Southwestern Geographer
Vol. 6, 2002, pp.1-31

Synoptic Associations of Regional Flooding Rainstorms in Louisiana, 1911-2000

Robert A. Muller and Robert V. Rohli

This research examines the frequencies and magnitudes of extreme regional flooding rainstorms in Louisiana between 1911 and 2000, based on published daily precipitation at all of the cooperative temperature/precipitation and first-order stations of the Weather Bureau/ National Weather Service. The criteria for event inclusion are 150 mm or more of precipitation during no more than three consecutive days at no less than 12 percent of the temperature-precipitation stations in the state at the time of the event. Assuming that these stations have always been relatively representative of precipitation patterns across the state, each event represents at least 150 mm of precipitation over at least 15,500 square kilometers (6,000 square miles) of Louisiana. A total of 109 events occurred during the 90 years. There is no evidence of an increasing or decreasing trend in frequency, but clusters of years with more or less frequent events are evident. However, when the events are classified synoptically as either frontal or tropical, a much greater frequency of frontal events exists in more recent decades, with a corresponding decreasing frequency of tropical events. There is also a strong association of frequencies of both frontal and tropical events with the El Niño/Southern Oscillation (ENSO) cycle. The magnitudes of the largest frontal events tend to be smaller than those of the largest tropical events. In recent decades, however, the frequency of larger frontal events has increased, and, at the same time, frequency of the larger tropical events appears to have decreased. There are no obvious changes in the magnitudes of the most extreme frontal or tropical events. *Key Words: Louisiana climate, regional flooding rainstorms, extreme rainfall events, El Niño, climatic variability.*

Questions about potential global change have tended to focus on temperature rather than precipitation, with numerous studies estimating global, continental, and regional temperature changes relative to increasing atmospheric concentrations of greenhouse-warming gases. Equal attention has not been directed toward precipitation changes, especially empirical studies of historical precipitation patterns through time.

Robert A. Muller is Professor Emeritus and Robert V. Rohli is Assistant Professor in the Department of Geography and Anthropology, Southern Regional Climate Center, Louisiana State University, Baton Rouge, LA 70803-4105. rmuller@srcc.lsu.edu

This is somewhat surprising given the environmental, economic, and social impacts on precipitation variability. Temporal analysis of the frequency and magnitude of extreme precipitation events is especially important because of the implications of local and regional flooding. It is also noteworthy that temporal studies of precipitation may be especially insightful because the technology of precipitation observations and the recording of official data over the last 100 years in the United States has not changed as much as for temperature; most of the daily observational data has been obtained with the standard 8-inch rain gauge and cooperative station observers.

Louisiana provides an excellent case study for interpretation of extreme rainfall and regional flooding events. Mean annual statewide precipitation is the highest of the 50 states, but the intrastate range of mean annual precipitation is also among the highest in the nation (Grymes, State Climatologist for Louisiana, personal communication). Figure 1 illustrates an area-weighted climate-division index of annual precipitation for the state since 1889 with the extreme range from 925 mm in 1889 to nearly 3,000 mm in 1991. There is also a suggestion of an upward trend over the years, with the five-year running mean at approximately 1,800 mm in the 1890s and approaching 2,200 mm for the last 30 years, with a maximum of 2,400 mm during the early 1990s.

Major storm and flooding events in Louisiana are associated with two different synoptic weather situations, the prevalence of which varies by season and possibly by long-term periods affected by low-frequency atmospheric and oceanic fluctuations over the central tropical Pacific and the North Atlantic. The most dominant flood-producing mechanism is the slow-moving upper-level trough together with surface synoptic features of midlatitude cyclones. In addition, Louisiana is positioned such that frontal precipitation, especially during winter and spring, is sometimes affected by El Niño/Southern Oscillation (ENSO) patterns in the tropical central Pacific (Livezey et al., 1997). Louisiana and the adjacent coastal states along the northern shores of the Gulf of Mexico are plagued by late fall and winter-spring regional floods from these frontal events. Figures 2a and 2b illustrate two examples of extreme precipitation generated by frontal events. Figure 2a shows the precipitation distribution associated with a nearly stationary cold front far ahead of a persistent upper-air trough over the southwestern United States. Figure 2b

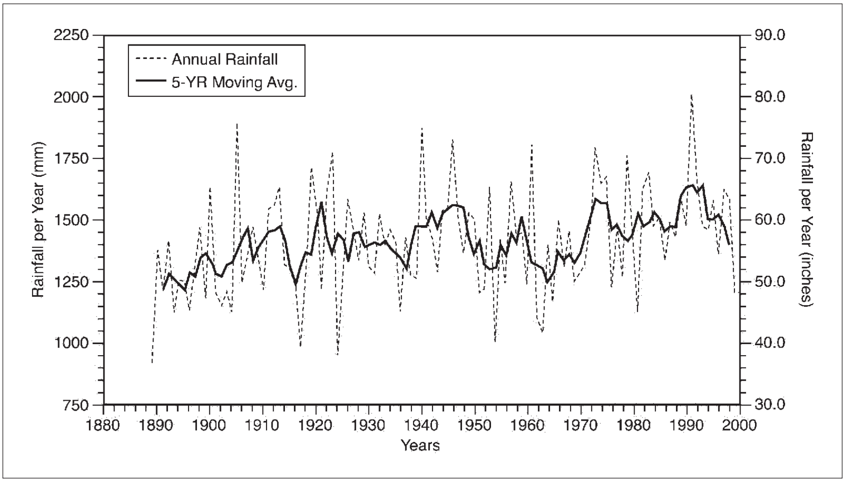

Figure 1. Annual statewide precipitation for Louisiana, 1889-2000.

shows the distribution of a frontal "train-echo" rain event with a very narrow southwest-to-northeast band of extreme rainfall over New Orleans (Muller et al., 1995), and very little rainfall at relatively short distances to the northwest and southeast. In these frontal events extreme rainfall totals are almost never observed statewide, and instead, they most often occur as southwest-to-northeast bands of very heavy rainfall. In more recent years these organized bands of thunderstorms and very heavy rainfall are sometimes identified as mesoscale convective systems (MCSs).

In summer and autumn, despite seasonally lower levels of soil moisture and groundwater storage, tropical disturbances, ranging from poorly-defined easterly waves to intense hurricanes, also generate extreme rainfall events and flooding. Figures 2c and 2d show storm precipitation patterns for two tropical events. Figure 2c is for slow-moving Tropical Storm Frances in September 1998 that also interacted with a stationary front to the north, producing heavy rainfall over almost all sections of Louisiana. The locally-excessive rainfall generated by a poorly-defined tropical wave drifting westward over southern Louisiana in early August 1983 is shown in Figure 2d. Tropical depressions and storms sometimes generate great rain and flooding events because they occasionally drift over Louisiana for three or more days. Interaction between tropical and frontal systems usually occurs later in the

