NOAA Technical Memorandum
NWS ER-101

A SEVERE WEATHER CLIMATOLOGY FOR THE RALEIGH, NC, COUNTY WARNING AREA

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May 2008

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service

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1. INTRODUCTION

The National Weather Service's (NWS) primary responsibility is the protection of life and property. NWS Weather Forecast Offices (WFO) are tasked with issuing severe weather watches and warnings for their areas of responsibility or County Warning Area (CWA). Across central North Carolina, the combination of abundant low-level moisture from both the Atlantic Ocean and Gulf of Mexico along with frontal boundaries that interact with this moisture often set the stage for strong to severe thunderstorm development. As a result, WFO Raleigh's CWA experiences a wide variety of severe weather phenomena, including severe thunderstorms that produce tornadoes, large hail, and damaging wind gusts. A local severe weather climatology is essential for determining the severe weather risk. This study provides a severe weather climatology for central North Carolina including topographical and demographic influences, frequency, magnitude, season and time of day.

2. DATA AND METHODOLOGY

The data used for this study includes 4,150 documented severe weather reports (tornado, hail, and severe convective wind damage or gust reports) for all counties in the Raleigh CWA over the Period of Record (POR) of January 1, 1950 through December 31, 2005. The SVRPLOT program (Hart 1993; Available from [http://www.spc.noaa.gov/software/svrplot2/]), which utilizes a database of severe weather events collected by the National Severe Storms Forecast Center (NSSFC) and NOAA's National Climatic Data Center (NCDC) in Asheville, NC (National Climatic Data Center 2008) provided online access to documented severe weather events. In addition, the determination of tropical-related tornadoes was derived using the "Historical Hurricane Tracks" tool from the NOAA Coastal Services Center in Charleston, SC (NOAA Coastal Services Center 2008). All times are referenced to Local Standard Time (LST).

As defined by the NWS, a severe local storm is one that is sufficiently intense to threaten life and/or property, including thunderstorms with large hail, damaging wind, or tornadoes. More specifically, severe thunderstorms (National Weather Service 2005) are further defined as a storm that includes one or more of the following:

- A tornado
- Hail of 0.75 inches (in.) in diameter or larger
- Wind of at least 50 knots (58 mph) or wind which causes damage, including trees or power lines blown down

3. TOPOGRAPHY AND DEMOGRAPHICS OF THE COUNTY WARNING AREA

3.1 Topography

WFO Raleigh's CWA (Fig. 1) is comprised of 31 counties including 10 counties in the northern Piedmont, 5 counties in the central Piedmont, 4 counties in the southern Piedmont, 4 counties in the northern Coastal Plain, 3 counties in the central Coastal Plain and 5 counties in the southern Coastal Plain. Raleigh's CWA covers 16,459 square miles and includes the metropolitan areas of Raleigh, Durham and Chapel Hill (Triangle), Greensboro, Winston-Salem and High Point (Piedmont Triad), Rocky Mount-Wilson and Fayetteville.

Topography has an influence on the initiation and evolution of convective storms (Fig. 2). The two principal topographic regions that encompass Raleigh's CWA are the Piedmont and Coastal Plain. The geologic boundary between the Piedmont and Coastal Plain is called the "fall line" which stretches from near Roanoke Rapids in Halifax County southwest to near Smithfield in Johnston County to near Laurinburg in Scotland County. The Piedmont is characterized by rolling hills and soils that are mainly loam and clay loam. A notable increase in elevation occurs across the Piedmont region in the RAH CWA. Elevations generally range around 250 feet near the "fall line" and increase to around 1100 feet in the extreme northwest part of the CWA. The Coastal Plain is characterized by flat terrain with a variety of soil types that are sedimentary in nature. The elevation generally ranges from 50 feet over the extreme eastern part of the CWA to approximately around 250 feet over the western portion of the Coastal Plain near the "fall line." Within the Coastal Plain is a smaller topographic area called the "Sandhills," where sand is the primary soil type.

On sunny days, as the sun heats the earth's surface, the air mass over the Sandhills often heats up more quickly than the air over the surrounding area. The differences in these soil types can create a differential heating boundary that enhances thunderstorm development (North Carolina State Climate Office 2004). While this phenomenon alone does not determine the severity of thunderstorms, it does have an impact in defining the areas that are more or less likely to experience convective storms.

