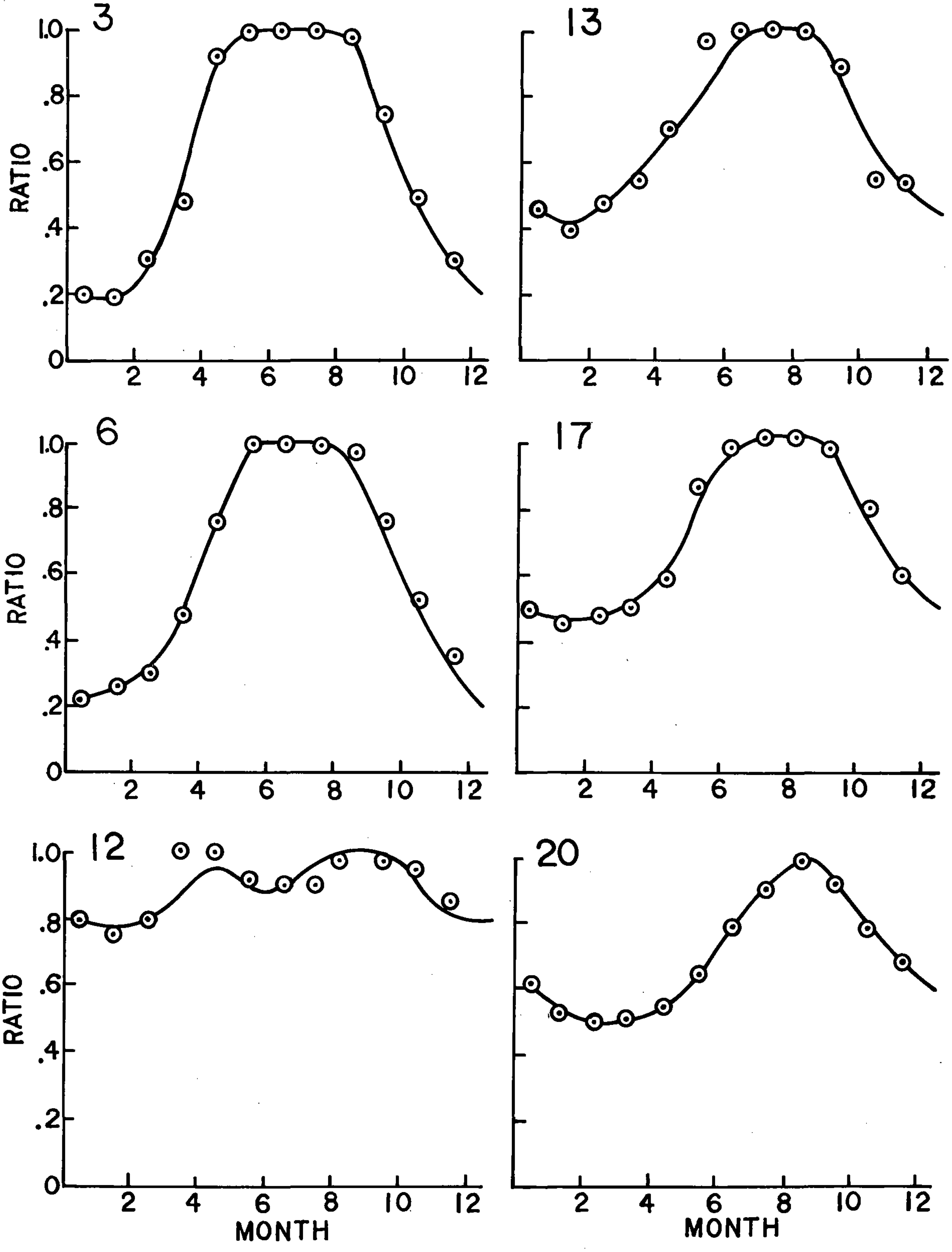


Figure 5c.--Seasonal variation of ratios of monthly maxima to the highest monthly 4% probability values for 6-hr duration (grid points 3, 6, 12, 13, 17, 20).

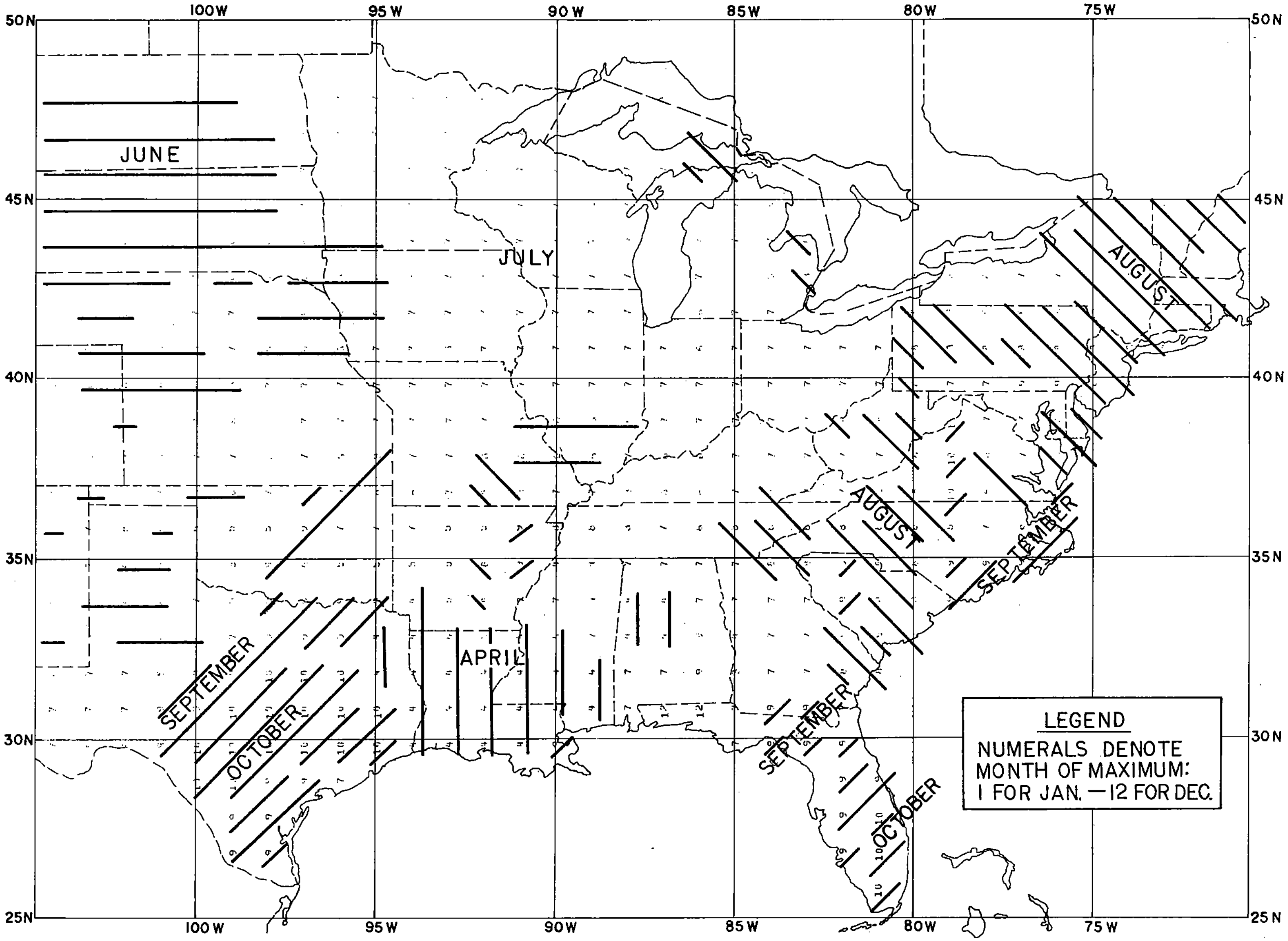


Figure 5d.--Month of maximum 4% probability values for 6-hours.

This procedure, applied to all pairs of successive months, was designed to avoid anomalous month-to-month variations.

For the 20 grid points (fig. 2) values were taken from the analyzed ratio maps and plotted on seasonal charts, one for each of the three durations. Figure 5c shows some examples of the results for 6 hours. Equating the highest value to all-season PMP and multiplying this depth by the percents of the maximum, gave us an estimate of PMP for each month based only on the 4 percent probability variation.

The analyzed maps showing the months of maximum and minimum months for the 4 percent, 1 percent and maximum of record levels (part 3 of table 4) also provided helpful information. Figure 5d is an example of the maps showing the month of maximum 4 percent probability level values for the 6-hr duration.

Part 4 of table 3 shows that maps were prepared giving the ratios of 6/24-, 12/24-, and 72/24-hr and 3-day/1-day rains (4 percent, 1 percent, and maximum of record levels). Such ratios are a guide to maintaining depth-durational consistency in the final product.

4.4 Maximum Observed Rainfall Values

Under par. 3.2 we discussed maps of maximum rainfall based on all the data sets listed in table 1. Such maps were developed for 6-, 12-, 24-, 48-, and 72-hr durations. Smooth regional analyses were made of data on each of these maps, taking into account in at least a gross manner, the maximum values on adjacent maps so that there would not be unrealistic changes from month to month. This resulted in a few extreme storms being undercut. Of course without moisture maximization and transposition these analyses give values that are too low for PMP. Figures 6a, 6b, and 6c are examples of maps of the extremes with analyses for 6-hr, 24-hr, and 72-hr durations, respectively, for November. These maps show storm depths with numbers in parentheses, in some cases, that correspond to the storm numbers in table 2.

From the map analyses, values were read for the 20 grid points (fig. 2). Smooth seasonal curves were drawn to these monthly maxima for each grid point separately. Another set of monthly curves were developed by expressing each month's depth in percent of the maximum (of the 12 months). The resulting smooth curve is, then, a seasonal variation of percents of the maximum month (100 percent) based only on the analysis of observed data. Figure 6d is an example of the seasonal variation of the ratios for 6-hour rainfall for 6 selected grid points.

4.5 Maximum Atmospheric Moisture

4.5.1 Precipitable Water in Soundings

Since we adjust record storms to maximum moisture (w_p), guidance to our work here is maximum observed moisture at upper-air sounding stations. Such w_p values have been computed for twice-a-day soundings for the period of reliable records for all U.S. stations and the maximum values extracted on a semimonthly basis (Ho and Riedel 1979). In that publication, such values have also been plotted on maps and analyzed for our study region. These analyses were smoothed seasonally as well as regionally. Figure 7a is an example of such maps taken from that publication.

4.5.2 Surface Dew Points

In par. 3.3.4 we briefly described maps of maximum 1000-mb 12-hr persisting dew points (T_d). These maps, being an index to moisture in the atmosphere, are also clues to smooth seasonal and regional patterns of extreme rainfall. An example of these maps is shown in figure 7b.

4.5.3 Seasonal Variation of Maximum Moisture

We determined the seasonal variation of both maximum w_p and maximum T_d (see figures 7a and 7b for examples) by expressing each month or half-month value as a percent of the highest of the year for each of the 20 grid points. Figure 7c shows examples of these smooth seasonal curves.

4.6 Seasonal Variation of Rainfall at Selected Long Record Stations (1912-61)

Daily precipitation amounts of some 50 selected stations with 50 years of record (1912-61) are recorded on magnetic tape. This record was processed in the same way as the 1948-73 tape data (par. 4.3), except that the data were not spatially averaged. Seasonal variations of these computed parameters were plotted for each station separately.

Figure 8 shows the unsmoothed and computer-produced plots for Duluth, Minn., and Kansas City, Mo., for the 3-day duration. For each month, the maximum observed value, the 1 and 4 percent probability values, and the ratio of each month's 4 percent probability value to the maximum monthly value for the year are given.

4.7 Rainfall Depth-Duration Relations

4.7.1 Within Storm

Depth-duration relations of rainfall in major storms and their variations within the region and seasonally, give guidance to depth-duration relations for PMP. The 6- to 24-hr (6/24) rain ratios together with 72- to 24-hr (72/24) rain ratios quite adequately define depth-duration relations from 6 to 72 hours. We computed these two sets of ratios for the major storms for 6, 24 and 72 hours given in *Storm Rainfall in the United States* for each month. High 6- and high 24-hr depths were both considered for 6/24 ratios in order not to bias the results. Similar data selection was carried out for the 72/24 ratios. Of course, for the storm to be counted, it had to last at least 24 hours for a 6/24 ratio and 72 hours for a 72/24 ratio.

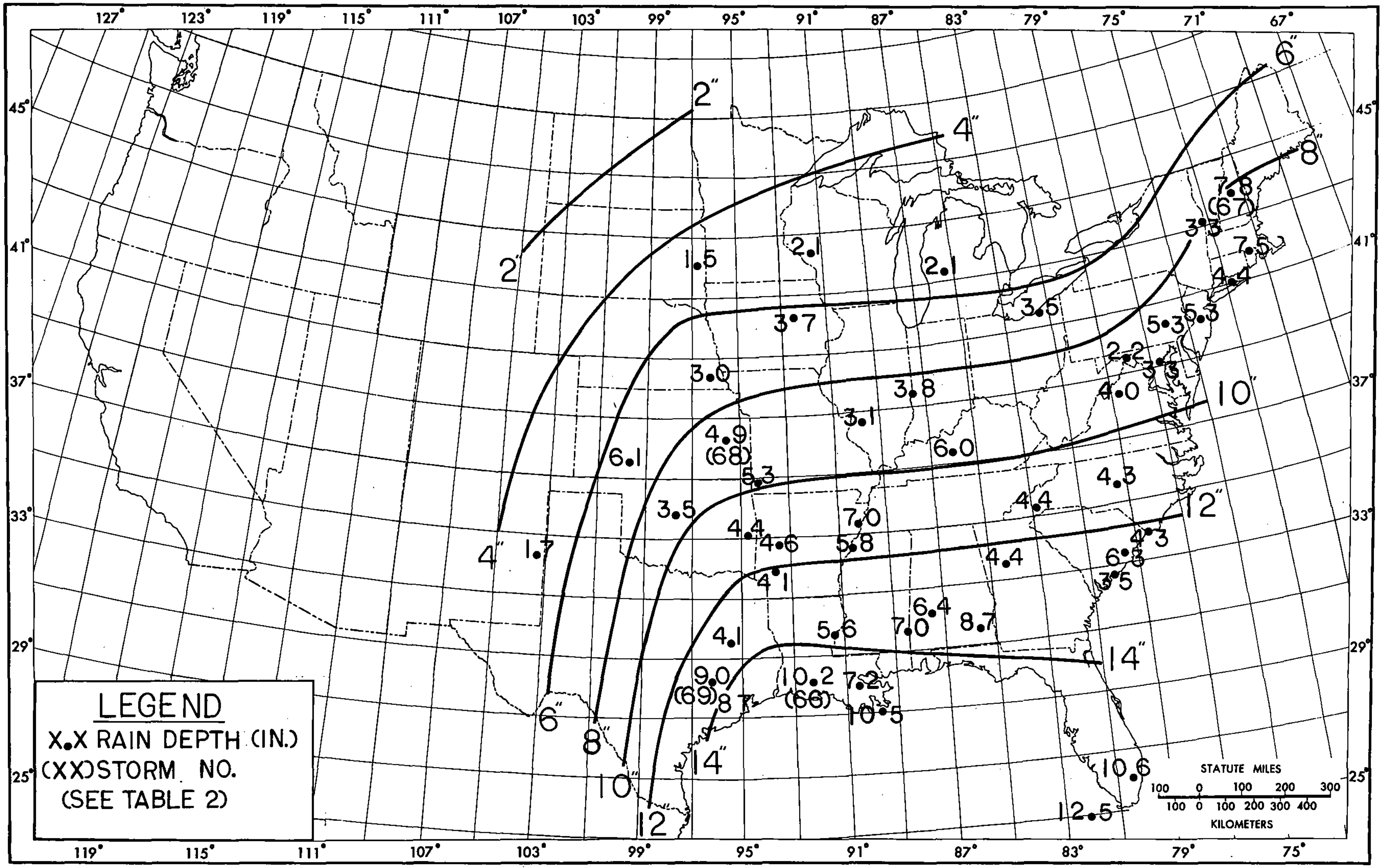


Figure 6a.--Example of analyzed maps of greatest observed 6-hr rainfall (November).

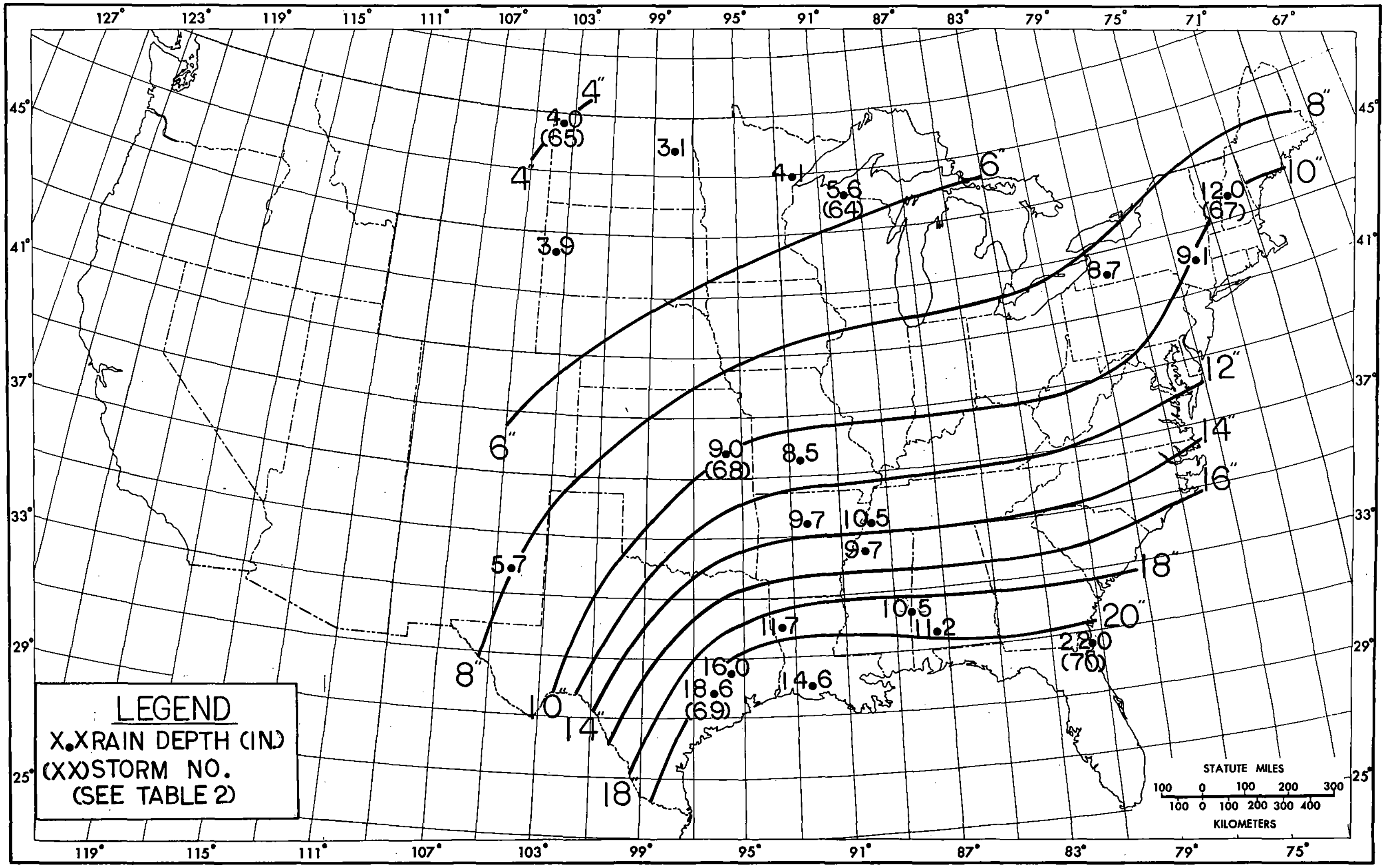


Figure 6b.--Example of analyzed maps of greatest observed 24-hr rainfall (November).

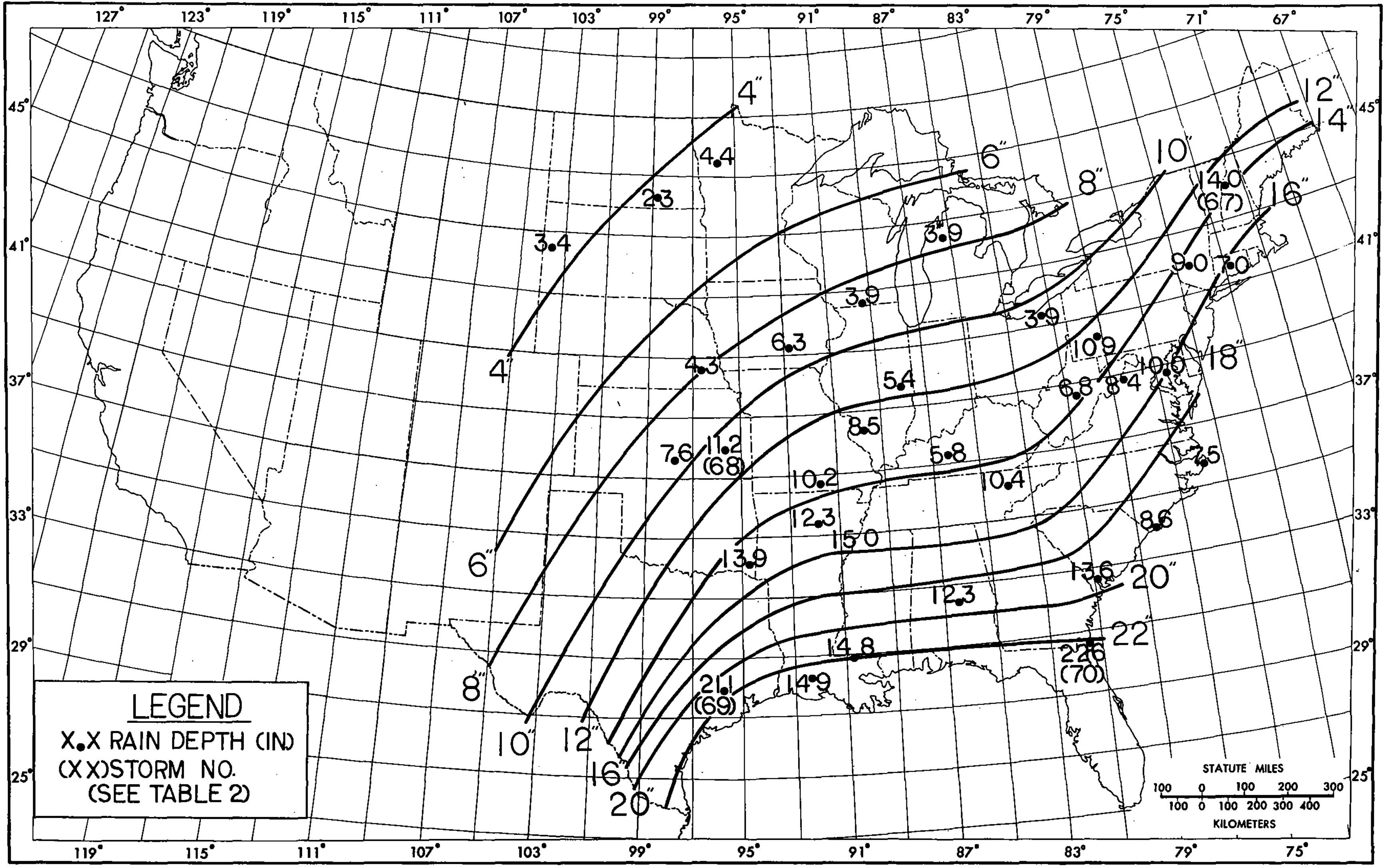


Figure 6c.--Example of analyzed maps of greatest observed 72-hr rainfall (November).

