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FREQUENCY OF HEAVY RAINFALL EVENTS IN NEW ORLEANS, LOUISIANA, 1900 TO 1991¹

Barry D. Keim and Robert A. Muller

The large number of recent heavy rainfall events in New Orleans, Louisiana, has raised concerns about change in the heavy rainfall climatology in the area. As a result, all rainfall events exceeding 125 mm were examined with respect to their generating mechanisms, seasonality, and changing frequencies through time. Two thirds of the storms were induced by frontal weather situations and tropical systems produced about a fourth. Storm seasonality was bimodal with peaks in late spring and early fall. With regard to changing frequencies through time, the entire New Orleans rainfall record suggests that storms may have a pattern of increasing occurrence. However, a temporally homogenous subset of these data were tested statistically and no significant change was found.

Recent heavy rainfall events in New Orleans, Louisiana, have raised concerns that climate regimes may be changing and that heavy rainfall events may be increasing in frequency and magnitude in the area (Keim, 1990; Keim and Muller, 1992). This is particularly problematic in New Orleans because the city is largely below sea level and is encircled by a levee system for flood protection from storm surges and elevated levels of the Mississippi River. These barriers, however, often exacerbate urban floods during local heavy rain events. As a result of the abundance of recent storms, many inconveniences, disruptions, and property damages have been incurred on inhabitants of the city between 1978 and 1983. Orleans Parish was ranked second nationally in receiving reimbursements from the National Flood Insurance Program (Louisiana Statewide Flood Control Program's Project Evaluation Committee, 1986). Although improvements in the drainage network have mitigated flood damage within the city since 1983, it does not appear that there has been a reduction in the number of events. In fact, there were several impressive storms during 1991 and that year was the wettest on record in New Orleans in over 100 years, with some areas of the city receiving over 3000 mm of precipitation.

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This paper investigates the frequency of heavy rainfall events in New Orleans from 1900 through 1991. The seasonality of heavy rainfall is analyzed in addition to the synoptic conditions which generate these events. Most importantly, however, the large number of recent events is compared to the long-term climate record of the city to determine whether large events have a pattern of increasing occurrence through time.

DEFINING A HEAVY RAINFALL EVENT AND ASSUMPTIONS. The definition of a heavy rainfall event can be ambiguous and can vary dramatically from one study to another due to varying applications and geographic locations. A heavy rainfall event in this study was identified when the sum of any two consecutive observational days of precipitation equaled or exceeded 125 mm. Sources for these data are published in U.S. Department of Agriculture and U.S. Department of Commerce climatological publications (U.S. Department of Agriculture, 1900–1906; U.S. Department of Agriculture, 1906–1909; U.S. Department of Agriculture, 1909–1913; U.S. Department of Agriculture, 1914–1940; U.S. Department of Commerce, 1940–1991).

Examining two observational day rainfall totals (rather than daily) was first implemented by Finch (1972) who found that these data were more accurately associated with flooding in Great Britain. Two-day amounts are more useful in these types of analyses because they reduce many of the problems associated with once-daily observations of continuous rainfall over short periods. For example, precipitation at the stations used in this analysis was recorded once daily and at a specified time in most instances. If a storm's duration overlapped a recording time, the storm precipitation total would have been recorded over a two-day period. Therefore, for two consecutive observational day totals, the assumption was made that the rainfall resulted from the same event. When precipitation fell on three consecutive days, the two consecutive days with the largest total was selected to represent the event. Since most heavy rainfall in this area is normally concentrated in periods of less than 24 hours (Belville and Stewart, 1983), two observational day events should index the majority of major storms across the city.

Examining all of the gauges in Figure 1 collectively gives an indication of the frequency of heavy rainfall events across the entire city rather than at any single gauge. Hence, a single event was defined regardless of whether one gauge equaled or exceeded the 125 mm threshold or

Fig. 1. New Orleans Raingauge Network from 1900-1991.

whether all available gauges surpassed the threshold during a particular storm event.

HEAVY RAINFALL EVENT TIME SERIES. All heavy rainfall events appearing in the published rainfall record of New Orleans between 1900 and 1991 were catalogued and are displayed in an annual time series in Figure 2. This figure, which includes data from a total of 11 separate station records, provides the data set for this analysis. As displayed beneath the years on the x-axis, however, the number of official gauges in operation at any given time within the city varied dramatically through time creating an inhomogeneous time series. This is of no real significance in the analysis of the seasonality and synoptic generating mechanisms of these events. A temporally homogenous subset of these data is used to analyze temporal change.