The Sandhills and Coastal Plain are in the southeastern most portion of the RAH CWA and these areas typically experience the greatest instability relative to other parts of the RAH CWA. In addition, the proximity of the Atlantic Ocean and the Piedmont Trough (Koch and Ray 1997) is a preferred location of thermal moisture boundaries that can provide enhanced convergence for thunderstorm development.

During specific synoptic patterns, a dome of cold, stable air can become established along the eastern slopes of the Appalachian Mountains. This situation is called Cold Air Damming (CAD) and it can have a significant impact on the weather between the crest of the Appalachian Mountains and the coastal plain. CAD can at times inhibit surface-based convection across the Piedmont, especially the Northwest Piedmont, which can curtail the potential for severe weather. CAD can also enhance the possibility of severe weather since the difference in temperature between the damming region and the coast can exceed 20°C during strong CAD events (Bell and Bosart 1988) and result in the development of a significant surface boundary.

3.2 Demographics

One statistical bias that appears in the data and that should be noted is the population density. Population statistics were obtained from the 2005 Census. The population of WFO Raleigh's CWA is approximately 3.95 million people (North Carolina State Demographics 2005). WFO Raleigh's CWA is home to 7 of the 10 largest municipalities in the state. Although the CWA contains these large population centers, the CWA has a low population density. Outside of these population centers, the CWA is mainly rural farmland or heavily forested, and contains sparse population. This uneven distribution of people across the CWA (Fig. 3) can lead to skewing of observed severe weather events toward the more heavily populated locations (e.g., Wake County).

4. TORNADO CLIMATOLOGY

There have been 284 tornadoes reported across the WFO Raleigh CWA from 1950 to 2005. All 31 counties in the WFO Raleigh CWA have had at least 2 confirmed tornadoes during that time frame. On average, five tornadoes occur within the WFO Raleigh CWA each year.

4.1 Monthly Distribution

The monthly distribution of tornadoes (Fig. 4) shows the Raleigh CWA has experienced tornadoes at any time of the year. However, tornadoes are most likely to occur during the spring (March through May) when 43% or 122 of the total 284 tornadoes have occurred (Fig. 5). The most active month is May when 59 of the total 284 tornadoes or 21% have been reported. Spring is the peak tornado season in the Raleigh CWA because instability is increasing while the area is still vulnerable to strong synoptic scale systems with jet stream influence. The number of tornadoes decreases dramatically during the summer months (June through August), as the jet stream migrates north. There is a pronounced, secondary peak of tornadoes in the fall (September through November) (Fig 4). The secondary peak tornado season is explained by land-falling tropical systems or their remnants and the southward migration of the jet stream from the U.S.-Canadian border.

4.2 Hourly Distribution

Diurnal trends indicate an increase in tornadoes after the noon hour (Fig. 6). Over half of all tornadoes (53%) occur between the afternoon and evening hours of 3 pm to 8 pm (LST). Tornado activity peaks in the late afternoon between 5 pm and 7 pm LST. Seventy-eight tornadoes (27% of the total) occurred during the 5 pm to 7 pm LST time frame. The data shows a gradual decrease in the occurrence of tornadoes during the evening hours, and that tornadoes occur infrequently during the late night through the mid-morning. Atmospheric instability is a key ingredient in the generation of tornadic thunderstorms and is typically maximized during the mid- to late-afternoon hours.

4.3 Intensity

The Fujita Scale (F-scale) (Table 1) attempts to classify tornado intensity based on the extent of the associated wind damage (Fujita, 1981). The F-scale was updated in February, 2007 and renamed the Enhanced Fujita Scale (EF-scale). The EF-scale value can simply be substituted for the F-scale value since only the wind speeds that are associated with a particular category (either EF or F) have been updated. Since the F-scale value, not the associated wind speed, is included in the historic tornado database, the previous data is still valid.

Of the 284 tornadoes that have been confirmed in Raleigh's CWA, over three-quarters (218 of the 284) were classified as F0 or F1 tornadoes (Fig. 7). Sixty-one tornadoes (22%) were rated strong (F2 or F3) and only 5 (2%) were rated as F4 tornadoes. Of the five F4 tornadoes, three occurred during the March 28, 1984 Carolina Tornado Outbreak. There has never been a documented F5 tornado in the RAH CWA.

