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A COMPARISON OF THE FREQUENCY DISTRIBUTION OF FOUR-HOUR TOTALS OF MANUALLY DIGITIZED RADAR DATA WITH FLOODING OVER A PORTION OF THE SOUTHEASTERN UNITED STATES

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ABSTRACT

A frequency distribution of four-hour totals of MDR data was developed from twelve months of data for a portion of the southeastern United States. This distribution was developed in ten categories of four-hour MDR totals for 98 grid squares under the surveillance of ten radars. The variations in the frequency distribution are examined for the radar range effect, seasonal changes and for variations associated with topography. The frequency distribution is compared with the maximum four-hour MDR totals assocated with flooding. Eighty-six percent of the maximum four-hour MDR totals associated with flooding occurred in the top ten percent of the frequency distribution. Four-hour MDR totals which correspond to the beginning of the top ten percent of the frequency distribution, the median four-hour MDR total associated with flooding, and the four-hour MDR total which begins the top one percent of the frequency distribution are derived for each grid square. A radar-derived precipitation frequency was also developed and areas of poor radar detection of precipitation are identified. Suggestions are made for improving radar estimates of precipitation; especially over mountainous areas.

INTRODUCTION

In the expanding computer revolution in the National Weather Service, the operational use of digitized radar (DR) data is becoming more prevalent. Programs have been developed to utilize DR data as an indicator of the probability of flash flooding (Moore, et al., 1974) and to improve upon computer-generated probability of precipitation (PoP) guidance (Moore & Smith, 1972; Peters & Barnes, 1973). Undoubtedly additional programs will be developed which will incorporate DR data, especially as aids in local warnings and forecast problems. The Techniques Development Laboratory also utilizes these data as predictors in some of their forecast programs.

In an effort to better understand and utilize DR data, a limited frequency distribution of four-hour manually digitized radar (MDR) totals was compiled. This frequency distribution is then related to observed flooding, but application to other programs which utilize DR data is also possible. Even though the basic DR program is undergoing change, the general patterns in the data should persist. Some of the limitations of the radar observational network will also be apparent.

DATA

Four-hour totals of MDR data from ten radars for the twelve-month period July 1973 through June 1974 were utilized in this study. The data sample consisted of 195,000 four-hour MDR totals for 98 grid squares which cover a portion of the southeastern United States (Figure 1). The four-hour MDR totals were computer-generated and were only available for Southern Region radar stations. Caution is suggested when applying values from this study to operational situations; despite the sizable data sample, some patterns depicted could be the result of a few significant precipitation events.

The MDR grid squares are approximately 40 nm (75 km) square. The hourly MDR value is a "snap-shot" reflecting the maximum precipitation rate indicated anywhere in the grid square and is determined by the radar operator near H+30 each hour and coded according to Table 1.

A frequency distribution was derived for each grid square in ten categories of four-hour MDR totals: 1 through 3, 4 through 7, 8 through 11, ...32 through 35, and 36. Values less than 0.5 percent will be indicated by an asterisk (*). The total number of hours for which data were possible was reduced by the number of hours of missing data. The number of four-hour MDR totals per grid square ranged from 933 to 2835. Data for Centreville, AL were missing for the period July through mid-August due to the destruction of the radar tower by a tornado. Radar station identifiers and their percentage of missing data are listed in the Appendix.

DISCUSSION

The frequency distribution of four-hour MDR totals for each of the ten categories is shown in Figures 2 through 11 (radar sites are marked with small crosses). Note the wide variation within each category across the grid, the seasonal changes and the range effect. Figure 12 shows the twelve-month average frequency distribution for the 98 grid squares combined along with the greatest and least frequency of occurrence for each category. Table 2 shows range averages of the frequency distribution for the twelve-month period along with the radar-derived average precipitation frequency for the various range groups. Relatively small variations occur in the range averages of the frequency distribution out to 70 nm (130 km) but beyond that distance the changes become more apparent with increasing range.

Frequency distributions in four-month groupings were also developed (Figures 2 through 11) to examine the variation resulting from predominant precipitation types. In an effort to keep the data sample as large as possible, the data were divided into four-month groups rather than the customary seasonal divisions. The groups are: air mass convection, July-October; winter frontal, November-February; and spring frontal, March-June. While these groupings are rather crude, the variations between the groups may be of interest to those developing operational programs using DR data.

Range averages of the frequency distribution for the four-month groupings are presented in Table 3. Note that the range effect is more apparent in the November-February group averages. The only four-hour MDR totals in the 36 category are reported in the November-February group, but in general the higher four-hour MDR totals occur with a greater frequency in the March-June group. The November-February and July-October groups have somewhat similar frequency distributions, but with differing predominant precipitation types. Stratiform precipitation dominates the November-February group with convection mainly associated with cold frontal passages. The July-October group has abundant convective activity of the air-mass type; however, the high precipitation rates are not maintained through an entire four-hour period with great regularity.

Radar station averages of the frequency distribution and radar-derived precipitation frequency for the twelve-month period are presented in Table 4. The averages were derived from grid squares with centers at ranges of less than 90 nm (167 km) for the eight radar stations with four or more grid squares. There is a large variation among the radar stations in the frequency of four-hour MDR totals of 20 or more, JAN and NPA having the greatest frequency of occurrence with 13 percent while TRI has only slightly more than one percent. TRI heads the list in the frequency of occurrence of four-hour MDR totals less than eight with 81 percent. This might be expected because the TRI grid squares primarily cover mountainous terrain. However, when a comparison of the radar-derived precipitation frequency is made, the greatest frequency occurs at NPA and BNA, near the Gulf Coast and west of the mountains. This anomaly results from the inability of radar to adequately detect stratiform precipitation over mountains, especially during the cool season (May, 1976).

Radar-derived precipitation frequencies for each grid square are shown in Figure 13. These values were derived from the hourly summations of four-hour MDR data. Note the predominance of the range effect on the radar data pattern with the greater frequencies at shorter ranges. Some of the grid squares near or containing the radar site exhibit slight anomalies in the precipitation frequencies, apparently due to ground clutter. Note the minimum in the radar-derived precipitation frequency pattern over southeast Alabama and southwest Georgia due to the range effect. The effect of the predominating precipitation type on the frequency pattern is also evident, especially over mountainous grid squares in the November-February period. This effect produces an apparent minimum in the precipitation frequency during the cool season while just the opposite is true.

FLOOD DATA

The flood events used in this study are those reported in the Environmental Data Service publications, Storm Data, and in the General Summary of National Flood Events section of monthly Climatological Data, National Summary. In an effort to relate the frequency distribution of four-hour MDR totals to observed flooding, the maximum four-hour MDR total was selected for the grid square in which flood-producing precipitation occurred. Only specifically identified flood events were utilized and those reported only in general terms were not included. Locations of maximum precipitation totals associated with flooding were included. Flooding followed maximum four-hour MDR totals within 12 hours.

The flood data were categorized as Flooding, Flash Flooding and Urban Flooding. The Urban Flood category was excluded from the data sample in this study because of the usually shorter duration of precipitation and the localized nature of this type of flooding. The published flood data were associated with 90 maximum four-hour MDR totals, of which two-thirds were categorized as Flash Flooding. The grid squares from which the MDR data were taken are indicated in Figure 14. This is not to imply that many of the remaining grid squares did not experience flood-producing precipitation. Thirty-nine percent of the flood events occurred during the March-June period, with 31 percent for the November-February period and 30 percent for the July-October period. The median value of the frequency distribution for the Flood category was only one percent below that of the Flash Flood category; therefore, the categories were combined.

A probabalistic approach has been suggested (Moore, et al., 1974) as the proper means of assessing the flash flood potential somewhere within a grid square. This potential depends in part on antecedent conditions, nature of terrain, etc. Four-hour MDR totals of, say, 20 or greater are suspect under almost all conditions, although just over half of the flood events in this study occurred with maximum four-hour MDR totals of less than 20. The percentage of hours with non-zero four-hour MDR totals of 20 or more for each grid square is shown in Figure 15. Note that all 98 grid squares had four-hour MDR totals of 20 or more during the twelve-month period but that this total is not reached during the November-February period over the Appalachians and is sparse over Georgia in the July-October period. Of the 42 flood events with maximum four-hour MDR totals of 20 or more, 95 percent maintained a value of 20 or more for two or more summation periods.

