AN EVALUATION OF URBAN-ENHANCED EXTREME 24-HOUR RAINFALL IN THE NEW ORLEANS AREA

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Abstract

To provide users with accurate magnitude-frequency relationships of extreme rainfall in a region one must consider how urban areas may produce localized enhancement of extreme rainfall values. In this study, the New Orleans, Louisiana area is examined to evaluate if and when the urban area enhances extreme rainfall. Daily rainfall records for eight sites with records in excess of thirty years are used for the analysis. The partial duration series of extreme daily events were generated and fit to the Gumbel extreme value distribution to determine magnitude-frequency relationships. These data were then adjusted to 24-hour moving-window equivalents. For display purposes, the 25-year, 24-hour storms are displayed. Overall, areas east and northeast of the central business district (CBD) were observed to have the greatest annual values. No distinct pattern was observed in winter but the east and northeast maximum appeared in spring and autumn. In summer, the maxima was focused more on the CBD itself. Across the city, statistically significant differences were found between seasonal intensities, but differences in intensities between locations were statistically insignificant despite two sites appearing to stand out from the rest of the stations. This study thus shows that there are mesoscale differences in extreme spatial rainfall frequency-magnitude patterns in the greater New Orleans area, differences which can be attributed to the physical characteristics of the surface.

1. Introduction

Enhanced rainfall in urban areas has been documented at several sites across the United States. The cities which have been shown to greatly effect the rainfall patterns in and downwind of their urban regions includes Chicago (Changnon, S. 1968), St. Louis (Changnon, S. et al. 1977) and Atlanta (Changnon, D. et al. 1992). This enhancement results from warmer urban temperatures (largely from land use changes which alter the local radiation balance) leading to increased atmospheric instability, water vapor introduced into the atmosphere through industrial processes (mostly from cooling towers) and other anthropogenic processes (Lutgens and Tarbuck 1989).

In an earlier study which examined New Orleans, Louisiana rainfall (Huff and S. Changnon 1973) it was suggested that the New Orleans area experienced urban-enhanced rainfall, based on *average* annual and seasonal data. This issue becomes significant when maps of state and regional extreme rainfall frequency-magnitude relationships are under development (Huff and Angel 1992) because it is prudent to determine whether anomalously high extreme rainfall values are the result of random patterns or physically-based processes. Currently, the Southern Regional Climate Center (SRCC) is in the process of updating *Technical Paper No. 40 (TP40)* which is the most recent document depicting extreme rainfall values for periods of up to 24 hours (Hershfield 1961). Therefore, the purpose of this paper is to determine whether there are localized changes in extreme rainfall events in the urban area of New Orleans, and if so, to determine the time of year when the differences are most apparent.

2. Data and Methods

Daily rainfall records from eight sites in the New Orleans urban area were selected for analysis (Fig. 1). The WSO City site is in the heart of the central business district (CBD). The "Crescent" of the Mississippi River lies to the south of Audubon and Jefferson. Each location has at least 40 years of record with the exception of Jefferson (30 years) (Table 1). Partial duration series of annual and seasonal extreme daily rainfall events were extracted to create the data sets necessary to determine the magnitude-frequency relationships at these sites. A partial duration series contains the largest daily storms occuring during the period of record regardless of the years in which they took place while the number of events in the partial duration series is in this case equivalent to the number of years of record. In other words, several storms may be in the series from the same year, while some of the "drier" years are not represented in the series. This type of series differs from the annual series which includes only the largest storm from each year. Partial duration series data are considered to be the more appropriate and accurate for the determination of frequency-magnitude relationships (Hershfield 1961; Dunne and Leopold 1978).

Once the annual and seasonal series for each site was extracted, the data were then fit to the Gumbel extreme value probability distribution to determine magnitude-frequency relationships. This is the same distribution used in *TP40* and also has been found to be one of the two most appropriate distribution for extreme rainfall analysis (Tiago de Oliveira 1986).

Table 1. Station histories for each of the sites used in the study.