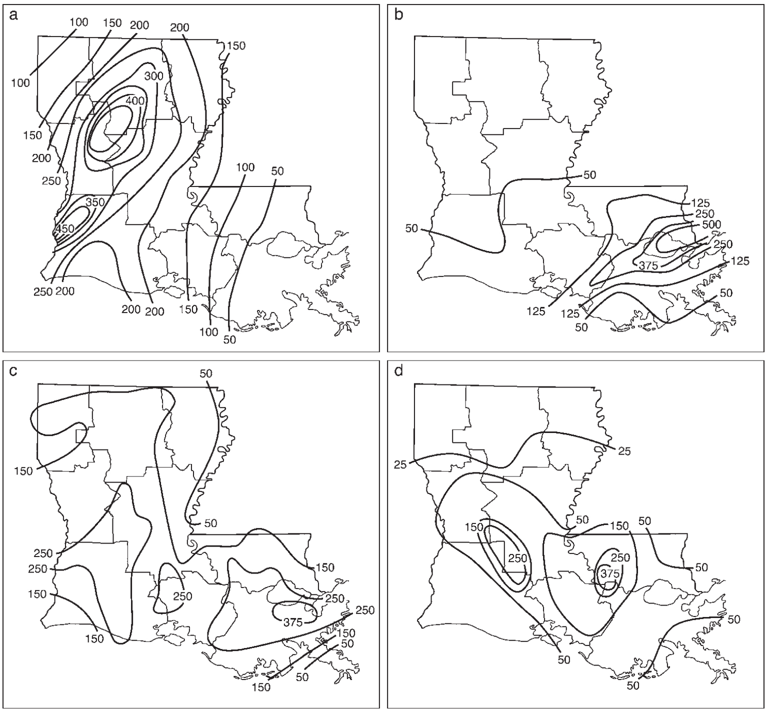

Figure 2. Statewide 3-day storm precipitation distributions*: a. The "Christmas Day" stationary-frontal event, Dec. 25-28, 1982. b. "Train-echo" frontal event around New Orleans, May 8-11, 1995. c. Interaction of tropical storm Frances and stationary front to north, September 10-14, 1998. d. Tropical depression, August 1-3, 1983. * *Rainfall totals at each station are for three consecutive days only; but storm circulations and rainfall are occasionally spread over more than three days.*

tropical cyclone season when tropical systems moving inland approach or merge with frontal systems to the north. More than one-third of the tropical events identified in this study exhibited some interaction with frontal systems as they approached or crossed Louisiana. It should be noted that summer local convective rainfalls, thunderstorms, and geographically-limited upper-air disturbances may produce localized extreme events and flash flooding, but these atmospheric disturbances rarely generate regional flooding.

Empirical studies of global precipitation suggest that mean annual global precipitation has increased over the last 100 years (Diaz et al. 1989). Karl and

Knight (1998) found that annual precipitation for the 48 contiguous states has increased about ten percent since 1910, and a regional analysis of the Southern states indicates an increase over the last 100 years (Vinnikov et al. 1990). A detailed analysis of the Louisiana monthly precipitation data set beginning with 1889 also suggests an increase of 10 percent or more (Figure 1), and it also emphasizes the great inter-annual variability and clusters of wetter and drier years.

A number of studies have documented particular heavy local and regional precipitation and flood events, the synoptic weather patterns generating precipitation, and pertinent antecedent conditions such as soil moisture, snowcover, and groundwater storage. However, very few studies have addressed the question of whether the magnitude and frequency of these events is changing. Karl et al. (1995) have published a study of daily precipitation data from the United States (187 stations from 1911-1994), the former Soviet Union (223 stations from 1967-1989), and China (197 stations 1952-1989); this study showed that the proportion of total precipitation due to storms greater than 51 mm has increased in the United States, especially during spring and summer. Karl and Knight (1998) followed up with a focus on the United States, concluding again that the frequency and intensity of extreme precipitation events increased over most of the country, but especially in the South.

When the magnitudes of 1- and 2-day rainfall events in Illinois for 1901-1940 and 1941-1980 were compared, the analysis indicated that magnitudes had increased by an average of about 10 percent (Huff and Changnon 1987). Kunkel et al. (1999) extended that analysis across the contiguous United States and Canada, and identified an increasing trend in extreme precipitation events, defined in terms of seven-day runs of stormy weather, over much of the United States and especially in southern Louisiana.

In another recent comprehensive study of the 48 contiguous states of the United States, Groisman et al. (2001) identified linear trends of increasing daily heavy precipitation events, defined as 100mm (4 inches) or more, across most of the eastern two-thirds of the country for 1900-1999. For the South, defined as Texas, Oklahoma, Kansas, Arkansas, Mississippi, and Louisiana, a linear increase of 36 percent occurred over the 100 years, providing more evidence of increasing frequencies of heavy precipitation events in Louisiana and surrounding states.

In the South there is additional evidence of a regional pattern of an increasing frequency of storm events through most of the twentieth century from eastern Texas northeastward to the southern Appalachians (Keim 1997). This analysis is based on 27 stations of the quality-controlled Historical Climatology Network/Daily (HCN/D) network with station records of 66 to 120 years, and a 75 mm precipitation threshold for 1 to 2 days. There is also some evidence for a decreasing trend adjacent to the Atlantic and Gulf Coasts from Cape Hatteras to the vicinity of Mobile, Alabama. In a related analysis, Keim (1996) had shown for eight of these same stations, 79 percent of the events were frontal, 13 percent were associated with disturbed tropical weather systems, and the remaining 8 percent were neither frontal nor tropical.

Partial duration series at more than 70 precipitation stations in and adjacent to Louisiana were developed to prepare updated maps of the magnitudes and frequencies of rainfall events (Faiers et al. 1994). When the new maps were compared to the "standard" maps in *Technical Paper No. 40* (Hershfield 1961), a swath of increased magnitudes extended from southwestern Louisiana northeastward into central Mississippi. A similar but more comprehensive analysis also showed that this swath of greater and more frequent storm events extended northeastward into eastern Tennessee (Faiers et al. 1997). Earlier studies of heavy rainfall events in metropolitan New Orleans from 1900 through 1991 identified rainfall events of 125 mm or more in two days at all of the official rain gauges in the city (Keim and Muller 1993). This study identified 119 events in 92 years, 68 percent of which were frontal, 24 percent were tropical, and 8 percent were neither frontal nor tropical, with a suggestion of increasing frequencies of events in recent decades. Collectively, these studies suggest that Louisiana, the South, and much of the nation may expect to experience increased frequencies and magnitudes of heavy rain events, and these events would presumably produce greater impacts than those currently experienced.

The National Climatic Data Center (NCDC) has continued to report on the alarming increasing frequency of billion-dollar weather and climate disasters in the United States since 1980 (NCDC, 2001). Several of the most recent events are associated with flooding rainstorms generated by both frontal and tropical events over Louisiana and the adjacent northern Gulf Coast states. This study focuses on the question of whether there is any evidence for increasing frequencies and magnitudes of extreme flooding rainstorm events in Louisiana from 1911 to 2000. In addition, synoptic situations and regionalization of these events in Louisiana are discussed along with an examination of their relationship to ENSO conditions.

Methodology

Official daily or 24-hour precipitation totals for cooperative stations and first-order weather stations have been published in *Climatological Data*, first by the Department of Agriculture, and later by various units of the Department of Commerce, including the Weather Bureau, the National Climate Center, and ultimately, by the NCDC. For identification of a station-event, a precipitation threshold of 150 mm or more within three consecutive observational days was established. It should be noted that other authors have selected smaller thresholds for other regions (Winkler 1988; Robinson and Henderson 1992; Kunkel et al. 1999), but with similar intents to define "events" appropriately for those regions. Since no standardized definition of heavy rainfall exists, we selected the greater 150mm threshold because in Louisiana typical infiltration rates, deeper soils above parent materials, soil-moisture storage capacities within rooting zones of vegetation, and mostly flat terrain with low relief, interact so that a minimum precipitation of 150 mm or more over one to three days is needed to generate local or regional flooding during all four seasons of the year. Although some rain-producing synoptic systems can persist for more than three days, most of the heaviest rains normally fall within 48 hours; therefore, identification of storm events in this study has been restricted to the maximum precipitation over three consecutive days, and not precipitation totals for entire storm events.

The focus in this study is on regional storms and flooding rather than local events, thereby requiring criteria for identification of regional storm events. In *Climatological Data* data are recorded once for every 24 hours, but the observational period can end early in the morning, usually at 0700 or 0800 local standard time (LST), noon, late afternoon, usually 1600 or 1700 hours, or at midnight. Because a single one-hour rainstorm at several nearby stations can be recorded on two different days, depending on the normal hour of observation at each station, identification of regional storm events from *Climatological Data* must take into account that the dates for nearby station-events may be offset by a day, earlier or later, depending on the observation hour of each cooperative station.