The maximum four-hour MDR total associated with flood-producing precipitation was compared with the twelve-month frequency distribution for that particular grid square. The percentile distribution of the 90 grid-square events and the distribution of the maximum four-hour MDR totals associated with flooding are shown in Figure 16. The top ten percent of the twelve-month frequency distribution contained 86 percent of the maximum four-hour MDR totals associated with flooding. Of the remaining 14 percent two flood events occurred following one-hour precipitation amounts in excess of five inches. Antecedent conditions, data summation period, and the "snap-shot" nature of the MDR value are other possible factors contributing to the lower ranking.

It appears that radar data can be of greatest assistance in those flood situations which are associated with maximum four-hour MDR totals in the top ten percent of the frequency distribution. The four-hour MDR totals which make up the top ten percent of the frequency distribution vary from grid square to grid square. Figures 17, 18 and 19 show the four-hour MDR totals which correspond to the 90th, the 97th and the 99th percentile. These values correspond to the four-hour MDR total which begins the top ten percent of the frequency distribution, the median four-hour MDR total associated with flooding and the four-hour MDR total which is the beginning of the top one percent of the frequency distribution. These values were interpolated from the individual summary categories. Several different four-hour MDR totals may fall into each percentile and the lowest value in these one percent groupings was selected.

Thirty-six percent of the Flash Flood events occurred with maximum four-hour MDR totals in the 99th percentile. Of these only 25 percent occurred in the July-October period while 40 percent occurred during the November-February period.

The maximum and minimum four-hour MDR totals corresponding to the 90th, 97th and 99th percentile were selected from the four-month groupings. The average difference in these four-hour MDR values was 3.5, 5.9, and 7.0, respectively. The seasonal group in which the largest and smallest four-hour MDR total corresponding to the 99th percentile occurred is shown in Figure 20. The majority of the largest four-hour MDR totals occurred during the March-June period. July-October group occurrences were in a few grid squares over the mountains, along the Gulf coast and over a portion of Tennessee. The November-February group occurrences were over southwest Kentucky and northwest Tennessee. Smallest four-hour MDR totals associated with the 99th percentile occurred in large part during the July-October period. November-February group occurrences were in grid squares over the mountains (except for the southernmost mountain grid squares) over eastern Tennessee, northern and southwestern Alabama, southeast Mississippi and southeast Georgia.

Table 5 shows the precipitation estimates and probability of occurrence corresponding to the various four-hour MDR totals. These values were derived from the nomogram developed by Moore, et al (1974). Precipitation estimates with a 50 percent probability of occurrence corresponding to the 90th, 97th and 99th percentile for each grid square are shown in Figures 21, 22 and 23. Precipitation estimates less than one inch are omitted. Return-period estimates of three-hour precipitation amounts for individual gauges from the "Rainfall Frequency Atlas of the United States" are shown in Figure 24. When values which correspond to the 99th percentile are compared with these return-period estimates of precipitation, mountain grid square radar estimates of precipitation are for the most part near or below one-year amounts while elsewhere, except for grid squares beyond 90 nm (167 km), most values are near 100-year amounts.

SUMMARY AND CONCLUSIONS

Geographical location, range and predominant precipitation type all influence the frequency distribution of four-hour MDR totals. Grid squares near the Gulf coast have the highest frequency of four-hour MDR totals of 20 or more while grid squares over the Appalachians have the lowest frequency. Changes in the frequency distribution due to the range effect become more apparent with increasing range beyond 70 nm (130 km). Higher four-hour MDR totals occur most often during the spring and least often during the winter.

Thirty-three percent of the maximum four-hour MDR totals associated with flooding occurred in the top one percent of the frequency distribution, 50 percent in the top three percent, and 86 percent in the top 10 percent. Although maximum four-hour MDR totals associated with flooding tend to occur near the top of the frequency distribution, the actual four-hour MDR totals vary widely over the study area. Because of this variation, a frequency distribution of four-hour MDR totals, or any DR data, for individual grid squares, geographical areas or drainage basins would be helpful. This would provide a relative ranking of DR values over an area and would be an improvement over a single "magic number" for all grid squares to indicate the probability of flooding. This ranking could be compared with a frequency distribution of climatological data to provide a probable estimate of precipitation which would not rely strictly on the Z-R relationship. This technique could improve precipitation estimates, especially over mountain areas. However, the radar apparently has some serious limitations over mountainous terrain and additional gauges and flood alarms appear to be the only viable solution to the mountain flood problem.

Seasonal variations in the frequency distribution appear to be sufficiently large to warrant the development of seasonal frequency distributions, at least over flood sensitive areas. Special additive data to radar messages or telephone calls to call attention to the occurrence of values in the top 10 percent, or certainly the top one percent, of the frequency distribution should be considered. The data indicate that the four-hour period is too long in most instances to identify the flash flood possibility associated with air-mass convection over much of this study area. The conclusions drawn from this study are based on a very limited time period and geographical area which should be expanded before developing operational programs.

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The author wishes to thank the staff of Scientific Services Division, National Weather Service, Southern Region Headquarters for providing four-hour totals of MDR data and the Environmental Data Service, Asheville, North Carolina for providing the flood data.

Thanks also to the staff at each of the ten radar stations whose data were used for this study. A special thanks to B. J. Smith and the staff of WSO, Athens for their valuable discussions and encouragement and to Mrs. Joan Hoffman for typing the manuscript.

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Moore, P. L., D. L. Smith, 1972: Updating of Numerical Precipitation Guidance. J. Appl. Meteor., 11, 1293-1298.

Peters, B. E., D. P. Barnes, 1973: Evaluation of an Objective Radar Technique for Updating Numerical Precipitation Guidance. NOAA Technical Memorandum NWS SR-73, 6 pp.

APPENDIX

Radar Station Identifiers and Percentage of Missing Data

	Station	Missing Data (%)		Station	Missing Data (%)
AHN	Athens, GA	3	JAN	Jackson, MS	6
AQQ	Apalachicola, FL	11	NPA	Pensacola, FL	15
AYS	Waycross, GA	3	NQA	Memphis, TN	17
BNA	Nashville, TN	13	SIL	Slidell, LA	6
CKL	Centerville, AL	24	TRI	Bristol, TN	5

Table I. Manually Digitized Radar (MDR) Code

Code No.	Coverage in Grid Square	Intensity Category	Rainfall Rate in/hr	Rainfall Rate mm/hr
0				
1	any VIP 1	Weak	<.1	< 2.5
2	≤1/2 of VIP 2	Moderate	.1-.5	2.5-12.7
3	>1/2 of VIP 2			
4	≤1/2 of VIP 3	Strong	.5-1	12.7-25.4
5	>1/2 of VIP 3			
6	≤1/2 of VIP 3 and 4	Very Strong	1-2	25.4-50.8
7	>1/2 of VIP 3 and 4			
8	≤1/2 of VIP 3,4,5,6	Intense or Extreme	> 2	>50.8
9	>1/2 of VIP 3,4,5,6			

Table 2. Range Averages of the Frequency Distribution (%) of Four-Hour MDR Totals, July 1973-June 1974

Four-hour MDR Total	<30 <56	40 74	60 111	80 148	100 185	>110 nm >204 km
	Range to Center of MDR Grid Square					
36		*	*			
32 - 35	*	*	*	*	*	
28 - 31	*	1	1	*	*	*
24 - 27	1	2	1	1	*	*
20 - 23	2	2	2	1	1	*
16 - 19	4	4	4	3	2	1
12 - 15	7	8	7	6	5	2
8 - 11	14	13	14	14	11	7
4 - 7	33	32	33	34	34	28
1 - 3	39	38	38	42	46	61
Precipitation Frequency	27	28	28	25	23	18

Table 3. Range Averages of the Frequency Distribution (%) of Four-Hour MDR Totals by Four-Month Groupings

	Range to Center of MDR Grid Square																	
	<30 <56			40 74			60 111			80 148			100 185			>110 nm >204 km		
Four-hour MDR Total	Nov-Feb	Mar-Jun	Jul-Oct	Nov-Feb	Mar-Jun	Jul-Oct	Nov-Feb	Mar-Jun	Jul-Oct	Nov-Feb	Mar-Jun	Jul-Oct	Nov-Feb	Mar-Jun	Jul-Oct	Nov-Feb	Mar-Jun	Jul-Oct
36				*			*											
32 - 35	*	*		*	*	*	*	*	*	*	*	*		*	*			
28 - 31	*	1	*	1	1	1	1	1	*	*	1	*	*	*	*		*	*
24 - 27	1	2	1	1	2	1	1	2	1	*	1	1	*	1	*		*	*
20 - 23	1	3	2	2	3	2	2	3	2	1	2	1	1	2	1	*	1	*
16 - 19	3	5	3	3	5	4	3	5	4	2	4	2	2	3	2	*	1	1
12 - 15	6	8	7	6	9	8	6	8	7	5	7	5	4	6	5	2	3	2
8 - 11	12	15	14	12	14	14	13	15	14	13	15	13	9	12	12	5	8	7
4 - 7	37	29	32	35	31	32	35	31	32	36	32	33	35	32	34	27	28	29
1 - 3	41	36	43	39	35	39	40	35	39	43	37	45	49	44	45	66	60	62
Precipit. Frequency	29	26	28	28	26	31	28	25	30	24	23	27	22	22	25	17	18	18

