1982

Diurnal Distribution of Very Heavy Precipitation Over the Central and Eastern United States

Kenneth A. Crysler
National Oceanic and Atmospheric Admionistration

Robert A. Maddox
National Oceanic and Atmospheric Administration

L. Ray Hoxit
National Oceanic and Atmospheric Administration

Bradley M. Muller
Embry-Riddle Aeronautical University, mullerb@erau.edu

DIURNAL DISTRIBUTION OF VERY HEAVY PRECIPITATION OVER THE CENTRAL AND EASTERN UNITED STATES

by

Kenneth A. Crysler (1), Robert A. Maddox (2), L. Ray Hoxit (3), and Bradley M. Muller (4)

NOAA, Environmental Research Laboratories
Office of Weather Research and Modification

Boulder, Colorado 80303

ABSTRACT

A climatology of heavy precipitation events for the states of Nebraska, Missouri, Illinois, Kentucky, Tennessee, West Virginia, Pennsylvania, and Virginia is developed from 10 years (1968-1977) of Hourly Precipitation Data. *Hourly precipitation events are categorized by severity, ranging from 1 to 2 inches (2.5 to 5.1 cm) in one hour or less (Type 1) to 4 or more inches (greater than 10.2 cm) in eight hours or less (Type 4). Hourly distributions of heavy precipitation events indicate that intense rainfalls of short duration occur most frequently during the afternoon and evening hours; whereas Type 4 events, which pose the most serious threat of flash flooding occur most often during the night and early morning hours in the central and eastern United States.*

1. INTRODUCTION

Within the last decade flash flooding has become one of the nation's most serious natural disaster problems. Research on meteorological aspects of flash flooding has primarily dealt with detailed case studies of notable individual storms. Examples are the Rapid City flood (5), the Big Thompson flood (6), the Las Vegas flood (7), the Oahu flood (7) the Johnstown flood (9,10). (Editor's note: another example is "The Pearl River Flood at Jackson, Mississippi," by Rutherford H. Platt, published in the February 1980 issue of the National Weather Digest.) However, Maddox et al. (11) studied more than 150 individual flash flood events that occurred in various geographical regions of the conterminous United States. The climatology of these events led them to conclude that significant heavy precipitation events and flash floods tend to occur most frequently during the late night and early morning over the eastern two-thirds of the United States.

The nocturnal maxima of thunderstorms and precipitation over the central United States are both well known and documented (12, 13). For example, Vrcek and Sangster (14) found that 12-h rains of > 1.27 cm tended to occur during the late night and early morning hours over eastern Nebraska, eastern Kansas and northwestern Missouri. However, Wallace's (13) comprehensive examination of precipitation data for Iowa infers that flood producing storms are most likely to occur during the late afternoon and evening. Thus, Vrcek and Sangster's results tend to substantiate the nocturnal flash flood characteristic noted by Maddox et al. (11) while Wallace's findings do not.

A global review of diurnal precipitation characteristics by Gray and Jacobson (15) resulted in their suggestion that, over land, the afternoon/evening convective maximum tends to shift to a nocturnal or early morning maximum as the degree of convective organization increases. They contend that heavy rainfall amounts are typically not observed except with organized weather systems of mesoscale extent which possess a significant lifetime. The frequent occurrence of large highly organized mesoscale convective complexes (16) over the central and eastern United States supports Gray and Jacobsons' contentions. These convective weather systems usually grow into organized mesosystems during early evening, reach maximum intensity and size just after midnight, and persist into the morning hours. Since these systems often produce torrential rains, Maddox (16) suggested that mesoscale convective complexes might be largely responsible for the nocturnal characteristics of flash floods over the eastern United States.

If organized convective mesosystems are indeed often associated with significant nighttime flash floods, the effects of these systems should be evident in the climatology of very heavy precipitation events. (Note that Maddox et al. (11), found that most central and eastern United States flash floods were produced by rainfall of > 10 cm during periods of considerably less than 12-h.) A 10-year survey of Hourly Precipitation Data, HPD, a NOAA

EDIS publication, was accomplished for eight different states to develop such a climatology.