The Weather Bureau maintained a continuously-changing network of first-order and cooperative stations where both temperature and precipitation were recorded daily. Since the cooperative stations were mostly without financial remuneration, even the most dedicated observers rarely maintained daily observations for periods longer than 10 to 20 years. The continuity of the historic climatological network was complicated further in 1948 when the hydrologic network and some "daily precipitation only" stations were added to the cooperative network, and the total number of first-order and cooperative stations recording daily precipitation in Louisiana increased by nearly 70 stations. For the period between 1911 and 2000, the number of cooperative and first-order stations with daily observations of precipitation ranged from a minimum of 41 stations in 1921 to between 100 to 150 after 1965. Clearly, for study and interpretation of any trends in the frequencies and magnitudes of storm events, the changing number of official stations must be taken into account.

In this study, only the temperature - precipitation cooperative and first-order stations are considered. These stations have tended to remain at the same locations longer than the "precipitation only" stations, and their total number, ranging from a minimum of 41 in 1921 to a maximum of 96 in 1964 and 1965, has varied less through the decades than the precipitation only stations. Furthermore, this original "A" network of stations where both temperature and precipitation were observed was reorganized in the late 1940s to roughly approximate a grid pattern over the state, with each station representing an area of about 635 square miles (1,645 square kilometers) (personal communication from Malcolm Moreau, retired NWS cooperative program manager for Louisiana). Hence, the temperature - precipitation station network can be considered a reasonably representative sample of storm rainfall across Louisiana.

For identification of regional storm events, we assumed that river-basin or regional flooding would normally require station-event thresholds over an area of 15,500 square kilometers, about 12 percent of the area of Louisiana, and about 10 percent larger than the average area of the NWS/NCDC nine climate divisions in Louisiana. Because the largest drainage basin totally within Louisiana is the Calcasieu with a drainage area of about 5,200 square kilometers, the minimum criteria for regional storm events implies that these events would usually generate flooding on two or more of the major drainage basins in Louisiana. Assuming that the year-by-year distribution of temperature - precipitation stations provides a representative sample of storm rainfall over the state, a regional storm event is identified when at least 12 percent of the temperature - precipitation stations equal or exceed station-event thresholds. For example, for identification of regional storm events during years with only an average of 50 temperature - precipitation stations in Louisiana (1916-1925), six or more station-events would need to be identified. At the upper extreme, during years with an average of 92 temperature - precipitation stations (1956-1965), at least 11 station-events would be required for identification of a regional storm event. Table 1 summarizes the numbers of station-events needed for identification of regional storm events by 5-year intervals.

Each of the 109 identified regional storm events was then associated with daily surface weather maps published in the historical Northern Hemisphere series (1907-1938), the daily northern hemisphere sea-level and 500 millibar charts (1939-1970), the daily surface and 500 millibar maps issued by the Weather Bureau / NWS, and the three stormy weather types, Frontal Overrunning (FOR), Frontal Gulf Return (FGR), and Gulf Tropical Disturbance (GTD) of the synoptic weather classification identified by Muller (1977) for Louisiana. For the 20-year period 1961-1980 at New Orleans, 41 percent of the total precipitation occurred in the warm sectors of mid-latitude cyclones or along the "tropical" sides of quasi-stationary cold fronts, together classified as FGR weather (Muller and Willis (1983). During FOR weather when polar fronts were south of the city, an additional 30 percent of the total precipitation was recorded; hence, the two frontal weather types accounted for more than two-thirds of precipitation over 20 years at New Orleans. An additional 10 percent was recorded during GTD weather, with the three stormy weather types together accounting for 81 percent of the total precipitation.

Table 1. Minimum number of temperature and precipitation stations in Louisiana needed for identification of regional storm events, 150mm of precipitation or more in three days.

1911-1915	7
1916-1920	6
1921-1925	6
1926-1930	7
1931-1935	7
1936-1940	8
1941-1945	8
1946-1950	9
1951-1955	10
1956-1960	11
1961-1965	11
1966-1970	10
1971-1975	10
1976-1980	10
1981-1985	9
1986-1990	9
1991-1995	9
1996-2000	9

For the objectives of this study, each regional storm event was classified simply as either frontal or tropical, with the few events that began as tropical and later merged with frontal systems over Louisiana classified as tropical/frontal, but tabulated with the tropical systems because it is assumed that the tropical circulations generated more of the rainfall than the fronts. Frontal storm precipitation was not separated into FOR and FGR situations, and tropical events were not subdivided into intensity classes. Because of the widespread regional extent of the precipitation threshold and the elimination of localized extreme events, all events could be associated with frontal or tropical weather systems. Appendix A lists the 109 regional storm events and selected properties.

Results

Regional Storm Event Frequencies

The frequency of regional storm events in Louisiana by five-year intervals from 1911 to 2000 is shown in Figure 3. During the 90-year record there were 109 storm events, an average of 1.21 events per year (Table 2). Frontal storms account for 80 events (0.89 per year), and tropical circulations 29 events (0.32 per year). The domination of frontal events (almost 75 percent of all regional storm events) is somewhat contrary to the popular image of the origins of regional flooding events in Louisiana. Twelve of the 29 tropical systems merged with stationary or cold fronts inland over northern Louisiana and Arkansas, resulting in more widespread rainfall over northern sections than was generated by tropical systems alone. An extreme example in 1998 was tropical storm Frances that came onshore in Texas near Corpus Christi, but with extreme rainfalls eastward across Louisiana in association with a stationary front extending eastward from Texas to the Florida Panhandle.

The maximum five-year period in Figure 3 is 1991-1995 when 12 events were identified (11 frontal and only one tropical). Minimum five-year periods with only three storms each occurred during 1916-1920, 1921-1925, and 1965-1970; eight of these are frontal and only one tropical. Perusal of Figure 3 suggests little evidence of a trend of increasing frequencies over the 90 years, but instead, for clustering of events for a few years and somewhat longer runs of years with very few events.

A very different result emerges, however, when the frontal and tropical storm events in Figure 3 and Table 2 are evaluated separately, especially when the 90-year data set is divided into two unequal periods, 1911-1965 (55 years), and 1966-2000 (35 years). The record indicates an increase of frontal storms of about 45 percent across the two sub-periods. By contrast, tropical events show a decrease of about 60 percent across the two sub-periods. Tropical events amounted to more than one-third of the storms between 1911 and 1965, but only 13 percent after 1965. The table also indicates that between 1911-1965 and 1966-2000 the total number of events increased by about 10 percent. These results have important implications for disaster planning and mitigation, because such efforts typically have focused on tropical weather emergencies in coastal regions, and not on widespread regional flooding events inland.

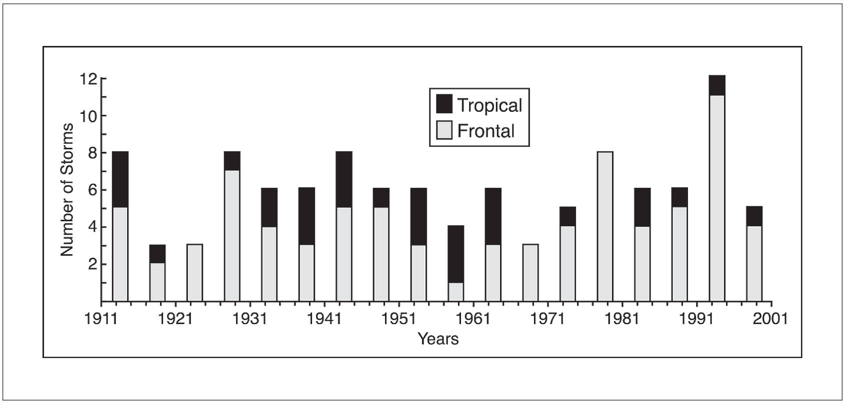

Figure 3. Frontal and tropical regional storm events in Louisiana by 5-year periods, 1911-2000.