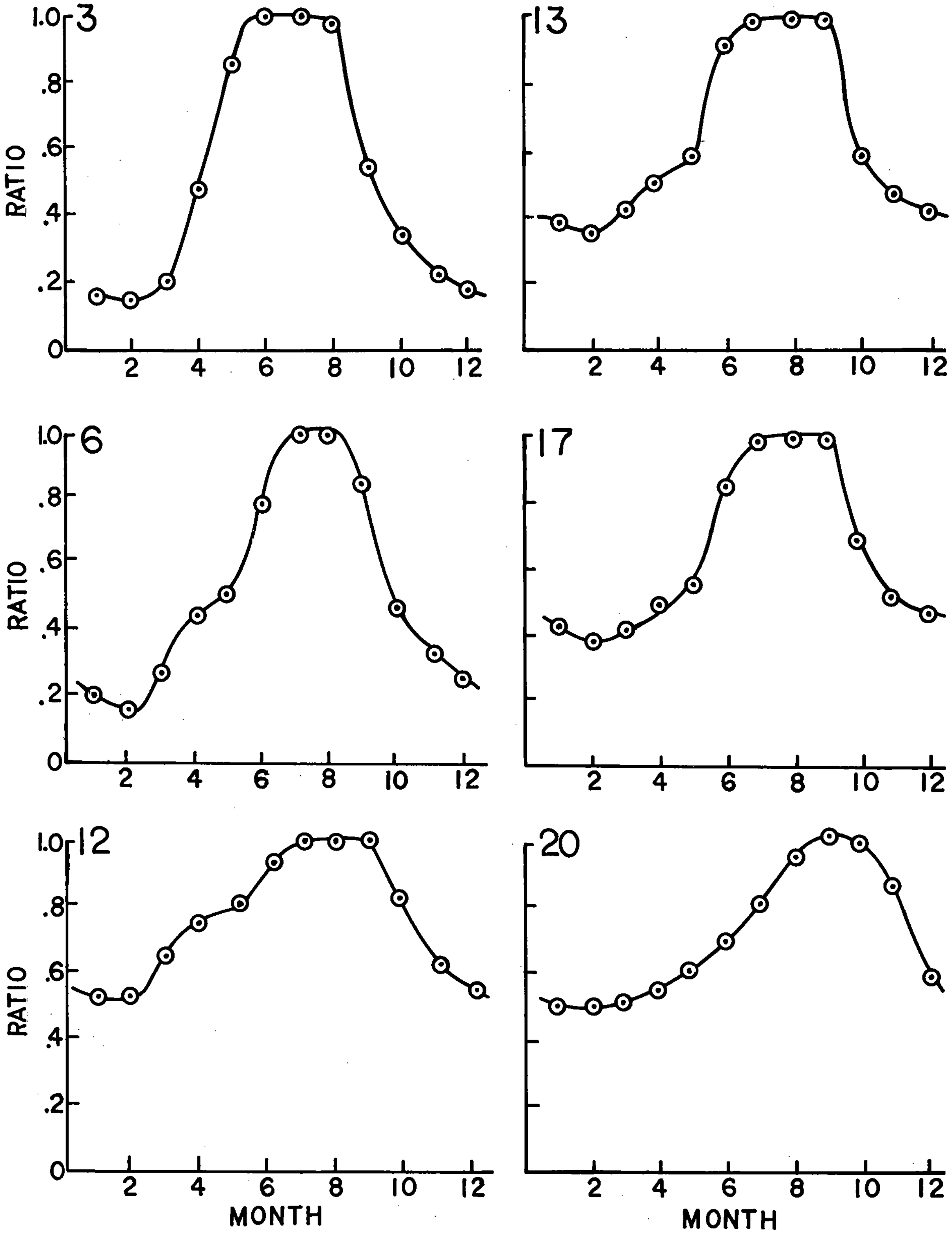
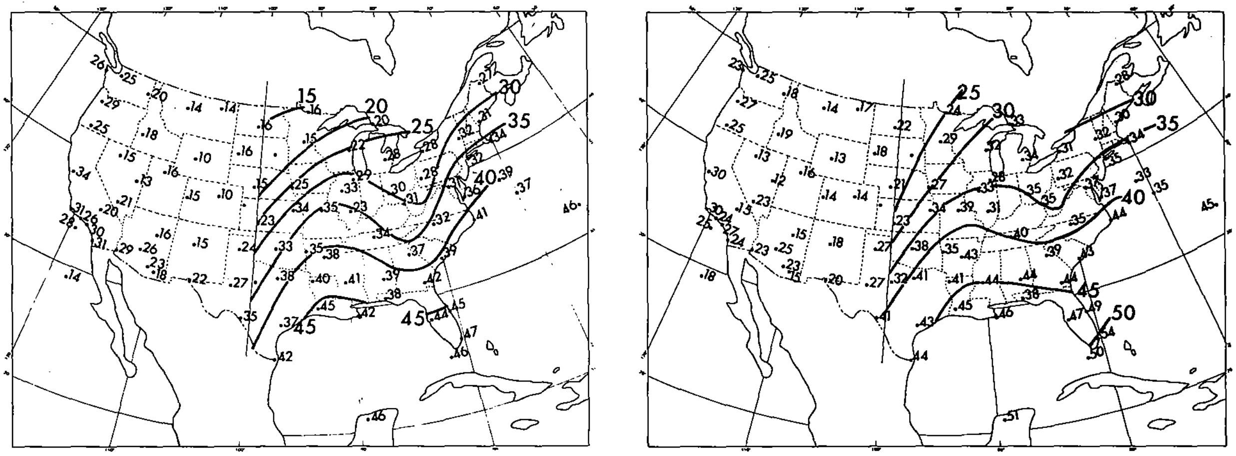
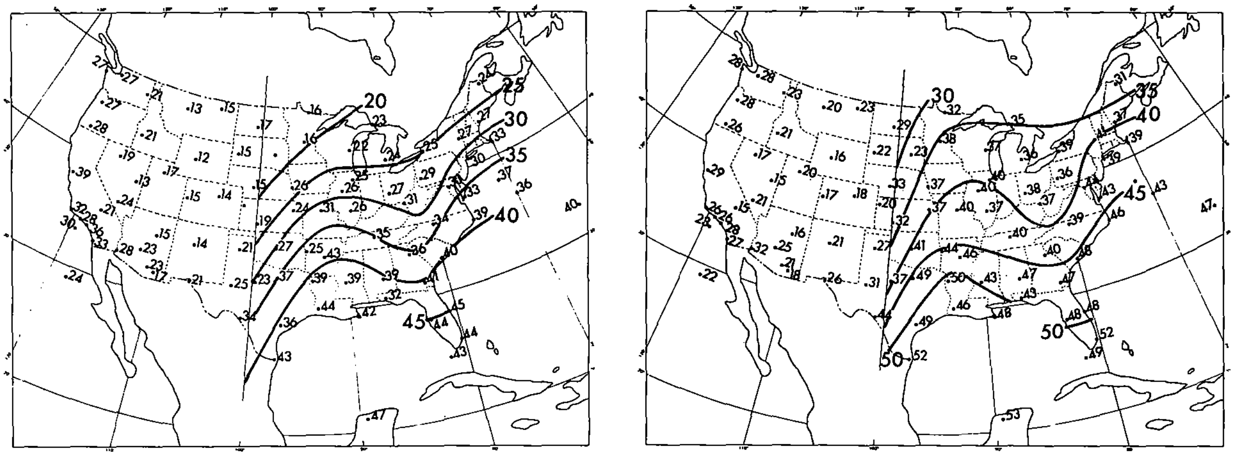


Figure 6d.--Seasonal variation of ratios of monthly maxima to the highest monthly maxima for maximum observed 6-hr rainfall (for grid points 3, 6, 12, 13, 17, 10).



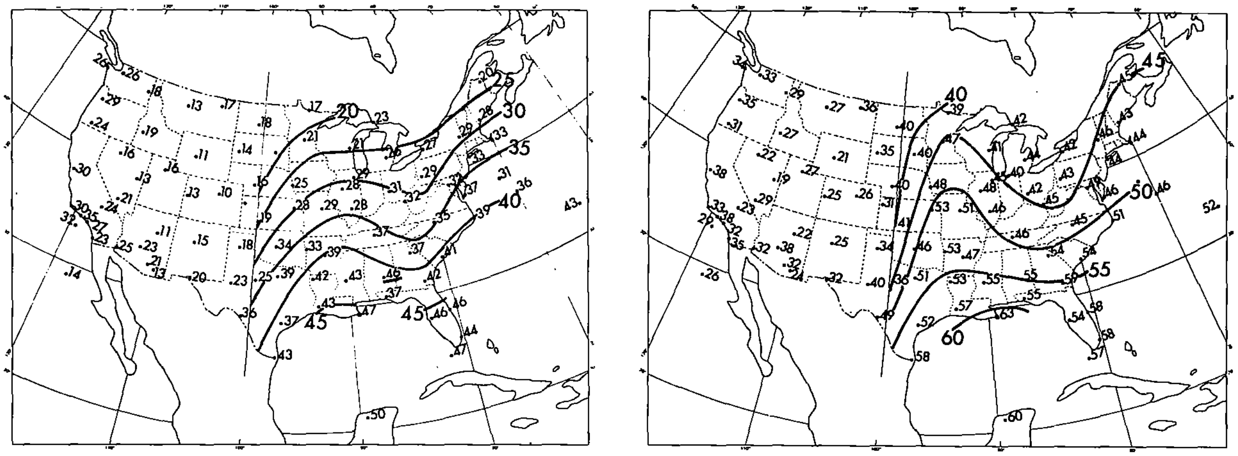
January 1-15

April 1-15



February 1-15

May 1-15



March 1-15

June 1-15

Figure 7a.--Contiguous United States, maximum w_p (mm), surface to 500-mb, by half months, January through June (from Ho and Riedel, 1979).

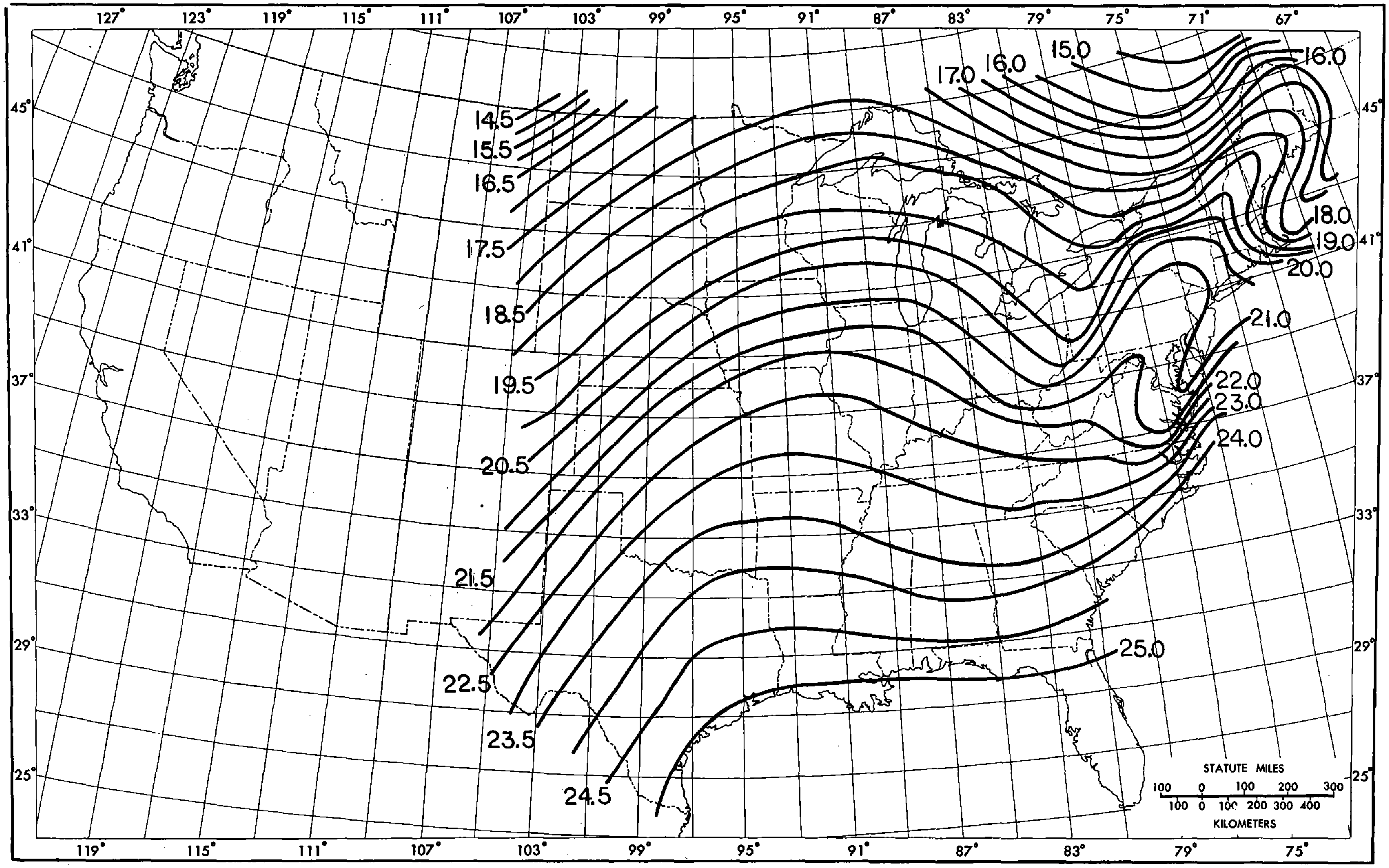


Figure 7b.--Maximum 12-hr persisting 1000-mb dew point (°C) for October (Environmental Data Service, 1968).

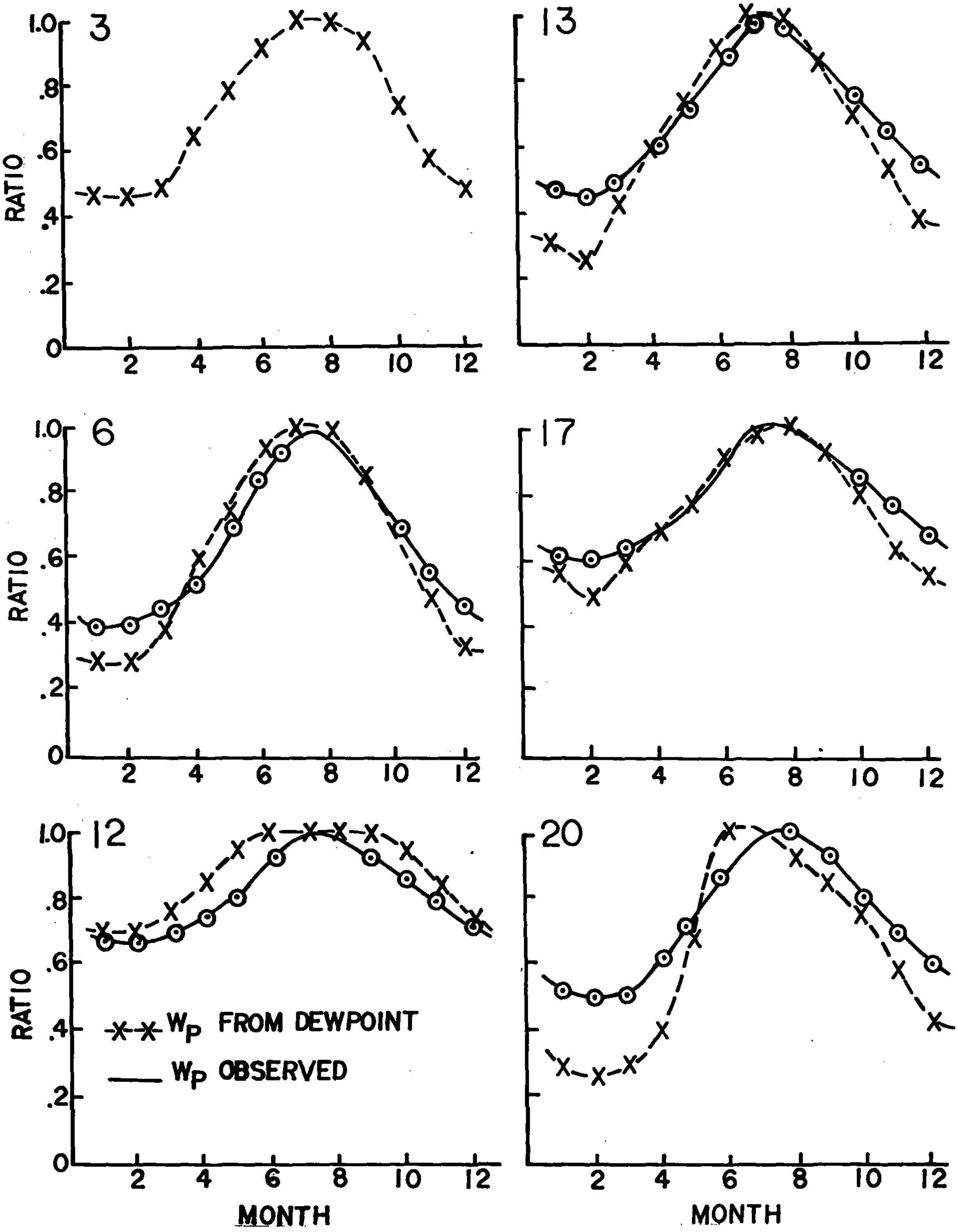


Figure 7c.--Seasonal variation of ratios of atmospheric moisture for each month to that for the highest month (grid points 3, 6, 12, 13, 17, 20).

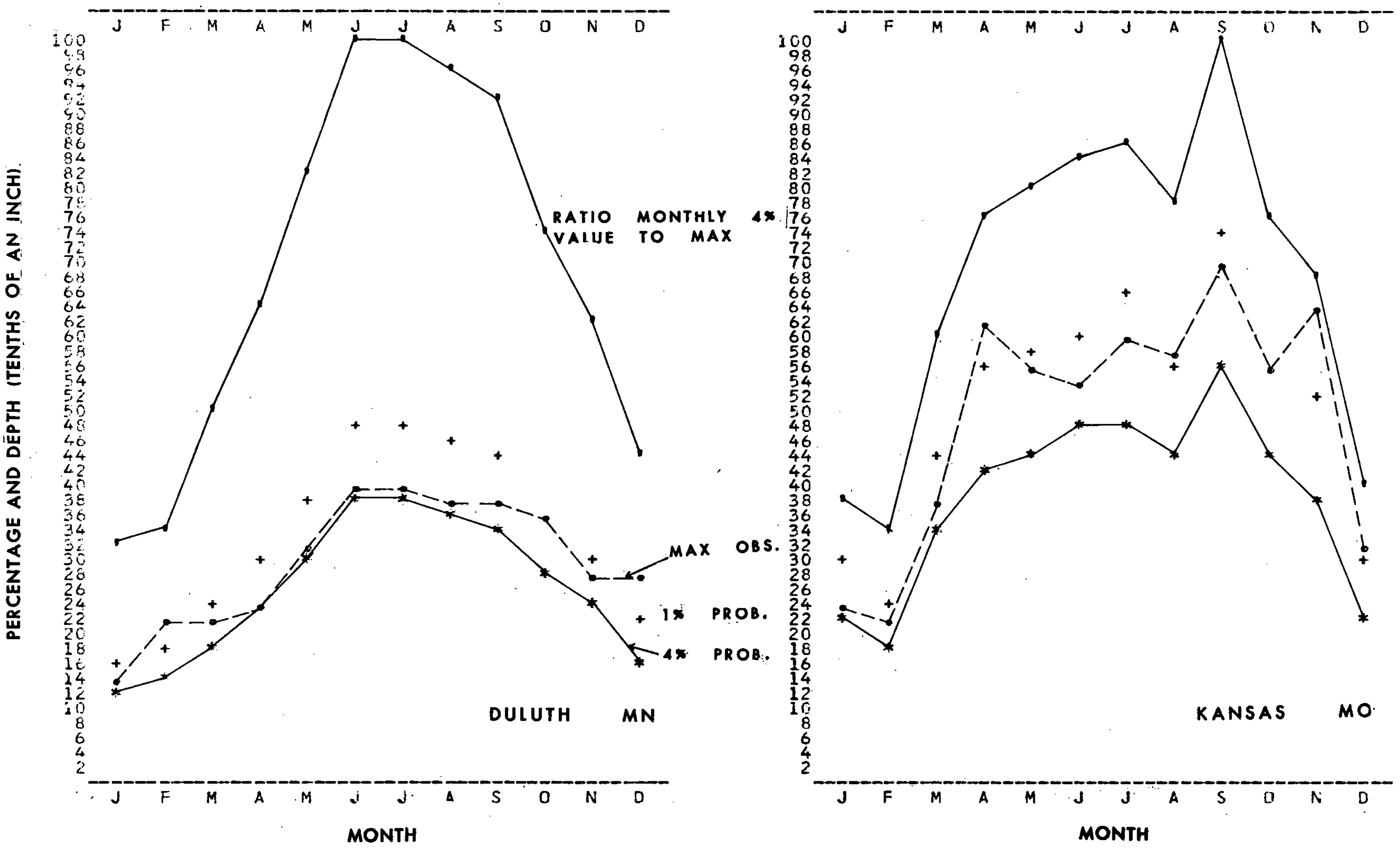


Figure 8.--Example of seasonal variations of 1% and 4% probability value, the maximum of record, and the ratio of each month's 4% probability value to that for the highest month. Three day rainfall for Duluth, Minnesota and Kansas City, Missouri (1912-61)

Figure 9 is a plot of the seasonal variation of the monthly 6/24 ratios for all the qualifying storms. The number of storms making up the averages, from a low of 10 in February to a high of 67 in September, are shown as well as the range in the ratio for each month. A fairly significant seasonal variation is indicated by the averages with generally higher ratios in the warm season. Figures 10a and 10b show maps of the 6/24 ratios for January and July, respectively. The data for January are too scanty to give a meaningful geographical pattern. We have identified certain ratios on the map for July (fig. 10b); those between 0.7 and 0.9 in boxes and those between 0.3 and 0.5 in circles to aid in discerning regional preference or bias in magnitude of the ratios. We conclude from the distributions shown that there is no significant regional pattern in magnitude of the ratios for our sample.

How the 6/24 ratios vary with rainfall magnitude is also of interest to our study. Figure 11 is a plot of the ratio vs. the 24-hr value in each ratio. Varying symbols are used to distinguish the four seasons. While a slight trend is shown in these data toward lower ratios with increasing 24-hr depths, one must be careful in interpreting this since all else being equal, the greater the 24-hr value (the denominator in the ratio) the lower the ratio. We conclude there is no signficant variation of 6/24 ratios with magnitude of the rainfall or season.

Plots were made for 72/24 ratios analogous to those for 6/24 ratios based on the same data base. Averages of these ratios by months (see fig. 12) show a smaller seasonal trend than for 6/24 ratios. Maps of the 72/24 ratios (not shown) give little evidence of regional patterns. As with the 6/24 ratios (see fig. 13) there is no significant trend in the 72/24 ratio with magnitude of the 72-hr rain.

4.7.2 Among Storms

Analyses of and compositing maps of the greatest observed rainfalls for 6-, 24-, and 72 hours implicitly sets 6/24 and 72/24 among storm ratios. these, along with the ratios given by HMR No. 51, were useful tools to our study.

4.7.3 Analyses

Since 6-, 24-, and 72-hr seasonal curves were plotted for the 20 grid points, the question of spacing between them comes up, that is, compatibility must be maintained in depth-duration relations. We strove for such compatibility through depth-duration plots for each grid point and month. Figure 14 is an example of these plots for 6 selected grid points for the month of November. On here are plotted transposed and moisture-maximized storm depths for all durations from 6 to 72 hours. Such plots insure that our 6-, 24-, and 72-hr PMP will properly envelop maximum depths for other intermediate durations. Storms are identified by number (see table 2). At top of the plots for each grid point we also show rain ratios: 6- to 24-hr and 72- to 24-hr from the PMP and from the 4 percent probability level rainfall (part 4 of table 4). The ratios from rainfall frequencies are a guide to maintaining depth-durational consistency in the final product.

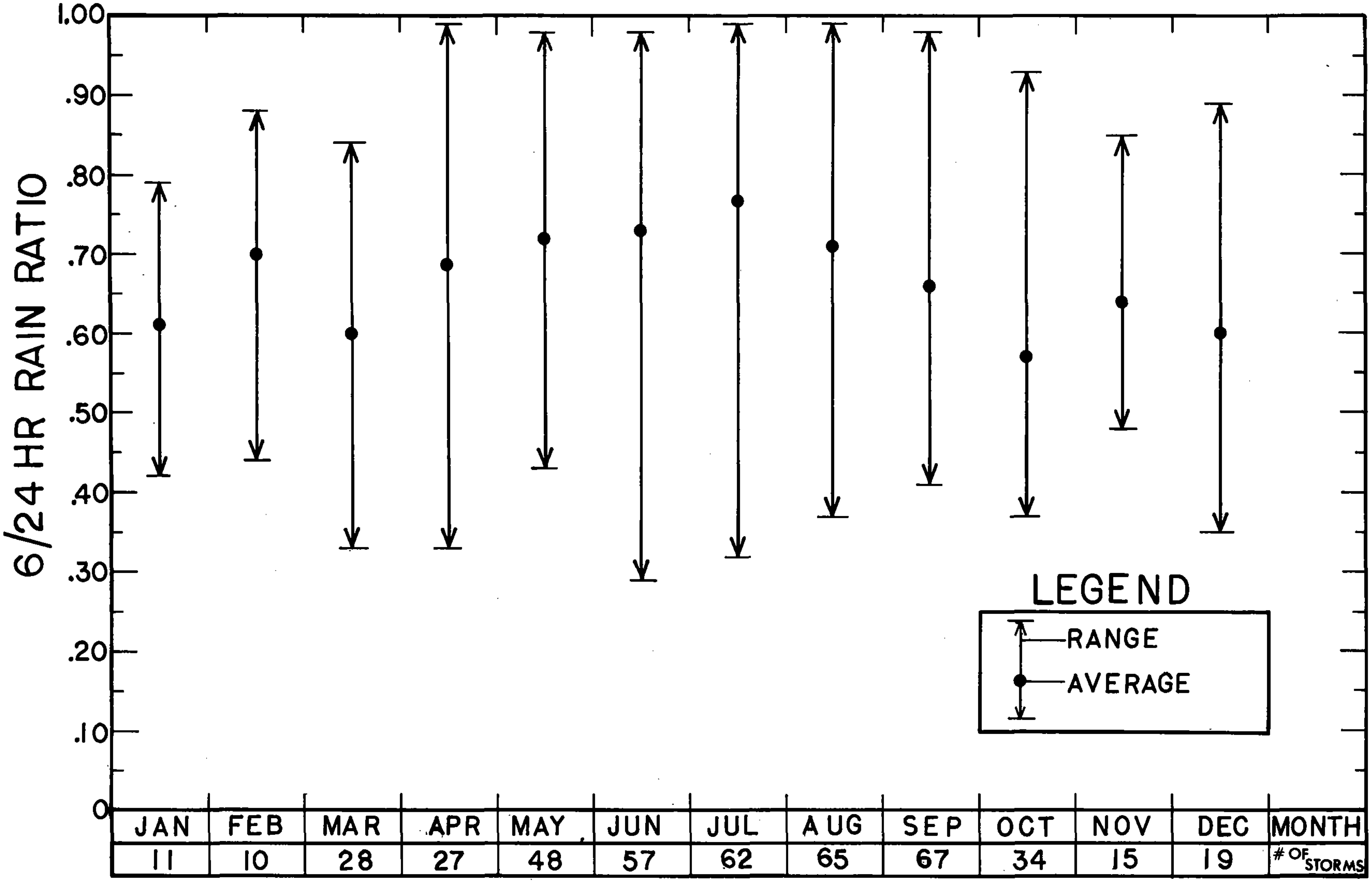


Figure 9.--Seasonal variation of within storm 6/24-hr rain ratios for major storms in the study region.

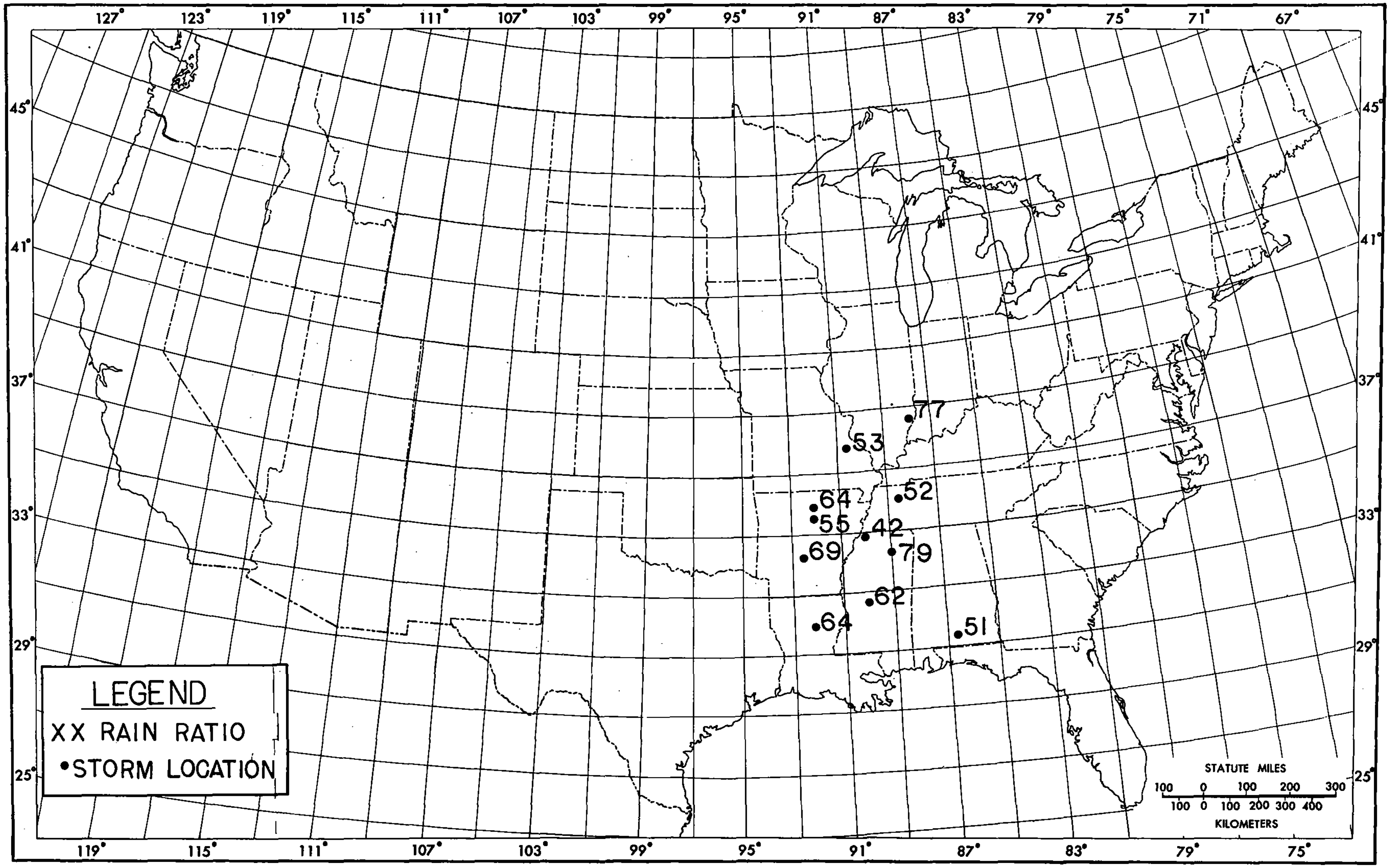


Figure 10a.--Within storm 6/24-hr rain ratios, January.