A majority of the strong to violent tornadoes in the RAH CWA touch down in the Sandhills and Coastal Plain regions (Fig. 8). The Sandhills and Coastal Plain are in the southeastern most portion of the RAH CWA and these areas typically experience the greatest instability relative to other parts of the Raleigh CWA. In addition, the proximity of the Atlantic Ocean and the Piedmont Trough (Koch and Ray 1997) is a preferred location of thermal moisture boundaries that can provide enhanced shear needed for tornadogenesis.

4.4 Association with Tropical Systems

During hurricane season, tropical cyclones or their remnants can track through the Southeast and Mid-Atlantic region. Tornadoes frequently occur in the northeast quadrant of northward advancing tropical systems or their remnants. Of the 284 tornadoes that were reported in Raleigh's CWA, 48 tornadoes (17%) were associated with tropical systems or their remnants. Of these, almost all (96%) were classified as weak (F0-F1) tornadoes. Additionally, tropical cyclones that produce tornadoes in the WFO Raleigh CWA can make landfall anywhere along the Gulf Coast states, the Southeast, or directly on the North Carolina coast (Fig. 9).

A record number of tornadoes were reported in 2004, and this was in large part due to the active hurricane season (National Oceanic and Atmospheric Administration 2004). Tropical Storm Bonnie and five land-falling hurricanes (Charley, Frances, Gaston, Ivan and Jeanne) affected the Mid-Atlantic and Southeast states during August and September. In fact, the active tropical season of 2004 accounted for 10% of all of the tornadoes reported within the WFO Raleigh CWA from 1950 to 2005.

5. HAIL CLIMATOLOGY

5.1 Monthly Distribution

The monthly distribution of severe hail events (hail diameter equal to or exceeding 0.75 in.) indicates a strong inclination toward the spring season (Fig. 10). There is a sharp increase in the number of hail reports from March (150) to the peak month of May (417). The large majority (78%) of the hail events occur during the months of April through July. There is a significant decrease in thunderstorms that produce hail during the transition from summer to fall (103 events in August and 29 events in September). The four month period between November and February is very inactive (15 events). The peak occurrence of hail in the spring is largely due to the existence of warm boundary layer temperatures along with relatively low cool mid levels of the atmosphere.

5.2 Hourly Distribution

Consistent with the hourly tornado distribution, there is a dramatic increase in severe hail after the noon hour (Fig. 11). Nearly two-thirds of the severe hail events, 955 of the 1,453 total occurrences (66%), were during the hours of 3 pm to 8 pm (LST). A steady decline of severe hail occurrences was indicated during the late afternoon and evening hours. Severe hail was rare during the overnight and morning hours. The peak of severe hail reports during the early-to-mid afternoon hours can largely be attributed to the peak of instability during this period. Strong updrafts are important to hail formation and they largely depend on the degree of atmospheric instability.

5.3 Magnitude (Hail Size)

More than half of the severe hail events (737 events or 51% of the total) in the Raleigh CWA were less than one-inch in diameter (Fig. 12). Occurrences of hailstones ranging from one to two inches accounted for 45% of the reports. Severe hail in excess of 2 inches in diameter accounted for only a small percentage of all severe hail events (~4%). The largest hailstone ever reported in the Raleigh CWA during the period was 4.5 inches in diameter. This softball-sized hailstone fell in Montgomery County on May 27, 1998 at 625 pm (LST) with a non-tornadic supercell thunderstorm.

6. SEVERE THUNDERSTORM DAMAGING WIND CLIMATOLOGY

6.1 Monthly Distribution

Strong, damaging winds resulting from severe thunderstorms are the most frequently observed severe weather event across the Raleigh CWA. The minimum wind speed for a thunderstorm to be considered severe is 58 mph (50 kts.). Over the 55-year period between 1950 and 2005, there were 2413 severe convective wind events (58% of all severe events). The frequency of severe convective wind events shows a steady increase during the spring and peaks in June (Fig. 13). Nearly 23% of the severe convective wind events (545) occurred in June. During the late spring and early summer months of May, June and July, 1,451 events or 61% of the total occurred.