Table 4. Station Averages of the Frequency Distribution (%) of Four-Hour MDR Totals, July 1973-June 1974*

Four-hour MDR Total	Radar Stations							
	NQA	BNA	TRI	JAN	CKL	AHN	NPA	AYS
36				*				
32 - 35	*	*	*	1	*	*	1	*
28 - 31	*	1	*	2	*	*	2	*
24 - 27	1	1	*	4	1	1	4	1
20 - 23	2	2	1	6	2	1	6	2
16 - 19	4	3	2	8	3	3	9	4
12 - 15	7	6	4	10	6	7	12	9
8 - 11	15	13	12	15	12	14	15	17
4 - 7	31	34	37	25	33	35	25	31
1 - 3	40	40	44	30	42	40	28	36
Precipitation Frequency	28	31	27	28	25	24	31	26

*Only grid squares with central ranges less than 90 nm (167 km) were averaged.

Table 5. Radar Precipitation Estimates

Four-hour MDR-Total	Estimated Four-hour Precipitation Amount		Probability of Occurrence (%)
17	< 1.0 in	< 25 mm	50
18	1.1	28	50
19	1.8	46	50
20	2.2	56	50
21	2.8	71	50
22	3.2	81	50
23	3.7	94	50
24	4.0	102	50
25	4.3	109	50
26	4.9	124	50
27	5.0	127	51
28	5.0	127	54
29	5.0	127	56
30	5.0	127	59
31	5.0	127	61
32	5.0	127	63
33	5.0	127	66
34	5.0	127	69
35	5.0	127	70
36	5.0	127	71

Derived from nomogram used to estimate precipitation amounts from MDR values (Moore, et al., 1974).

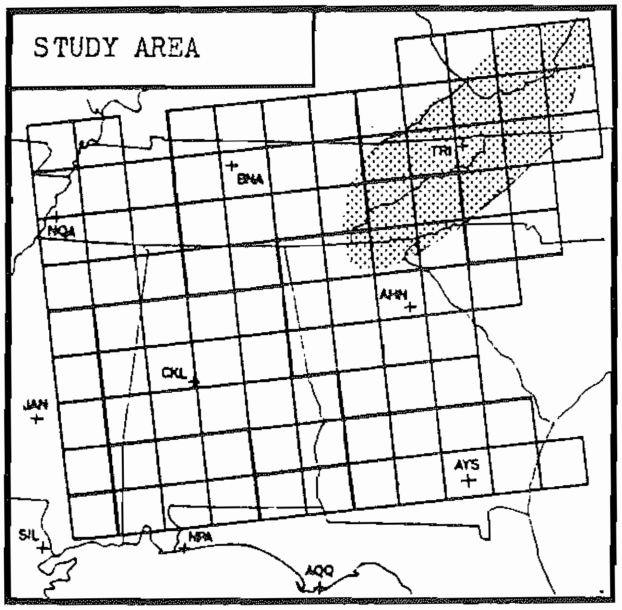


Figure 1. Location of radars which cover the MDR grid used in this study. Radar coverage areas are separated by heavy lines. See Appendix for station identification. Approximate mountainous area indicated by stippling.

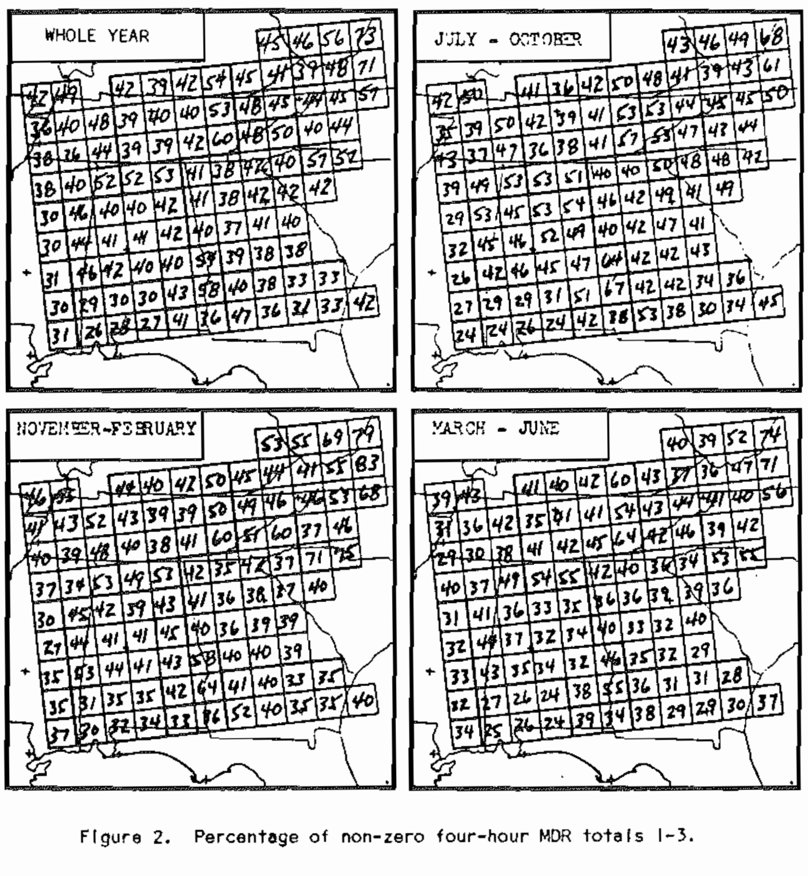


Figure 2. Percentage of non-zero four-hour MDR totals 1-3.

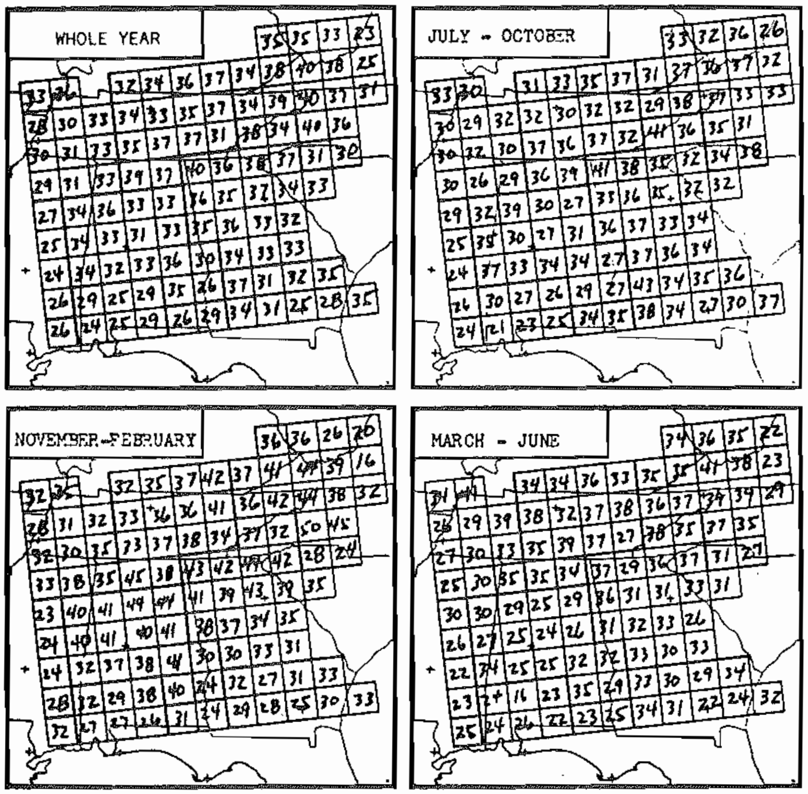


Figure 3. Percentage of non-zero four-hour MDR totals 4-7.