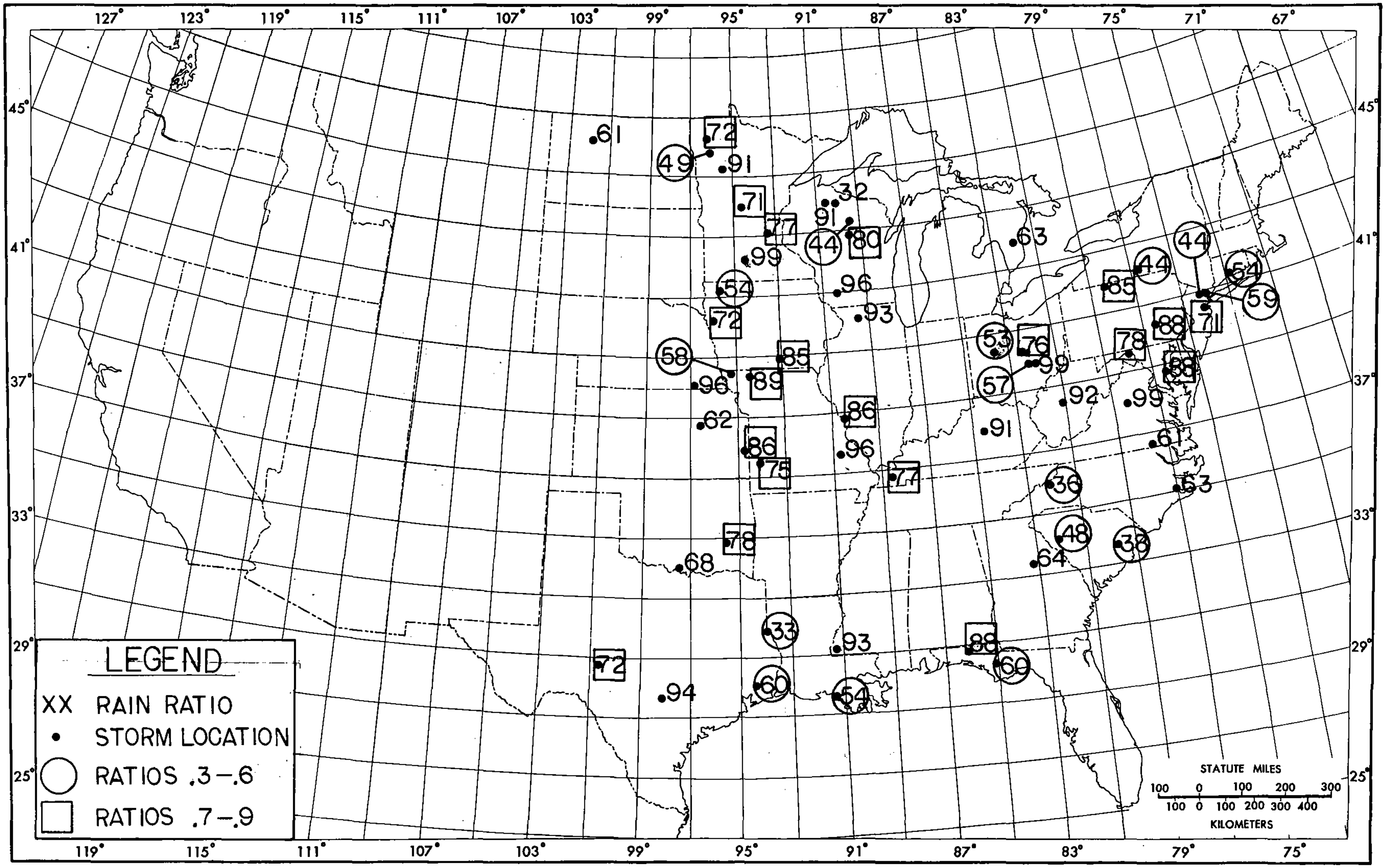


Figure 10b.--Within storm 6/24-hr rain ratios, July.

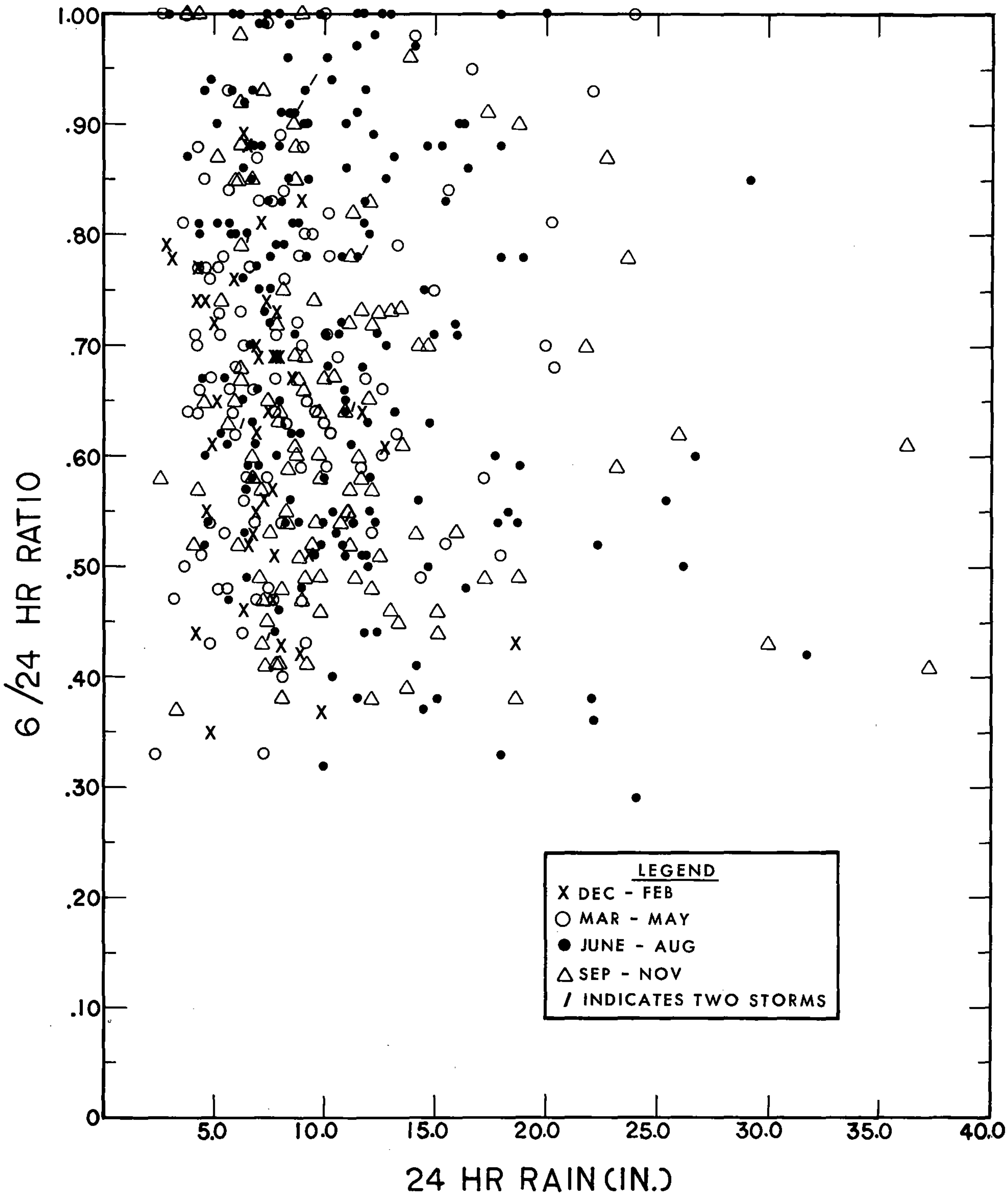


Figure 11.--Within storm 6/24-hr rain ratios vs. magnitude of 24-hr depths.

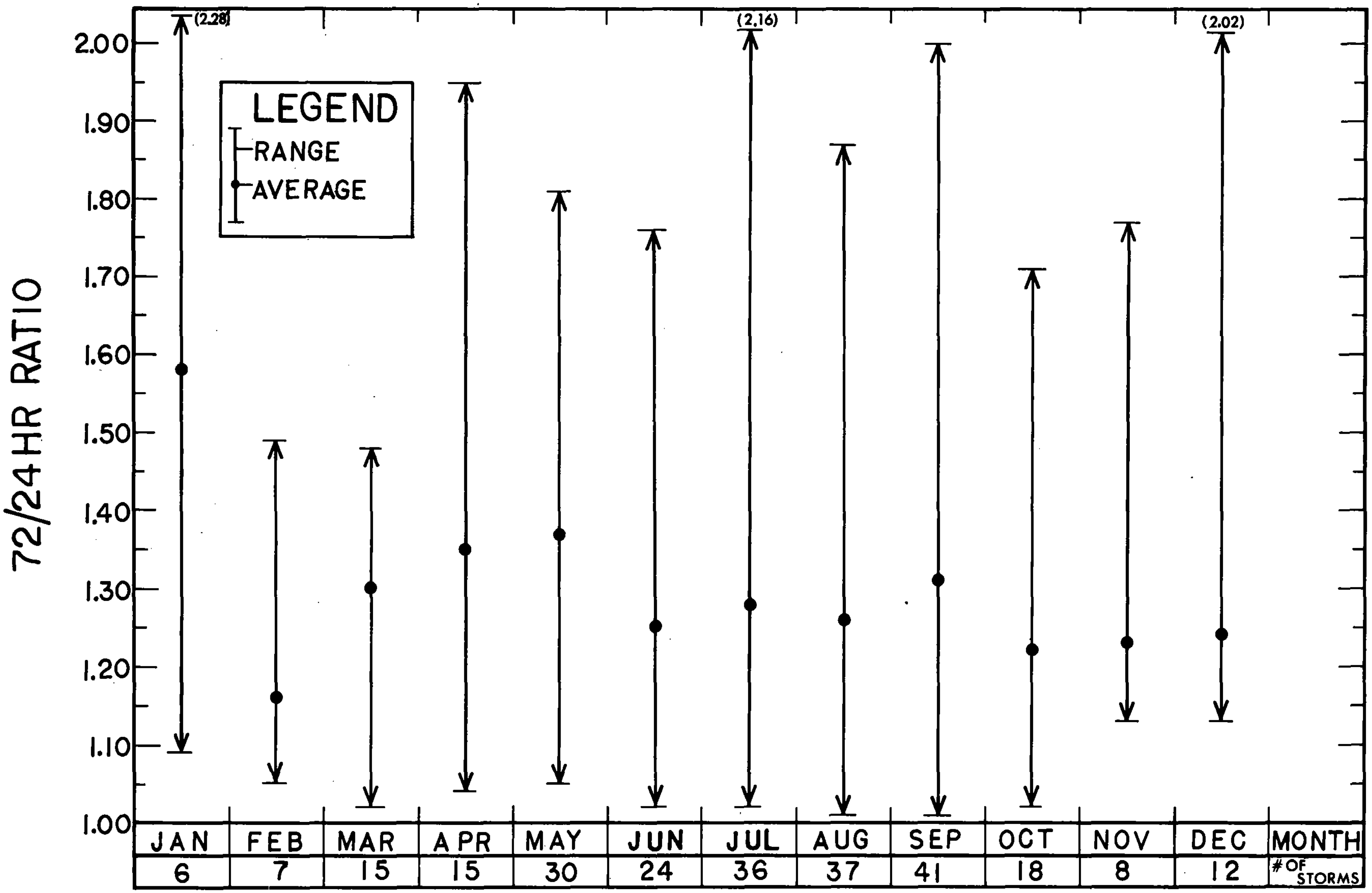


Figure 12.--Seasonal variation of within storm 72/24-hr rain ratios for major storms in the study region.

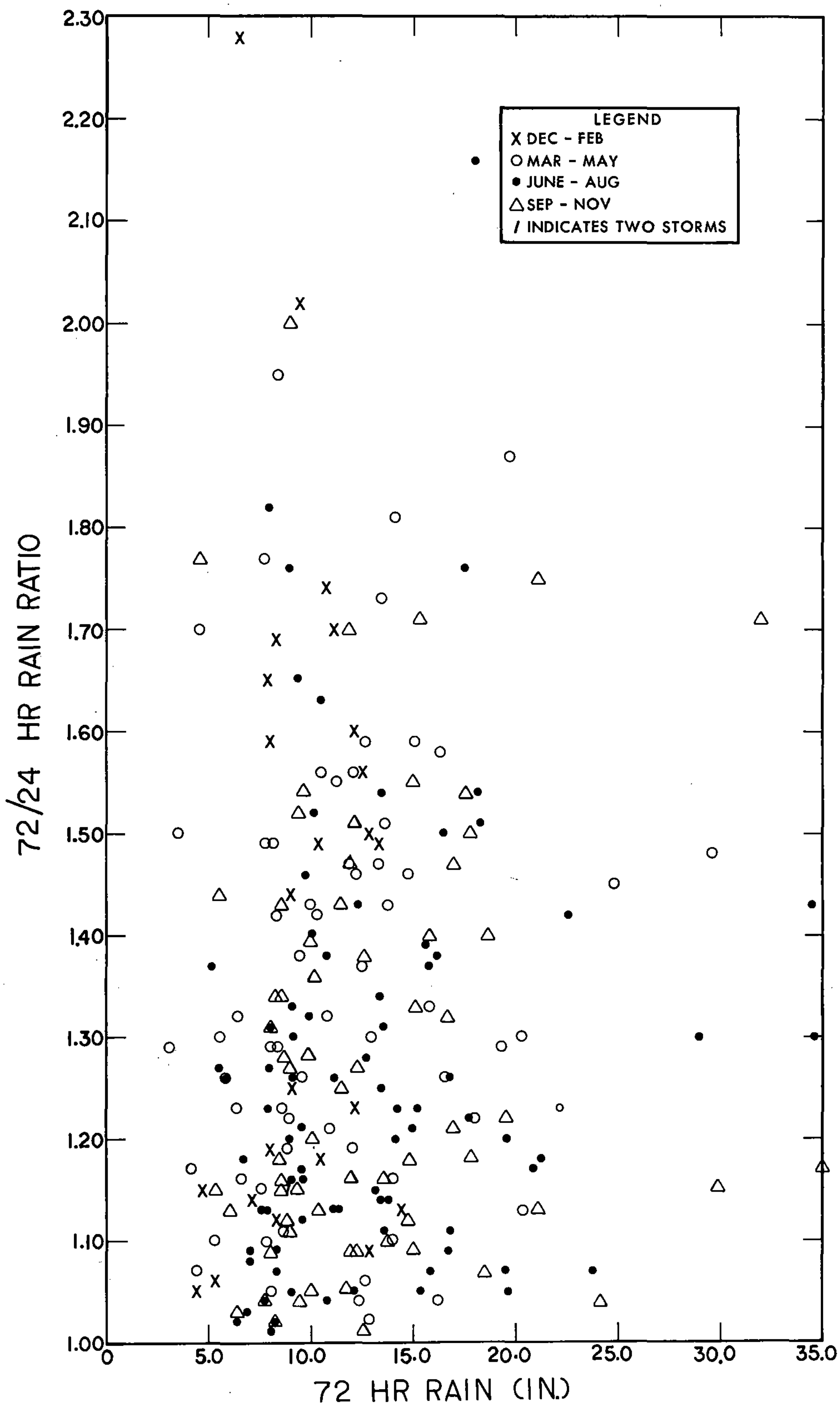


Figure 13.--Within storm 72/24-hr rain ratios vs. magnitude of 72-hr depths.

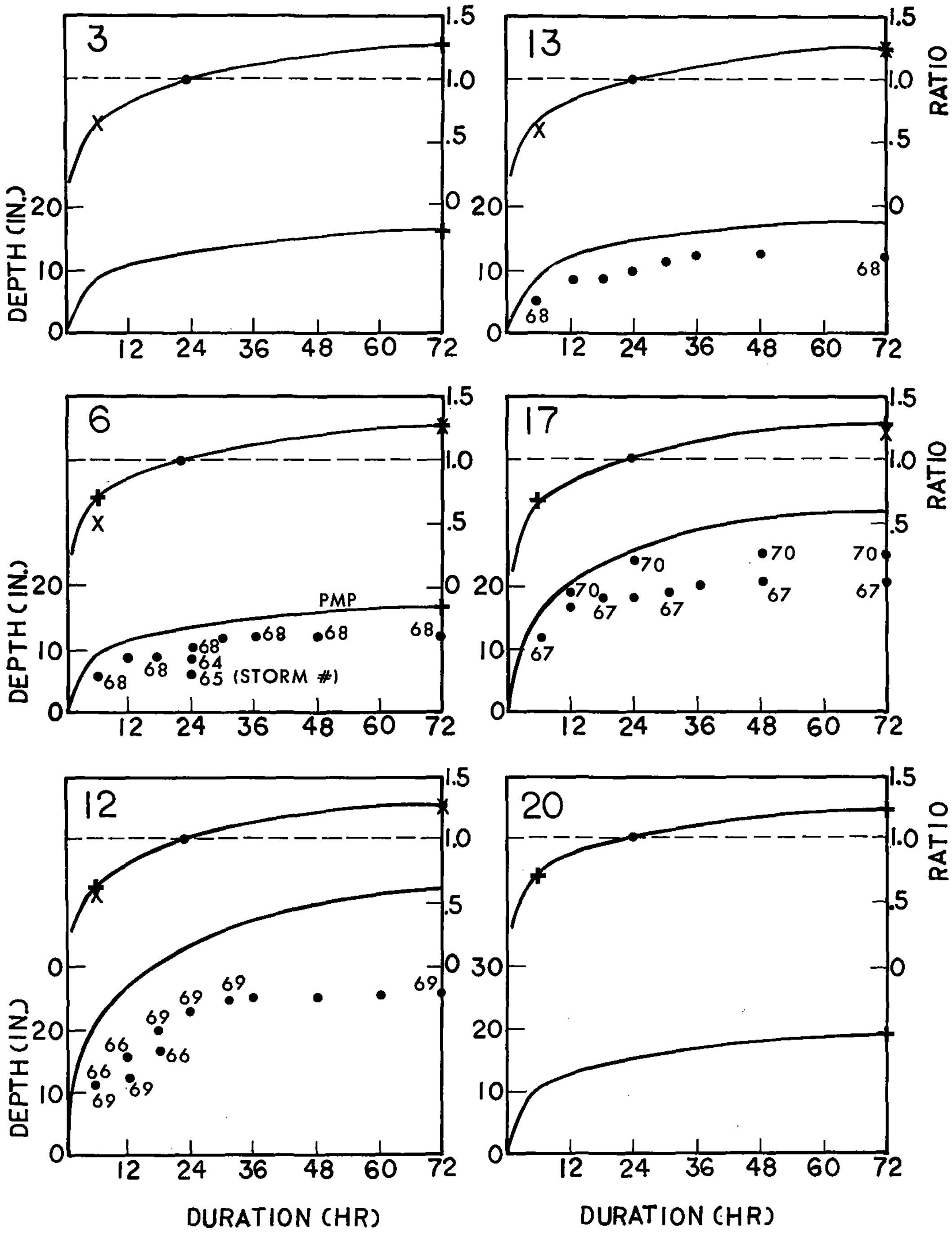


Figure 14.--Depth-duration plots for November (grid points 3, 6, 12, 13, 17, 20). Upper curves are the ratios of rainfall for various durations to the 24-hr values (+ from PMP; X from 4% probability values). Lower curves show PMP values. Maximized rainfall values transposed to the grid point are shown with storm number (table 2).

We found an inverse relation between the 6/24 ratio and that for 72/24. That is, if the 6/24 ratio is high, the 72/24 ratio is low, and visa versa. This appears to be meteorologically reasonable. For example, a high 6/24 ratio, expected in summer with brief thunderstorm type rainfall, is associated with a low 72/24 ratio.

4.8 Regional PMP Gradients

We have insisted PMP should not show sharp demarcations or changes from one point to the next unless explainable by terrain effects. Thus, we have plotted the 6-, 24-, and 72-hr PMP depths against selected latitudes and longitudes, covering the region in order to eliminate sharp changes. Figure 15 is an example of such plots .... showing 6-hr PMP along longitude 91°W for latitudes 30° to 47°N for each month.

4.9 Some Observations on PMP Patterns

The objectives or requirements of a) smooth patterns and gradients of PMP for each month and each duration (6, 24, 72 hours), b) smooth progression of increasing depths with duration, c) a smooth progression of PMP depths from month to month, and d) envelopment of moisture maximized and transposed storm rainfalls required numerous iterations. As one of the four objectives is approached, changes in analysis effect the other three. We should repeat a fifth objective uppermost in our thoughts during the study; this was to avoid undue indirect maximization and envelopment in achieving the objectives.

Some specific indications from the guidance material that were incorporated in the PMP patterns are as follows:

The semimonthly maximum w_p maps (see example in fig. 7a) indicate a gradual progression of moisture from the Gulf Coast northward in early spring. A ridge of high moisture extending from the Gulf coast to the Great Plains can be identified easily in the summer months. The maximum w_p maps indicate that moisture remains high through September.

The maps of 4 percent probability rainfall also show higher values extending inland from the Louisiana and Mississippi coasts during April and May than in adjacent months.

Maps of greatest observed rainfall depths show maximum precipitation in June in the northwestern portion of our study region. This set of maps reveals that maximum rainfall occurs in September along the eastern seaboard and in the gulf states. Scattered high values also appear in early October in some coastal regions, especially in Texas.

Some of the data, particularly the probability level values, show a longer season of maximum rainfall for the states bordering the Gulf and Atlantic coasts than for the interior regions. The plateau extends into September and early October. This can be explained by the greater opportunity for tropical

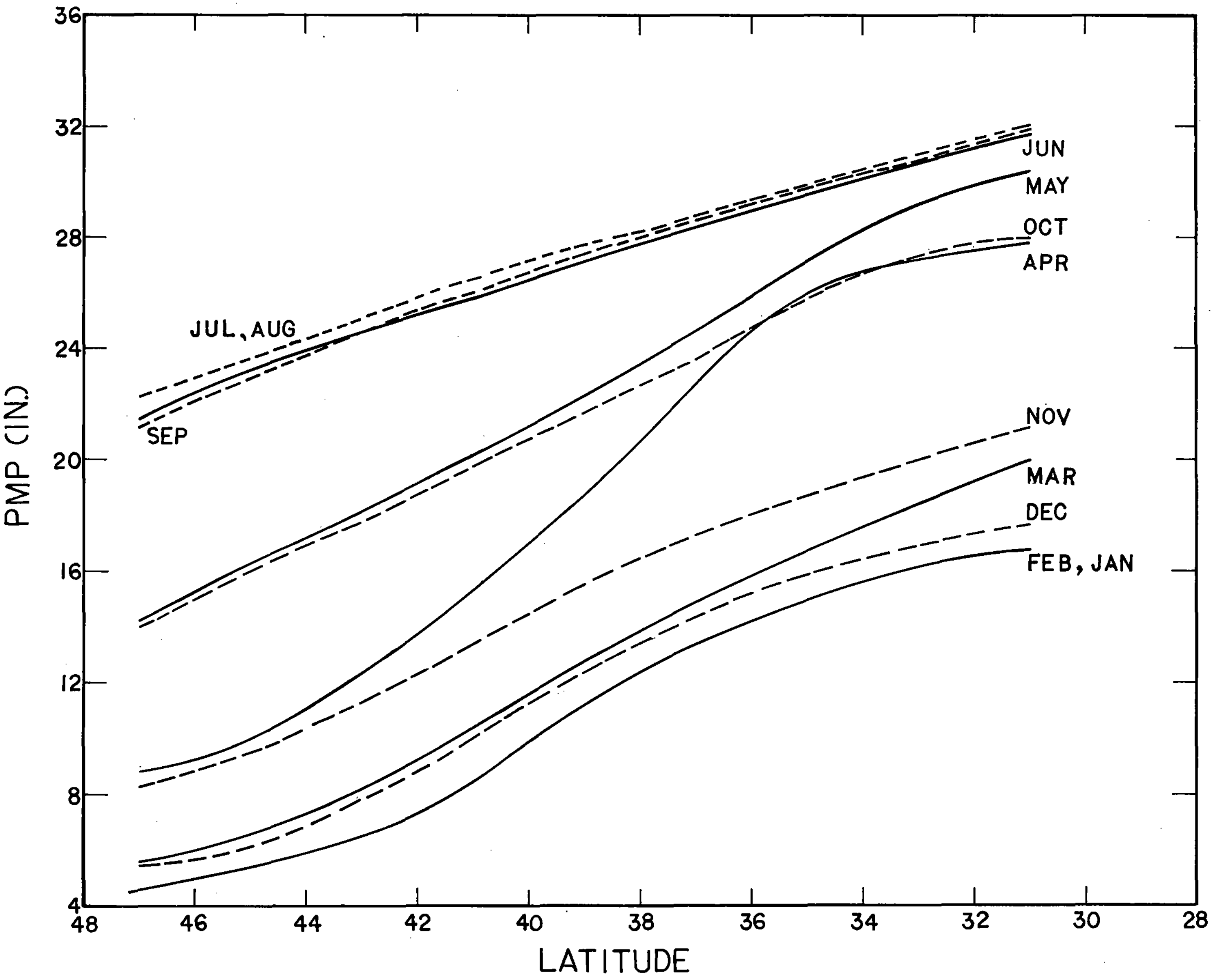


Figure 15.--Latitudinal variation by month of 6-hr PMP along longitudinal 91°W.

storm rainfall there .... and the fact that such storms can occur well into October. This aspect has been preserved in the seasonal variation of PMP. All-season PMP values extend to October for the coastal states and to September for much of the interior.

Comparison of maximum rainfall values in the interior for durations from 6 to 72 hours shows some tendency for peak values to extend over a longer season for 72 hours than for 6 hours. We find however, that the peak season for 24 and 72 hours have about the same length. This last indication has guided us to show the same length for all-season PMP for all durations.

5. RESULTING PMP

Figures 16 to 45 show midmonth maps of PMP for 6, 24, and 72 hours. A plot of depths for 6, 24, and 72 hours on a depth-duration chart joined by a curve through the point of origin (0,0) can be used to interpolate PMP for other durations. If PMP is required for some other data than midmonth, interpolate arithmetically.