Location	Years of Record	Additional Comments
Algiers	1948–90	
Audubon	1948–90	
Dublin	1948–90	Called Water Plant (1978–)
Jefferson	1948–78	
Jourdan	1948–90	Called D.P.S. 5 (1978–)
London	1948–90	Called D.P.S. 3 (1978–)
Metairie	1949–90	Called D.P.S. 6 (1979–)
WSO City	1930–79	Called New Federal (1962–)

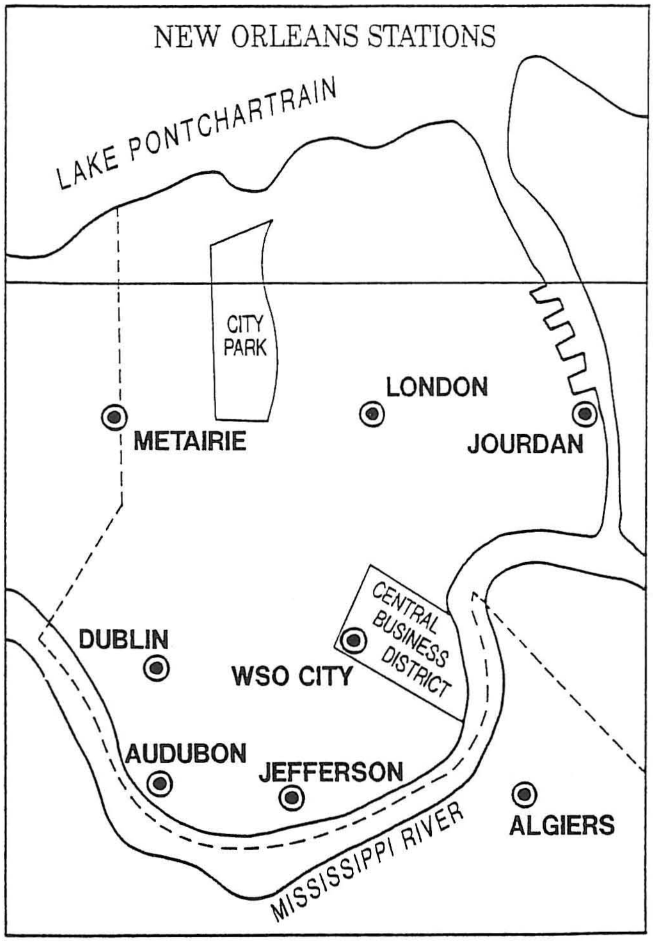

Fig. 1. Locations and names of the New Orleans urban rainfall sites.

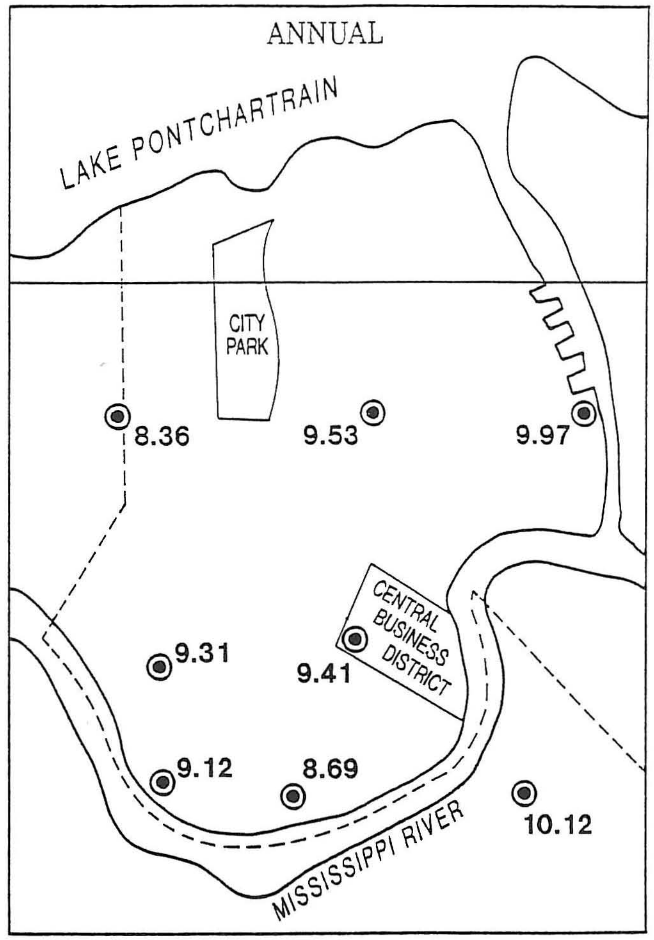

Fig. 2. Annual 25-year, 24-hour rainfall values in the New Orleans urban area (in inches).