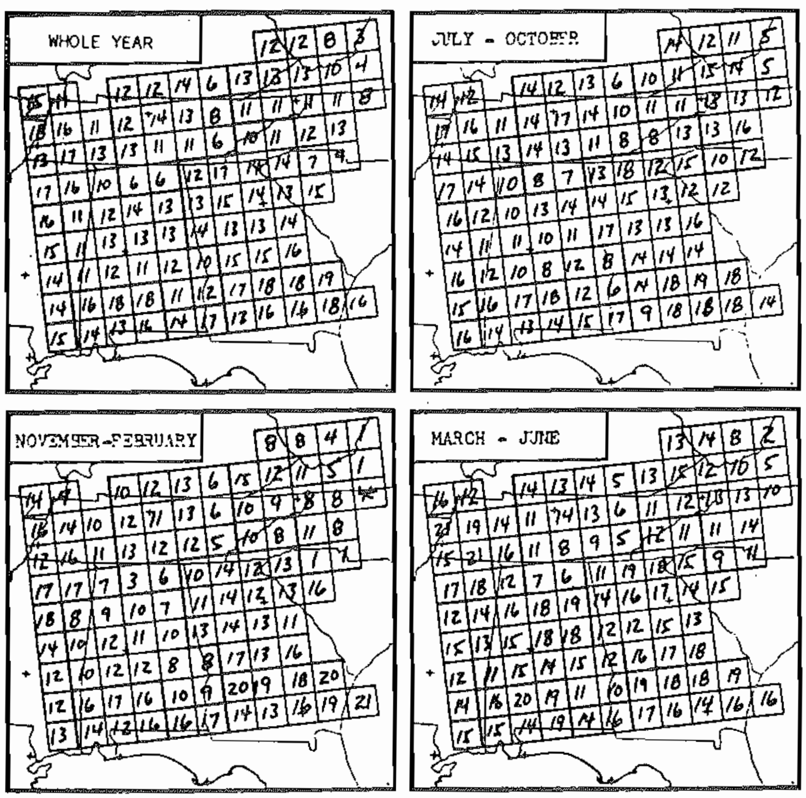


Figure 4. Percentage of non-zero four-hour MDR totals 8-11.

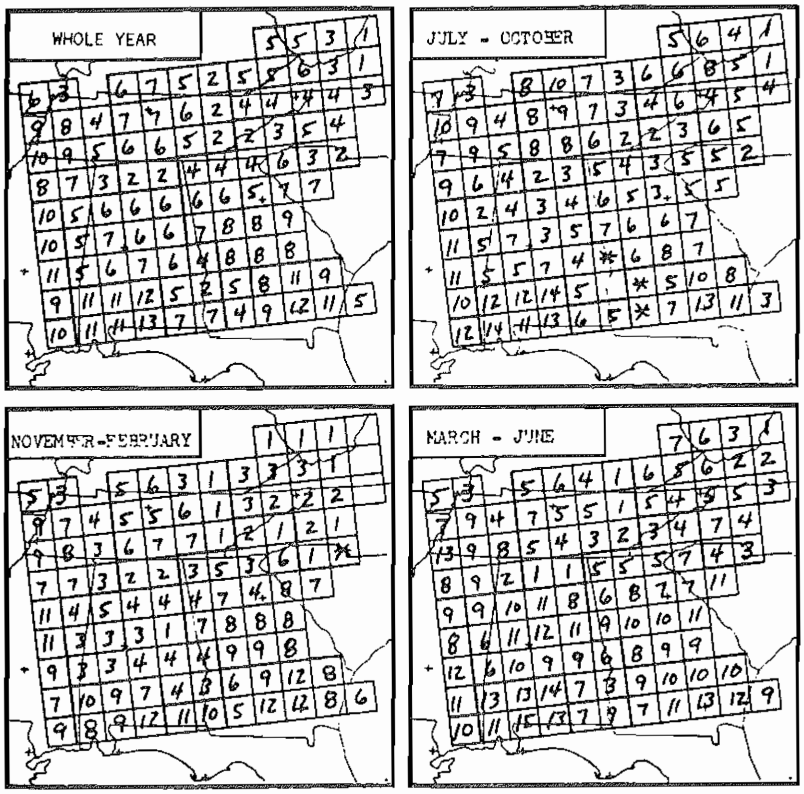


Figure 5. Percentage of non-zero four-hour MDR totals 12-15.

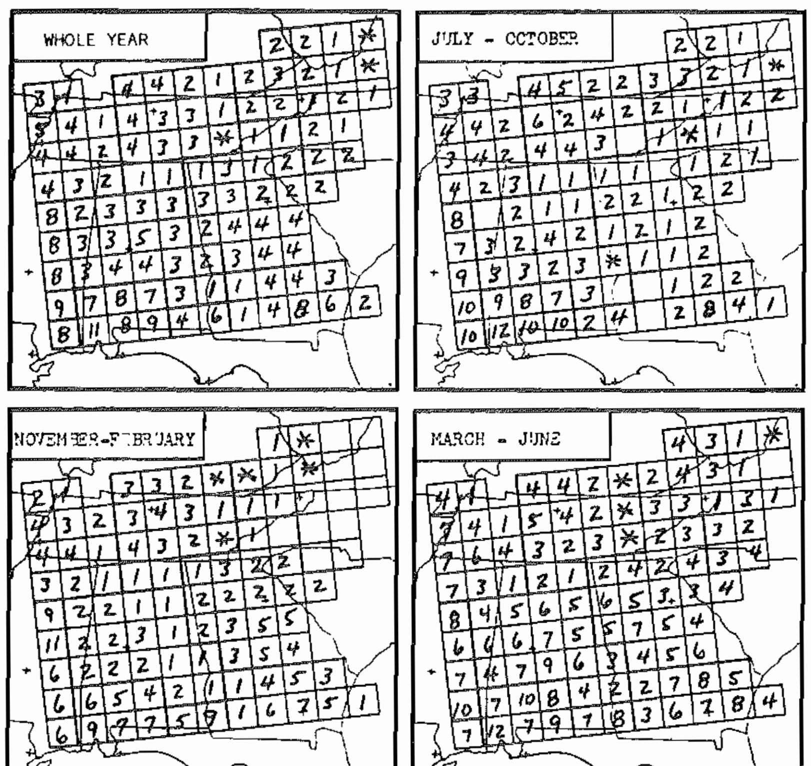


Figure 6. Percentage of non-zero four-hour MDR totals 16-19.

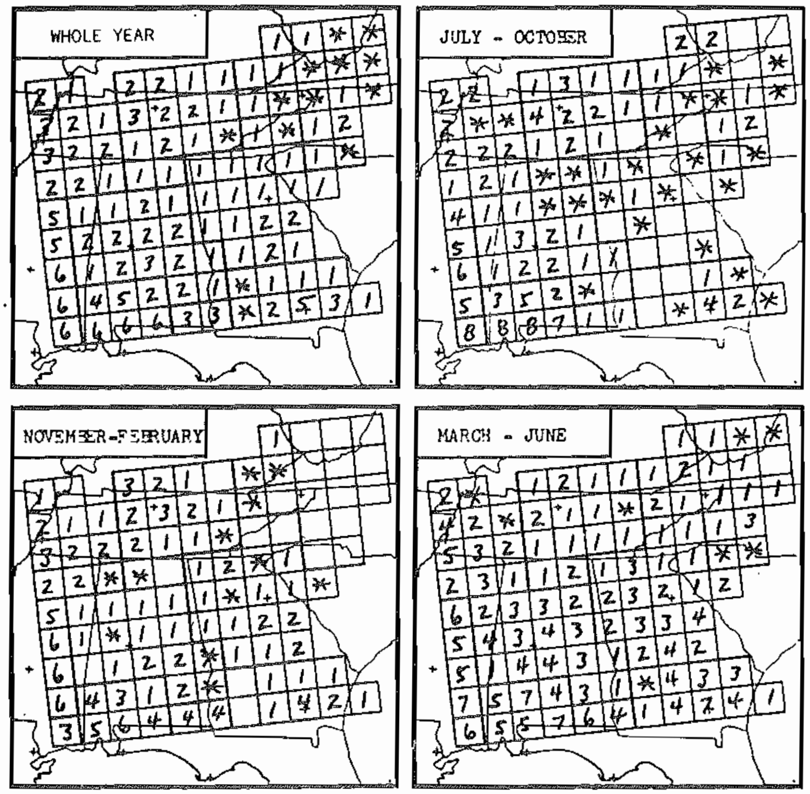


Figure 7. Percentage of non-zero four-hour MDR totals 20-23.