6. EXAMPLE OF USE OF PMP MAPS

In this example, assume 10-mi^2 PMP is required for exactly April 8 for 22 hours duration at 40° 30'N latitude and 87°30'W longitude.

		March 15		April 15
a.	6-hr PMP (fig. 17)	= 9.5 in.	(fig. 18)	= 13.1 in.
	24-hr PMP (fig. 27)	= 14.9 in.	(fig. 28)	= 19.0 in.
	72-hr PMP (fig. 37)	= 18.8 in.	(fig. 38)	= 23.5 in.

b. Depth-duration plots (fig. 46) of these depths joined by smooth curves through (0,0) give 14.7 in. for March 15 and 18.9 in. for April 15, for 22 hours.

c. Linear interpolation for April 8 gives 18.0 inches.

7. SPECIAL PROBLEMS

7.1 Stippled Regions on PMP Maps

As for the all-season generalized PMP, our maps are stippled in two regions, (a) the Appalachian Mountains extending from Georgia to Maine and (b) a strip between the 103rd and 105th meridians. This stippling outlines areas within which the generalized PMP estimates might be deficient because detailed terrain effects have not been evaluated.

In developing the maps of PMP, it was sometimes necessary to transpose storms to or from higher terrain. Determination of storm transposition limits (par. 3.4.2) took into account topographic homogeneity in a general sense, thereby avoiding major topographic considerations. However, regional analysis required definition across mountains such as the Appalachians.

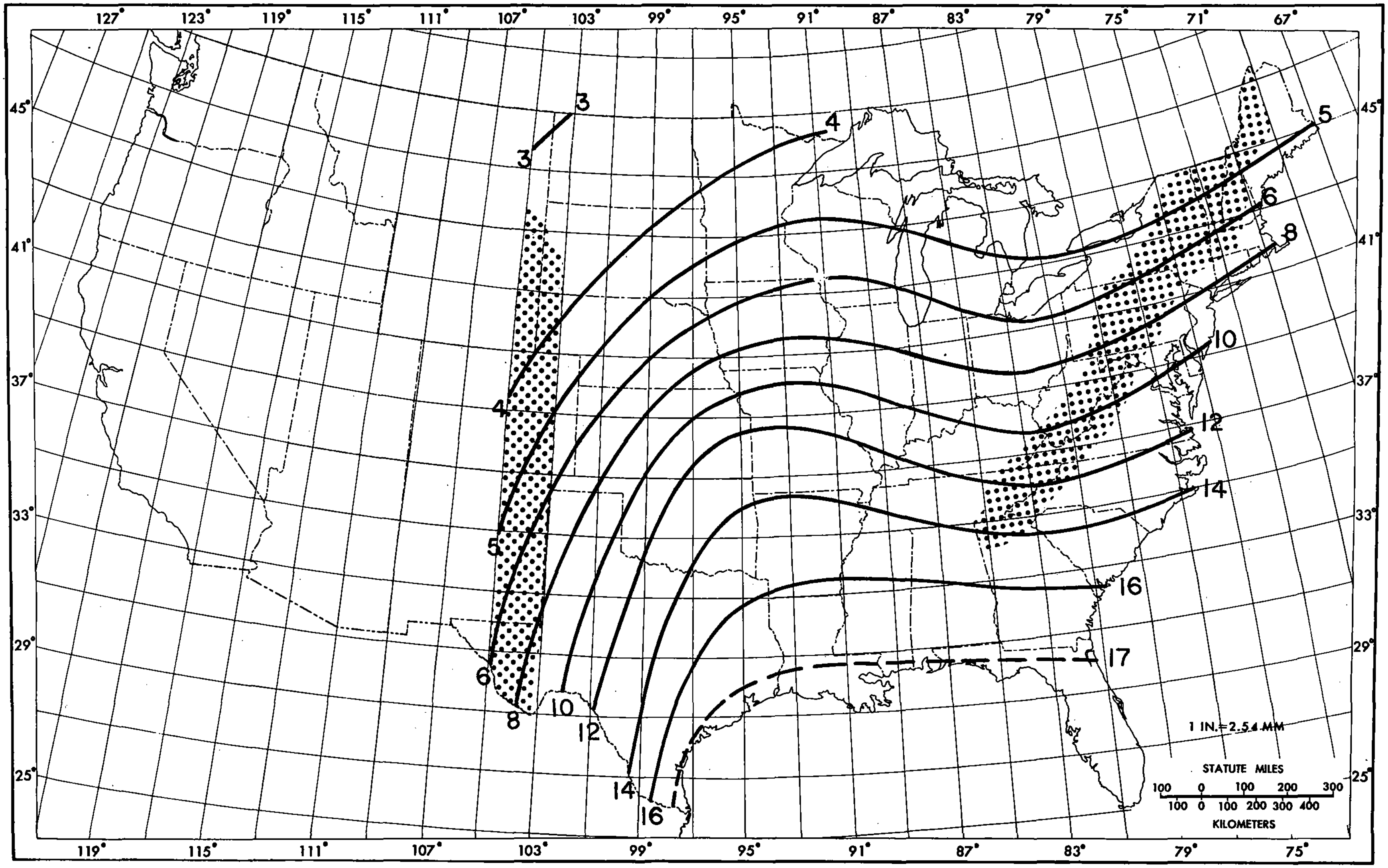


Figure 16.--6-hr 10-mi^2 PMP, January and February , (in.).

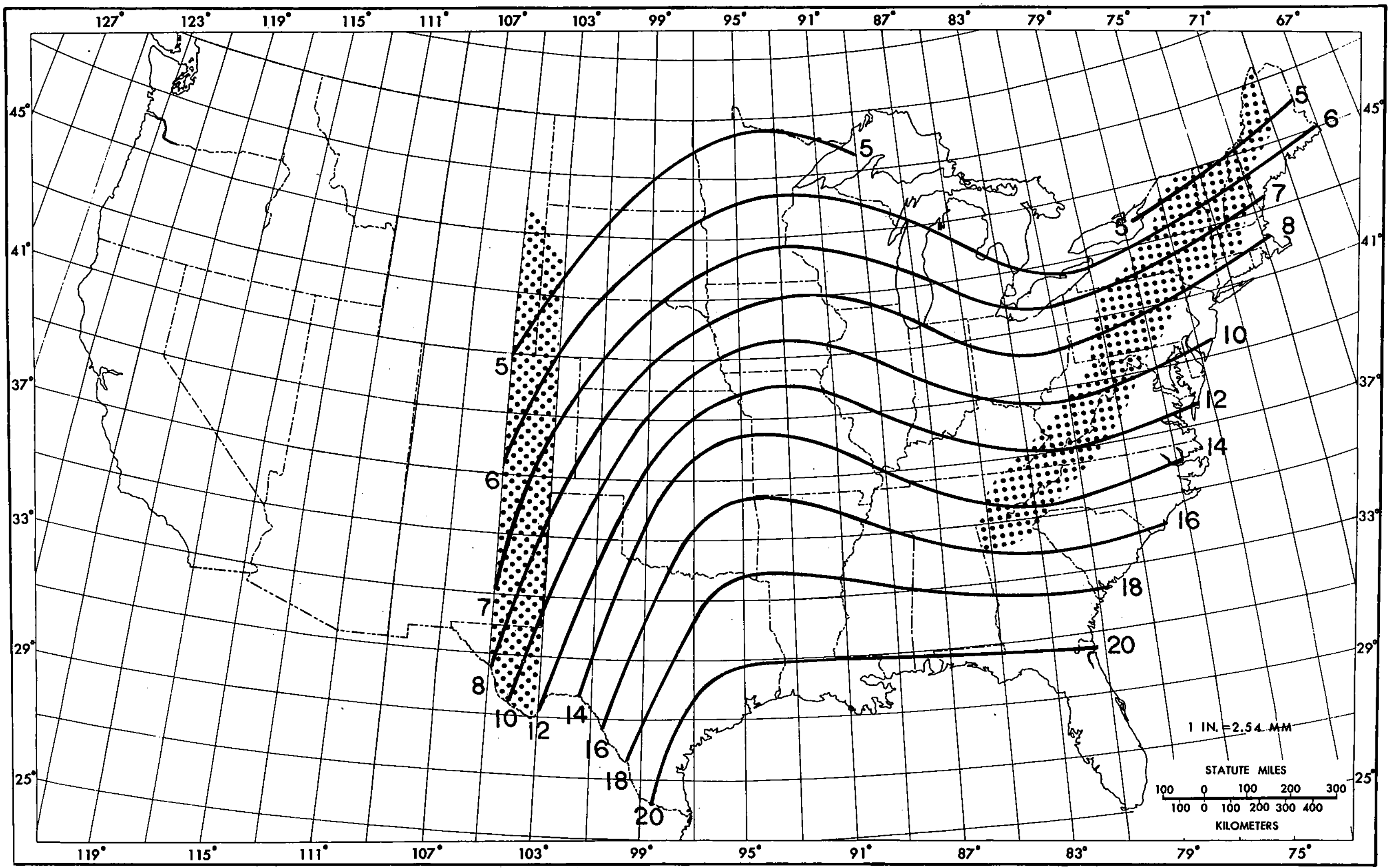


Figure 17.---6-hr 10-mi² PMP, March, (in.).

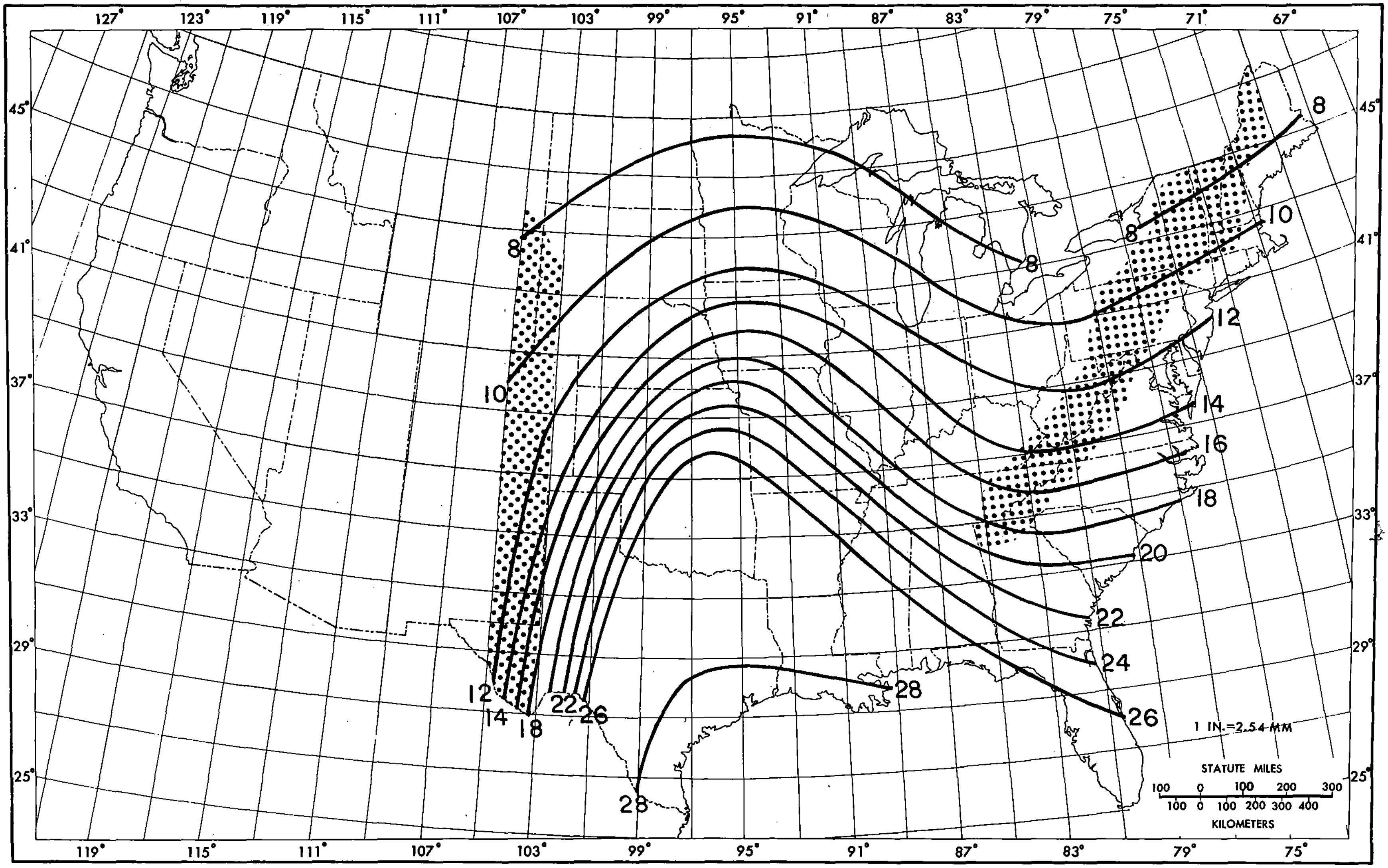


Figure 18.--10-mi^2 PMP, April, (in.).

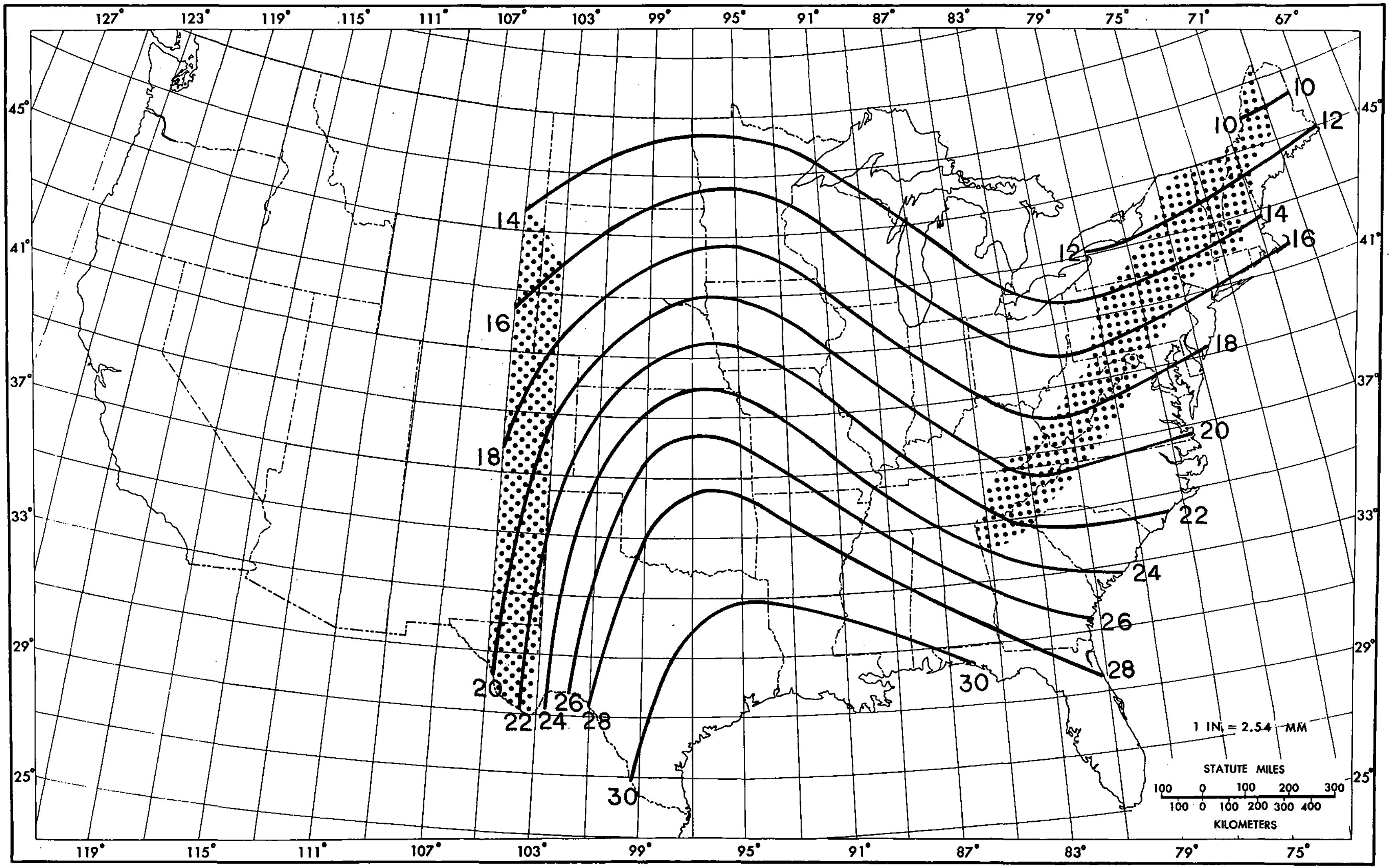


Figure 19.--6-hr 10-mi^2 PMP, May, (in.).

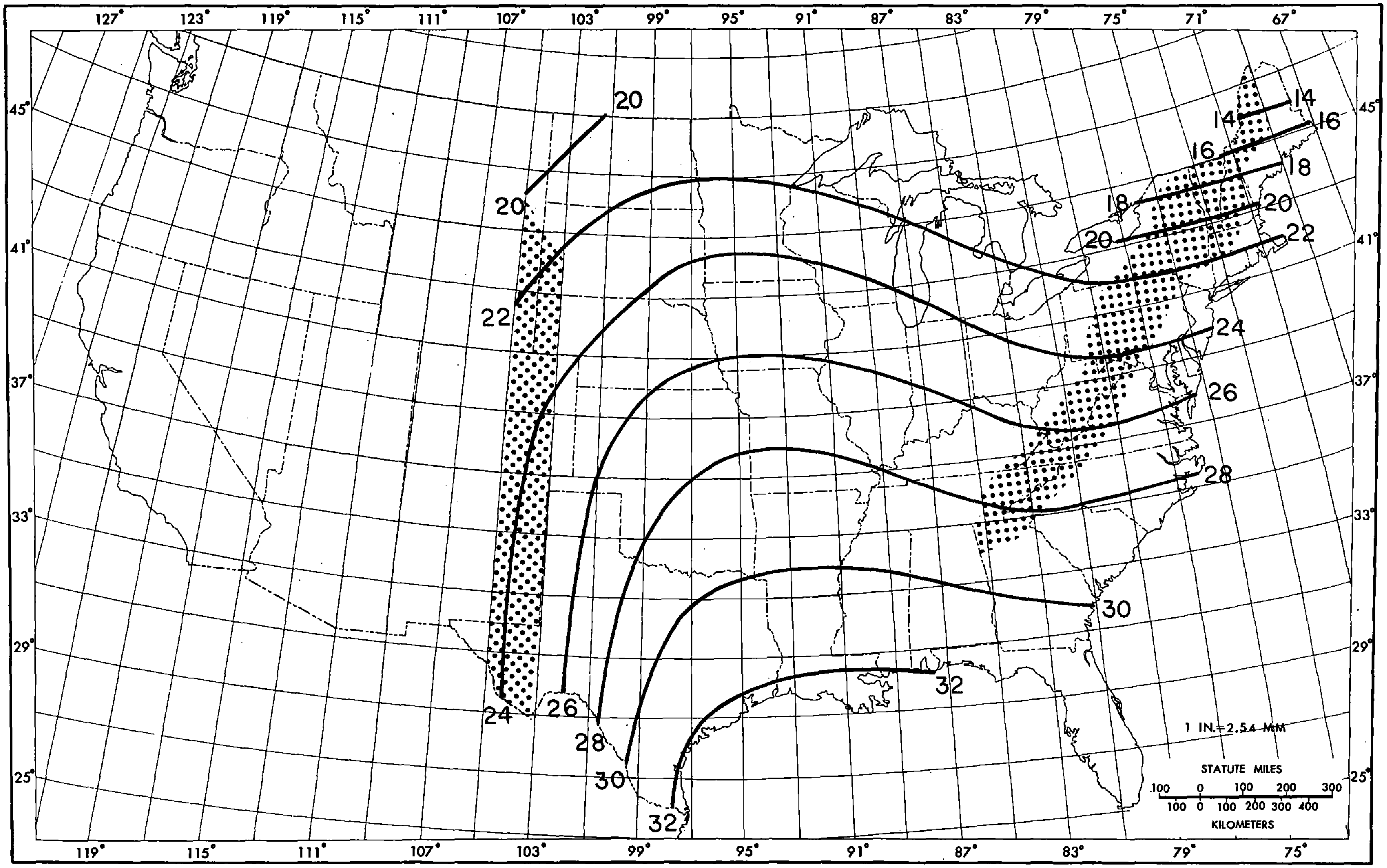


Figure 20.--6-hr 10-mi^2 PMP, June, (in.).

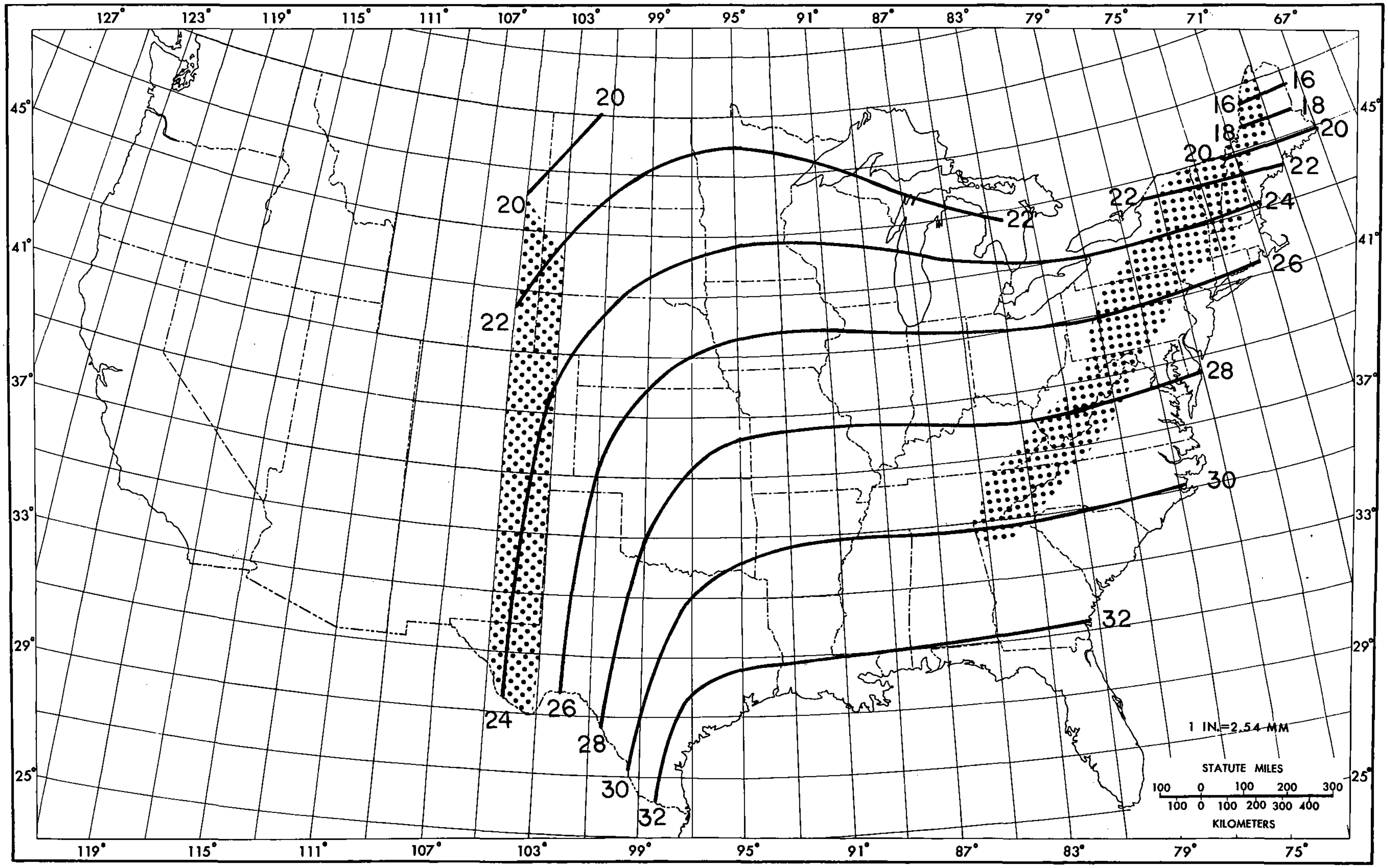


Figure 21.--6-hr 10-mi^2 PMP, July and August, (in.).

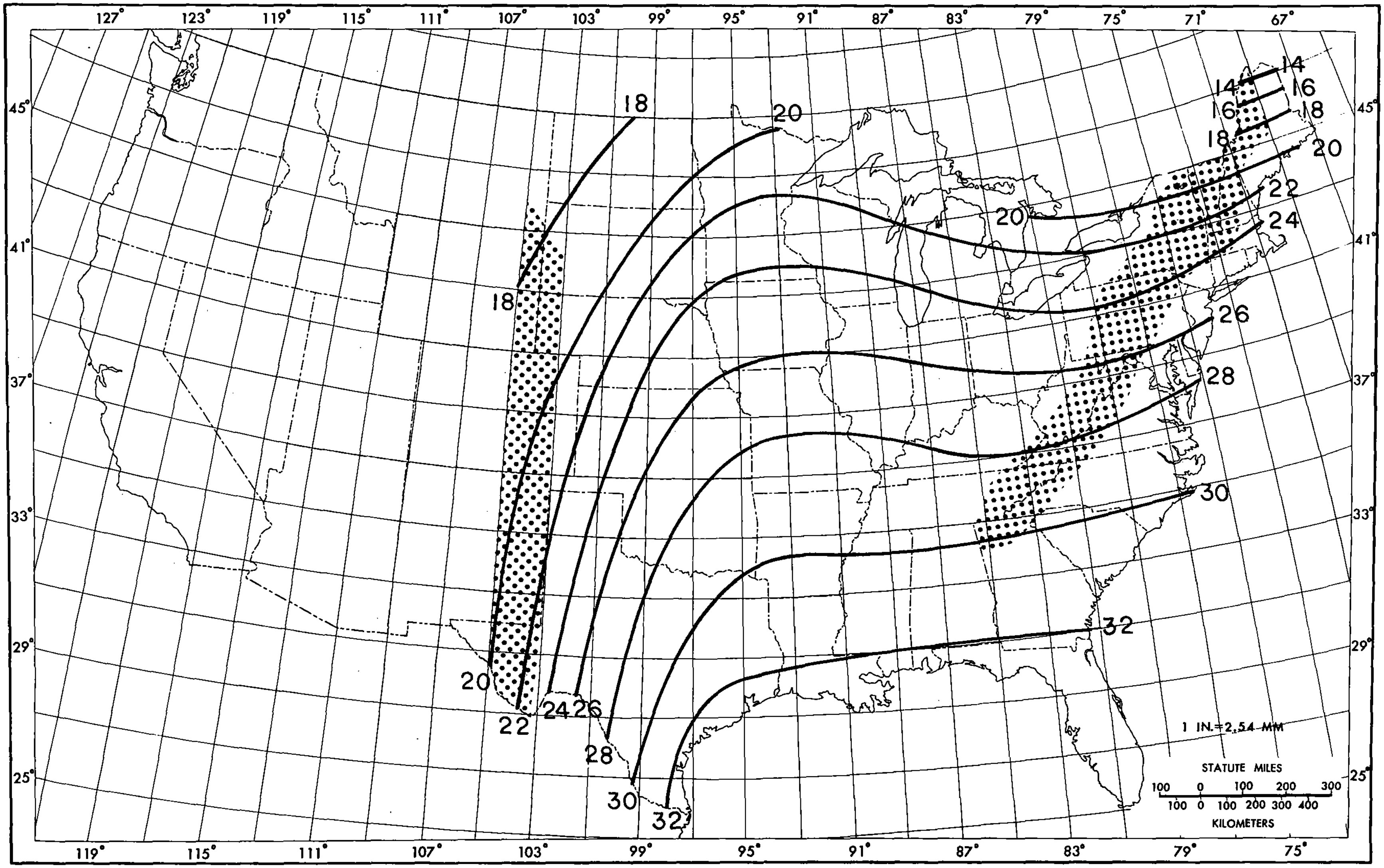


Figure 22.--6-hr 10-mi^2 PMP, September, (in.).