After the values were determined for 2, 5, 10, 25, 50 and 100-year storms, the magnitudes were adjusted to 24-hour moving-window equivalents. This is important because extreme storms sometimes are split into two observational days resulting from the once daily, discrete method of observing a continuous process (Observational days differ from calendar days in that the once-daily observations can be made at 0800 LST, 1700 LST or at any other time of day as long as the observational times are consistent). The end result is a reduction in the magnitude of the events in the daily series. In *TP40,* in addition to a recent *TP40* update by the Midwest Regional Climate Center (Huff and Angel 1992), and in an evaluation of Louisiana extreme rainfall data at the SRCC (Faiers et al. 1993), a 1.13 relationship has been found to represent the difference between the daily and the 24-hour moving-window series derived from hourly data. This implies that frequency-magnitude relationships derived from daily data need to be adjusted with a 13% increase to produce the equivalent hourly series data. Hence, this 1.13 adjustment was also applied to the New Orleans area storm magnitudes in this study.

3. Results and Analysis

For practical reasons, only 25-year estimated return periods are included in the analysis and discussion, but all of the return periods create patterns which are similar. The 25-year storm values are the most frequently requested for design purposes and therefore it was considered the most appropriate for display. As displayed in Fig. 2, the lowest storm magnitude is found in the northwest area (Metairie) while the largest magnitudes are east and northeast of the CBD. Given that the majority of extreme rainfall events in New Orleans result from frontal systems (Keim 1990; Keim and Muller 1992), if there is an urban enhancement, it should be over and east-northeast of the CBD due to the fact that upper air winds which direct frontal and pre-frontal thunderstorms are generally from the southwest or west. Note the anomalously low value at Jefferson. This tendency towards low values compared to neighboring sites is likely the result of the shorter period of record at Jefferson. This trend also appears in other recurrence intervals on an annual and seasonal basis.

To determine when this enhancement is taking place, daily rainfall at all sites was divided into four seasons (Winter: December, January, February, etc.). Again, partial duration series were derived and magnitude-frequency relationships established using the same methods utilized in the annual analysis.

During winter (Fig. 3a), no urban effect is noted. The absolute maximum is again noted at Algiers, but the magnitude at Metairie is also large while the values in the CBD are depressed relative to the surrounding sites. This apparent lack of an urban effect in winter is not surprising given the fact that the bulk

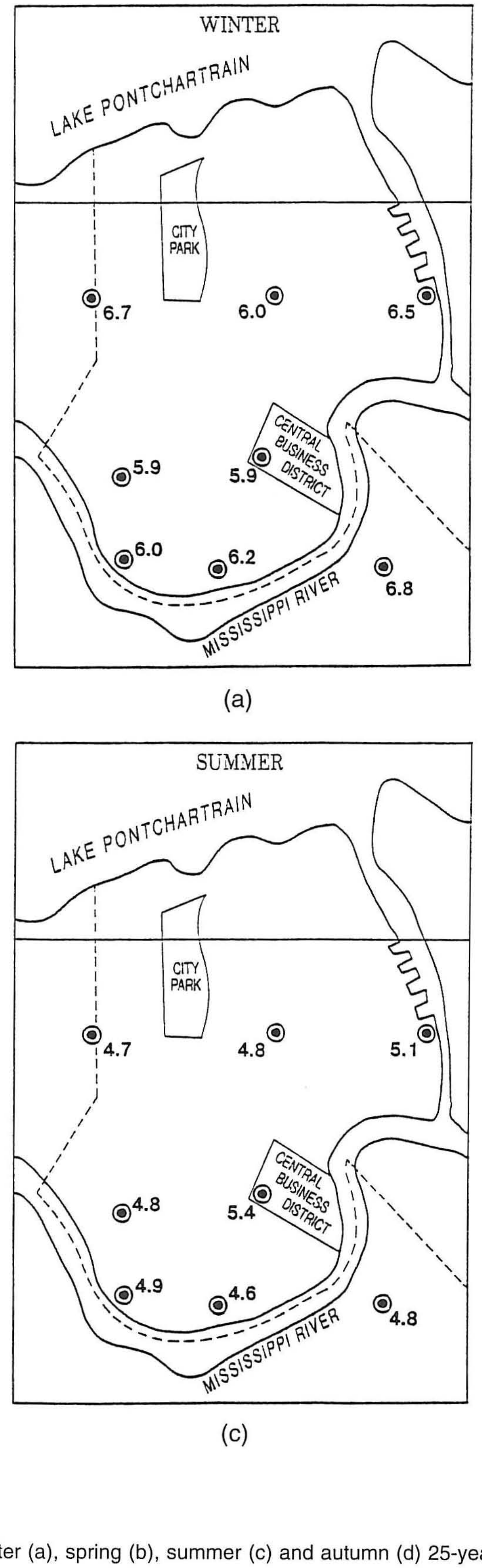

Fig. 3. Winter (a), spring (b), summer (c) and autumn (d) 25-year, 24-hour rainfall values in the New Orleans urban area (in inches).