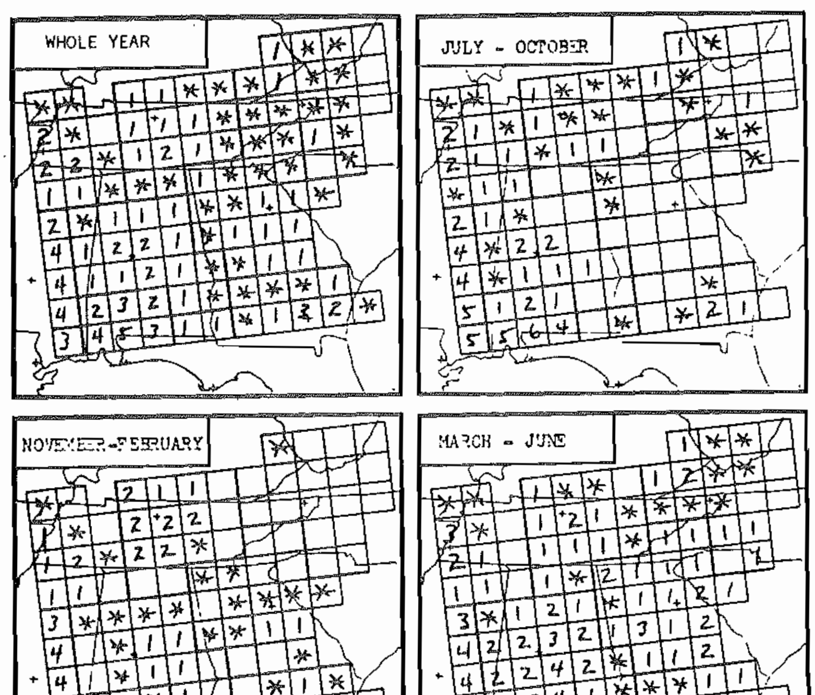


Figure 8. Percentage of non-zero four-hour MDR totals 24-27.

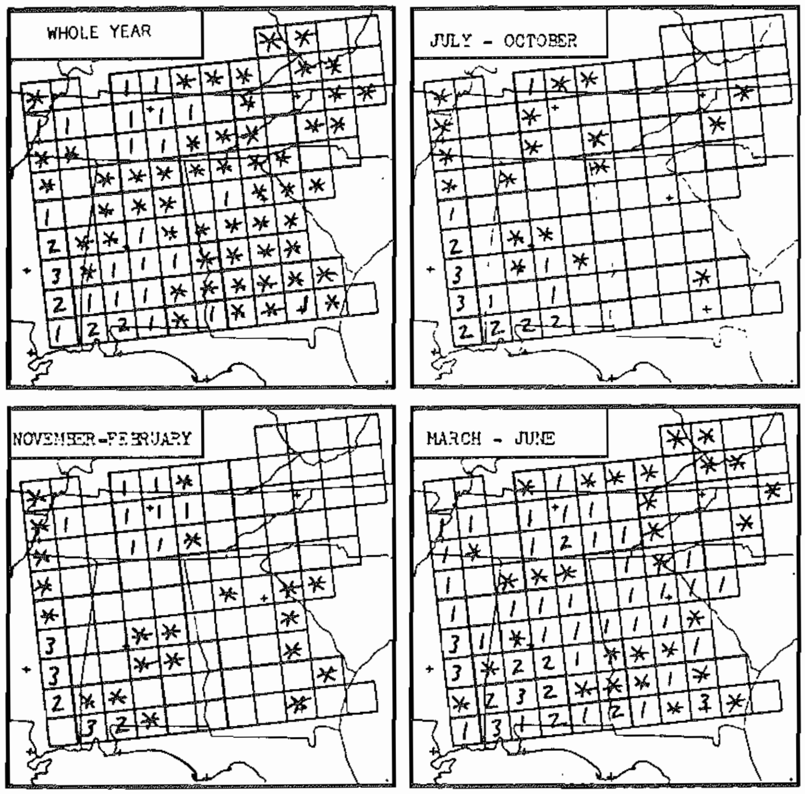


Figure 9. Percentage of non-zero four-hour MDR totals 28-31.

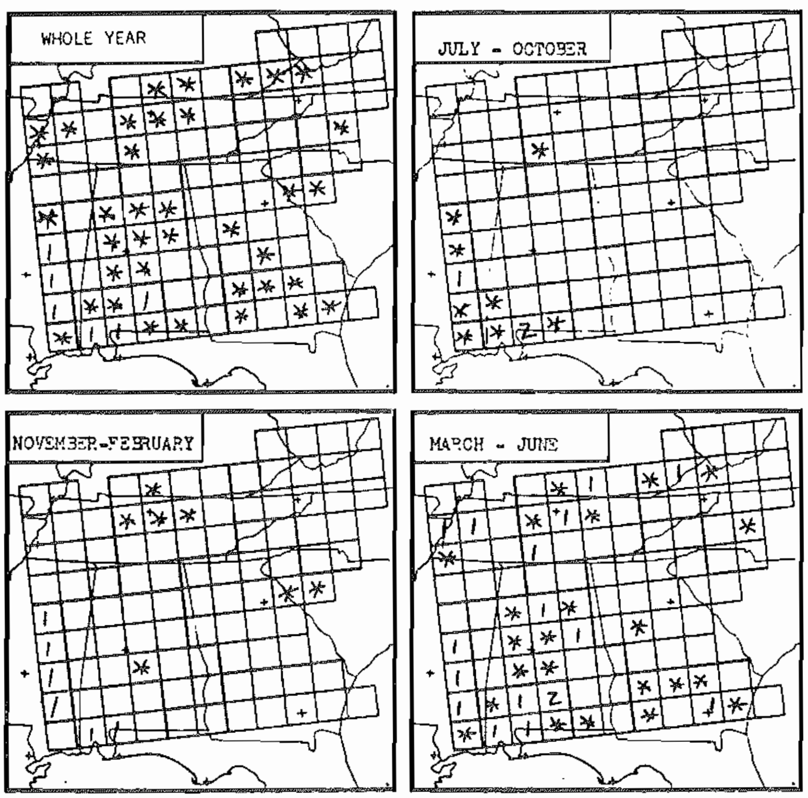


Figure 10. Percentage of non-zero four-hour MDR totals 32-35.

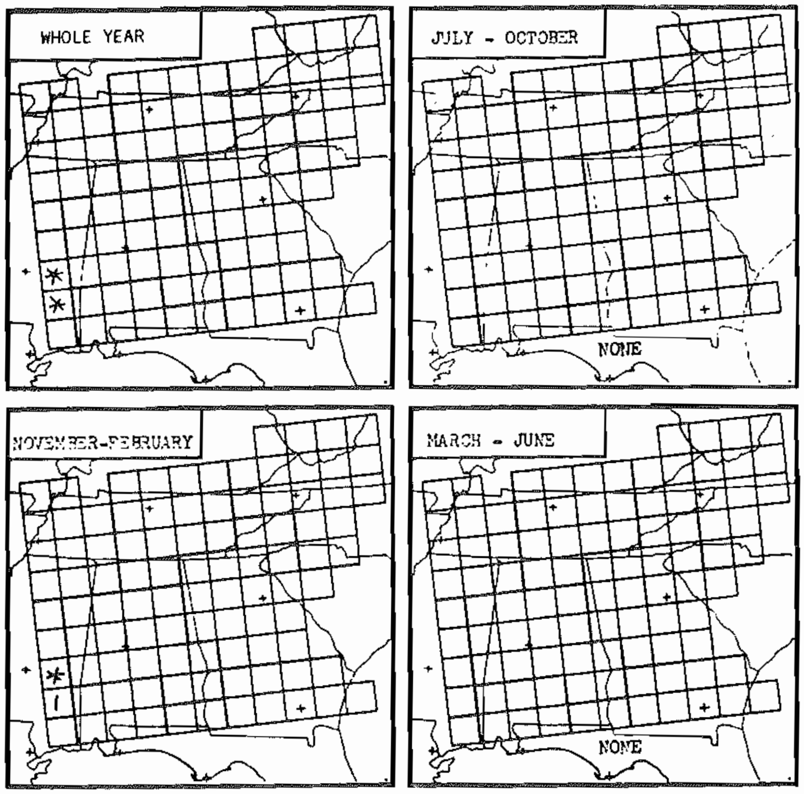
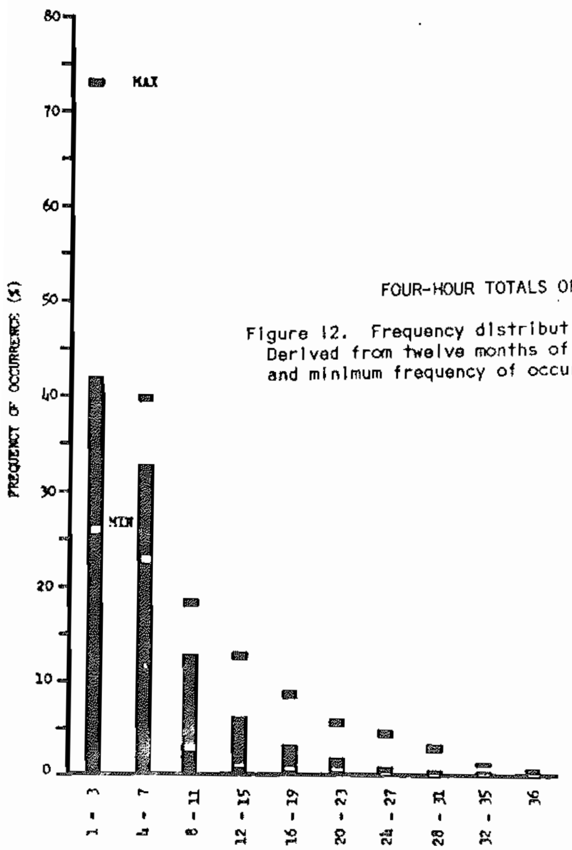


Figure 11. Percentage of non-zero four-hour MDR totals 36.