2. CLIMATOLOGICAL DATA

Heavy precipitation events reported in the HPD were utilized to document their diurnal characteristics. HPD data are available for a relatively dense (with respect to the hourly surface observation network) national network of stations, and reports from the years 1968 through 1977 were surveyed for Nebraska, Missouri, Illinois, Kentucky, Tennessee, West Virginia, Pennsylvania, and Virginia. The data were compiled with reference to date, hour, location and duration for four categories of precipitation events. These categories, which indicate increasing flash flood potential, were:

- Type 1 - one to < two inches (2.5 to < 5.1 cm) of rainfall in ≤ 1 hour
- Type 2 - two to < three inches (5.1 to < 7.6 cm) of rainfall in ≤ 2 hours
- Type 3 - three to < four inches (7.6 to < 10.2 cm) of rainfall in ≤ 4 hours
- Type 4 - four or more inches (> 10.2 cm) of rainfall in ≤ 8 hours

The categories were mutually exclusive so that a heavy precipitation event was placed in only in the highest possible category. For example, a 3 inch rain in one hour followed by rains of .3 inches/hour for one to three hours was logged as a Type 3 event, events of 5 inches in two hours and 4 inches in six hours were both logged as Type 4 events, while hourly rains such as 1 inch, 2 inches, 1/2 inch, 0, 0, 1 inch, 1 inch in a seven hour span were logged as a Type 4 event rather than a Type 3 and Type 2.

Table 1 shows a comparison, by state, of the tabulation of data from HPD, as well as some statistics which aid in the interpretation of the data. Pennsylvania has by far the most dense network of HPD recording stations, with almost twice as many stations per 1000 Km^2 than Tennessee, Missouri, or Kentucky. However, the latter three states had more than twice the number of HPD events per station than did Pensylvania, indicating that heavy precipitation occurs more frequently in these states. Stations in Tennessee had the highest number of HPD events. but Missouri, Kentucky and Illinois were not far behind. Surprisingly, Nebraska had a higher number of events per station than did Pennsylvania or West Virginia. Only three Type 3 and no Type 4 events were captured in West Virginia. Virginia had the least dense station distribution, and in fact had large areas in the southeastern part of the state that were not represented in the data. Nevertheless, Virginia ranked second to Missouri in the number of Type 4 events per station. However, tropical storms Agnes and Camille affected Virginia and eastern Pennsylvania, greatly increasing the number of Type 4 events for those states.

3. HEAVY PRECIPITATION CLIMATOLOGIES

Hourly frequency distributions for each type precipitation event (combined for all of the states considered) are shown in Figure 1. All times are Local Standard Time (LST) and the frequency curves were smoothed using a simple three-point binomial scheme. It is interesting to note the gradual phase shift in the time of maximum frequency for the four types of precipitation events. Type 1 and 2 events peak during the late afternoon at about 1700-1800. Heavier Type 3 events maximize around 2100 while potentially dangerous Type 4 events exhibit a broad nocturnal maximum peaked at about 0100 to 0200.