of winter rainfall occurs during Frontal Overrunning weather situations (Muller 1977; Muller and Willis 1983) and that regional synoptic patterns will negate the weak localized convection during these cooler months.

In spring (Fig. 3b), values over nine inches are observed at Algiers, Jourdan and London while the absolute minimum is at the Metairie site. With the exception of the anomalously low value at WSO City, the spring pattern closely resembles the annual geographic distribution. Again, the southwest-northeast and west-east motion of most frontal storms explains these results.

During the summer months (Fig. 3c), the extreme rainfall magnitudes tend to be greater in and around the CBD. The highest values are found at WSO City, Jourdan and Audubon. In the months of July and August especially, frontal passages become less frequent and afternoon convective storms become more important in the production of heavy rain. Extreme rainfall from easterly waves, tropical storms and hurricanes is less significant in summer than in autumn (Faiers et al. 1994) in the New Orleans area. This decrease in frontal activity impacts the overall rainfall intensity (note how the values are greatly depressed relative to spring). The smaller rainfall amounts in summer result from the dynamics and duration of the various mechanisms which are dominant in the different seasons. For example, frontal boundaries produce much more dynamic lifting for longer periods of time than do the afternoon air mass storms which tend to produce rain for a much shorter duration. Also during the summer, the surface and upper air wind flow is weak, resulting in little or no movement of storms. In some instances, storms move toward the west or northwest, contrary to the predominant flow pattern of winter-spring, but in line with the prevailing summer flow patterns south of the subtropical ridge line. Given that the urban influence will generally not be expanded due to the weak surface and upper air flow in summer, the extreme rainfall tends to be more focused on the heart of the CBD. The WSO City site is also the focus for the heaviest rain in autumn (Fig. 3d), with the next highest values found at Jourdan and Algiers to the northeast and east. This pattern takes on some of the characteristics of both the summer and spring distributions. Given that autumn includes September (a month which still has afternoon air mass storms as well as tropically disturbed storms such as easterly waves and hurricanes) and November (a month more dominated by frontal storms), this pattern is not surprising.

Figure 4 illustrates how the 25-year, 24-hour storm magnitudes from the New Orleans area stand out from those from nearby sites in a preliminary study of Louisiana extreme rainfall (Faiers et al. 1993). The extreme New Orleans values (especially at Algiers and Jourdan) are one to two inches above those found in the surrounding area. Given these findings, any state-wide or regional analysis of extreme rainfall should incorporate the New Orleans area urban enhancements.

Two methods were selected to statistically evaluate whether the deviations in extreme rainfall amounts are significantly different from each other. In Table 2, the 25-year storm values are displayed on an annual and seasonal basis. Those locations with amounts which are one or more standard deviations above the annual or seasonal mean are highlighted. Four sites have seasonal or annual amounts which are greater than one standard deviation above the mean. These sites are Algiers (winter, spring, and annual), Jourdan (spring, summer, and annual), WSO City (summer and autumn), and Metairie (winter). The only one of these sites which does not fit the urban-enhanced model is the winter maximum at Metairie while the other three sites are indicative of urban enhancements.

Table 2. 25-year, 24-hour rainfall estimates at each of the study sites on a seasonal and annual basis. Values equal to or greater than one standard deviation above the seasonal or annual mean are highlighted.

Location	Winter	Spring	Summer	Autumn	Annual
Algiers	**6.8**	**9.6**	4.8	6.8	**10.1**
Audubon	6.0	8.6	4.9	6.5	9.1
Dublin	5.9	8.6	4.8	5.8	9.3
Jefferson	6.2	8.6	4.6	5.6	8.7
Jourdan	6.5	**9.5**	**5.1**	6.9	**10.0**
London	6.0	9.2	4.8	6.4	9.5
Metairie	**6.7**	7.4	4.7	6.4	8.4
WSO City	5.9	7.9	**5.4**	**7.7**	9.4

For each of the four seasons, the ranking of each location (by amount) was determined and the Friedman two-way nonparametric analysis of variance test was performed to determine whether there were significant differences in storm rank on a seasonal and locational basis. The annual ranks were not included in this analysis because they represent storms from all of the seasons and would thereby violate the independence assumption for this test. It was found that the ranks are significantly different at the .01 level on a seasonal basis, which primarily results from the low-intensity rainfall in the summer. Between-site differences were significant at an alpha of .13, indicating a tendency towards intensity differences between sites, but not at an acceptable significant level. However, Algiers and Jourdan do have rankings which stand out when compared to the other six sites.