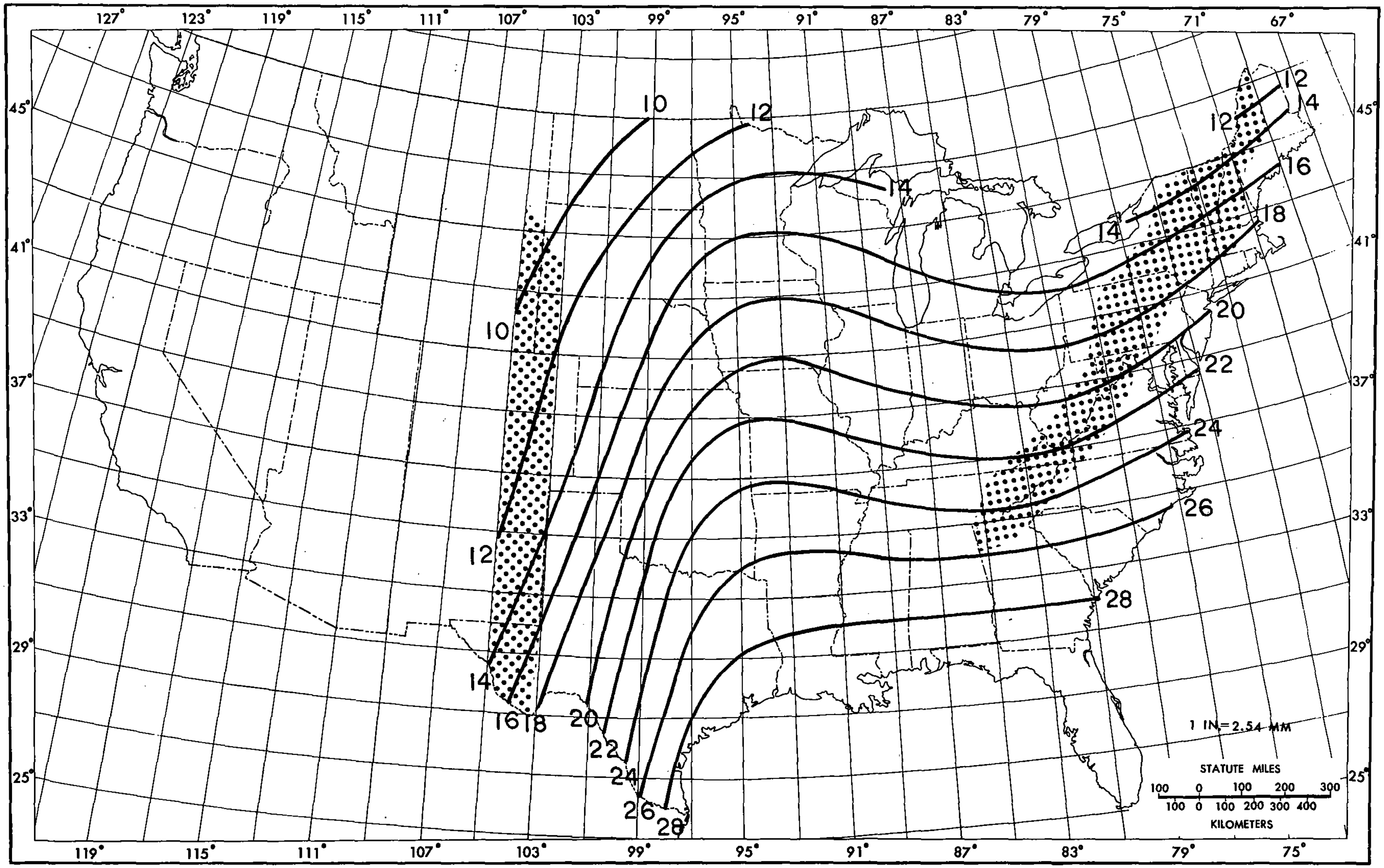


Figure 23.--6-hr 10-mi^2 PMP, October, (in.).

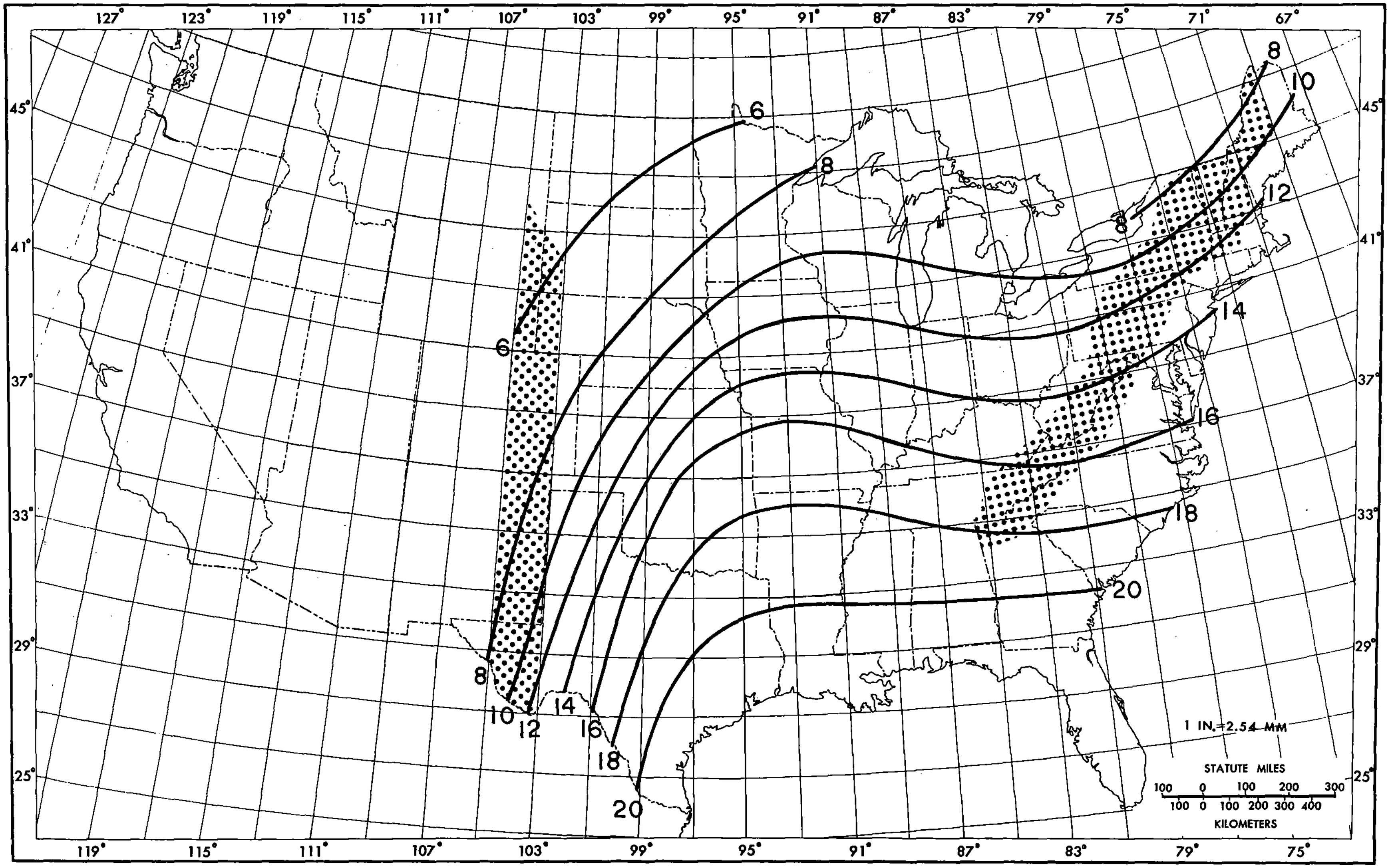


Figure 24.--6-hr 10-mi^2 PMP, November, (in.).

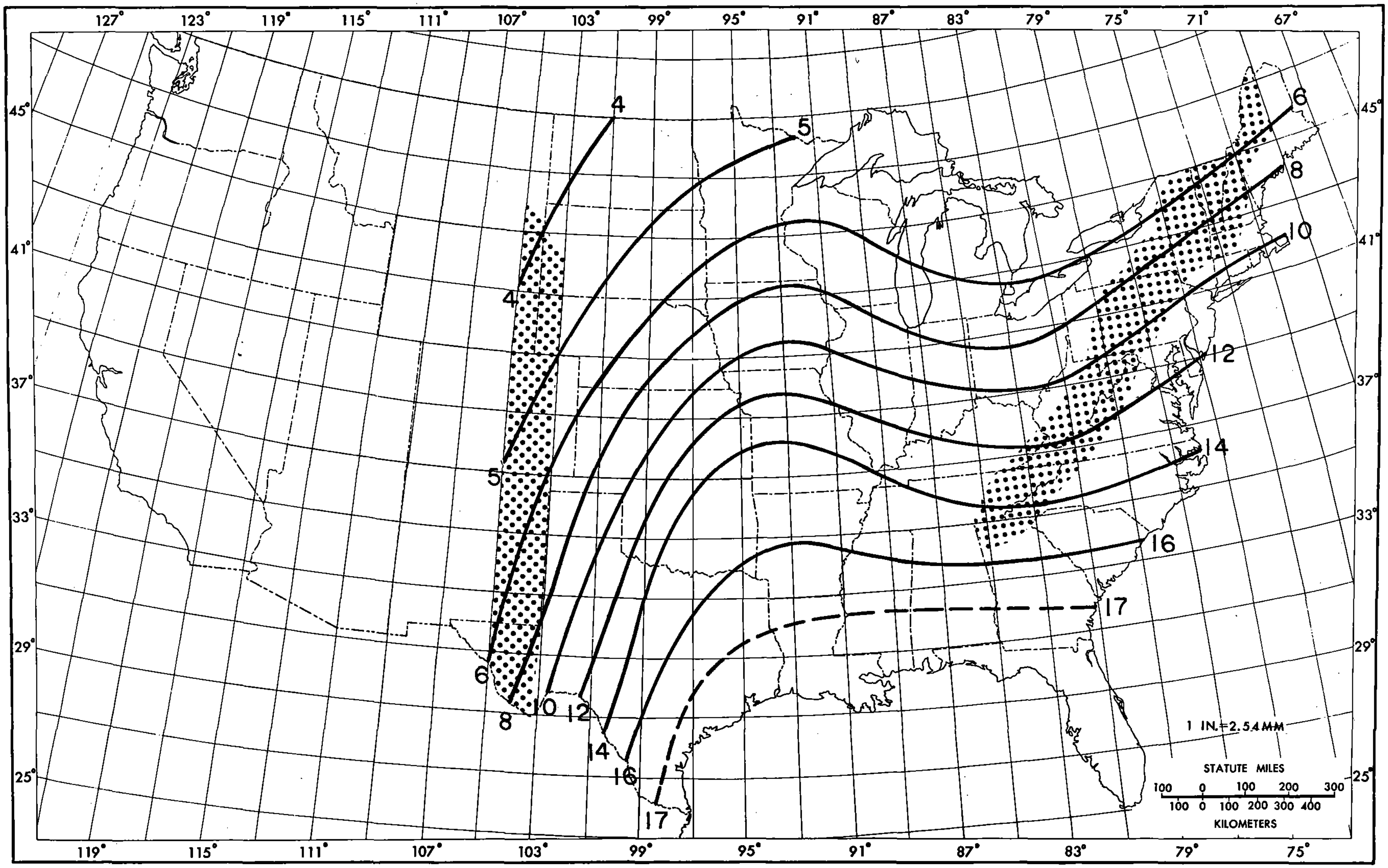


Figure 25.--6-hr 10-mi^2 PMP, December, (in.).

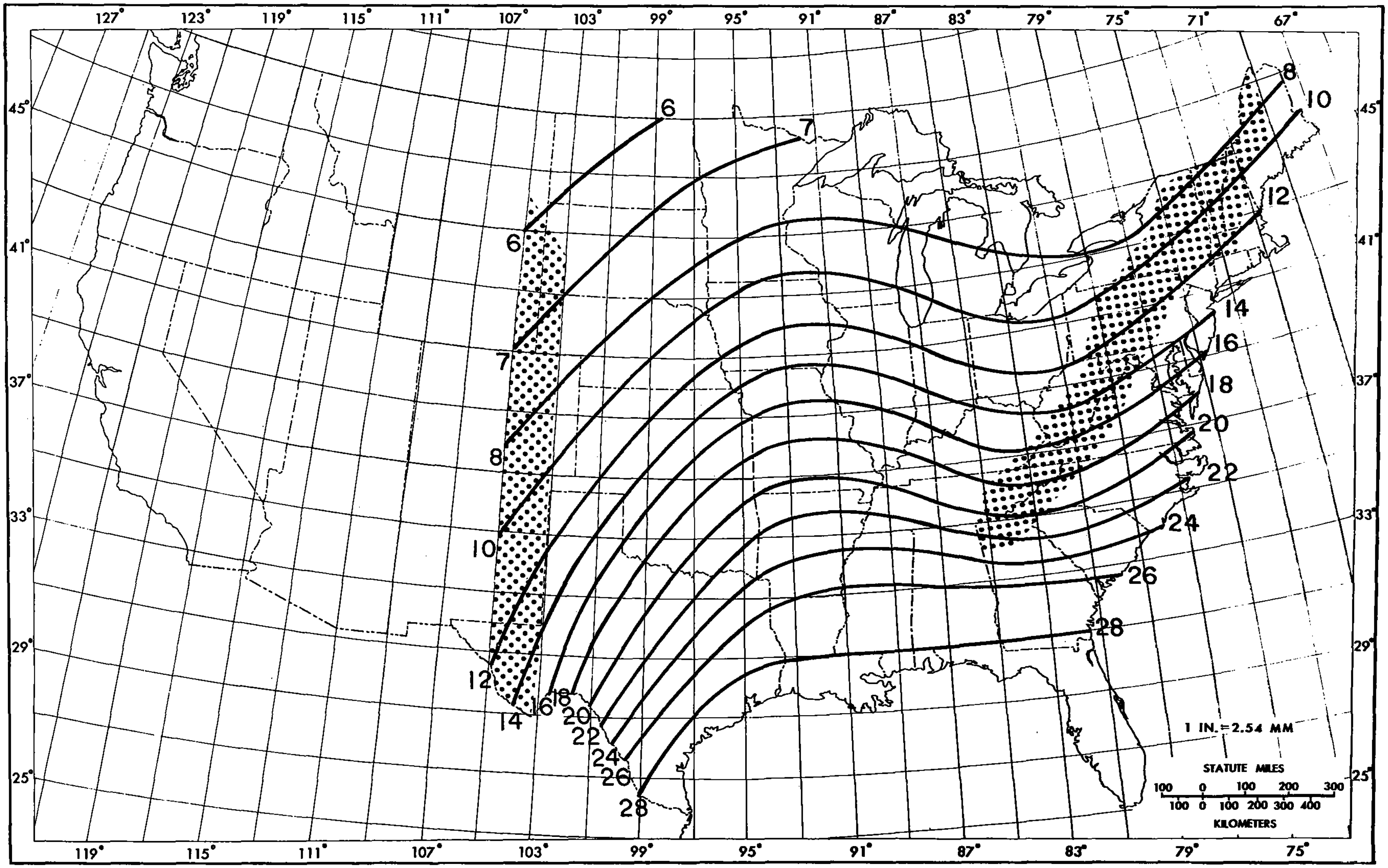


Figure 26.--24-hr 10-mi^2 PMP, January and February, (in.).

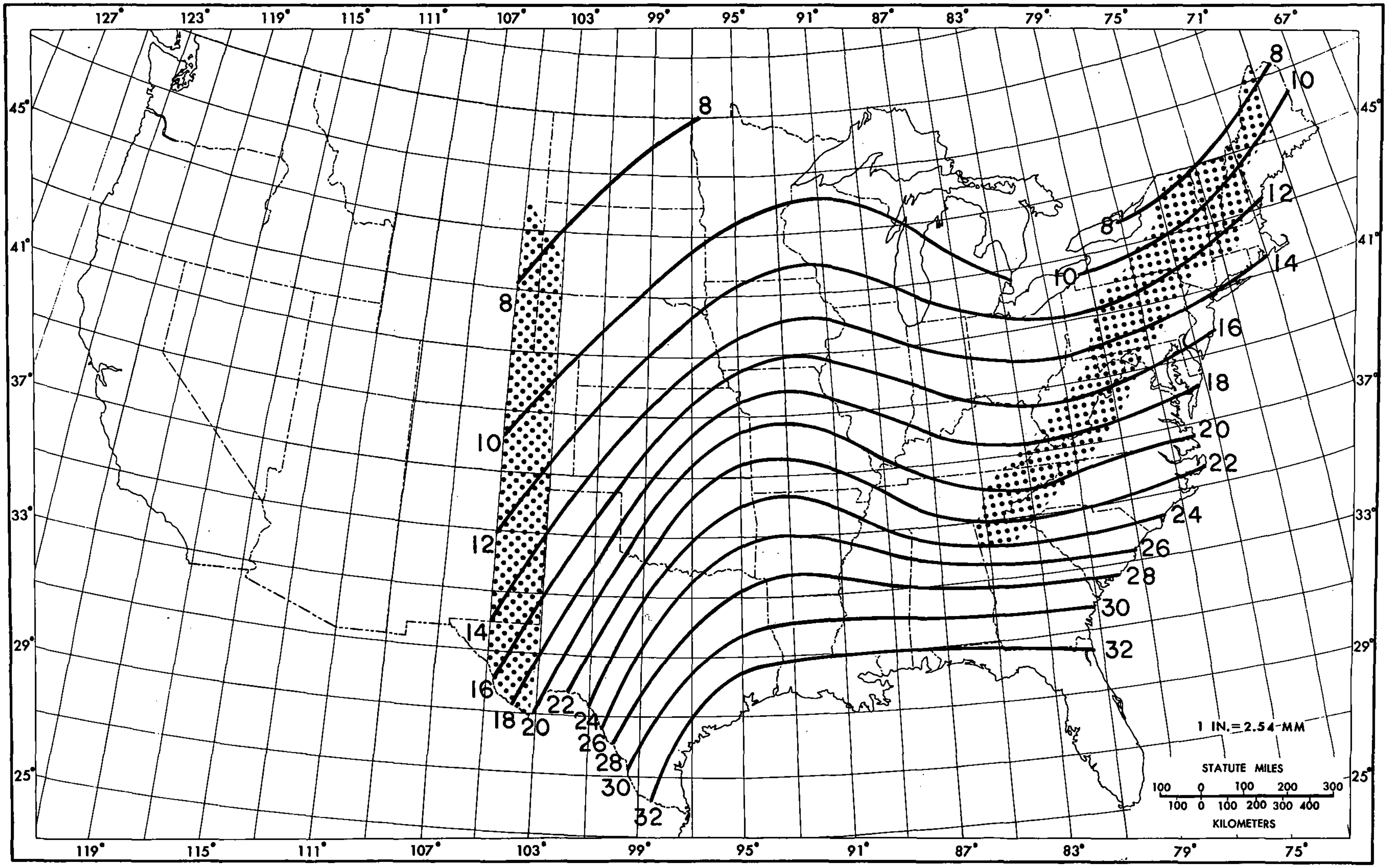


Figure 27.--24-hr 10-mi^2 PMP, March, (in.).

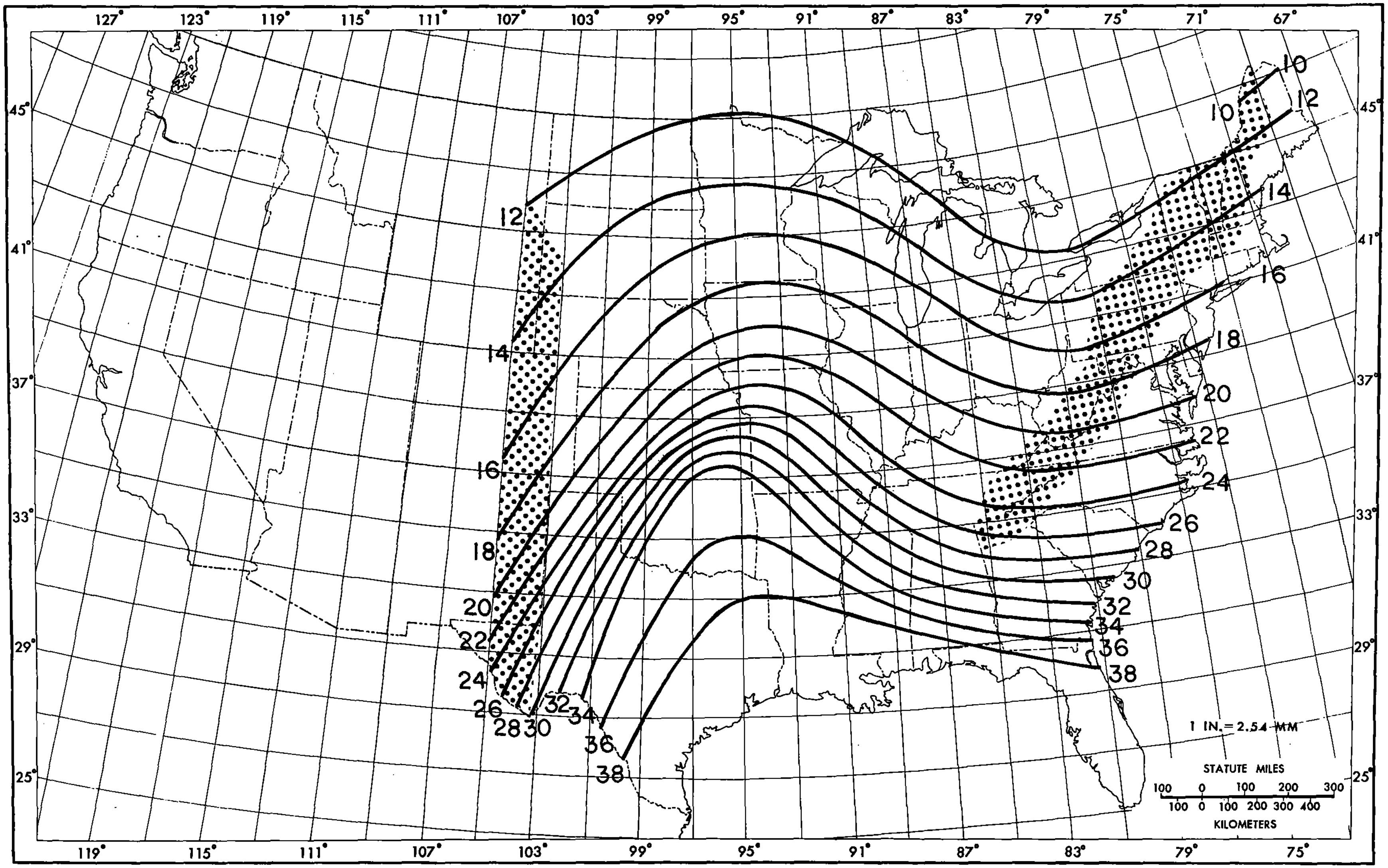


Figure 28.--24-hr 10-mi^2 PMP, April, (in.).

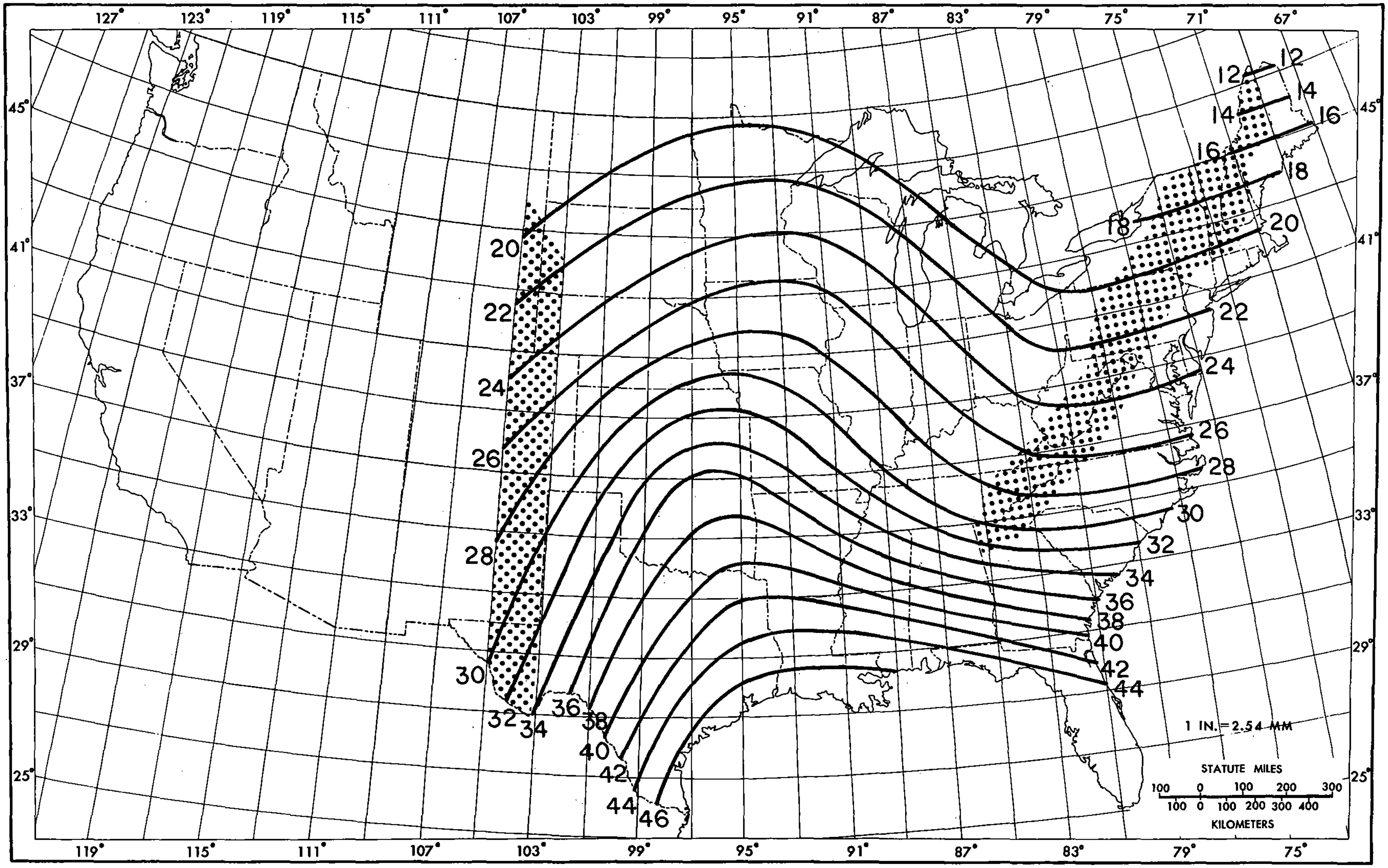


Figure 29.--24-hr 10-mi^2 PMP, May, (in.).