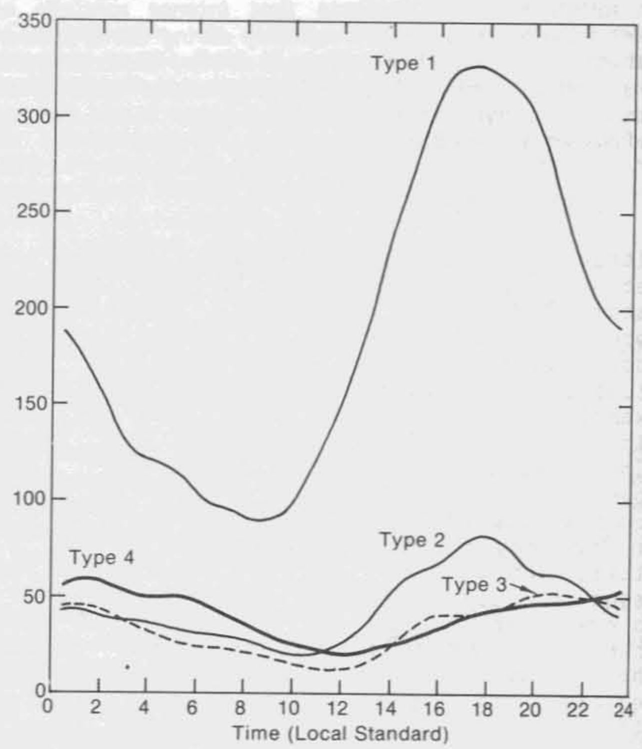

Figure 1. Number of times the four types of precipitation events occurred in all eight states during a particular hour.

Figures 2-4 display the distributions of Type 1 and Type 4 precipitation events for the individual state. In Nebraska, heavy rainfalls of lesser magnitude (Type 1) had highest frequencies of occurrence during the evening and early morning hours (Figure 2a) in contrast to the other states.

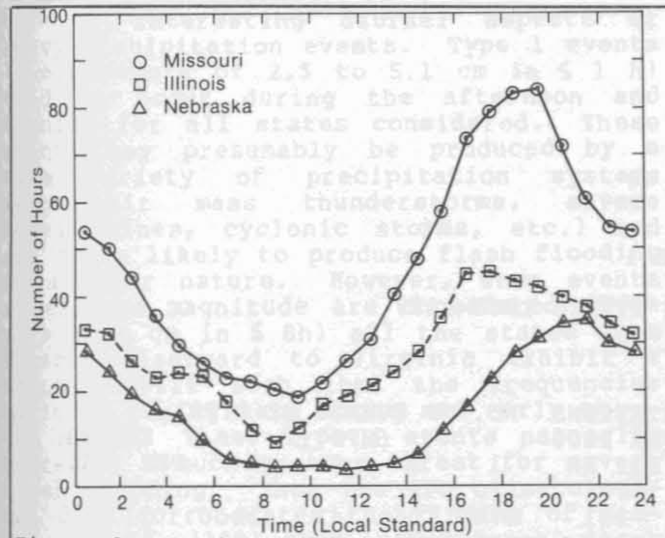

Figure 2a. Number of times a Type 1 event occurred during a particular hour (NE, MO, IL).

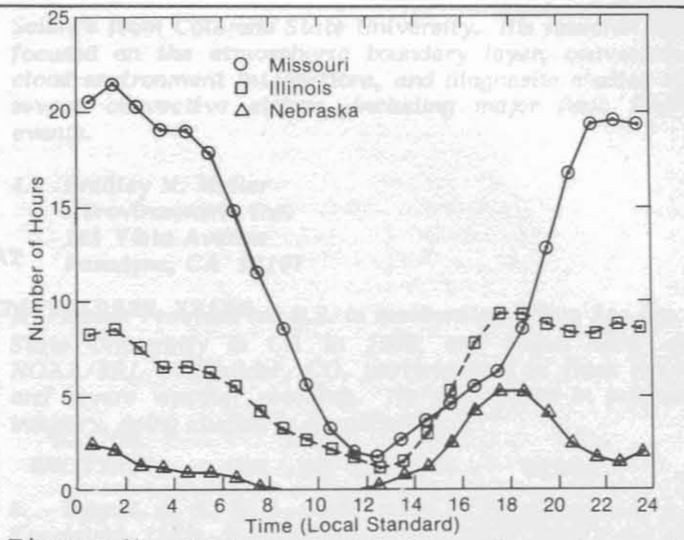

Figure 2b. Number of times a Type 4 event occurred during a particular hour (NE, MO, IL).