4. Conclusion

The New Orleans urban area enhances extreme 24-hour rainfall in all seasons except winter. The enhancement is east and northeast of the CBD in spring, primarily in the CBD proper through the summer months and in the CBD as well as northeast and east of the CBD during autumn. These findings indicate that the New Orleans urban enhancement should be included in statewide and regional research projects related to extreme rainfall magnitude-frequency relationships.

Further research into urban-enhanced extreme rainfall in the South Central United States will continue. Synoptic aspects of these extreme rainfall patterns also need investigation to subsequently determine under which synoptic situations these enhancements are most developed.

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Gregory E. Faiers is currently the Applied Regional Climatologist at the Southern Regional Climate Center (SRCC). He is also an Assistant Professor in the Department of Geography and Anthropology at LSU. His primary responsibilities are to conduct funded applied climatic research for the center. Current

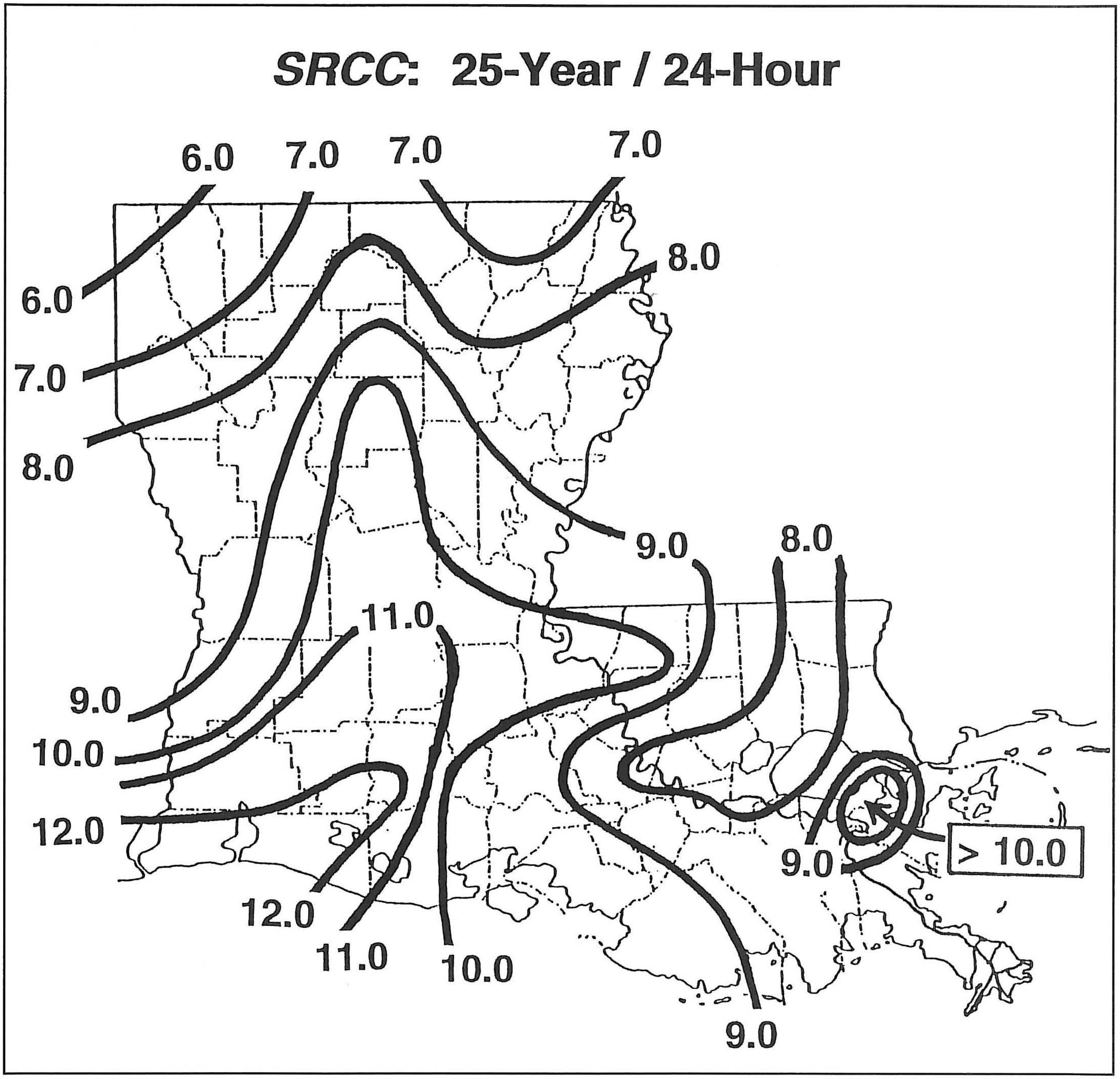

Fig. 4. Preliminary estimates of 25-year, 24-hour rainfall values for Louisiana (in inches).

projects include an update of NOAA *Technical Paper No. 40* for the South Central U.S., water balance evaluations of Texas and Louisiana, and spatial and temporal aspects of extreme temperature departures in the region. His primary research interests address precipitation climatologies (especially extreme rainfall and diurnal precipitation), synoptic climatology, and hydroclimatology. He received a B.A. (1978) and M.S. (1980) in Geography from Memphis State University and a Ph.D. in Geography (1986) from Louisiana State University. He has also held teaching positions in geography at Bowling Green State University (1985–1989) and the University of Pittsburgh-Johnstown (1989–1992).

References

Changnon, D., C. Lawson, J. Jacobson and D. J. Smith, 1992: Initial results from analyses of large precipitation events. *Southeastern Climate Review* 3, 3–11.