Seasonality of Regional Storm Events

Table 3 shows the monthly and seasonal distributions of the 109 regional storm events between 1911 and 2000, with the first day of the event identifying the month and season. The year is divided into four three-month seasons; for example, winter consists of December, January, and February. Table 3a shows that approximately one-third of the events occurred during spring months, another third in the fall, with the remaining third divided equally between winter and summer. The comparative frequencies of frontal and tropical events changes dramatically by season, however. As expected, all of the regional storm events during winter were frontal. During spring two of the 37 events were the result of out-of-season tropical systems, both occurring in May. In summer, 13 of the 17 events were tropical in origin; the four frontal events included one each in June and July, and two in August. In fall, about two-thirds were frontal and one-third tropical, with all of the tropical events restricted to September and October (Table 3b).

Magnitudes of Regional Storm Events

The maximum three-day precipitation station totals during each regional storm event provide an interesting perspective on the events, but total storm precipitation was sometimes significantly greater than the three-day totals described here.

Table 2. Average number of frontal and tropical storm events per year 1911-1965 and 1966-2000.

	Frontal		Tropical		Total	
	(1)	(2)	(1)	(2)	(1)	(2)
1911-1965	41	0.75	23	0.42	64	1.16
1966-2000	39	1.11	6	0.17	45	1.29
Totals	80	0.89	29	0.32	109	1.21

(1) = number of events (2) = average number of events per year

Appendix A lists the maximum three-day rainfalls rounded to the nearest inch for all temperature-precipitation stations during each storm event, as well as the maximum storm total for more than three days. Table 4 shows the number of storm events with three-day storm totals greater than arbitrarily-selected thresholds. For example, 40 of the 80 frontal events included a station-event with more than 300 mm of precipitation. By contrast, 76 percent of the tropical events included a station-event of more than 300 mm. Clearly, the magnitudes of the wettest tropical events have exceeded those of the wettest frontal events. The greatest three-day tropical event of 850 mm (34 inches) occurred at Crowley, in the Southwest climate division (Figure 4) 75 kilometers east of Lake Charles, in August 1940, and the greatest frontal event of 600 mm (24 inches) occurred at Slidell, in the East-Central climate division, 40 kilometers northeast of New Orleans, in May 1995. For the 90-year period 15 tropical and ten frontal events with three-day maximum totals greater than or equal to 375 mm (15 inches) have occurred. The greater magnitudes of the very wettest tropical events may have contributed to the popular belief that tropical systems are far more frequent and important flood-producing disasters than midlatitude cyclones and associated fronts in Louisiana and probably elsewhere along the Gulf Coast.

To address the question of whether magnitudes are greater in more recent years, Table 5 shows the frequency of regional storm events with magnitudes greater than 375 mm (15 inches) for the 1911-1965 period, compared with the 1966-2000 period. Only five percent of the 41 frontal

Table 3. Annual Regimes of Monthly Frontal and Tropical Regional Storm Events.

a. Seasonality of Regional Storm Events, 1911-2000

	All Events		Frontal		Tropical	
	(1)	(2)	(1)	(2)	(1)	(2)
Winter	17	16%	17	21%	0	0%
Spring	37	34%	35	44%	2	7%
Summer	17	16%	4	5%	13	45%
Fall	38	35%	24	30%	14	48%
Total	109	100%	80	100%	29	100%

(1) = number of events (2) = percent by season

b. Annual Regimes of Monthly Regional Storm Events, 1911-2000

	D	J	F	M	A	M	J	J	A	S	O	N	Total
Frontal	6	5	6	9	15	11	1	1	2	3	7	14	80
Tropical	0	0	0	0	0	2	1	6	6	9	5	0	29
Total	6	5	6	9	15	13	2	7	8	12	12	14	109

regional storm events between 1911 and 1965 included maximum three-day totals of 375 mm (15 inches) or greater, while for the latter 35 years, by contrast, 20 percent of the 39 frontal events met this threshold. The table shows that the frequency of these frontally-induced excessive rain events increased four times when the first 55 years are compared with the most recent 35 years, suggesting that the magnitudes of the larger frontal events may have increased during recent decades. By contrast, not only have tropical events decreased in frequency during the last 35 years, but the frequencies of the largest events have also decreased.

Geographical Distribution of Regional Storm Events

The geographic pattern of events is analyzed by the nine climatic divisions of Louisiana (Figure 4). A regional storm event in a division is tabulated

Table 4. Regional Storm Events with Three-day Totals Exceeding Selected Magnitudes.

	Events			Percent		
	(1)	(2)	(3)	(1)	(2)	(3)
Frontal	80	40	10	100%	50%	12%
Tropical	29	22	15	100%	76%	52%
Total	109	62	25	100%	57%	23%

(1) = greater than or equal to 150mm (6 inches) (2) = greater than or equal to 300mm (12 inches) (3) = greater than or equal to 375mm (15 inches)

when at least one station-event was observed at a temperature - precipitation station located within the division. Figure 5 shows the number of regional storm (frontal and tropical) events by divisions and by season. For frontal events for all seasons together, the figure shows a southwest-to-northeast axis with 60 events in the Central division, 50 events in the Southwest division, and more than 40 each in the East-Central and South-Central divisions (assuming that the unequal sizes of the divisions do not change the geographical patterns significantly). Frontal events have been somewhat less frequent in the Southeast division, and much less frequent toward the north.

Tropical events occurred most frequently in the south near the Gulf (Figure 5). Combining the frontal and tropical events, the southwest-to-northeast axis is preserved. Each of the five climatic divisions toward the south and east experienced 55 or more events, with maxima of 79 in the Central division and 71 in the Southwest division. The total number of events decreases rapidly toward the northwest (Figure 5).

In the climate divisions toward the north and west, frontal events are most frequent in spring with a secondary peak in fall (Figure 5). In the remaining three divisions to the south and east, however, winter replaces fall as the second-most-frequent season for frontal events. In all climate divisions summer ranks last, but there is a gradient from almost no summer frontal events toward the north and west to two to four events in climate divisions toward the southeast. This geographical pattern is apparently associated with

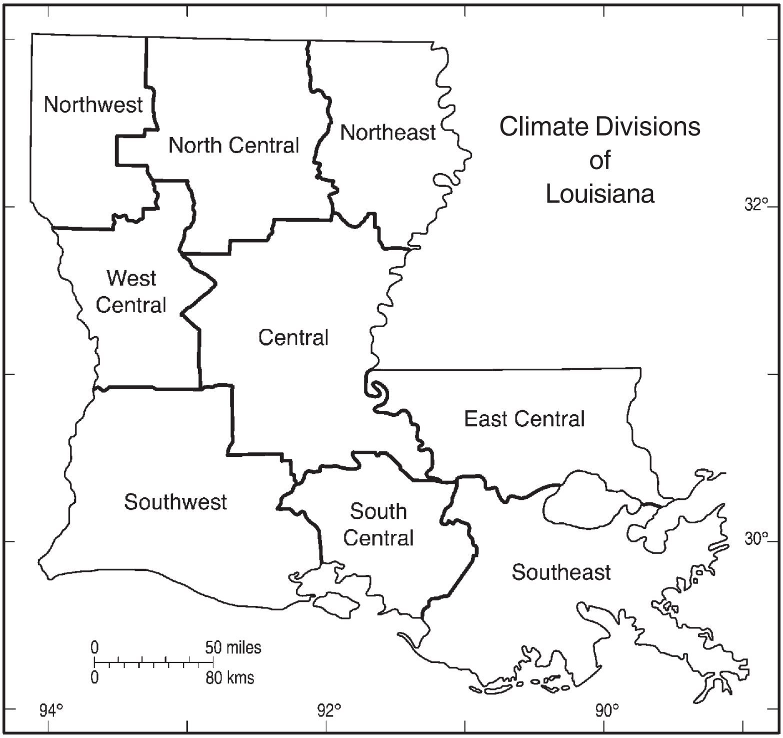

Figure 4. The nine climatic divisions of Louisiana, according to NWS/NCDC.

the not-so-common summer cold fronts that traverse over northern Louisiana, becoming stationary over central and southern sections, and then allowing for Gulf moisture ahead of the fronts to generate heavy showers and thunderstorms for 24 to 48 hours.