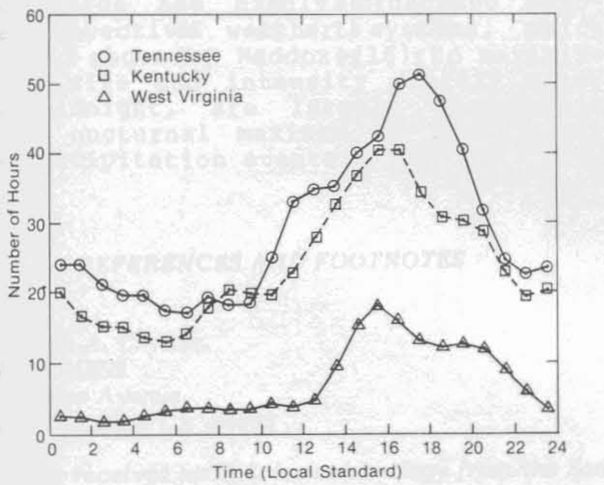

Figure 3a. Number of times a Type 1 event occurred during a particular hour (KY, TN, WV).

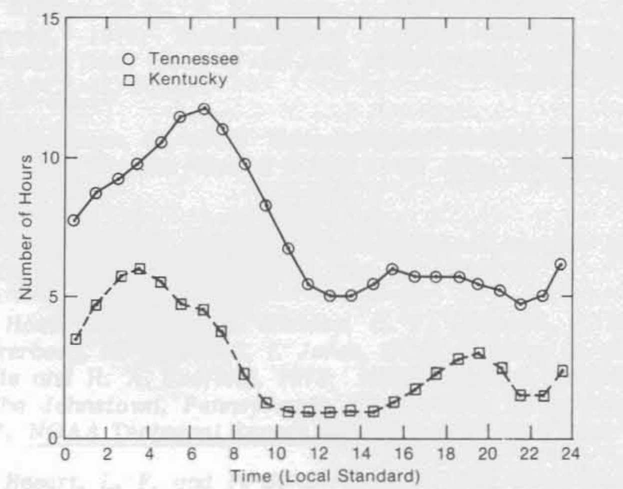

Figure 3b. Number of times a Type 4 event occurred during a particular hour (KY, TN).

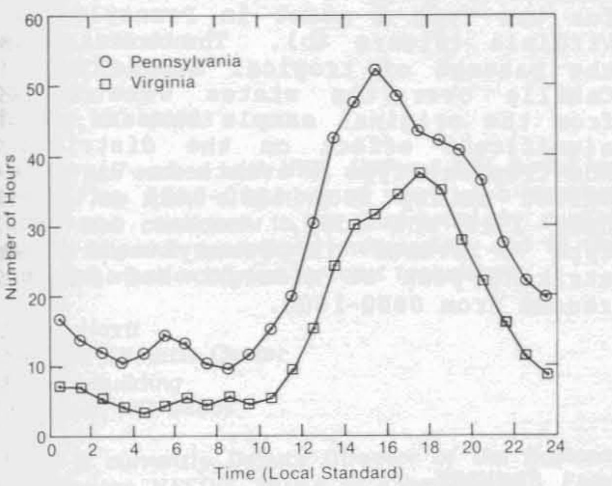

Figure 4a. Number of times a Type 1 event occurred during a particular hour (PA, VA).

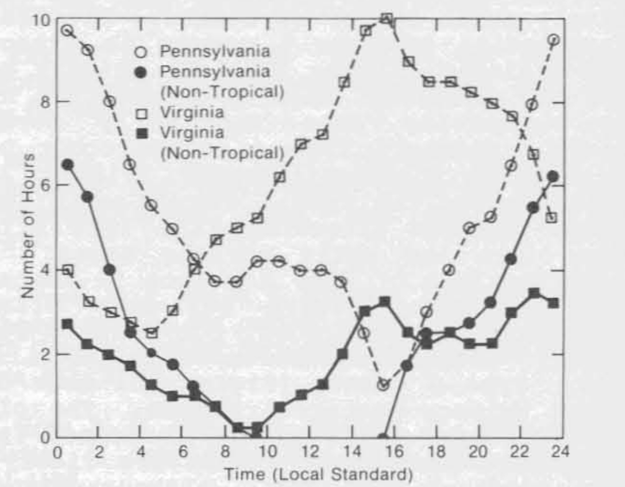

Figure 4b. Number of times a Type 4 event occurred during a particular hour (PA, VA).