Changnon, S. A., Jr., 1968: The LaPorte anomaly—fact of fiction? *Bull. Amer. Meteor. Soc.*, 49, 4–11.

——————, F. A. Huff, P. T. Schickedanz, and J. L. Vogel, 1977: *Summary of METROMEX, Volume 1: Weather Anomalies and Impacts.* Champaign, IL: Illinois Water Survey Bulletin 62.

Dunne, T. and L. B. Leopold, 1978: *Water in Environmental Planning.* San Francisco: W. H. Freeman and Company.

Faiers, G. E., J. M. Grymes, III, B. D. Keim, and R. A. Muller, 1993: A Re-evaluation of the frequency-magnitude relationships of extreme 24-hour rainfall in Louisiana. *Accepted for publication in Climate Research.*

______________, B. D. Keim and K. K. Hirschboeck, 1994: A synoptic evaluation of extreme three hour and twenty-four hour rainfall in Louisiana. *Accepted for publication in the Professional Geographer* (to appear May 1994).

Hershfield, D. M., 1961: Rainfall frequency atlas of the United States. *U.S. Weather Bureau Technical Paper 40.* Washington, DC.

Huff, F. A. and J. R. Angel, 1992: *Rainfall Frequency Atlas of the Midwest.* Champaign, IL: Illinois Water Survey, Bulletin 71.

______________ and S. A. Changnon, Jr., 1973: Precipitation modification by major urban areas. *Bull. Amer. Meteor. Soc.* 54, 1220–1232.

Keim, B. D., 1990: Synoptic weather, frequency and magnitude analyses of heavy rainfall events in New Orleans, Louisiana: 1871–1989. M. S. Thesis, Louisiana State Univ.

______________ and R. A. Muller, 1993: Frequency of heavy rainfall events in New Orleans, Lousiana from 1900 to 1991. *Southeastern Geographer* (to be published November, 1993).

Lutgens, F. K. and E. J. Tarbuck, 1989: *The Atmosphere: An Introduction to Meteorology,* 4th Edition. Englewood Cliffs, NJ: Prentice-Hall.

Muller, R. A., 1977: A synoptic climatology for environmental baseline analysis: New Orleans. *J. Appl. Meteor.,* 16, 20–33.

______________ and J. E. Willis, 1983: *New Orleans Weather 1961–1980: A Climatology by Means of Synoptic Weather Types.* Baton Rouge: L.S.U. School of Geoscience Miscellaneous Publication 83–1.

Tiago de Oliveira, J., 1989: Extreme values and meteorology. *Theor. Appl. Climatol.* 37, 184–193.