6.2 Hourly Distribution

Severe convective wind damage is most common during the mid-afternoon through evening hours (Fig. 14). Although severe convective wind events peak between 4 pm and 7 pm (LST), they do not decline significantly until after 9 pm (LST), when the contribution of daytime heating on atmospheric instability is lost. The majority (74% or 1,597) of all severe convective wind events occurred during the 2 pm to 9 pm (LST) time frame. Severe thunderstorm damaging wind events drop off significantly between 3 am and 8 am (LST). However, severe convective wind events may occur during any hour of the day (Fig. 13).

7. CONCLUSIONS

The severe weather climatology for the WFO Raleigh CWA provides a historical resource for forecasters to use to increase their situational awareness and to better anticipate severe weather threats. Understanding the type and frequency of seasonal and diurnal severe weather events, as well as the local topography and demographics will greatly enhance severe weather warning decisions. In summary:

• Of all severe thunderstorm events in the Raleigh CWA during the 55 year study period, 58% of the events resulted from severe convective winds, 34% from hail, and less than 7% from tornadoes.

• While tornadoes can and do develop at any time of the year, over half of the tornadoes (55%) occurred between March and June, peaking during the month of May.

• A secondary peak in tornado events occurred in September, and is likely due to the impact of tropical cyclones or their remnants along with a southward adjustment of the polar jet.

• Nearly 17% of all tornadoes reported in the WFO Raleigh CWA from 1950 to 2005 were associated with a tropical cyclone or its remnants.

• More than half (53%) of all tornadoes occurred between the afternoon hours of 3 pm and 8 pm (LST) with the activity peaking between 5 pm and 7 pm (LST).

• Over three quarters (77%) of all tornado events were classified as weak tornadoes (F0 or F1). Only 5 tornadoes (2% of the total) have been reported at an F4 intensity. There were no reports of tornadoes rated as F5 intensity over the POR.

• Nearly 78% of severe hail events occurred between April and July, with 66% of events observed between the hours of 3 pm and 8 pm (LST).

• Just over half (51%) of all severe hail reports were less than one inch in diameter.

• Over half (61%) of all severe convective wind events occurred in the late spring and early summer months of May, June and July and peaked in June.

• A large majority (74%) of all severe convective wind events occurred during the 2 pm to 9 pm (LST) time frame, peaking between 4 pm and 7 pm (LST).

• Counties with a higher population density are more likely to report events while counties with lower population densities are more likely to have events that are unreported. This results in an inherent bias of severe weather events toward counties with a larger population density.

• The population in Raleigh's CWA has grown tremendously during the past 55 years. The reporting of severe weather events has increased as a result during this period.

ACKNOWLEDGEMENTS

The author would like to thank Jeff Orrock, Warning Coordinator Meteorologist, and Scott Sharp, Lead Forecaster, at WFO Raleigh for assistance in validating data. The author would particularly like to thank Jonathan Blaes, Science Operations Office at WFO Raleigh and Kermit Keeter, former Science Operations Officer at WFO Raleigh, for their careful review of this paper and offering many helpful suggestions for improvement.

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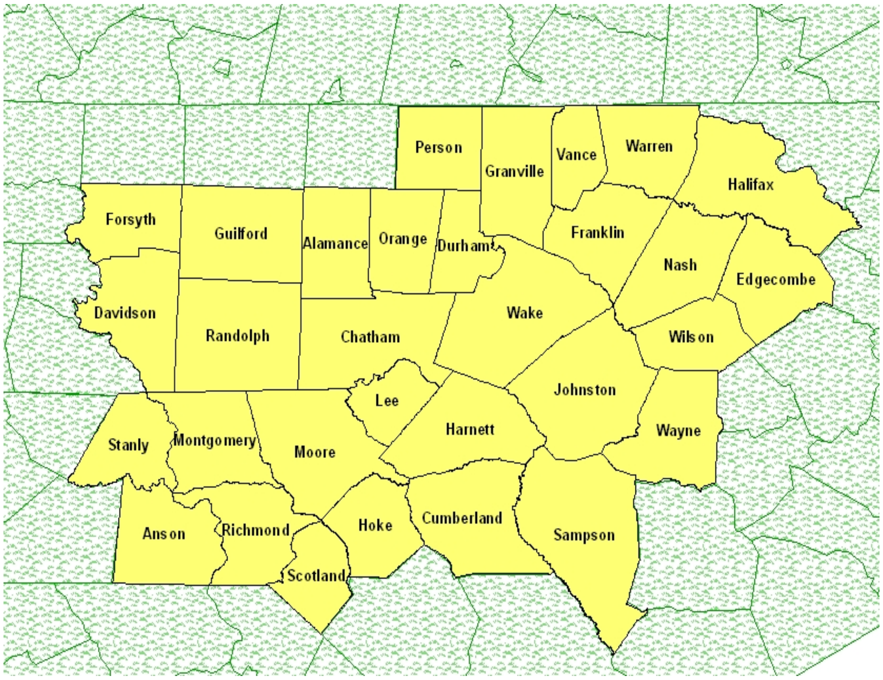