TABLE 1

HEAVY PRECIPITATION EVENTS 1968-1977

STATE	AREA (1000 SQ. KM)	NO. OF STATIONS	STATIONS PER 1000 SQ. KM	NO. OF EVENTS BY TYPE (HPD) 1	2	3	4	EVENTS PER STA.
Illinois	146.1	74	.51	678	106	42	29	11.6
Kentucky	104.6	54	.52	577	85	24	12	12.9
Missouri	180.5	101	.56	1116	129	73	51	13.6
Nebraska	200.0	65	.33	393	48	22	10	7.3
Penn.	117.4	118	1.01	615	70	23	21	6.2
Tennessee	109.4	48	.44	705	96	31	31	18.0
Virginia	105.7	42	.40	359	43	21	25	10.7
W. Virginia	62.6	36	.58	172	29	3	0	5.7

Type 4 events (Figure 2b) indicated a maximum frequency from 1700 to 1900, which may not be significant due to the relatively small number of events. The hourly frequencies of Type 1 events in Missouri and Illinois (Figure 2a) have primary maxima at 1600-2000, with a substantial number occurring into the early morning hours. Missouri Type 4 events occur primarily as nocturnal events (Figure 2b). In Illinois, the Type 4 events exhibited a broad maximum extending from late afternoon into the early morning hours. The distributions of Type 1 events in Kentucky and Tennessee (Figure 3a) show primary maxima in the afternoon, but exhibit relatively high frequencies throughout the day. Type 4 events (Figure 3b) have distinct primary nocturnal maxima. The climatologies for Kentucky and Tennessee indicate that heavy rain events are likely at any time of the day. Although Type 1 events in West Virginia occurred mid to late afternoon, the sample size is small and no Type 4 events occurred at the HPD stations. Type 1 events in Pennsylvania and Virginia (Figure 4a) clearly have afternoon maxima. Two curves are shown for the Type 4 event in Pennsylvania and Virginia (Figure 4b). The events due to the passage of tropical storms Agnes and Camille over the states were extracted from the original sample because of their significant effect on the distributions. Non-tropical Type 4 events in Virginia occurred mainly from 1300-0400 with maxima near 1500 and 2300, whereas non-tropical Type 4 events in Pennsylvania show a striking peak at midnight and few occurrences from 0800-1600.

4. SUMMARY

Although this climatology is far from comprehensive, the results illustrate a number of interesting diurnal aspects of heavy precipitation events. Type 1 events (i.e. amounts of 2.5 to 5.1 cm in $\leq$ 1 h) tend to occur during the afternoon and evening for all states considered. These events may presumably be produced by a wide variety of precipitation systems (e.g. air mass thunderstorms, severe squall lines, cyclonic storms, etc.) and are quite likely to produce flash flooding of a minor nature. However, when events of extreme magnitude are considered (Type 4, > 10.2 cm in $\leq$ 8h) all the states from Missouri eastward to Virginia exhibit a diurnal shift such that the frequencies maximize during late night and early morning hours. These Type 4 events naturally represent a much greater threat for severe flash flooding. Thus the HPD climatological data corroborates the finding of Maddox et al (11) that significant flash floods over the eastern two-thirds of the United States were distinctly nocturnal in nature. It is hypothesized that long-lived, large and highly organized mesoscale convective weather systems, which have been shown by Maddox (16) to maximize both in size and intensity shortly after local midnight, are largely responsible for the nocturnal maximum of Type 4 extreme precipitation events.