FOUR-HOUR TOTALS OF MANUALLY DIGITIZED RADAR DATA

Figure 12. Frequency distribution of non-zero four-hour MDR totals. Derived from twelve months of data for 98 grid squares. Maximum and minimum frequency of occurrence for each category are indicated.

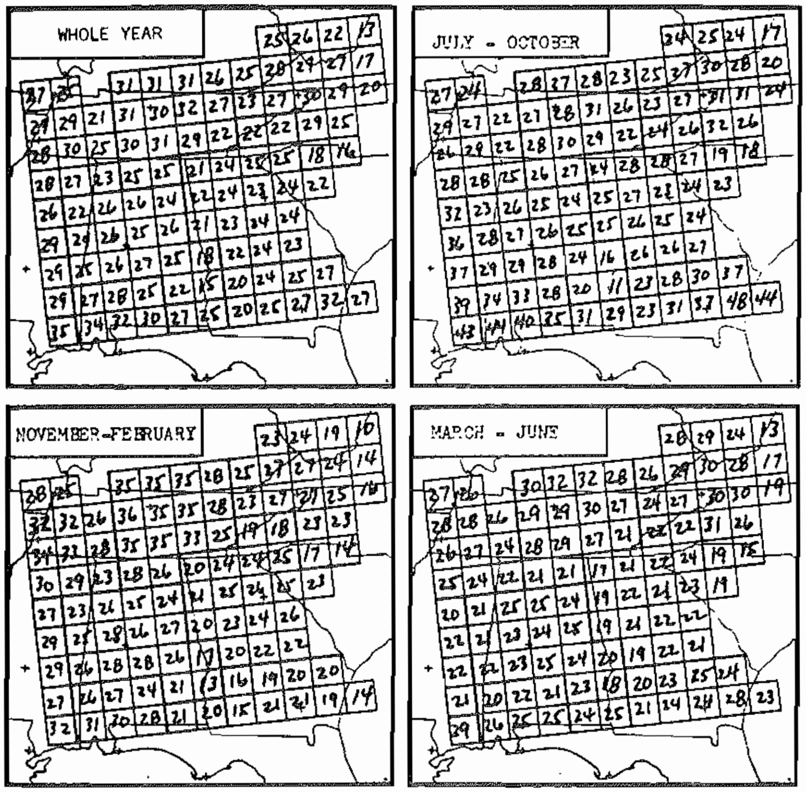


Figure 13. Radar-derived precipitation frequency (%).

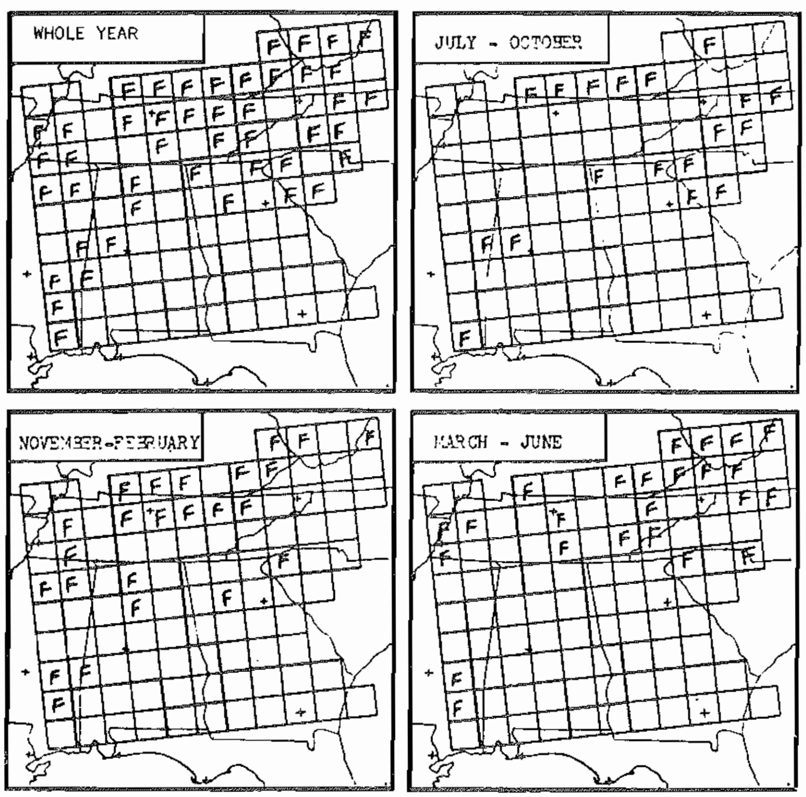


Figure 14. Grid squares in which flood-producing precipitation fell are indicated by "F".

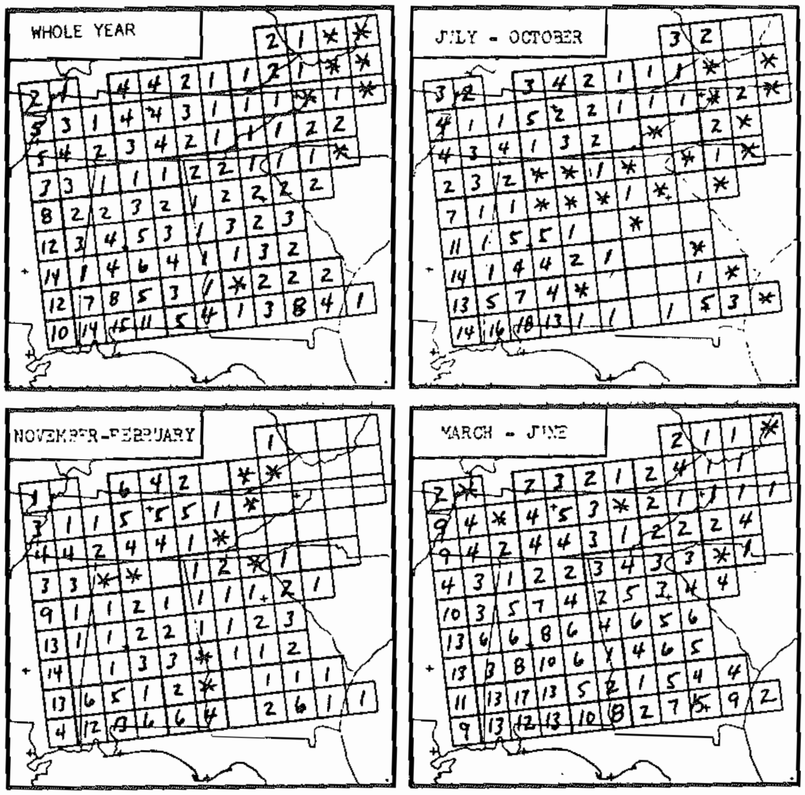


Figure 15. Percentage of non-zero four-hour MDR totals 20 or more.