Fig. 2. Annual Time Series of Heavy Rainfall Events in New Orleans. Note the fluctuating number of gauges through time beneath years on the x-axis.

Despite the inconsistent number of gauges through time, Figure 2 displays the impressive number of events during the latter half of the series, especially since 1978. Furthermore, the number of years with two or more events is nearly double during the latter half of the series (12 vs. 22), and there was no year with four or more events during the first 55 years of the series while the last 37 years had seven. Therefore this time series clearly suggests that an extraordinary number of events occurred during the most recent period despite the changing number of available gauges in the city.

SYNOPTIC SITUATIONS AND SEASONALITY OF EVENTS. Synoptic methods can be defined as the classification of meteorological elements by weather or air mass type (Barry and Perry, 1973). There are numerous methods used to classify the weather synoptically for various types of research, and synoptic analyses are often implemented in the interpretation of heavy rainfall and flooding events (Maddox et al., 1980; Hirschboeck, 1987; Winkler, 1988; Davis and Rogers, 1992). All heavy rainfall events in this analysis were classified as either frontal, tropical,

or other. Frontal events were defined when frontal systems were in such proximity to New Orleans that they clearly generated the rainfall event. Tropical events are those induced by any tropical disturbance ranging from relatively weak easterly waves to rare but severe hurricanes. The "other" category includes all events that were neither frontal nor tropical and consists of localized airmass convective showers and storms generated by upper air disturbances which exhibited no surface manifestation (see Muller, 1977).

Of the 119 events which occurred in the 92 years from 1900 through 1991, 79 were frontally induced (66%), 28 (24%) were tropical in origin, and 12 (10%) were neither. These findings dispel the current assumption that most heavy rainfall in this area is generated by hurricanes and tropical storms. Clearly, frontal systems are the most frequent generators of destructive rainfall events in the city, a finding that concurs with results reported by Hershfield and Wilson (1960).

The bimodal seasonality of these events is displayed in Figure 3. The first peak in the annual cycle occurs in late spring (April and May) and consists primarily of frontal events. The second peak occurs in September

Fig. 3. Seasonality of Heavy Rainfall Events in New Orleans by Generating Mechanism.

ber and is dominated by events of tropical origin. The period of reduced frequencies in late fall and winter is likely due to an inadequate availability of atmospheric moisture needed to produce heavy precipitation. Cooler temperatures associated with these months reduce the atmospheric capacity for storing water vapor. Also, minimal surface heating in late fall and early winter enhances atmospheric stability which suppresses vertical mixing needed to produce precipitation. Reduced summer frequencies are due to the absence of both frontal and tropical systems. During this time of year, most frontal systems are too far north to affect New Orleans and conditions are not yet ideal for the development of well-organized tropical disturbances.

Although clusters of years with atypical numbers of events are apparent in the time series, there also seems to be temporal groupings of storms by the same synoptic-generating situation (Fig. 2). For example, clusters of events produced by non-frontal (tropical and other) situations are prevalent in the late 1950s and again in the early 1970s. Moreover, dense clusters of frontal events are evident from 1909 to 1913 and again from 1988 to 1991. It is likely that these atypical periods are associated with changing global circulation patterns that create or suppress opportunities for heavy rainfall. Persistent periods of meridional or zonal upper air flow and changing positions of upper air ridges and troughs are probably related to these temporal-synoptic patterns. Trenberth (1990) reported a shift from zonal to more meridional atmospheric circulation patterns in the Northern Hemisphere in 1977 and this shift is probably related to the change in storm frequencies (especially frontal events) which occurred at that time.

TEMPORAL FREQUENCY ANALYSIS. Of the 11 precipitation recording stations within New Orleans, five were chosen for the frequency analysis of heavy rainfall events. The stations include New Federal, Audubon, Water Plant, D.P.S. 3, and Algiers (Fig. 1). These stations were selected because they yield temporally continuous data from 1902 through 1991, with the exception of a nine-year period of missing data for three of the five stations (Water Plant, D.P.S. 3, and Algiers) from 1937 through 1945. Although data were available for New Federal and Audubon during the period of missing data, that entire time span (1937–1945) was dropped from the analysis to avoid biasing the time series. Moreover, data were available for all five stations for parts of 1901 and 1937 and these partial years were also not included in the temporal analysis.