REFERENCES AND FOOTNOTES

1. *Kenneth A. Crysler*
NOAA/NESS
660 Price Avenue
Redwood City, CA 94063

Mr. Crysler received his B.S. in meteorology from the San Jose State University in 1980. He began work at NOAA/ERL/OWRM in Boulder, CO, working in mesoscale and flash flood studies, and co-authored a paper with L. R. Hoxit and R. A. Maddox. In 1981 he transferred to NOAA/NESS in San Francisco.

2. *Robert A. Maddox*
NOAA/ERL OWRM
325 Broadway
Boulder, CO 80303

Dr. Maddox has worked with NWS, AWS and ERL during his career. He has spent a number of years as a weather forecaster and continues to be interested in studies designed to improve operational meteorology and in the actual implementation of new forecast techniques.

3. *L. Ray Hoxit*
National Climatic Center
Federal Building
Asheville, NC 28801

Dr. Hoxit is currently Deputy Director of the National Climatic Center, NESDIS, NOAA, in Asheville, NC. From 1974-1981 he was a research meteorologist at NOAA/ERL in Boulder, CO. He has earned a M.S. in Meteorology from Florida State University and a Ph.D in Atmospheric Science from Colorado State University. His research has focused on the atmospheric boundary layer, convection cloud-environment interactions, and diagnostic studies of severe convective storms, including major flash flood events.

4. *Bradley M. Muller*
Aerovironment, Inc.
145 Vista Avenue
Pasadena, CA 91107

Mr. Muller received his B.S. in meteorology from San Jose State University in CA in 1980, and began work at NOAA/ERL in Boulder, CO, participating in flash flood and severe weather research. He now works in private industry, doing studies in air pollution.

5. *Dennis, A. S., R. A. Schlensener, J. H. Hirsch, and A. Koscielski, 1973: Meteorology of the Black Hills Flood of 1972. Institute of Atmos. Sci. Report 73-4, South Dakota School of Mines and Technology, Rapid City, 41 pp.*

6. *Maddox, R.A., F. Caracena, L. R. Hoxit, and C.F. Chappell, 1977: Meteorological aspects of the Big Thompson flash flood of 31 July 1976. NOAA TR ERL 388- APCL 41, 84 pp.*

7. *Randerson, D., 1976: Meteorological analysis for the Las Vegas, Nevada flood of 3 July 1975. Mon. Wea. Rev., 104, 719-727.*

8. *Schroeder, J. A., 1977: Meteorological analysis of the Oahu flood. Mon. Wea. Rev., 105, 458-468.*

9. *Hoxit, L. R., R. A. Maddox, C. F. Chappell, F. L. Zuckerberg, H. M. Mogil, I. Jones, D. R. Greene, R. E. Saffle and R. A. Scofield, 1978: Meteorological analysis of the Johnstown, Pennsylvania, flash flood, 19-20 July 1977. NOAA Technical Report ERL 401-APCL 43, 71 pp.*

10. *Bosart, L. F. and F. Sanders, 1981: The Johnstown flood of July 1977; J.Atmos. Sci., 38:8, pp. 1616-1642.*

11. *Maddox, R. A. , C. F. Chappell and L. R. Hoxit, 1979: Synoptic and mesoscale aspects of flash flood events. Bull. Amer. Meteor. Soc., 60, 115-123.*

12. *Kincer, J. B., 1916: Daytime and nighttime precipitation and their economic significance. Mon. Wea. Rev., 44, 628-633.*

13. *Wallace, J. M., 1975: Diurnal variations in precipitation and thunderstorm frequency over the conterminous United States. Mon. Wea. Rev., 103, 406-419.*

14. *Vrcek, B. A. and W. E. Sangster, 1974: Climatology of heavy rains in the central United States. Preprints, Fifth Conf. on Weather Forecasting and Analysis, AMS, St. Louis, MO., 87-89.*

15. *Gray, W. M. and R. W. Jacobson, Jr., 1977: Diurnal variation of deep convection. Mon. Wea. Rev., 105, 1171-1188.*

16. *Maddox, R. A., 1980: Mesoscale convective complexes. Bull. Amer. Meteor. Soc., 61, 1374-1387.*