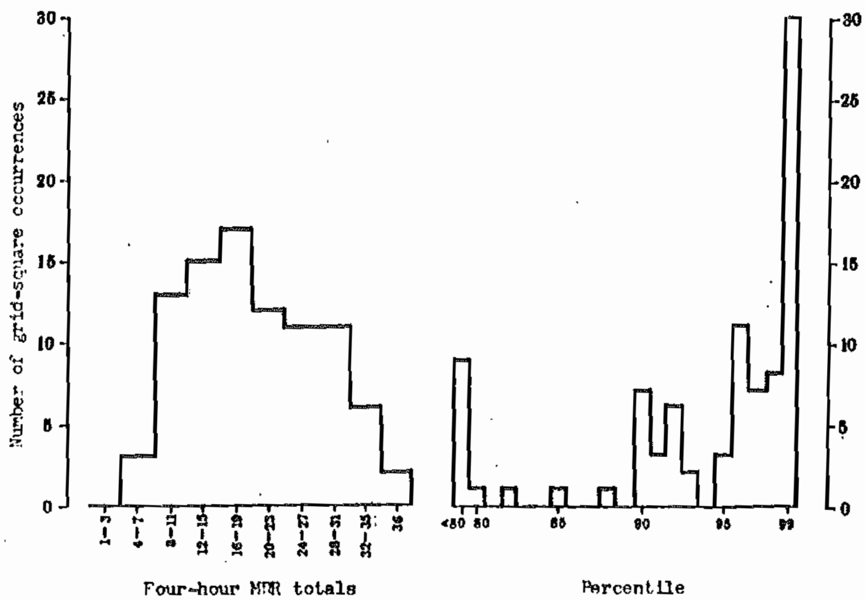


Figure 16. Distribution of four-hour MDR totals associated with flooding. Maximum four-hour MDR totals associated with flooding were compared with the twelve-month frequency distribution for the grid square in which the precipitation occurred. These rankings were then summed in one percent groups to produce the percentile distribution of four-hour MDR totals associated with flooding.

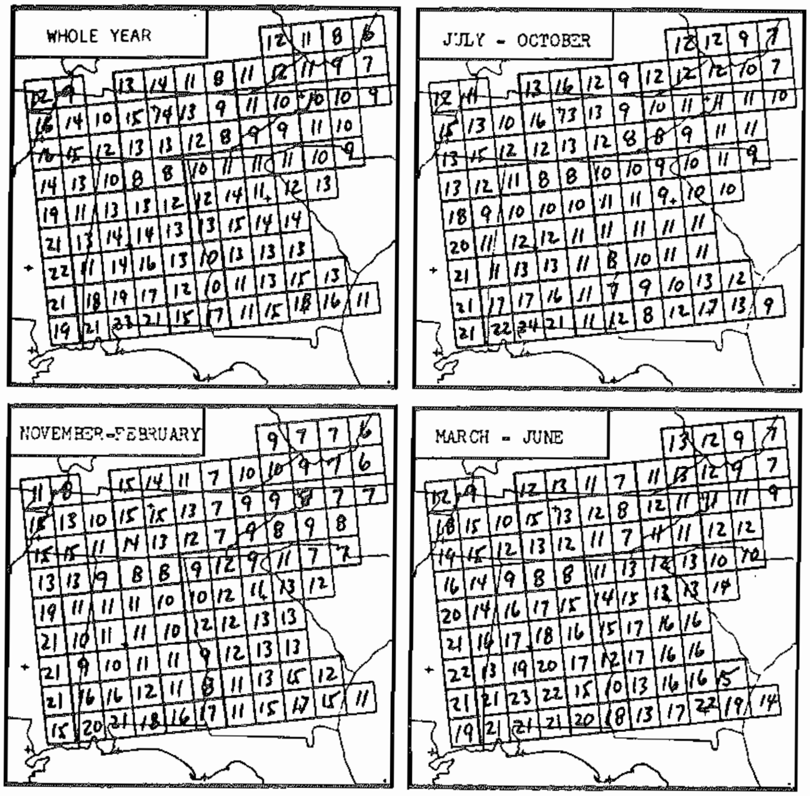


Figure 17. Four-hour MDR totals which begin the 90th percentile.

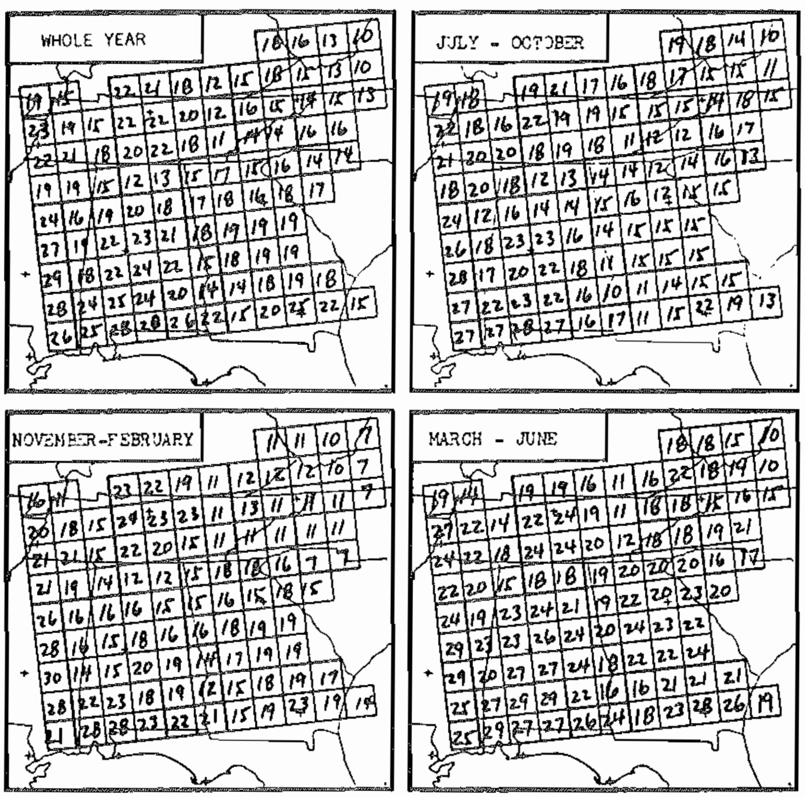


Figure 18. Four-hour MDR totals which begin the 97th percentile.

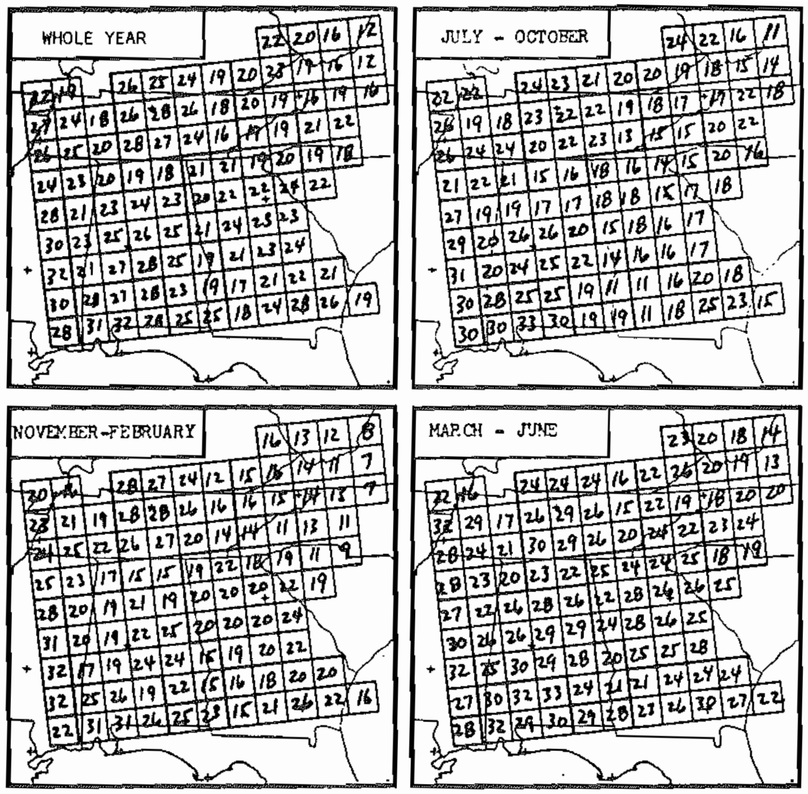


Figure 19. Four-hour MDR totals which begin the 99th percentile.

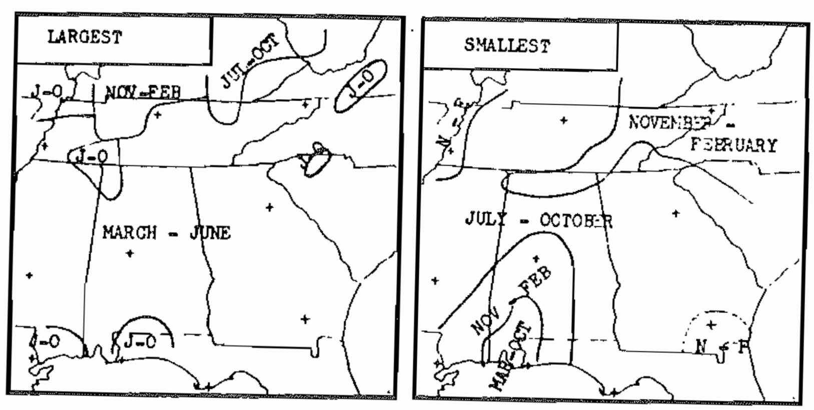


Figure 20. Period of occurrence of the largest and smallest four-hour MDR total which begins the 99th percentile.