Tropical events are restricted to summer and fall, with the addition of a single spring event in each of the five divisions toward the southeast. Frequencies tend to be nearly equal in summer and fall except in the East-Central and Southeast divisions where there are more frequent events in fall rather than summer.

When the frontal and tropical events are combined, the seasonal regimes across Louisiana are a bit more complex (Figure 5). For the three westernmost climate divisions, fall ranks first, followed in turn by spring, summer, and

Table 5. Regional Storm Events with Station Events Greater Than or Equal to 375mm (15 inches).

	Frontal			Tropical		
	(1)	(2)	(3)	(1)	(2)	(3)
1911-1965	3	41	0.05	13	23	0.24
1966-2000	7	39	0.20	2	6	0.06

(1) = regional storm events with station equal to or greater than 375mm (15 inches) (2) = total number of regional storm events (3) events per year

winter. For the six central and eastern divisions, fall and spring rank first or second, with relatively small differences in frequencies between spring and fall. Winter ranks third or is tied for third and summer is last; the only exception is the Southeast division where summer ranks third and winter last.

ENSO Relationships to Regional Storm Events

In recent decades there is increasing evidence of teleconnections between widespread and persistent oceanic temperature anomalies and monthly and seasonal atmospheric temperature and precipitation departures from long-term normals over adjacent continents. One of the most noteworthy of the teleconnections is the "see-saw" of atmospheric pressure patterns across the equatorial Pacific Ocean during El Niño and La Niña events, represented by the Southern Oscillation Index (SOI) and associated regional "pools" of warmer and cooler oceanic surface waters.

Douglas and Englehart (1981) were among the first to identify an association of wetter winter seasons in Florida to El Niño events. A few years later Ropelewski and Halpert (1986) established more comprehensive relationships between ENSO periods and increased precipitation during much of fall and winter along the central Gulf Coast from Texas to Florida. In recent years the Climate Prediction Center (CPC) of NOAA has continued to develop analyses of monthly and seasonal precipitation anomalies by climatic divisions during moderate and strong El Niño and La Niña events (CPC 2002). During El Niño events, precipitation during November and

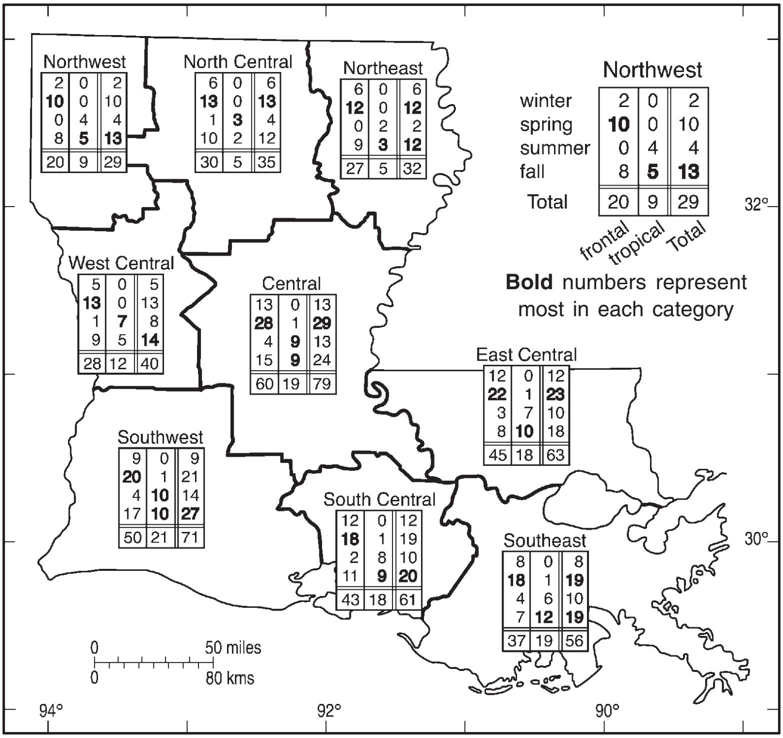

Figure 5. Seasonal frontal and tropical regional storm events in each climatic division.

December averages as much as 35 percent greater than normal over northwest Louisiana down to 10 percent greater than normal in the southeast (Livezey et al. 1997). For January through March, however, the increase over southeastern Louisiana averages about 30 percent but decreases to less than five percent over northwestern sections (Livezey et al. 1997).

La Niña events, in contrast, tend to be associated with below-normal precipitation, especially during fall and winter, except over northwestern Louisiana where precipitation is above normal during winter and spring on the average (personal communication, J.M. Grymes III, State Climatologist for Louisiana).

To investigate the association between ENSO seasons and regional storm events in Louisiana, the storm events were associated with the monthly SOI.

"Strong" anomalies were considered to occur when the SOI was less than minus 1 (El Niño) and greater than plus 1(La Niña), and "neutral" conditions were considered to occur during other times. Although the duration of the storms is only three days or less, the intent here is to determine whether the frequencies of regional storm events varies during extreme phases.

Table 6 shows the frequencies of frontal and tropical regional storm events by season and by the phase of the SOI. For strong ENSO events frontal regional storm events during spring and fall occurred nearly twice as frequently during El Niño than La Niña seasons (Table 6). During winter there was little difference. When the neutral months are classified as either El Niño (SOI less than 0 but greater than -1), or La Niña (SOI greater than 0 but less than +l), the frequencies of frontal regional storm events in winter and spring during El Niño months was nearly twice the frequency during La Niña months, but the difference during fall was very much smaller.

A number of investigators have determined that fewer tropical cyclones occur over the Atlantic, Caribbean, and Gulf waters during El Niño events (Elsner and Kara 1999). Table 6 also shows that the frequency of tropical regional storm events during La Niña months was two to three times greater than during El Niño months. Again, when the neutral months are classified as either El Niño or La Niña, frequencies during La Niña months in summer and fall are two to nearly three times greater than for El Niño months. Therefore, Table 6 suggests that frontal regional storm events occur more frequently during El Niño periods, and that tropical regional storm events occur more frequently during La Niña periods.

Discussion and Summary

Global change studies have focused mostly on temperature, but prediction of overall seasonal and annual precipitation, and the potential for changing frequencies and intensities of major rainstorms, is equally significant. Many GCM-based studies predict greater precipitation and more frequent extreme events under two-times carbon dioxide scenarios, but there remains large regional differences among the various model predictions. This empirical study focuses, instead, on identification of the historical record of extreme flooding rainstorm events in Louisiana over 90 years between 1911 and

Table 6. Seasonal Frontal and Tropical Regional Storm Events and Southern Oscillation Index (Expressed as Events per Month)

a. Frontal Events During Months with Strong SOI: (El Niño = less than or equal to -1; La Niña = greater than or equal to +1)

	(El Niño)	(Neutral)	(La Niña)
Winter	4/59 = .068	10/148 = .068	3/57 = .053
Spring	10/45 = .222	20/177 = .113	4/37 = .108
Summer	1/54 = .018	2/170 = .012	0/32 = .000
Fall	8/57 = .140	13/165 = .079	4/40 = .100

b. Frontal Events when SOI less than (El Niño) or greater than (La Niña) 0:

Winter	11/133 = .083	1/9 = .111	5/122 = .041
Spring	22/124 = .177	0/14 = .000	12/121 = .099
Summer	2/134 = .015	0/10 = .000	1/112 = .009
Fall	15/138 = .109	0/8 = .000	10/116 = .086

c. Tropical Events During Months with Strong SOI

Spring	0/45 = .000	2/177 = .011	0/37 = .000
Summer	2/54 = .037	5/170 = .029	3/32 = .094
Fall	1/57 = .018	9/165 = .055	2/40 = .050

d. Tropical Events when SOI less than (El Niño) or greater than (La Niña) 0:

Spring	1/124 = .008	0/14 = .000	1/121 = .008
Summer	3/134 = .022	0/10 = .000	7/112 = .062
Fall	4/138 = .029	0/8 = .000	8/116 = .069

2000, and interpretation of the varying frequencies and magnitudes of these events during this period of rising concentrations of atmospheric greenhouse-warming gases.