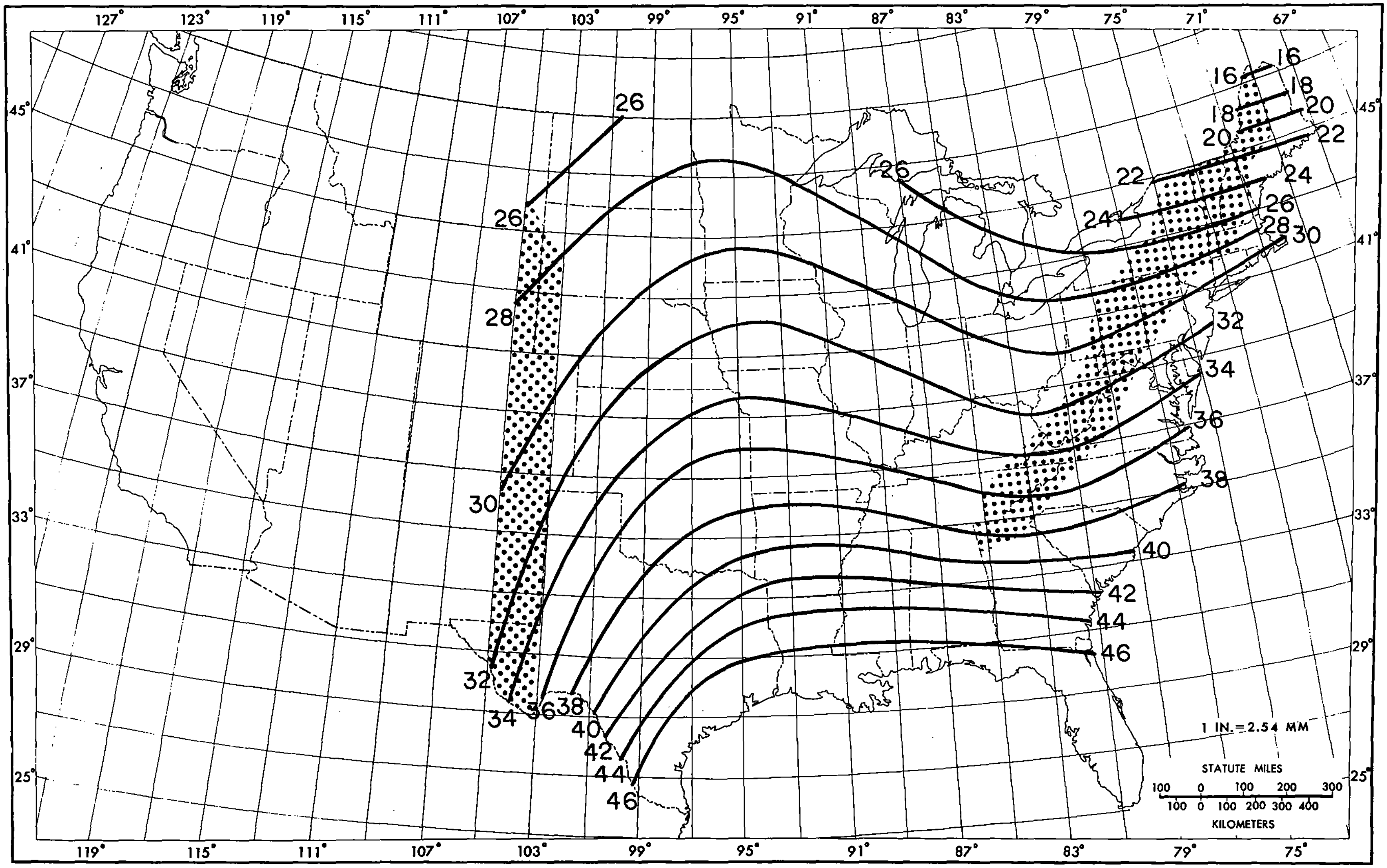


Figure 30.--24-hr 10-mi^2 PMP, June, (in.).

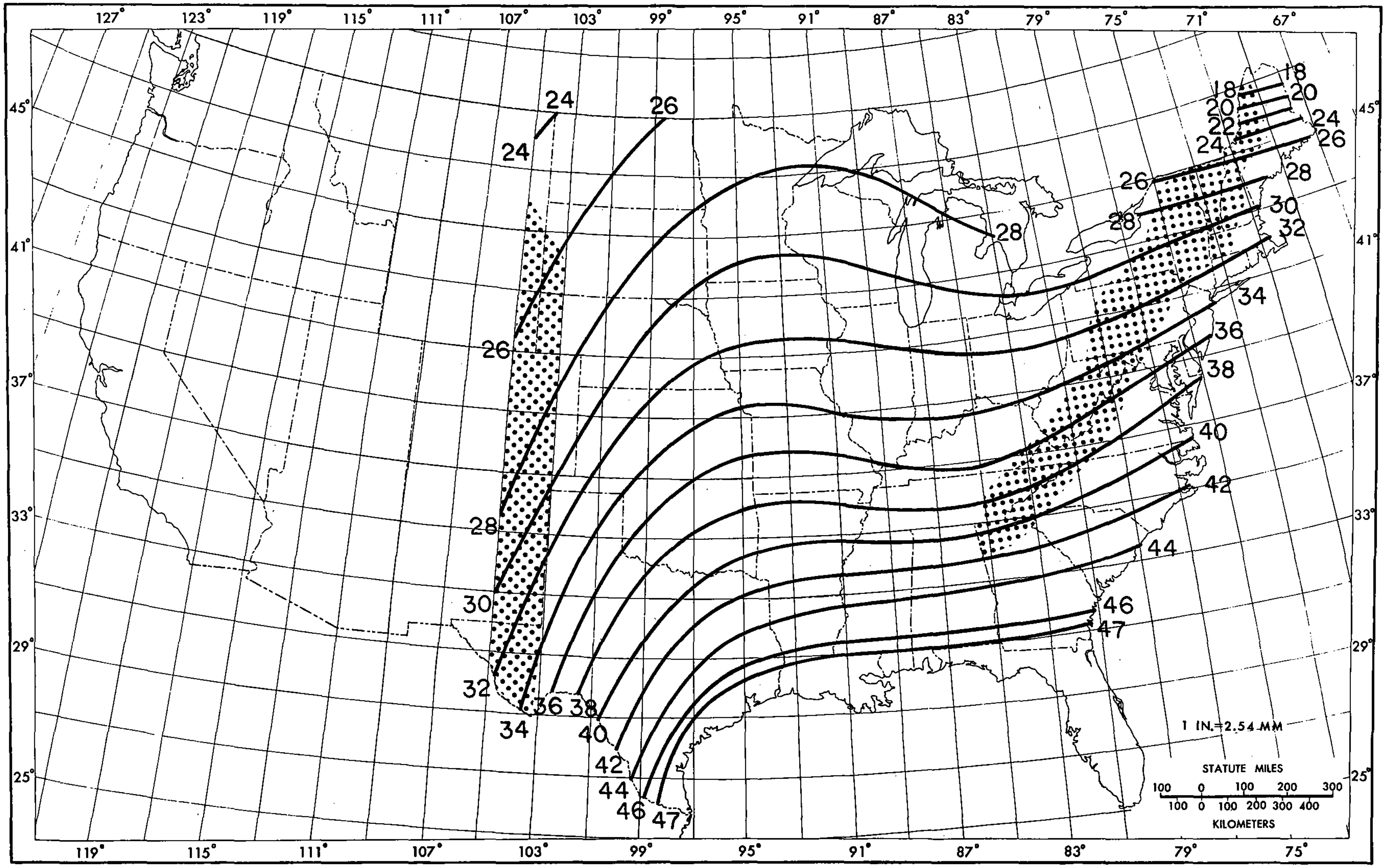


Figure 31.--24-hr 10-mi² PMP, July and August, (in.).

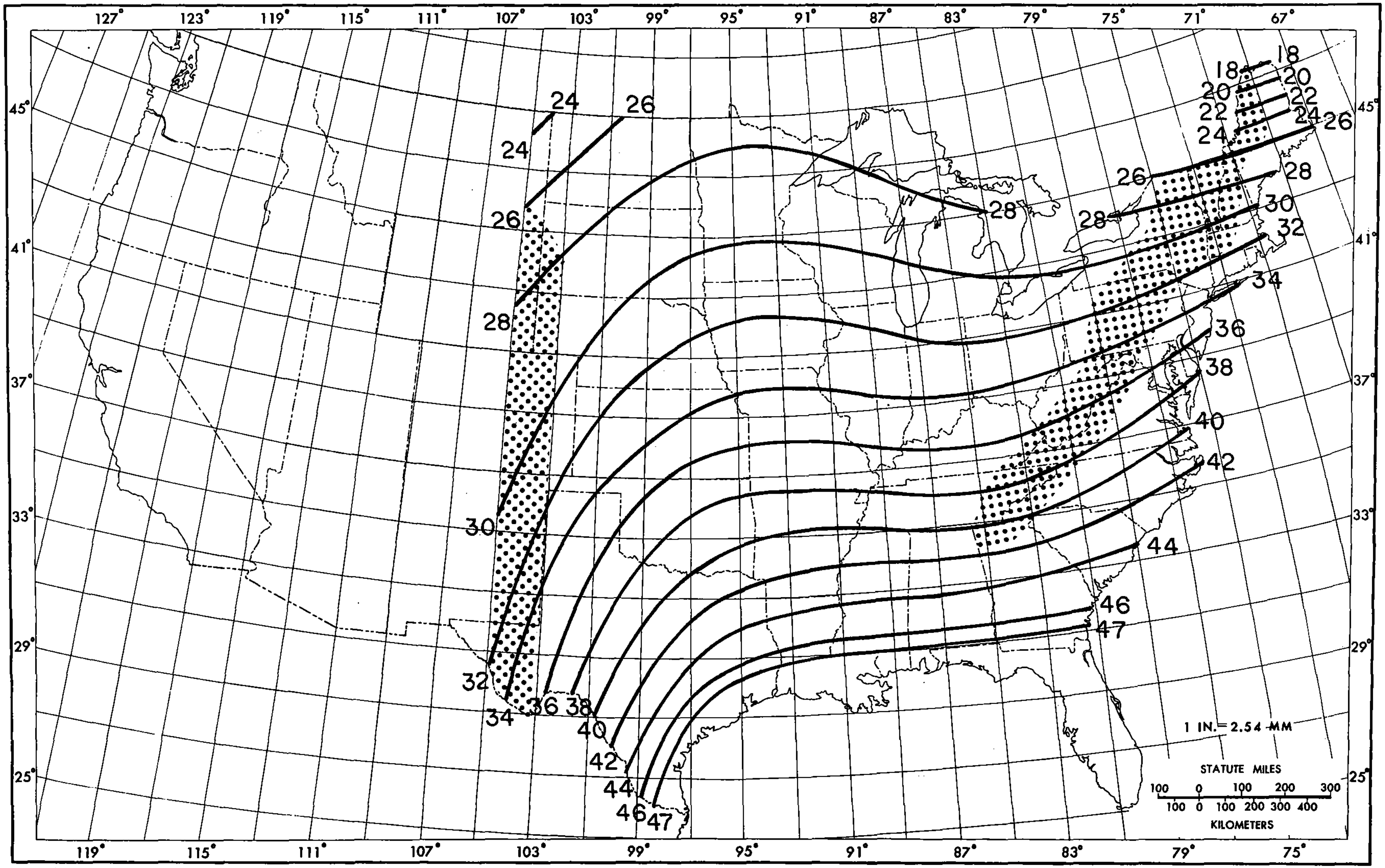


Figure 32.--24-hr 10-mi^2 PMP, September, (in.).

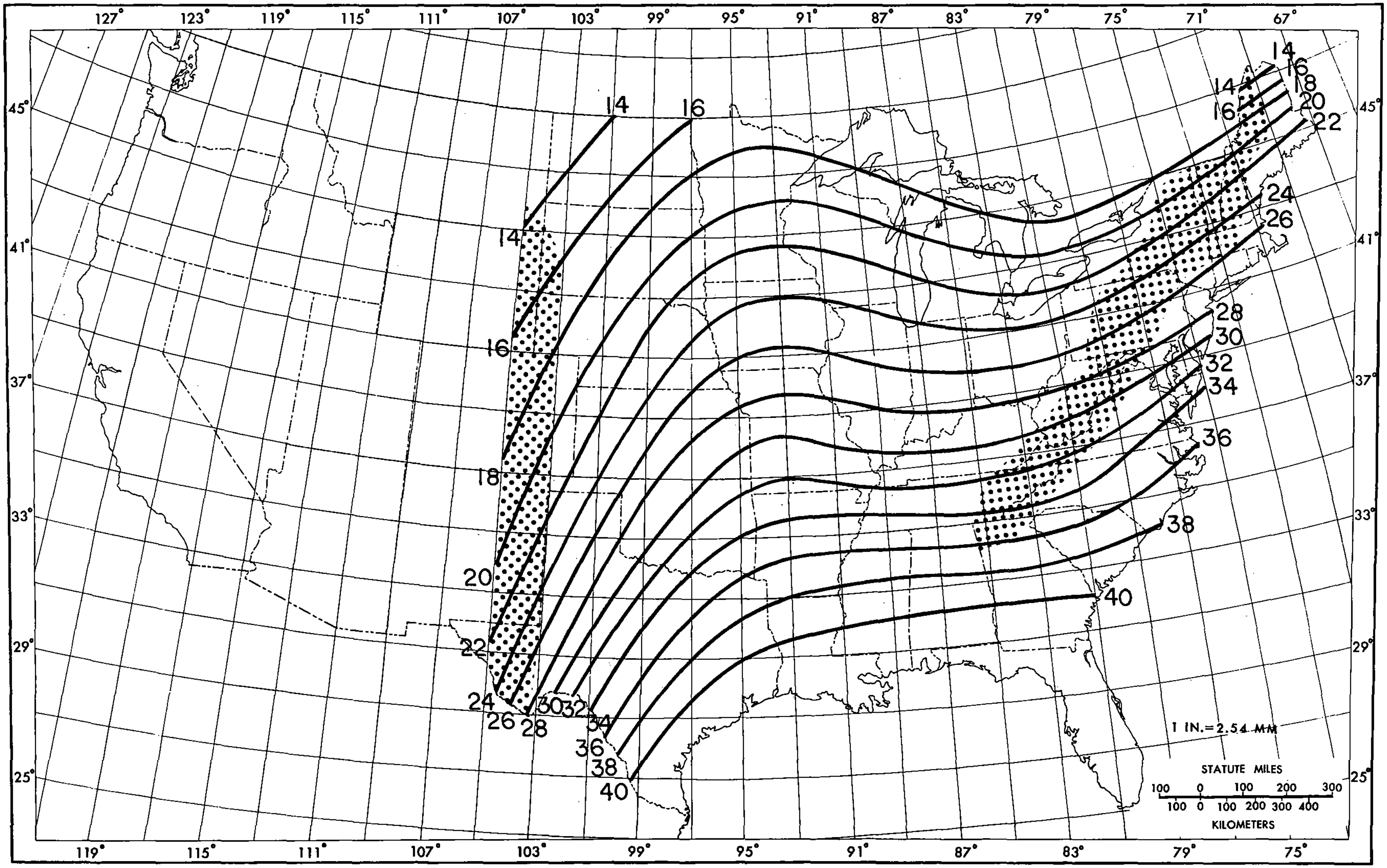


Figure 33.--24-hr 10-mi^2 PMP, October, (in.).

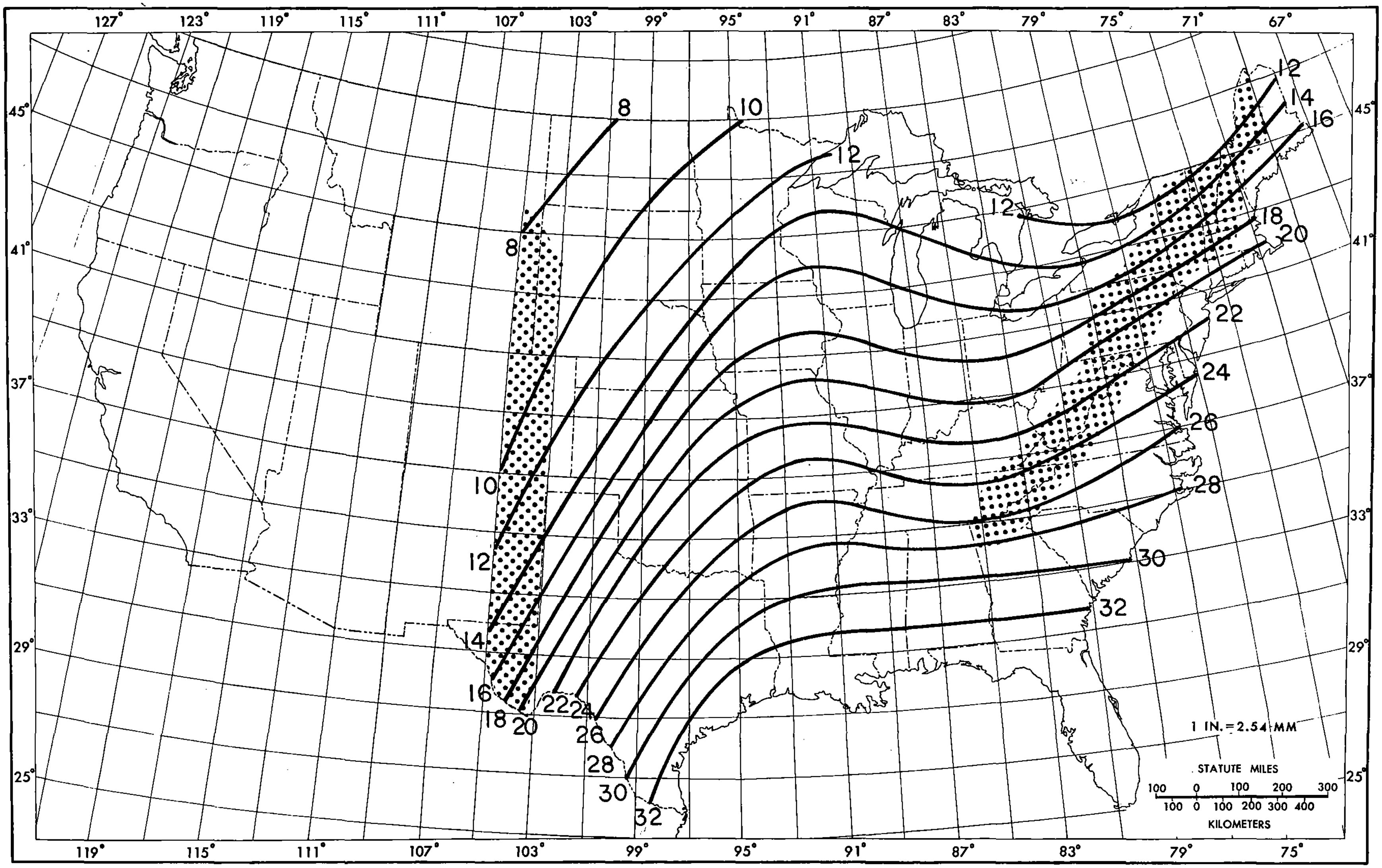


Figure 34.--24-hr 10-mi^2 PMP, November, (in.).

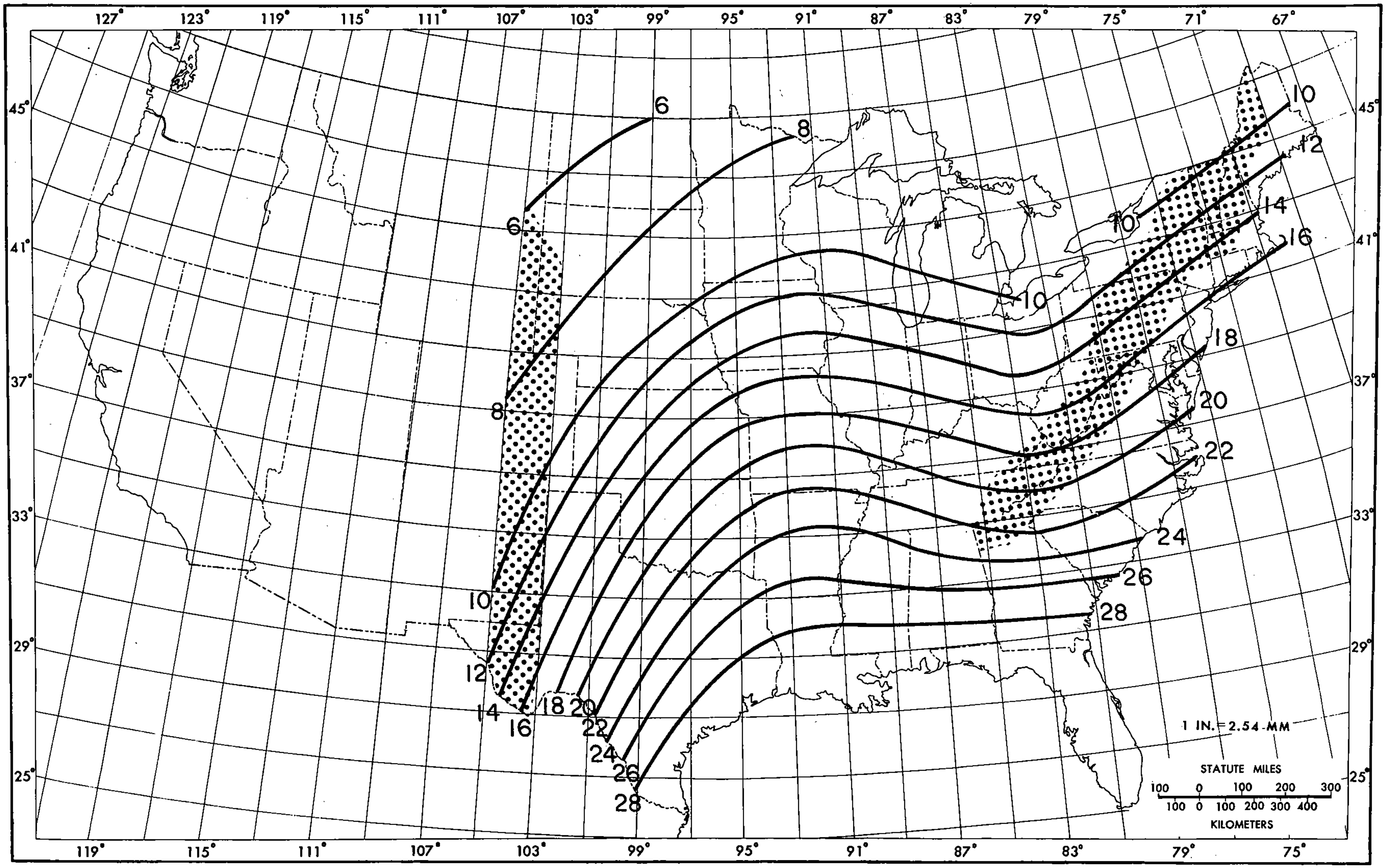


Figure 35.--24-hr 10-mi^2 PMP, December, (in.).

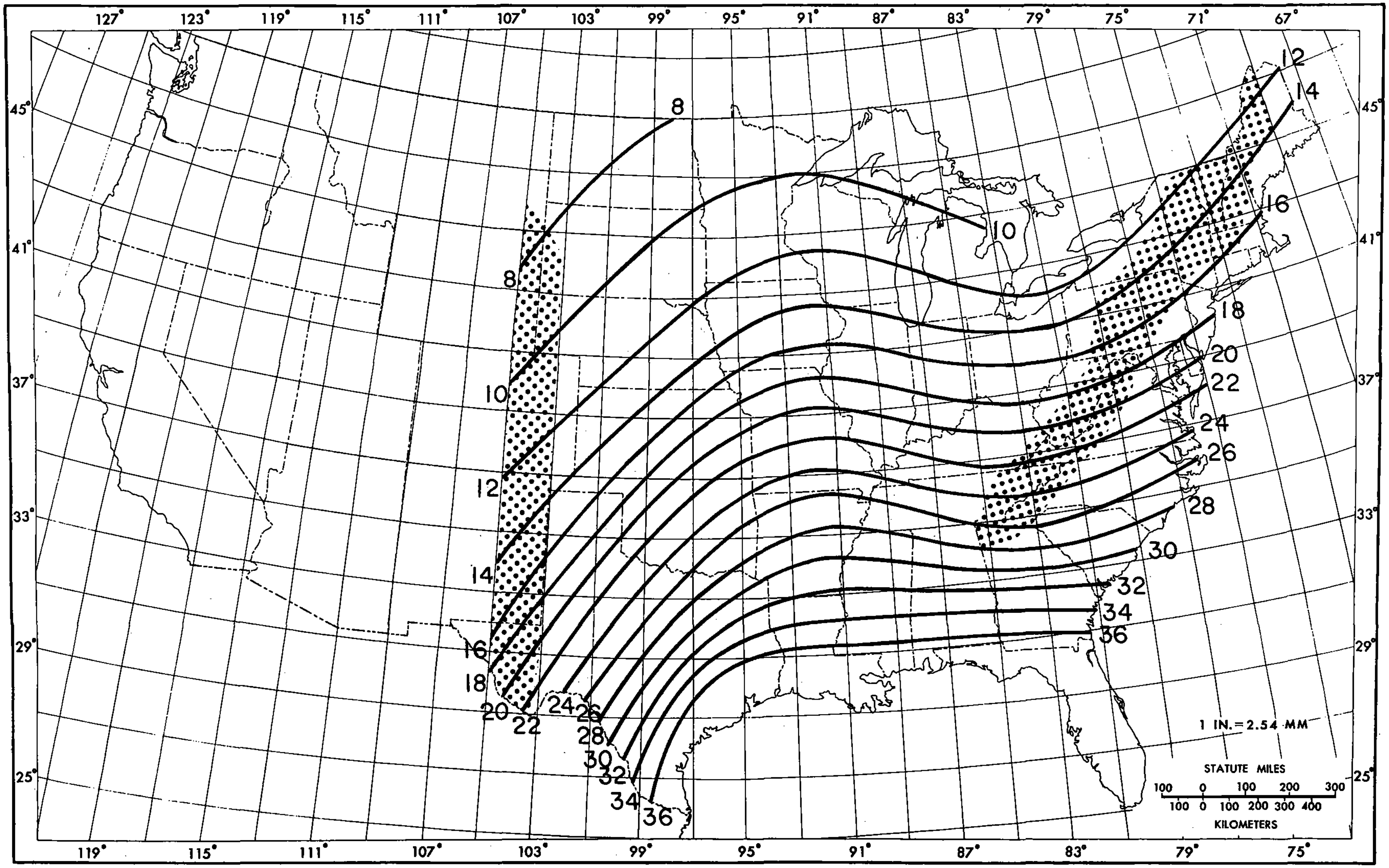


Figure 36.--72-hr 10-mi^2 PMP, January and February, (in.).