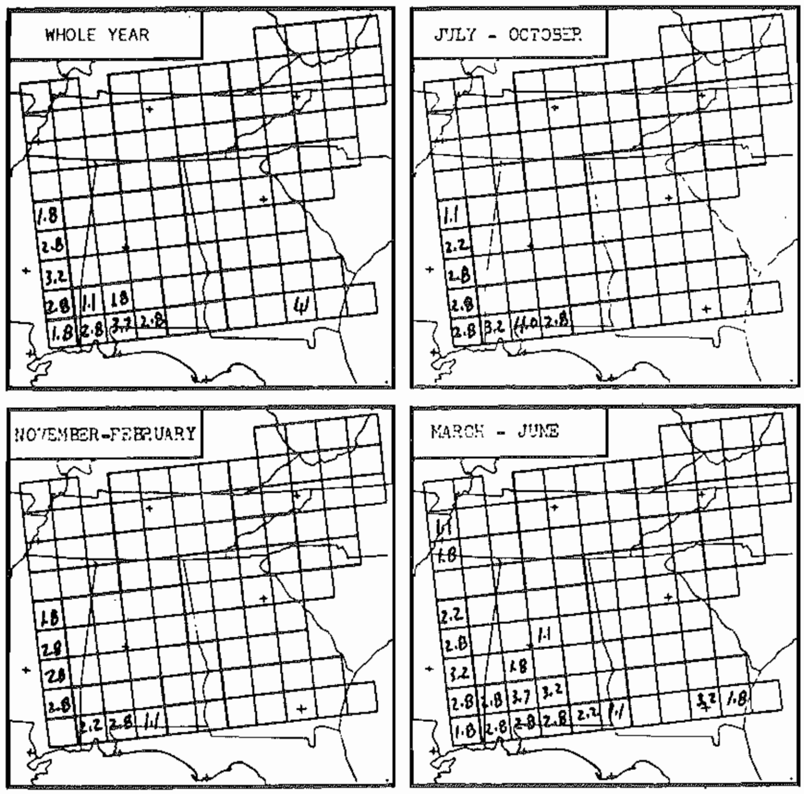


Figure 21. Radar-estimated four-hour precipitation amounts (inches) with a 50 percent probability of occurrence corresponding to four-hour MDR totals which begin the 90th percentile. Amounts less than one inch are omitted.

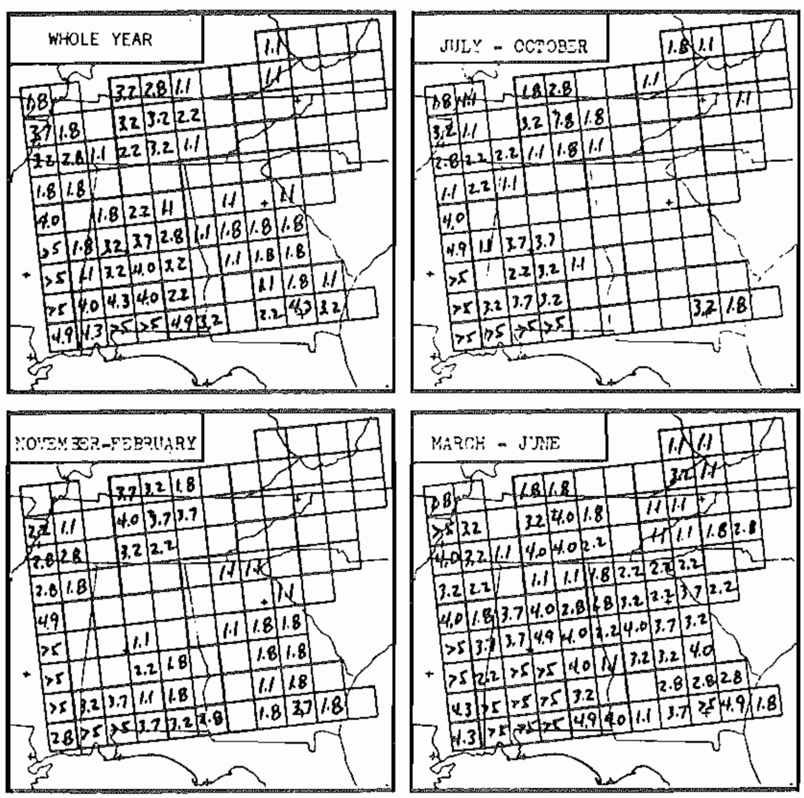


Figure 22. Radar-estimated four-hour precipitation amounts (inches) with a 50 percent probability of occurrence corresponding to four-hour MDR totals which begin the 97th percentile. Amounts less than one inch are omitted.

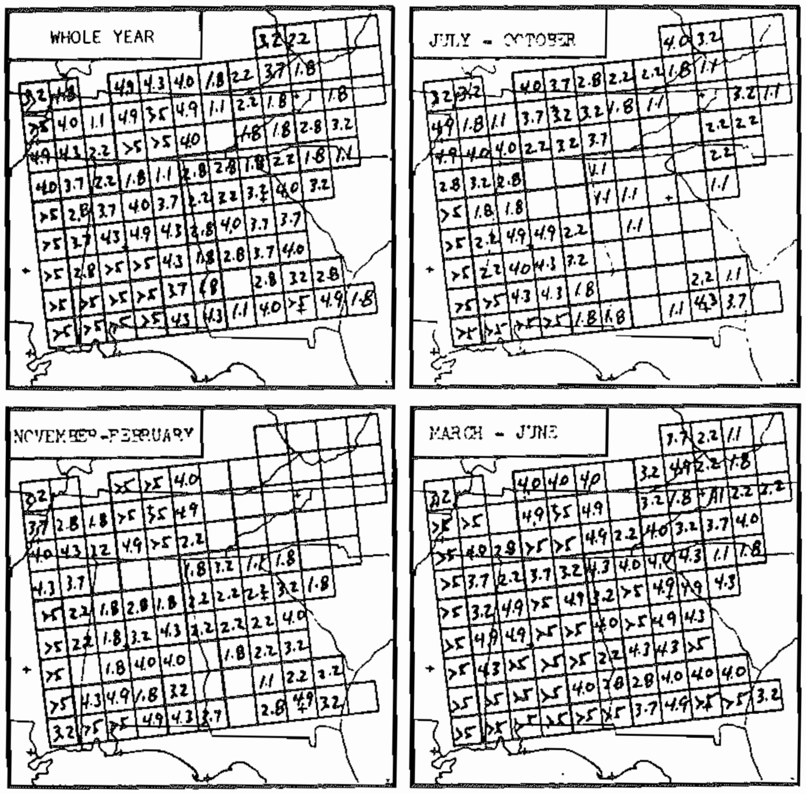


Figure 23. Radar-estimated four-hour precipitation amounts (inches) with a 50 percent probability of occurrence corresponding to four-hour MDR totals which begin the 99th percentile. Amounts less than one inch are omitted.

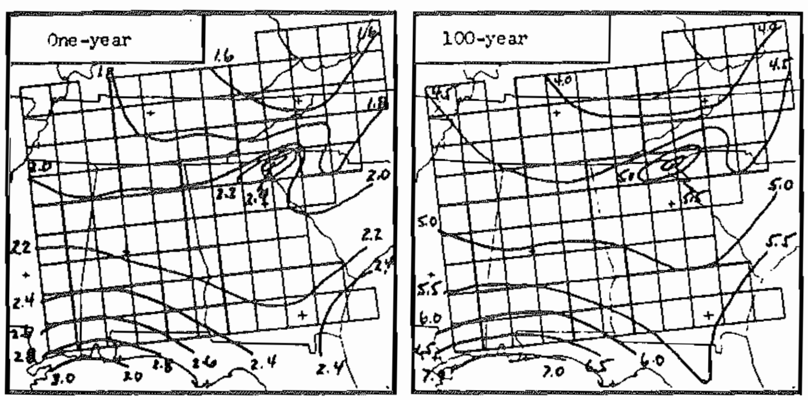


Figure 24. Return-period estimates of three-hour precipitation amounts (inches). From "Rainfall Frequency Atlas of the United States", U. S. Department of Commerce, Weather Bureau, Washington, D.C. 1961.