The best solution for a standardized identification of regional storm events through time was a threshold of 150 mm (6 inches) of rainfall in no more than three days over areas of Louisiana of at least 15,500 square kilometers, and then to treat the varying number of temperature-precipitation stations as a representative sample of the storm rainfall distributions. Assuming that the geographical pattern of temperature-precipitation stations has remained relatively representative of a statewide sample, identification of regional storm events should be consistent throughout the years of record, recognizing, nevertheless, that the sample density is less representative of all storm events during the earlier decades. This minimum area ensures that regional flooding did occur on at least one of the major drainage basins in Louisiana.

Interpretation of the frequencies of regional storm events by five-year intervals (Figure 3) indicates clusters of years with more or fewer events. No persistent upward trend is obvious. However, if the analysis had been terminated in 1995 the most frequent events during 1991-1995 might well have supported a cautious conclusion of an upward trend through the 85 years.

Contrary to conventional opinions about the synoptic generation of regional flooding events in Louisiana, only about 25 percent of the 109 storm events can be associated with tropical systems, ranging from poorly-defined easterly waves to great hurricanes, even when "hybrid" systems whereby tropical storms interact or merge with frontal weather are counted as tropical rather than frontal. The remaining 80 events are all identified with surface frontal weather situations normally in association with slow-moving upper-air troughs or closed lows over or to the west of Louisiana. Increasing frequencies of frontal events have more than offset decreasing frequencies of tropical events.

Two-thirds of the events occurred during spring and fall, with the remaining third divided almost equally between summer and winter. All of the winter events were frontal, and all except two events in spring were also frontal. In summer, 13 of 17 events were tropical in origin, and in fall, two-thirds were frontal and one-third tropical.

In terms of magnitudes 50 percent of the frontal events and 76 percent of the tropical events included at least one station event with rainfall greater than 300 mm. The greatest three-day rainfall totals for tropical and frontal events respectively are 850 mm (34 inches) at Crowley in August 1940, and 600 mm (24 inches) at Slidell in May 1995. The frequency of regional storm events with single-station magnitudes greater than 375 mm (15 inches) increased four times between 1911-1965 and 1966-2000, with the increase associated with frontal rather than tropical events.

An axis of most frequent frontal events extends from southwest

Louisiana near Lake Charles northeastward into southwest Mississippi north of Baton Rouge, with frequencies decreasing somewhat toward New Orleans in the southeast, and decreasing much more toward Shreveport in the northwest. For tropical events there is the expected gradient from coastal areas northward toward the border with Arkansas.

The frequencies of regional storm events associated with ENSO periods in terms of the monthly SOI index are summarized in Table 6. Frontal events during spring and fall occurred nearly two times more frequently during strong El Niño rather than La Niña seasons, as well as a smaller increase during winter. There was also an even greater frequency increase for tropical events during La Niña over El Niño periods.

Although this study was limited to compilation and interpretation of observed precipitation data only for Louisiana, our preliminary analyses of synoptic weather events and storm precipitation along the Gulf Coast suggest similar frequency and magnitude patterns from between Corpus Christi and Houston in Texas eastward across Mississippi, Alabama, and the Florida Panhandle. The few unrecognized regional storm events that "bridged" across the borders of Louisiana with Texas, Arkansas, and Mississippi, could also be identified and added as a supplemental listing to Appendix A.

Future research should also focus on whether the variability of regional storm events can also be associated with water temperature and atmospheric pressure patterns over the North Atlantic and Pacific basins, including the Pacific Decadal Oscillation (PDO) and the North Atlantic Oscillation (NAO).

References

Climate Prediction Center. 2002. Crosscutting Themes: El Niño/La Niña. http://www.cpc.ncep.noaa.gov/.

Diaz, H.F., R.S. Bradley, and J.K. Eischeid. 1989. Precipitation Fluctuations over Global Land Areas Since the Late 1800s. *Journal of Geophysical Research* 94, 1195-1210.

Douglas, A.V. and P.J. Englehart. 1981. On a Statistical Relationship Between Autumn Rainfall in the Central Equatorial Pacific and Subsequent Winter Precipitation in Florida. *Monthly Weather Review* 190, 2377-2382.

Elsner, J.B. and A.B. Kara. 1999. *Hurricanes of the North Atlantic*. New York:

Oxford University Press, 488pp.

Faiers, G.E., J.M. Grymes III, B.D. Keim, and R.A. Muller. 1994. A Reexamination of Extreme 24-hour Rainfall in Louisiana, USA. *Climate Research* 4, 25-31.

Faiers, G.E., B.D. Keim, and R.A. Muller. 1997. Rainfall Frequency/Magnitude Atlas for the South-Central United States. *Southern Regional Climate Center Technical Report* 97-1, 40pp.

Groisman, P.Y., R.W. Knight, and T.R. Karl. 2001. Heavy Precipitation and High Streamflow in the Contiguous United States: Trends in the Twentieth Century. *Bulletin of the American Meteorological Society* 82, 219-246.

Hershfield, D.M. 1961. Rainfall Frequency Atlas for the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years. *Technical Paper* No. 40, Washington DC, U.S. Weather Bureau.

Huff, F.A., and S.A. Changnon. 1987. Temporal Changes in Design Rainfall Frequencies in Illinois. *Climate Change* 10, 195-200.

Karl, T.R., R.W. Knight, and N. Plummer. 1995. Trends in High-Frequency Climate Variability in the Twentieth Century. *Nature* 377, 217-220.

Karl, T.R. and R.W. Knight. 1998. Secular Trends of Precipitation Amounts, Frequency, and Intensity in the United States. *Bulletin of the American Meteorological Society* 79, 231-241.

Keim, B.D. 1996. Spatial, Synoptic, and Seasonal Patterns of Heavy Rainfall in the Southeastern United States. *Physical Geography* 17, 313-328.

Keim B.D. 1997. Preliminary Analysis of the Temporal Patterns of Heavy Rainfall Across the Southeastern United States. *Professional Geographer* 49, 94-104.

Keim, B.D. and R.A. Muller. 1993. Frequency of Heavy Rainfall Events in New Orleans, Louisiana, 1900 to 1991. *Southeastern Geographer* 33, 159-171.

Kunkel, K.E., K. Andsager, and D.E. Easterling. 1999. Long-Term Trends in Extreme Precipitation Events over the Conterminous United States and Canada. *Journal of Climate* 12, 2515-2527.

Livezey, R.E., M. Masutani, A. Leetmaa, H. Rui, M. Ji, and A. Kumar. 1997. Teleconnective Response of the Pacific-North American Region Atmosphere to Large Central Equatorial Pacific SST Anomalies. *Journal of Climate* 10, 1787-1820.

Muller, R.A. 1977. A Synoptic Climatology for Environmental Baseline

Analysis: New Orleans. *Journal of Applied Meteorology* 16, 20-33.

Muller, R.A., J.M. Grymes III, and R.V. Rohli. 1995. Fort Worth, Dallas, and New Orleans Severe Weather Events, May 5-9, 1995. *Southern Regional Climate Center Misc. Report* 95-3, 24pp.