Figure 1. WFO Raleigh, NC (RAH) County Warning Area (CWA).

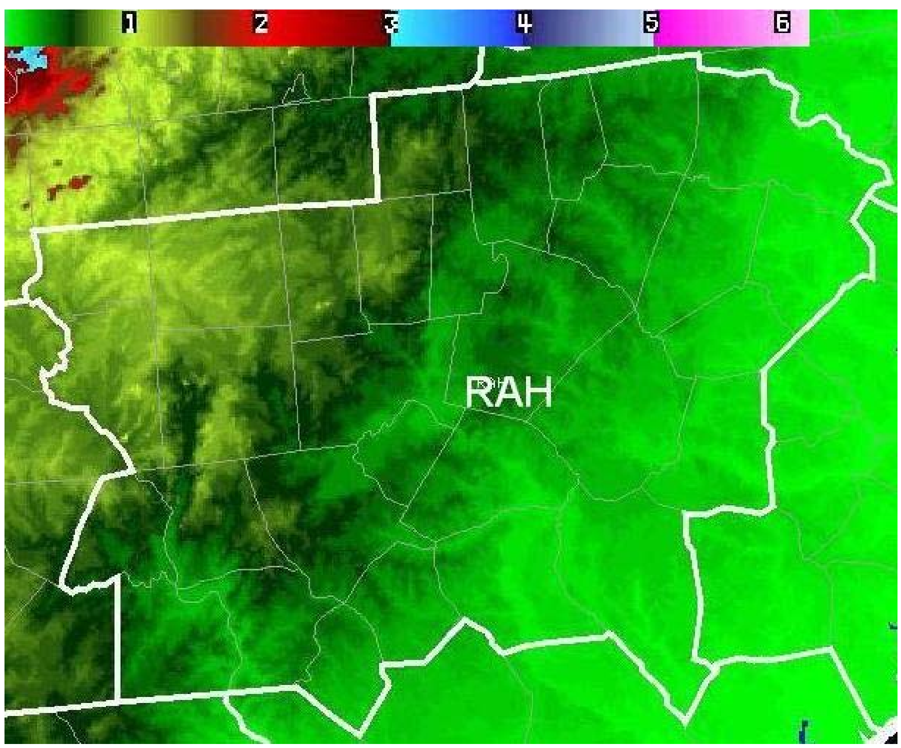

Figure 2. Topographic map of the WFO RAH CWA. Elevation shown in thousands of feet.