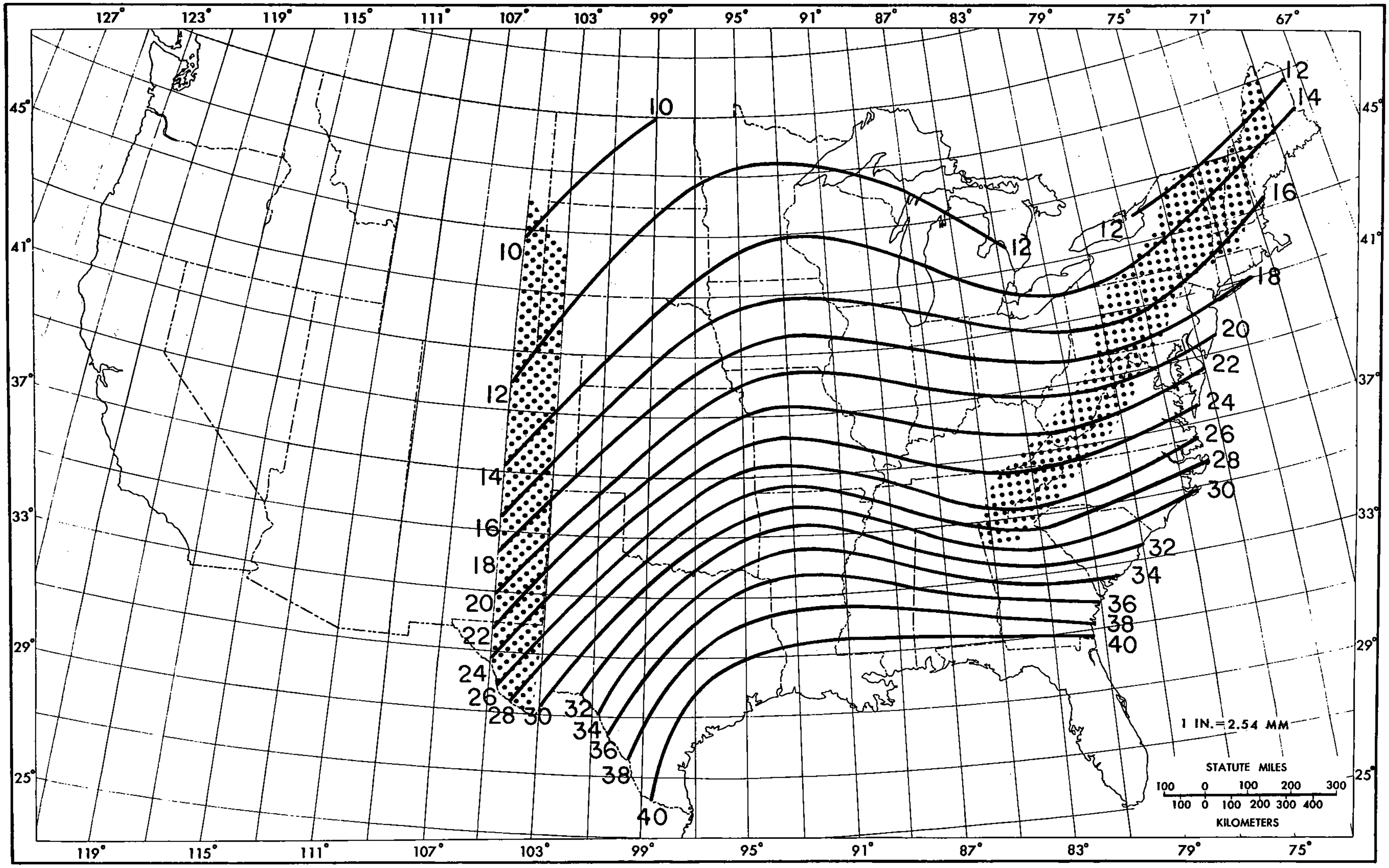


Figure 37.--72-hr 10-mi^2 PMP, March, (in.).

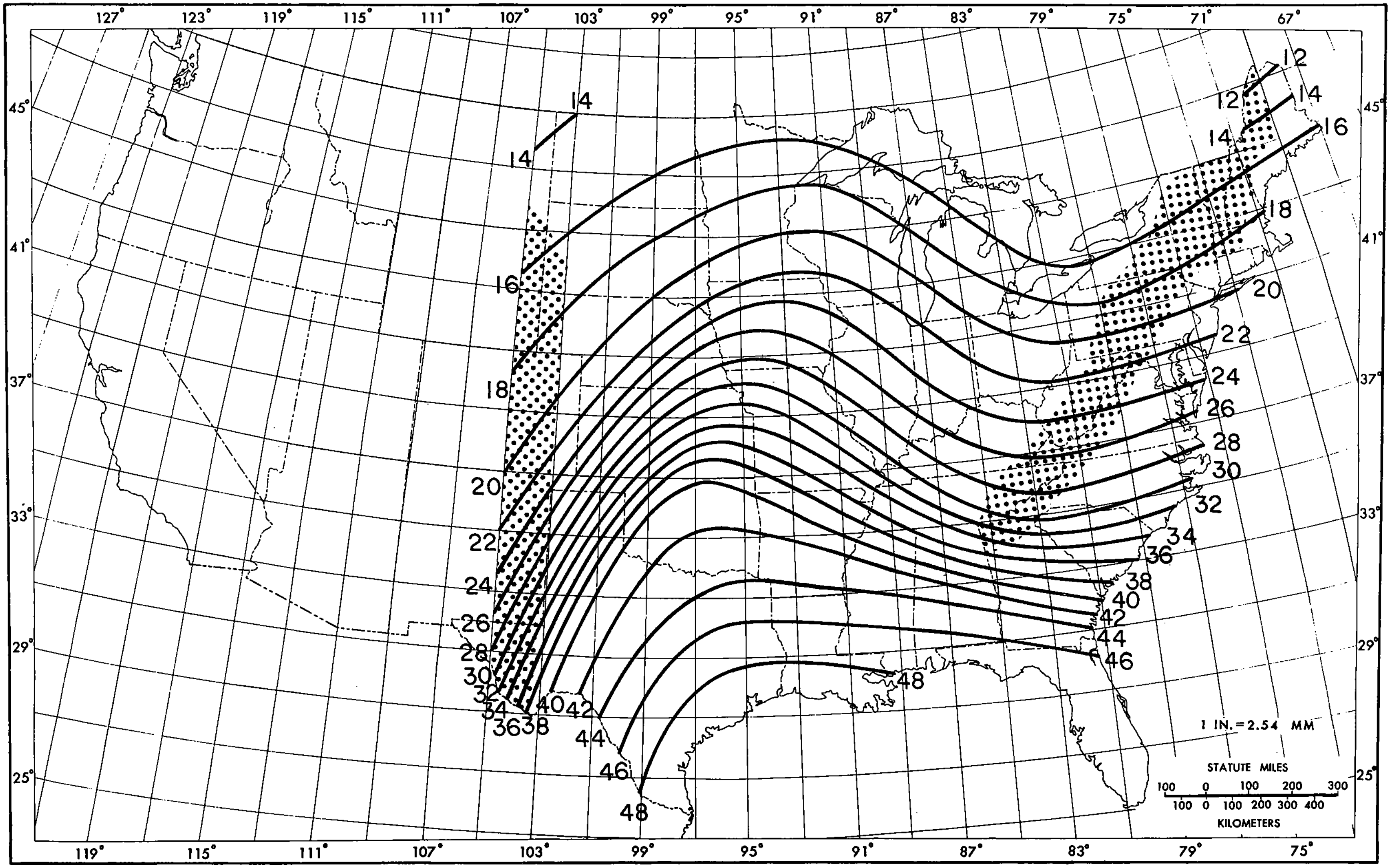


Figure 38.--72-hr 10-mi^2 PMP, April, (in.).

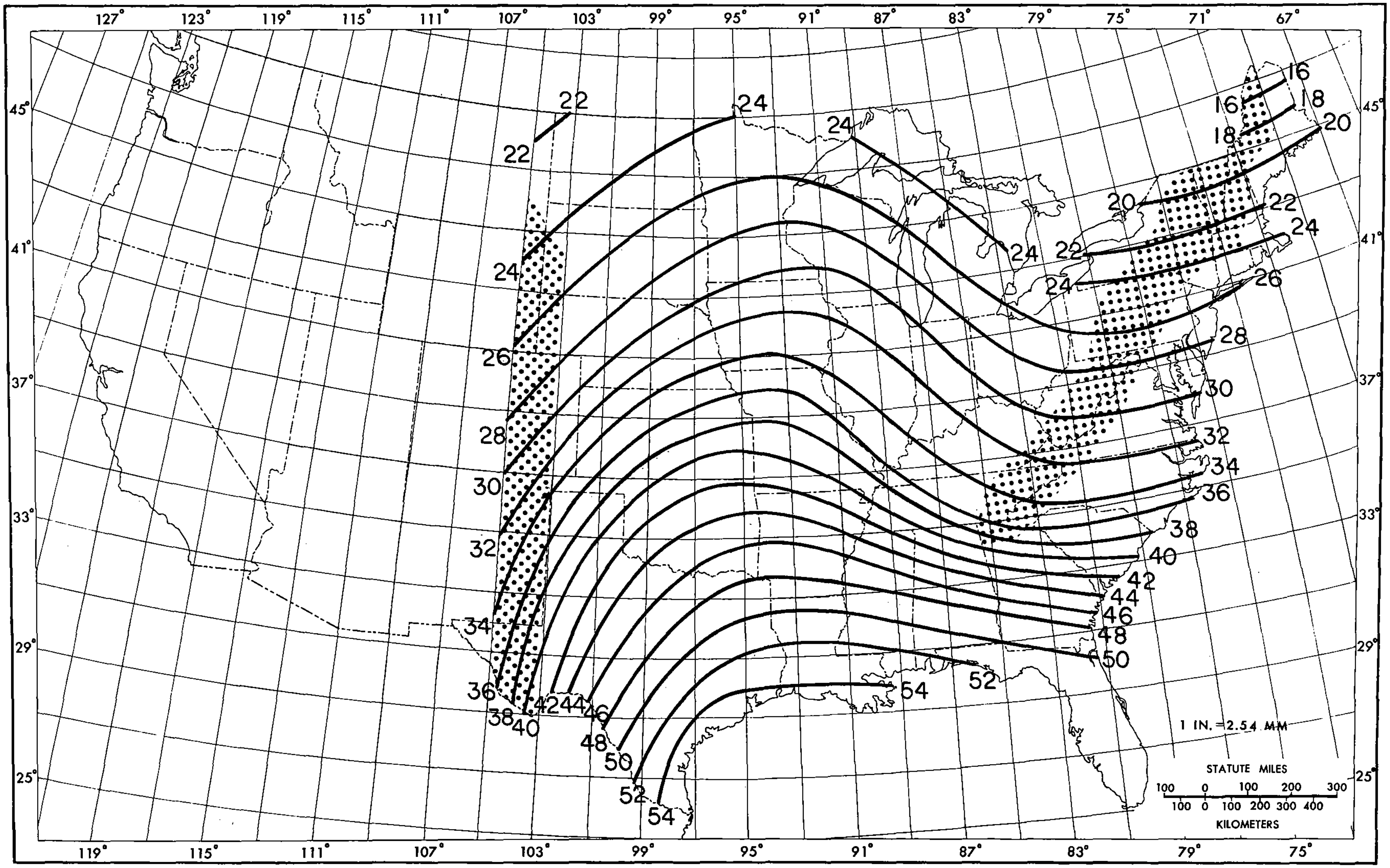


Figure 39.--72-hr 10-mi² PMP, May, (in.).

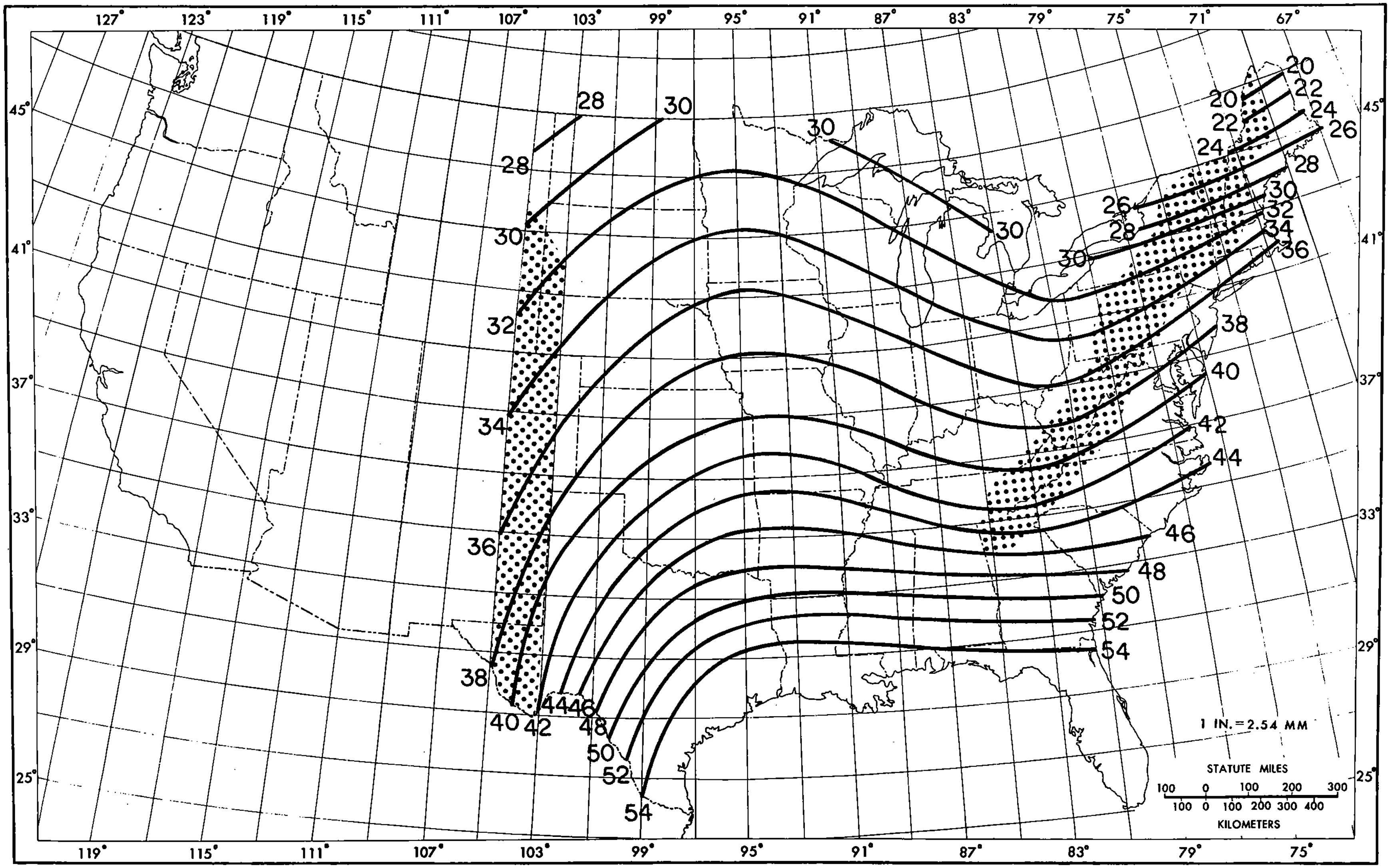


Figure 40.--72-hr 10-mi^2 PMP, June, (in.).

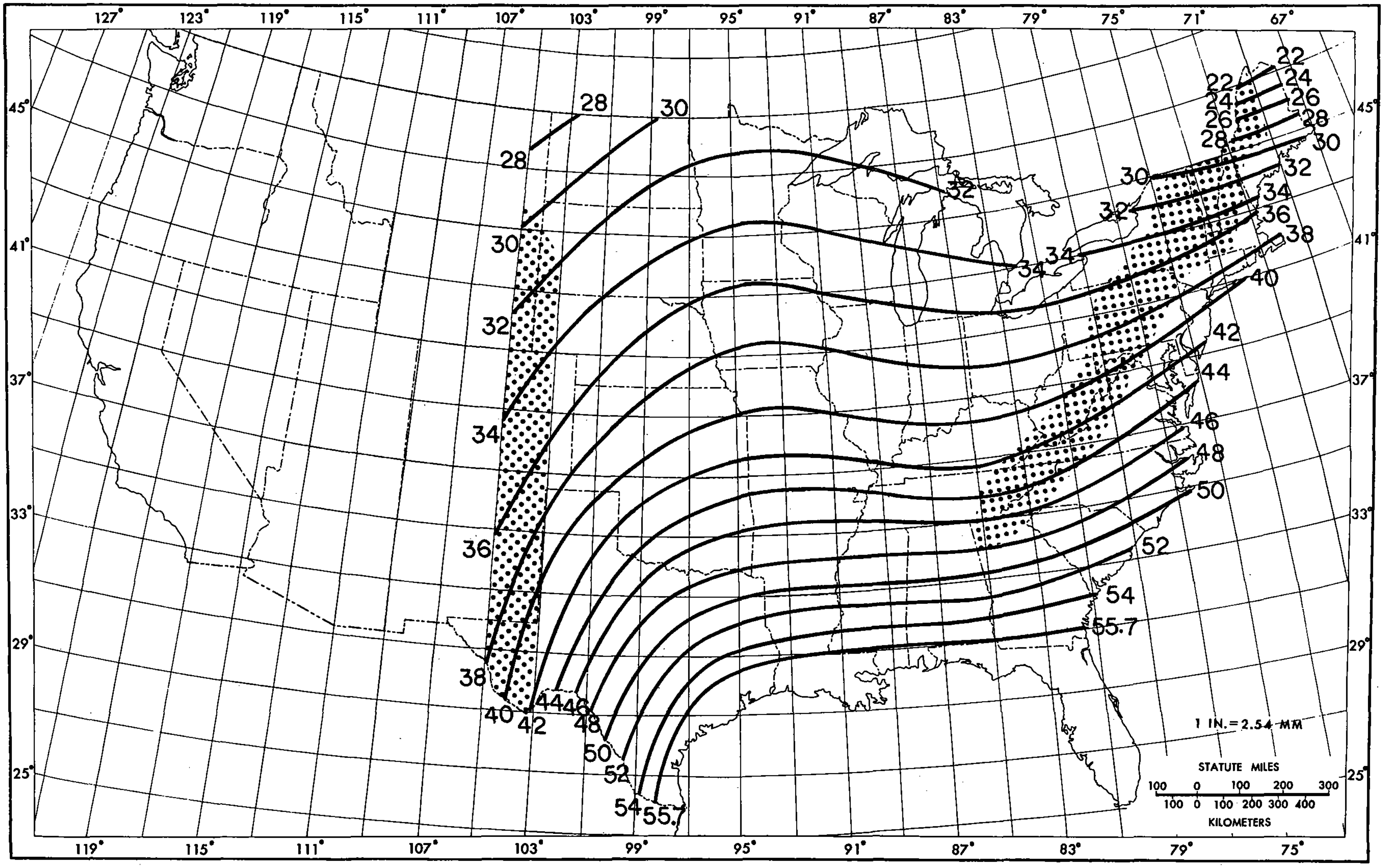


Figure 41.--72-hr 10-mi^2 PMP, July and August, (in.).

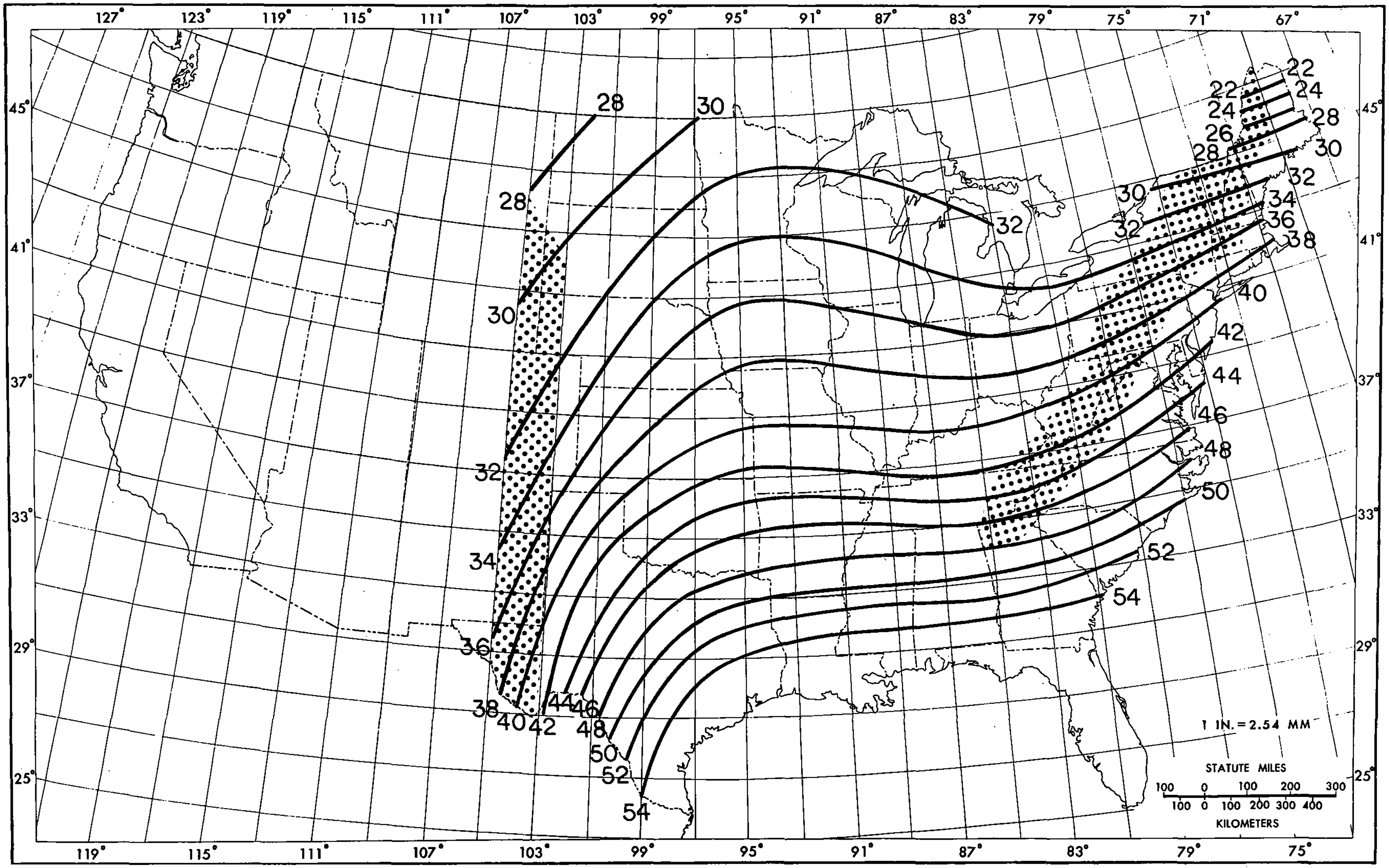


Figure 42.--72-hr 10-mi^2 PMP, September, (in.).

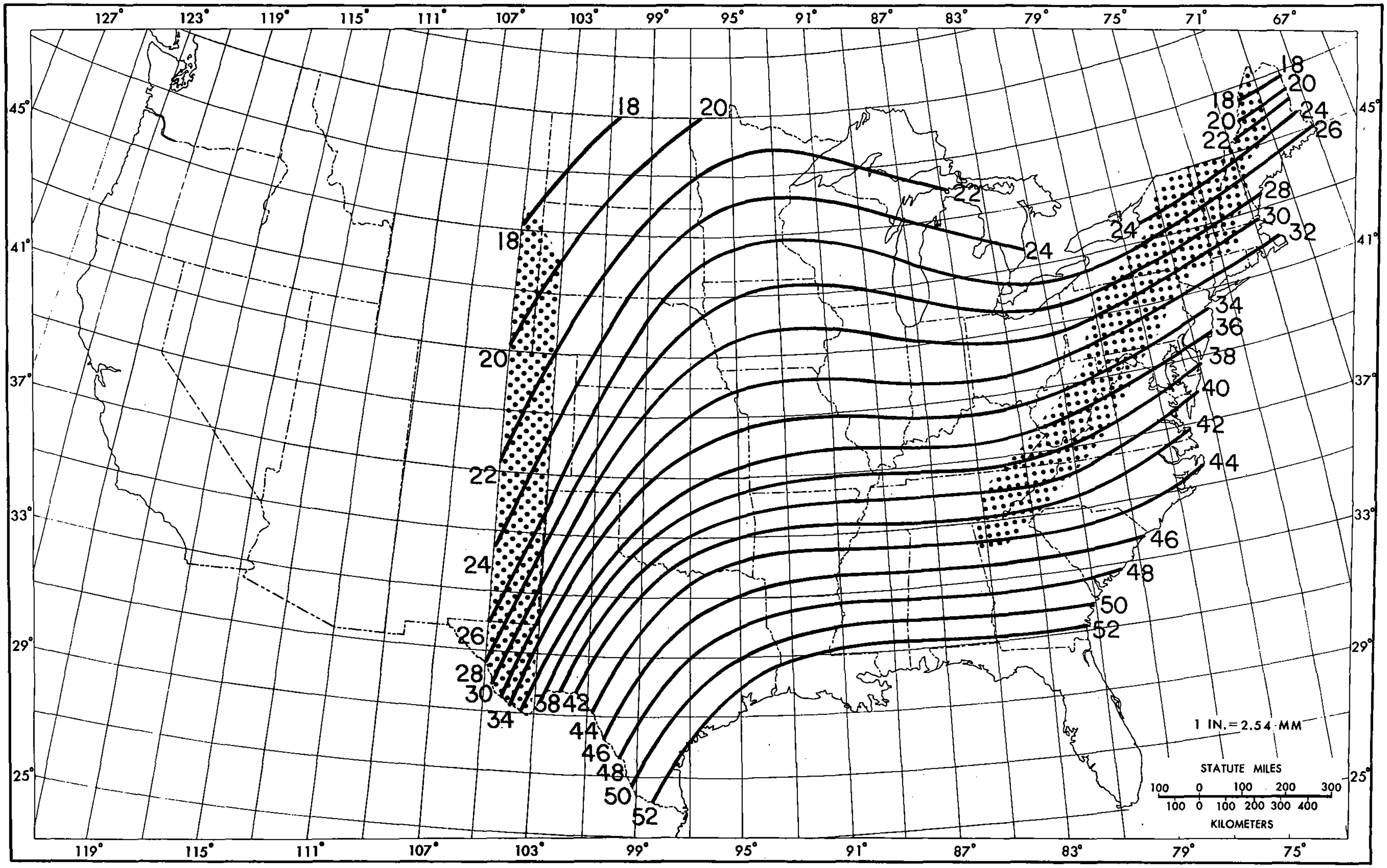


Figure 43.--72-hr 10-mi^2 PMP, October, (in.).