Analysis. There were 96 heavy rainfall events recorded at the five rain gauges collectively during the years 1902–1936 and 1946–1991. The frequency distribution shows that 30 of the 96 events were limited in area so that only one of the five gauges exceeded the threshold, and 30 of the 96 events exceeded the threshold at all five stations (Table 1). Classes two through four had relatively modest frequencies, indicating that heavy rainfall events are typically localized or encompass most of the city and are much less frequently intermediate in size.

The number of times each individual gauge exceeded the threshold is tabulated in Table 2. Station frequency variability ranges from 64 events recorded at New Federal to 47 events recorded at the Water Plant. A distinct spatial pattern does not appear to exist, which is not surprising considering the number and proximity of stations. It is noteworthy, however, that the downtown site experienced the highest frequency of events, as this supports observations by Huff and Changnon (1973) and Changnon et al. (1976) where precipitation is enhanced in and downwind of the Central Business District of New Orleans. Other urban biases associated with increasing urbanization through time should be minimal because the population of New Orleans has remained remarkably stable throughout most of the century and the majority of the study area has been urban for over 100 years.

Smoothing of Heavy Rainfall Event Frequencies. The annual frequency series subset of heavy rainfall events is shown in Figure 4. Although the annual frequencies vary greatly from one year to the next, it appears that certain periods, or clusters of years, have greater frequencies than others.

TABLE 1
NUMBER OF THE FIVE GAUGES EXCEEDING THE 125 MM
THRESHOLD FOR 96 STORM EVENTS IN NEW ORLEANS, 1902–1936
AND 1946–1991

Number of Gauges	Frequency
1	30
2	14
3	14
4	8
5	30

Sources: U.S. Department of Agriculture and U.S. Department of Commerce Climatological Publications for Louisiana.

TABLE 2
NUMBER OF TIMES EACH OF THE FIVE GAUGES EXCEEDED THE
125 MM THRESHOLD

NF	AUDN	WRPLT	DPS#3	ALGRS
64	60	47	54	57

Sources: U.S. Department of Agriculture and U.S. Department of Commerce Climatological Publications for Louisiana.

For example, seven events occurred in five years from 1909 to 1913, 12 events in seven years from 1926 to 1932, 10 events in five years from 1953 to 1957, 15 events in seven years from 1977 to 1983, and 13 events in four years from 1988 to 1991. Moreover, there were extended periods when very few events occurred, i.e., the years 1921–1925, 1934–1937, and 1984–1987, when only one event occurred in a four-to-five year period, and the years from 1968 through 1970 when no events were recorded.

Fig. 4. Time Series of Heavy Rainfall Events at 5 Gauges in New Orleans with 5-year Weighted Moving Average.

To accentuate those periods when frequencies appear to cluster, the series was smoothed through the use of a five-year weighted moving-average filter (Panofsky and Brier, 1968) displayed in Figure 4. The definition of the weighted average filter is as follows:

$$SV = [.06F_{(n-2)} + .25F_{(n-1)} + .38F_{(n)} + .25F_{(n+1)} + .06F_{(n+2)}]$$

where SV = Smooth Value

and F = Average Frequency for Year n

The series of weights, which decreases smoothly and symmetrically from the central weight, is multiplied by consecutive time series values. Filtering of the data in this manner dampens the short-term variations and allows for easier viewing of the long-term trends. Unweighted moving averages are often used in time series analysis, but are not recommended because they distort the series by producing spurious cycles (Reynolds, 1978).

The smoothed time series shows the extended periods (or clusters of years) where the frequencies were above and below the long-term annual mean of 1.2 events. Although the extreme years (those with three or more events) appear to be growing more extreme, the moving average does not suggest that a distinct upward trend in the number of heavy rainfall events has occurred. However, the three latter periods of above average frequencies consist of a greater concentration of events than the two former periods and the most recent cluster of events is quite impressive, primarily resulting from the six recorded events in 1991 alone.