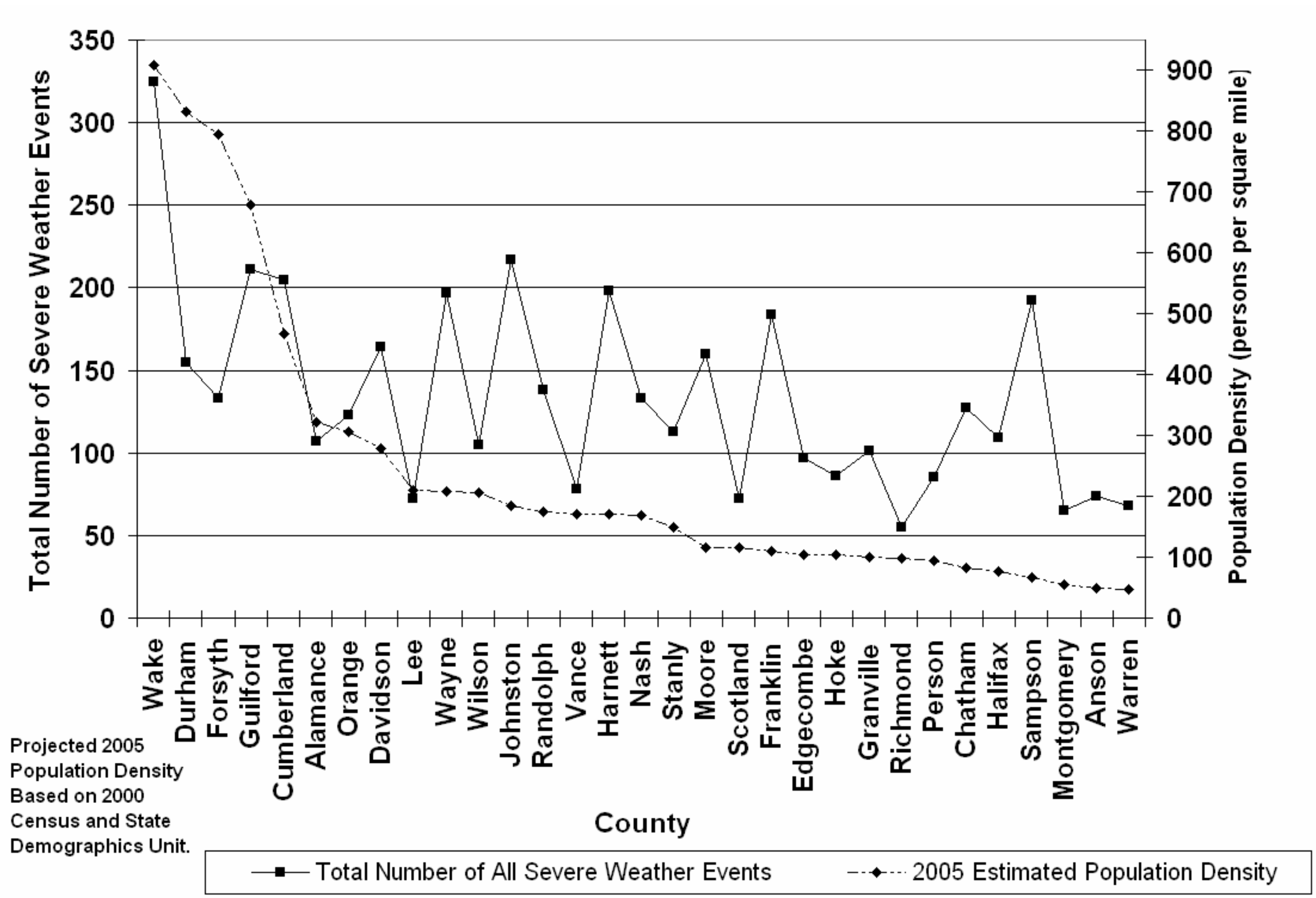

Figure 3. Comparison of projected county population density (dashed) to the number of severe events reported from 1950-2005 (solid) for the WFO Raleigh CWA.