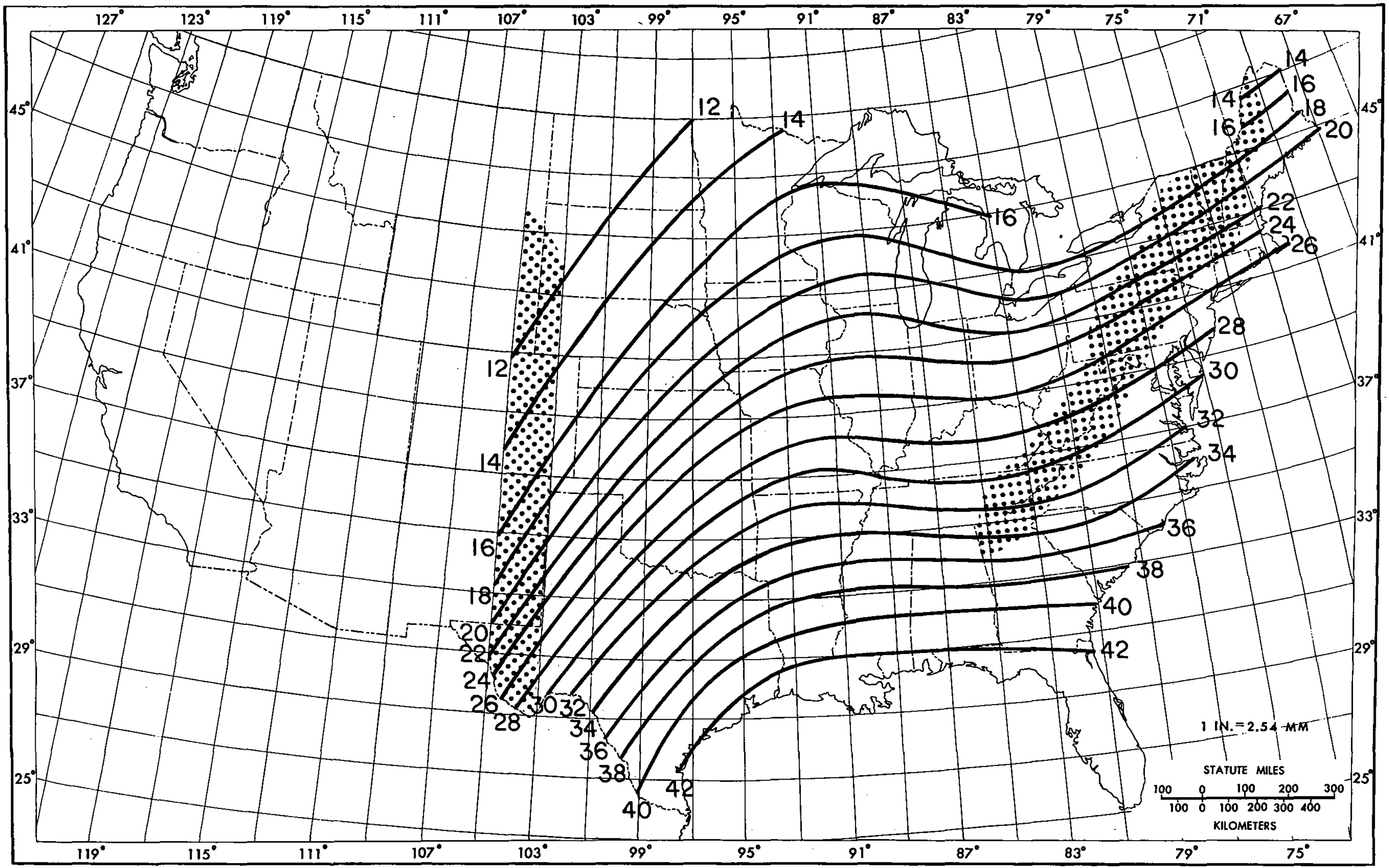


Figure 44.--72-hr 10-mi^2 PMP, November, (in.).

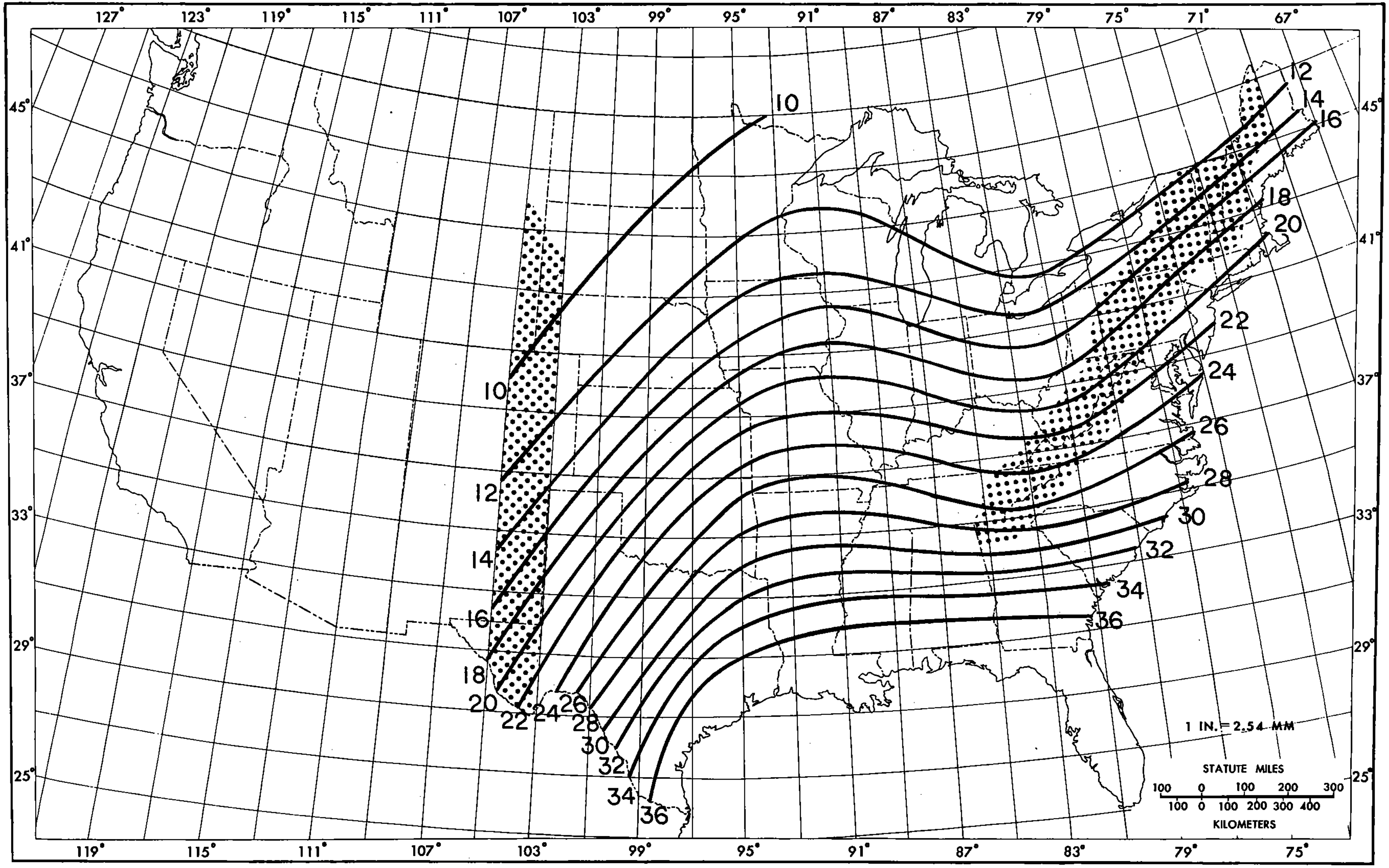


Figure 45.--72-hr 10-mi^2 PMP, December, (in.).

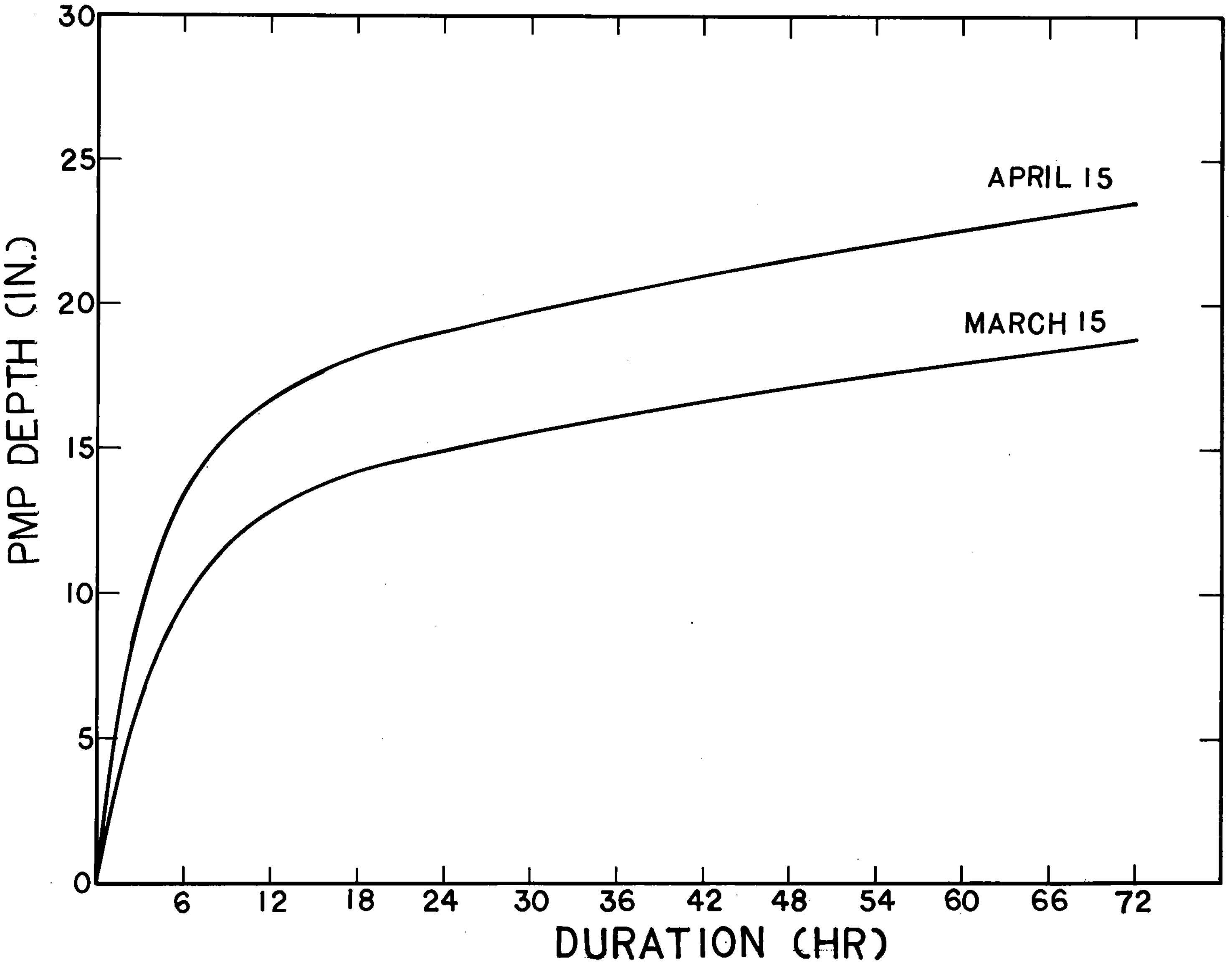


Figure 46.--Example of variation of PMP depths with duration for mid-month of March and April for 40.5°N 87.5°W (see sec. 6).

For such regions, the assumption was made that the reduced height of the column of moisture available for processing at higher elevations is compensated by intensification from steeper terrain slopes at these higher elevations.

In contrast to the use of these simplifying assumptions, studies of PMP covering portions of the Western States (U.S. Weather Bureau 1961, 1966, and Hansen et al. 1977) and Tennessee River drainage (Schwarz and Helfert 1969) do take into account detailed terrain effects. A laminar flow orographic precipitation computation model, useful in some regions where cool-season precipitation is of greatest concern, gave detailed definition for some of the Western States. For the Tennessee River drainage, nonorographic PMP was adjusted for terrain effects by considering numerous different rainfall criteria and taking into account meteorological aspects of critical storms of record.

We expect future studies of the Hydrometeorological Branch will involve detailed generalized studies covering the stippled regions. Until these studies are completed, we suggest that major projects within the stippled regions be considered on a case-by-case basis as the need arises.

7.2 Extreme Precipitation at Mt. Washington, N.H.

Some very extreme precipitation values have been observed in winter at Mt. Washington, a location in the stippled regions of the PMP maps. Three of the most extreme are listed in table 5. The editor of the *Mount Washington Observatory News* Bulletin gives the following description of the February 10-11, 1970 storm:

> *On the 10th and 11th there was a little storm that deposited a whopping 10.12 inches of water equivalent into the precipitation gage in 24 hours for another new record in this department! During part of the storm dense ice accumulated at the rate of five inches per hour and Summit structure eventually exhibited accumulations two feet thick in places. Wind during the storm peaked at 128 mph.*

Since Mount Washington Observatory, at an elevation of 6,262 feet, is located well above the mean elevation in the region we did not attempt to transpose such precipitation to other locations. We did not make adjustments for maximum moisture, but did ensure that the observed values were enveloped by the PMP isolines.

7.3 Point Rainfall vs. 10 mi^2 Average Rainfall

This study estimates PMP for 10-mi^2 areas. The basic data (Corps of Engineers, U.S. Army 1945-) often use point rainfall as 10-mi^2 rainfall depths. This is done in order to at least partially compensate for the slim chance of *catching* the most intense rainfall in any storm. The question may then be raised as to whether PMP for areas less than 10 mi^2 would be greater than the 10-mi^2 values of this report. For the all-season PMP taken from HMR No. 51, this is answered by the fact that with few exceptions the

Table 5.--Extreme precipitation amounts observed at Mt. Washington, N.H. (44°16N; 71°18W) during the winter season.

Storm date	6	12	18	24	48	72
	Duration (hr) Recorded precipitation amounts (in.)					
Feb. 10-11, 1970	4.7	9.2		10.1		
Dec. 26-28, 1969	3.3			8.6	10.2	10.3
Feb. 25-27, 1969	3.4			8.4	12.5	14.1

critical storm values establishing PMP for 10 mi^2 came from 10-mi^2 average rainfalls rather than single station values. Therefore, all-season PMP for areas less than 10 mi^2 exceed those given here for 10 mi^2.

What about storms controlling other seasons? PMP estimates for points during the cool season, say October - April, would reasonably be not much different from the 10-mi^2 values given in this report. This is so, since in winter rains are less variable from place to place because there is much less convective activity than in summer.

7.4 Storm Adjustments Greater than 150 Percent

Extreme increase in one parameter, say moisture, could well counteract other important factors; therefore, total storm adjustments that increased rainfalls by more than 50 percent were given further attention. If a storm had an adjustment giving an increase greater than 50 percent, but its adjusted depth was supported quite closely by surrounding storm depths with only moderate adjustments, the high adjusted value was accepted. If a high adjustment (greater than 50 percent) gave an amount that stood out among all other storms in a region, a value obtained by multiplying the observed depth by 150 percent was used. This limitation was also applied to HMR No. 51.

8. OBSERVED STORMS WITHIN 50 PERCENT of PMP

To give the user some insight on the magnitude of PMP, we have identified the known storm depths that are $\geq$ 50 percent of PMP. For simplification the PMP for the midmonth in which the storm occurred is compared with the storm depth. For example, if a storm occurred on any day in March it is compared with PMP for mid-March. A March 1 storm would actually be a higher percent of March 1 PMP and a March 31 storm would be a lower percent of March 31 PMP. No comparisons were made for July and August, the months for which we accept the all-season PMP of HMR No. 51. Comparisons of observed rainfall to all-season PMP in HMR No. 51 are given by Riedel and Schreiner, 1980.

Figure 47 shows a seasonal plot of the number of known storms that are $\geq$ 50 percent of 10-mi^2 PMP for 6, 24, and 72 hours. As discussed earlier, undoubtedly, many more storms have reached 50 percent of PMP than have been sampled by the sparse network. That there are fewer cases in winter than

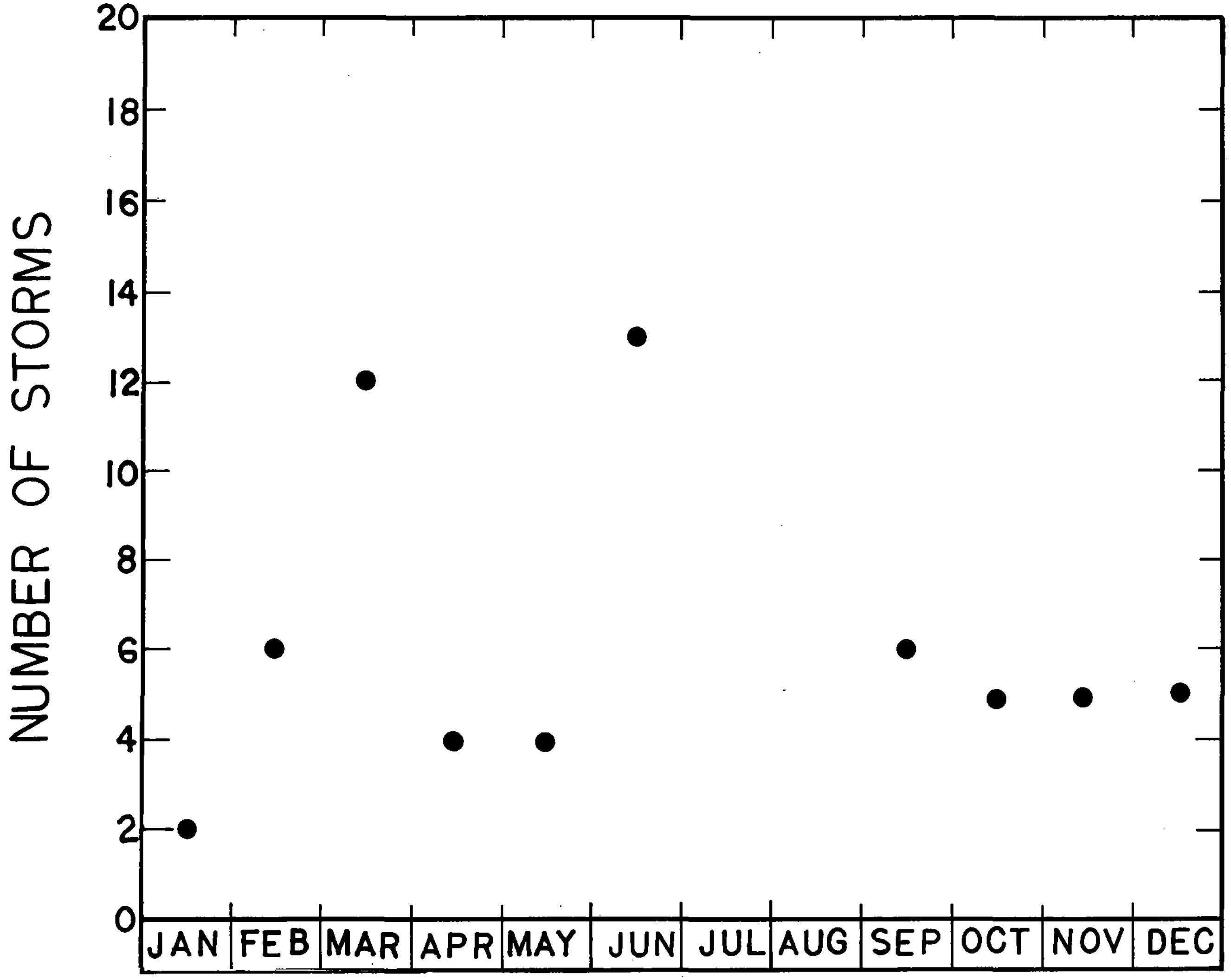


Figure 47.--Number of separate storms with rainfall ≥ 50% of PMP for 6, 24, and 72 hours (number of storms ≥ 50% of PMP for July and August can be obrained from Riedel and Schreiner 1980).

summer is in the right direction: fewer storms have been studied in the cool season and fewer surveys made after storm events to find extremes.

Table 6 lists chronologically the storms that have observed depths $\geq$ 50 percent of PMP for each month. Some of course are identical to the major storms of table 2.

We only show comparisons for rainfall depths for 6, 24, and 72 hours. If more durations were added (between 6 and 72 hours) many more storms would reach 50 percent of PMP and the percentages shown would be higher.

Table 6.--Known storm rainfalls for 6, 24 and 72 hours that are within 50 percent of mid-month PMP for the month in which the storm occurred (July and August storms not included)

Date	Storm number	Lat.	Long.	Dur. (hrs)	Obs. Precip. (in.)	% of PMP	COE Assign. No.	Source*
Jan.1-2,1941	3	48°00	89°42	24	4.7	65		TP No. 16
Jan.22-27,1949	5	35°52	92°19	6	7.5	52	SW3-10	STR
				24	11.7	54		
Feb.2-18,1883		41°42	77°16	6	3.6	60	OR5-11	STR
Feb.12,1886		41°54	71°23	24	7.9	56		STR
Feb.6,1960		43°07	73°35	24	5.1	61		DTD
Feb.25-27,1969	12	44°16	71°18	24	8.4	86		DTD
				72	14.1	68		
Feb.10-11,1970	13	44°16	71°18	6	4.7	89		DTH
				24	10.2	100		
Feb.1,1973	14	32°56	92°36	6	10.6	65		DTH
Mar.13,1888		42°43	73°18	24	6.1	52		TP No. 16
Mar.28,1902		35°41	85°48	24	11.0	50		TP No. 16
Mar.23-27,1913	17	40°22	83°46	24	7.3	55	OR1-15	STR
				72	10.4	61		
Mar.11-16,1929	19	31°25	86°04	6	14.0	73	LMV2-20	STR
				24	20.0	65		
				72	29.6	74		
Mar.12,1936		44°16	71°15	24	6.5	66		TP No. 16
Mar.22,1949		44°25	72°16	24	5.0	55		TP No. 16 (update)
Mar.31,1951		41°56	74°23	24	6.7	57		TP No. 16 (update)
Mar.25,1964	21	35°37	84°12	6	7.5	55		DTH
Mar.16-18,1965	22	46°53	90°49	72	6.6	54		DTD
Mar.25,1965		41°34	75°52	6	4.3	57		DTH
Mar.2-5,1966	23	47°14	98°35	24	4.7	57		STR
Mar.14,1973	24	44°21	103°46	24	5.7	71		DTD
Apr.11-14,1933	26	43°08	70°56	6	4.9	52	NA1-23	STR
Apr.3-4,1934	27	35°37	99°40	6	17.3	73	SW2-11	STR
Apr.24-28,1937	28	39°40	77°54	72	11.3	53	SA5-13	STR
Apr.21,1951		33°21	94°30	6	14.2	53		DTH
May 30-June 1, 1889		41°45	77°17	6	7.4	53	SA1-1	STR
May 30-31,1935	34	39°36	102°08	6	16.5	82	MR 3-28A	STR
				24	22.2	83		
May 6-12,1943	35	35°29	95°18	72	24.9	56	SW2-20	STR
May 12-20,1943		35°52	96°04	6	15.9	56	SW2-21	STR
June 13-18,1886	38	31°19	92°33	72	29.0	53	LMV4-27	STR
June 27-Jul.1, 1899		30°52	96°32	72	34.5	64		STR
June 17-21,1921	39	47°18	105°35	6	10.5	55	MR4-21	STR
				24	13.3	53		
				72	14.6	53		
June 30,1932		30°01	99°07	24	31.7	75	GM5-1	STR
June 19-20,1939		32°44	100°55	6	18.8	71		STR
June 10-13,1944		41°52	97°03	6	13.4	53	MR6-15	STR
June 23-24,1948	42	29°22	100°37	24	26.2	66		STR
June 23-28,1954	43	30°12	101°35	6	16.0	61	SW3-22	STR
				24	26.7	71		
				72	34.6	77		

See notes at the end of the table.

Table 6.--Known storm rainfalls for 6, 24 and 72 hours that are within 50 percent of mid-month PMP for the month in which the storm occurred (July and August storms not included) (Continued)

Date	Storm number	Lat.	Long.	Dur (hrs)	Obs. Precip. (in)	% of PMP	COE Assign. No.	Source
June 8-10,1962		44°12	103°31	72	14.9	62		DTD
June 23-24,1963	45	41°14	97°05	6	14.6	57		STR
				24	16.2	51		
June 24,1966	46	47°21	101°19	6	11.1	53		STR
June 9,1972	47	44°12	103°13	24	14.9	54	MR10-12	STR
June 20-22,1972	48	42°05	78°10	24	14.3	52	NA2-24A	STR
				72	18.5	58		
Sept.8-10,1921	49	30°35	97°18	6	22.4	74	GM4-12	STR
				24	36.5	84		
				72	37.6	72		
Sept.17-19,1926	50	43°12	96°00	6	15.1	62	MR4-24	STR
				24	21.7	71		
Sept.14-18,1936		31°47	100°50	24	26.0	68		STR
				72	30.0	65		
Sept.1,1940	52	39°42	75°12	6	20.1	76	NA2-4	STR
Sept.2-6,1940	53	36°15	96°36	6	18.4	65	SW2-18	STR
				24	23.6	64		
Sept.3-7,1950	54	29°03	82°42	24	38.7	81	SA5-8	STR
				72	45.2	82		
Oct.7-11,1903	56	40°55	74°10	24	13.7	51	GL4-9	STR
Oct.17-22,1941	57	29°48	82°57	24	30.0	73	SA5-6	STR
				72	35.0	66		
Oct.11-18,1942	58	38°31	78°26	72	18.7	52	SA1-28A	STR
Oct.30-Nov.1, 1969	70	30°41	81°28	24	22.0	67		DTD
				72	22.6	56		
Oct.10-11,1973	63	36°25	97°52	6	16.9	77		STR
Nov.7,1915	65	48°54	103°18	24	4.0	56		TP No. 16
Nov.2-4,1927	67	44°03	71°45	6	7.8	78	NA1-17	STR
				24	12.0	79		
				72	14.0	71		
Nov.22-25,1940	69	30°08	96°08	24	18.6	59	GM5-13	STR
				72	21.1	53		
Nov.1,1948		37°02	99°59	6	6.1	50		DTH
Nov.13,1954		24°33	81°48	24	19.9	62		TP No. 2
Dec.5-8,1935	72	29°54	95°37	24	18.6	66	GM5-4	STR
				72	20.8	57		
Dec.29-Jan.1, 1949	73	42°40	73°19	24	8.1	62	NA2-18	STR
				72	12.6	73		
Dec.20,1959		37°25	82°01	6	6.7	56		DTH
Dec.26-28,1969	74	44°16	71°18	6	3.3	55		DTD
				24	8.6	77		
				72	10.4	70		
Dec. 26-28,1969		44°40	70°09	24	6.0	51		TP No. 16
				72	10.0	71		(update)

COE:	Corps of Engineers
* :	Source
STR:	Storm rainfall
TP No. 16:	Technical Paper No. 16
DTD:	Data tape; daily precipitation
DTH:	Data tape; hourly precipitation

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