Muller, R.A. and J.E. Willis. 1983. New Orleans Weather 1961-1980: A Climatology by Means of Synoptic Weather Types. *Miscellaneous Publication* 83-1, School of Geoscience, Louisiana State University, 70pp.

National Climatic Data Center. 2001. Billion Dollar U.S. Weather Disasters 1980-2000. http://www.ncdc.noaa.gov/publications/billionsz.html

Robinson, P.J. and K.G. Henderson. 1992. Precipitation Events in the South-east United-States-of-America. *International Journal of Climatology* 12, 701-720.

Ropelewski, C.F. and M.S. Halpert. 1986. North American Precipitation and Temperature Patterns Associated with the El Niño/Southern Oscillation (ENSO). *Monthly Weather Review* 114, 2352-2362.

Vinnikov, K.Y., P.Y. Groisman, and K.M. Lugina. 1990. Empirical Data on Contemporary Global Climate Changes (Temperature and Precipitation). *Journal of Climate* 3, 662-667.

Winkler, J.A. 1988. Climatological Characteristics of Extreme Rainfalls in Minnesota. *Annals of the Association of American Geographers* 78, 57-73.

Acknowledgements

The authors wish to acknowledge Gregory Faiers and Barry Keim who helped to focus our attention on synoptic situations associated with extreme storm events across the South, and Jay Grymes and Malcolm Moreau who helped with the assembly of the historical precipitation data sets and interpretation of questionable data.

Appendix A

Regional Station Events: Louisiana 1911-2000

1	2			3	4	5	6	7	8	9								
7	1912	3-Dec	7-Dec	F	8	1	10	11	Donaldsonville					5	6		8	9
	1913	12-Sep	14-Sep	F	7	0	8	8	Collinston	1	2	3				7		9
	1913	25-Sep	29-Sep	F	23	6	14	17	Jeanerette	1	2		4	5		7	8	
	1914	25-Mar	28-Mar	F	8	3	13	13	Merryville		2	3		5	6	7	8	
	1914	12-Jul	15-Jul	TD	11	2	10	10	Cinclaire					5	6	7	8	
	1915	3-Jul	5-Jul	F	11	1	10	10	Reserve					5	6	7	8	9
	1915	16-Aug	20-Aug	TH	7	3	16	16	Merryville	1			4			7		
	1915	28-Sep	30-Sep	TH/F	8	2	14	14	Franklinton	1					6			9
6	1916	20-May	23-May	F	10	1	11	11	St Gabriel					5	6		8	9
	1916	16-Oct	19-Oct	TH/F	10	2	13	13	Burwood								8	9
	1918	19-Dec	21-Dec	F	7	0	7	7	Paradis						6			9
6	1923	27-Nov	29-Nov	F	7	1	10	10	Houma						6		8	9
	1925	15-Jan	18-Jan	F	6	1	10	10	Clinton					5	6	7		
	1925	3-Nov	5-Nov	F	9	1	10	10	Ruston	1	2		4	5				

1 = Number of station events needed to identify regional storm events by five-year intervals
2 = First and last dates with storm precipitation as reported in Climatological Data, Louisiana
3 = Synoptic identification: F=frontal; TD=tropical depression; TS=tropical storm; TH=hurricane
4 = Number of station events greater than or equal to 6 inches in 3 days
5 = Number of station events greater than or equal to 10 inches in 3 days
6 = Maximum precipitation in inches for 3 consecutive days
7 = Maximum precipitation in inches for total storm (more than 3 days)
8 = Station with maximum 3-day precipitation
9 = Climate divisions with at least one station event

1	2		3	4	5	6	7	8	9								
7	1926	20-Mar	22-Mar	F	8	1	10	10	St Francisville					5	6			9
	1926	23-Aug	26-Aug	TH/F	9	3	15	15	Donaldsonville					5	6		8	9
	1927	11-Feb	14-Feb	F	12	1	10	10	Clinton					5	6	7	8	9
	1927	14-Apr	16-Apr	F	15	7	18	18	Avoca Is - Pharr	1	2			5			8	9
	1928	1-Jun	5-Jun	F	20	7	14	15	Pearl River					5	6	7	8	9
	1929	28-Oct	31-Oct	F	11	0	9	13	Donaldsonville			3		5	6		8	9
	1929	11-Nov	14-Nov	F	15	4	12	13	Melville			3		5	6	7	8	
	1930	16-May	19-May	F	7	1	11	12	Lake Providence	1	2	3		5				
7	1931	13-Jul	17-Jul	TS	10	1	10	10	Burrwood						6			9
	1932	16-May	19-May	F	7	3	12	12	New Orleans						6			9
	1933	22-Jul	26-Jul	TS/F	17	13	21	21	Logansport	1	2		4	5		7		
	1934	20-Nov	22-Nov	F	8	0	8	8	Simmesport		2	3		5		7	8	
	1935	4-May	7-May	F	9	3	14	14	Melville	1		3		5	6	7	8	
	1935	18-May	20-May	F	9	3	14	14	Simmesport				4	5	6	7		
8	1937	1-Oct	4-Oct	TS	15	7	17	17	New Orleans					5	6			9
	1938	5-Apr	8-Apr	F	10	1	12	12	Cheneyville				4	5		7		
	1938	13-Aug	16-Aug	TH	8	5	15	15	Jennings					5		7		
	1940	6-Aug	10-Aug	TH	30	12	34	35	Crowley				4	5	6	7	8	9
	1940	10-Nov	11-Nov	F	9	1	11	11	Hackberry					5		7	8	
	1940	22-Nov	25-Nov	F	16	2	17	17	Logansport	1	2	3	4	5		7		

1	2			3	4	5	6	7	8	9								
8	1941	27-May	31-May	TD	9	3	12	14	Gueydan					5		7		
	1941	30-Oct	1-Nov	F	18	1	10	10	Ruston	1	2	3	4	5		7		
	1942	15-Feb	17-Feb	F	8	0	9	9	Belle Chase									9
	1942	15-Sep	17-Sep	TD	10	1	15	15	Franklin					5	6	7	8	9
	1943	16-Sep	20-Sep	TH/F	34	12	16	18	Franklin			3		5	6	7	8	9
	1943	6-Nov	7-Nov	F	8	1	11	11	Lake Arthur						6	7		9
	1944	24-Nov	26-Nov	F	8	1	12	12	Schriever							7		9
	1945	30-Mar	1-Apr	F	10	1	11	11	Winnfield		2		4			7		
9	1947	12-Mar	13-Mar	F	12	1	10	10	Atchafalaya					5	6	7	8	
	1947	7-Apr	12-Apr	F	9	1	10	10	Urania		2	3	4	5		7		
	1948	1-Mar	5-Mar	F	9	3	12	16	New Orleans					5	6		8	9
	1948	16-Nov	19-Nov	F	14	3	12	14	Leesville		2	3	4	5	6			9
	1949	26-Mar	29-Mar	F	10	1	10	10	Schriever		2	3		5			8	9
	1949	2-Oct	4-Oct	TH	9	0	8	8	Shreveport	1			4			7		

1 = Number of station events needed to identify regional storm events by five-year intervals
2 = First and last dates with storm precipitation as reported in Climatological Data, Louisiana
3 = Synoptic identification: F=frontal; TD=tropical depression; TS=tropical storm; TH=hurricane
4 = Number of station events greater than or equal to 6 inches in 3 days
5 = Number of station events greater than or equal to 10 inches in 3 days
6 = Maximum precipitation in inches for 3 consecutive days
7 = Maximum precipitation in inches for total storm (more than 3 days)
8 = Station with maximum 3-day precipitation
9 = Climate divisions with at least one station event