1902–1936 vs. 1946–1991. If the frequency of heavy rainfall events has increased temporally, then the statistical properties of the latter portion of the time series should differ from the former. To make this determination, the annual frequency series was split into two samples divided by the artificial break of missing data from 1937 to 1945. This break conveniently falls during a period when global carbon dioxide emissions, a primary suspected agent of climate change in the last century, made a transition from a gradual to a more rapid rate of increase (Idso, 1983). Three tests were implemented to test whether the distributions differ significantly between the two samples.

The mean annual frequency of the two sample distributions should give a measure of the central tendency for the two time periods. The means for samples one and two are 0.97 (1902–1936) and 1.32 (1946–1991), respectively. The paired t-test concluded, however, that these two

sample means do not differ significantly ($t = 0.72$; $p = 0.47$). In addition, the Mann-Whitney test was used. Based on the locations of the two sample distributions, the Mann-Whitney test also showed that the two samples are not significantly different ($z = 0.532$; $p = 0.59$).

It is evident that these frequency distributions differ, especially the two classes with the greater frequencies (Table 3). Eighteen of the 44 years in the latter sample experienced two or more heavy rainfall events compared to only nine in 35 years in the former sample. Furthermore, the latter sample had three years (or observations) with four or more events compared to zero in the former. The years with four or more events, however, are placed in the class with three or more events because implementation of the chi square test requires a minimum frequency of three for each class (Clark and Hosking, 1986). Like the other two tests, the chi square test concluded that the two distributions (1902–1936 vs. 1946–1991) do not differ significantly (chi square = 1.682; $p = 0.64$). It is worth mentioning, however, that the testing of two samples in this manner does not take into account the shorter-term clustering of years with (and without) heavy rainfall events.

Storm Frequencies vs. Stormy Weather Conditions. To examine whether these periods above and below the long-term mean are associated with periods of increased or decreased stormy weather, the relationship between the annual number of heavy rainfall events and annual Storminess Index values developed by Muller and Willis (1983) was tested for the period 1961 through 1991 (Fig. 5). The Storminess Index gives a measure of the opportunities for precipitation before, during, and after the passage of a frontal system in addition to tropically disturbed conditions by showing the percentage of time that these unstable atmospheric

TABLE 3
FREQUENCY OF HEAVY RAINFALL EVENTS IN TWO SAMPLES,
1900–1936 AND 1946–1991

Frequency Class	1902–1936	1946–1991
0	13	14
1	13	14
2	6	11
≥3	3	7

Sources: U.S. Department of Agriculture and U.S. Department of Commerce Climatological Publications for Louisiana.

Fig. 5. Frequency of Heavy Rainfall Events in New Orleans Relative to the Storminess Index Developed by Muller and Willis (1983): 1961–1991.

conditions persist in the area. Spearman correlation analysis showed, however, that the two variables were weakly associated during the 31-year period ($r_s = 0.35$; $p = .06$). This relationship probably exists because many Storminess Index days consists of frontal overrunning weather soon after the passage of a cold front. Although cloudy skies and the potential for precipitation characterize these periods, many of these days do not receive measurable rainfall.

SUMMARY AND CONCLUSIONS. Synoptic analysis of heavy rainfall events in New Orleans concluded that the majority of events are generated by frontal weather situations. Surprisingly, less than a third of all events were induced by tropical disturbances. The seasonality of events is bimodal with a frontal season in the spring (primarily April and May) followed by a tropical season centered around September.

Temporally, the complete record of storm events for New Orleans suggests that events may be increasing in frequency and that the number of events since 1975 has been atypical. Also, the frequency series of heavy rainfall events shows extended periods of above and below nor-

mal frequencies, especially after the series was smoothed. Although these periods are unrelated to temporal fluctuations in the persistence of unstable weather conditions in the area, these periods may have an association with changing larger-scale upper air phenomena.

With a temporally homogenous time series, change in the frequency of heavy rainfall events was examined between two samples (1902–1936 and 1946–1991), divided by a period of missing data. Although three statistical tests found no significant difference in the number of events between the two periods, some change appears to have occurred from a qualitative viewpoint. Moreover, in light of predictions of global warming, these results do not mean that the New Orleans heavy rainfall climatology is not undergoing subtle changes which may exhibit distinctly different features sometime in the future.

NOTE

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