1	2			3	4	5	6	7	8	9								
10	1953	28-Apr	29-Apr	F	15	3	13	13	Camp Polk	1	2		4	5		7		
	1953	12-May	17-May	F	29	15	17	17	Melville	1	2	3	4	5	6	7		
	1954	27-Jul	29-Jul	TS	10	2	13	13	Franklin			3	4	5		7	8	9
	1955	4-Feb	6-Feb	F	16	1	12	12	Oberlin					5	6	7	8	
	1955	13-Jul	14-Jul	TD	10	0	7	7	Belah Fire Tower		2		4	5		7		
	1955	30-Jul	2-Aug	TS	11	2	21	21	Jennings	1			4			7	8	9
11	1957	16-Sep	18-Sep	TS/F	11	4	18	18	Quarantine						6			9
	1958	22-Aug	24-Aug	TD	14	0	9	9	Many		2		4	5		7		9
	1958	16-Sep	20-Sep	F	21	5	20	20	Vinton	1	2	3	4	5		7		
	1959	29-May	31-May	TS	11	3	13	13	Paradis						6		8	9
11	1961	16-Feb	22-Feb	F	13	1	11	17	Amite			3		5	6	7	8	9
	1961	10-Sep	13-Sep	TH	12	1	14	14	Many	1			4	5		7	8	9
	1961	12-Nov	16-Nov	F	14	3	13	13	Donaldsonville						6	7	8	9
	1961	9-Dec	12-Dec	F	11	1	12	14	Bogalusa		2	3			6		8	9
	1963	14-Sep	18-Sep	TH/F	11	1	18	18	Vinton						6	7	8	9
	1964	2-Oct	4-Oct	TH/F	19	5	18	18	Jeanerette					5	6		8	9
10	1966	9-Feb	12-Feb	F	30	4	12	13	Leesville		2	3	4	5	6		8	
	1967	13-Apr	15-Apr	F	24	5	16	16	Old River Lock				4	5	6	7		
	1970	11-Oct	13-Oct	F	10	1	11	11	Elizabeth			3		5		7		

1		2		3	4	5	6	7	8	9								
10	1971	2-Dec	6-Dec	F	19	3	13	13	Lake Arthur					5	6	7	8	
	1973	23-Mar	24-Mar	F	11	0	7	7	Bunkie					5	6	7		
	1973	15-Apr	18-Apr	F	34	5	13	13	Morgan City				4	5	6	7	8	9
	1973	2-Sep	7-Sep	TS/F	20	4	11	13	New Iberia					5		7	8	
	1974	12-Apr	15-Apr	F	11	2	11	11	Winnfield		2	3	4	5	6	7		9
10	1977	19-Apr	21-Apr	F	24	7	14	14	Grand Coteau					5	6	7	8	9
	1977	20-Aug	25-Aug	F	11	0	9	10	Woodworth					5	6	7		9
	1979	3-Feb	6-Feb	F	10	0	7	8	Reserve								8	9
	1979	20-Apr	23-Apr	F	20	5	12	12	Jeanerette					5	6	7	8	9
	1979	17-Sep	20-Sep	F	16	4	14	15	Oberlin			3	4	5		7		
	1980	26-Mar	29-Mar	F	12	0	9	10	Bunkie					5	6	7	8	9
	1980	11-Apr	13-Apr	F	22	3	12	12	Thibodaux	1			4	5	6		8	9
	1980	13-May	18-May	F	26	4	19	21	Lake Charles					5	6	7	8	9

1 = Number of station events needed to identify regional storm events by five-year intervals
2 = First and last dates with storm precipitation as reported in Climatological Data, Louisiana
3 = Synoptic identification: F=frontal; TD=tropical depression; TS=tropical storm; TH=hurricane
4 = Number of station events greater than or equal to 6 inches in 3 days
5 = Number of station events greater than or equal to 10 inches in 3 days
6 = Maximum precipitation in inches for 3 consecutive days
7 = Maximum precipitation in inches for total storm (more than 3 days)
8 = Station with maximum 3-day precipitation
9 = Climate divisions with at least one station event

1	2			3	4	5	6	7	8	9								
9	1982	25-Dec	28-Dec	F	39	16	15	18	Winnfield		2	3	4	5		7	8	
	1983	5-Apr	8-Apr	F	23	8	14	14	Amite			3		5	6		8	9
	1983	19-May	22-May	F	27	1	11	13	Olla	1	2	3	4	5		7	8	
	1983	1-Aug	3-Aug	TD	9	0	9	9	Crowley					5	6	7	8	
	1984	18-Oct	23-Oct	F	23	3	14	18	New Iberia	1	2		4	5	6	7	8	
	1985	26-Oct	31-Oct	TH/F	37	8	14	18	Galliano				4	5	6	7	8	9
9	1986	22-Nov	26-Nov	F	12	1	10	10	Bunkie	1			4	5	6	7		
	1987	15-Nov	16-Nov	F	22	9	18	18	Jena	1	2	3	4	5		7		
	1988	30-Mar	3-Apr	F	15	2	12	14	New Orl-Audubon					5	6		8	9
	1989	15-May	18-May	F	19	3	18	18	Coushatta	1	2		4	5	6	7		
	1989	26-Jun	1-Jul	TS	37	14	19	20	Winnfield	1	2	3	4	5	6	7	8	
	1990	17-Jan	20-Jan	F	11	0	9	11	Boyce	1	2	3		5				
9	1991	12-Apr	14-Apr	F	10	3	18	20	Minden	1	2	3	4					
	1991	24-Apr	28-Apr	F	13	5	14	14	Bastrop	1	2	3					8	9
	1991	8-May	10-May	F	14	3	14	14	Thibodaux					5	6	7	8	9
	1991	27-Oct	31-Oct	F	9	0	8	8	Elizabeth	1	2		4			7	8	
	1992	25-Aug	27-Aug	TH	14	2	11	11	Hammond						6		8	9
	1993	19-Jan	20-Jan	F	14	2	11	11	Lafayette					5	6	7	8	
	1993	13-Nov	15-Nov	F	9	1	10	10	New Roads					5		7	8	
	1994	15-Oct	18-Oct	F	19	1	10	12	Alexandria	1	2		4	5		7		
	1995	10-Apr	11-Apr	F	10	2	13	13	Bunkie					5	6	7		9
	1995	20-Apr	23-Apr	F	16	1	13	14	Natchitoches	1	2	3	4	5				
	1995	8-May	11-May	F	11	9	24	24	Slidell						6		8	9
	1995	16-Dec	18-Dec	F	14	1	10	10	Rockefeller WR				4	5	6	7	8	

1	2			3	4	5	6	7	8	9								
9	1996	24-Oct	26-Oct	F	27	2	11	13	Amite					5	6	7	8	
	1998	4-Jan	8-Jan	F	34	2	12	12	Galliano		2		4	5	6	7	8	9
	1998	10-Sep	14-Sep	TS/F	59	19	20	21	Terrytown	1	2	3	4	5	6	7	8	9
	1999	28-Jan	30-Jan	F	20	5	12	12	Natchitoches	1	2	3	4	5				
	2000	16-Nov	19-Nov	F	26	1	11	11	Morgan City						6		8	9
9	2001	5-Jun	11-Jun	TS	43	24	21	31	Thibodaux	1			4	5	6	7	8	9

1 = Number of station events needed to identify regional storm events by five-year intervals
2 = First and last dates with storm precipitation as reported in Climatological Data, Louisiana
3 = Synoptic identification: F=frontal; TD=tropical depression; TS=tropical storm; TH=hurricane
4 = Number of station events greater than or equal to 6 inches in 3 days
5 = Number of station events greater than or equal to 10 inches in 3 days
6 = Maximum precipitation in inches for 3 consecutive days
7 = Maximum precipitation in inches for total storm (more than 3 days)
8 = Station with maximum 3-day precipitation
9 = Climate divisions with at least one station event