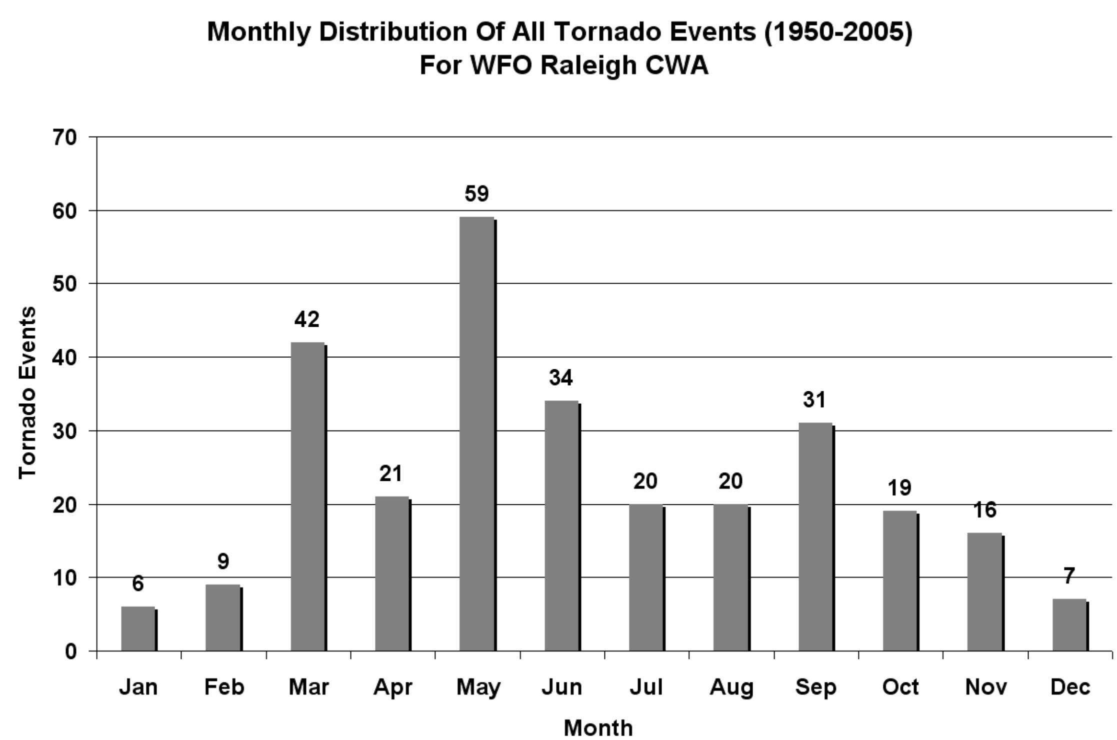

Figure 4. The monthly distribution of tornadoes (1950-2005) in the WFO Raleigh CWA.

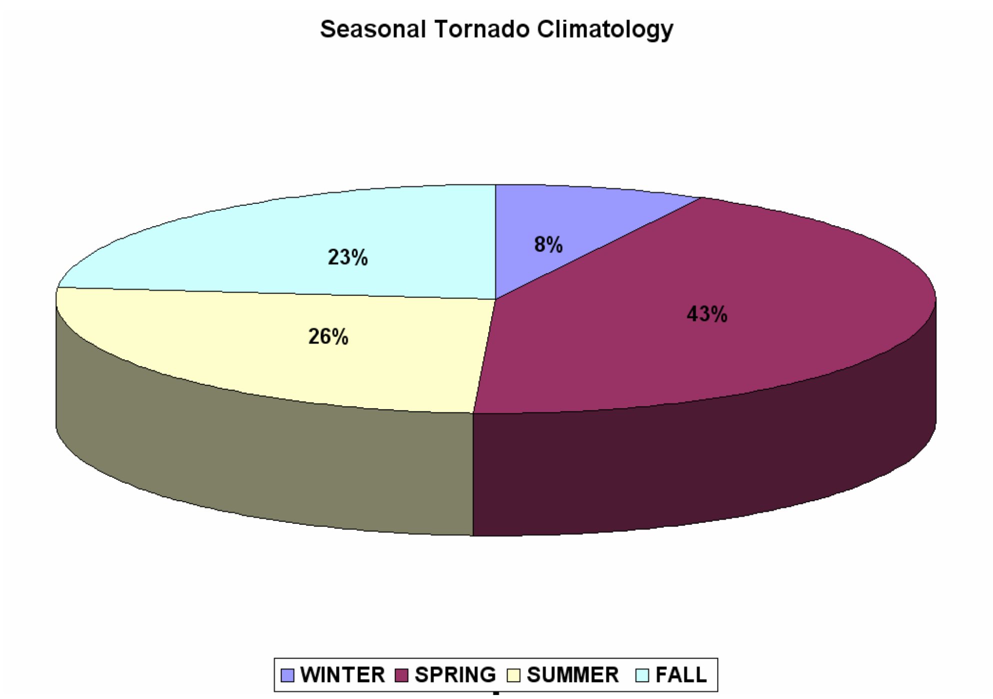

Figure 5. Seasonal tornado climatology (1950 to 2005) in the WFO Raleigh CWA.

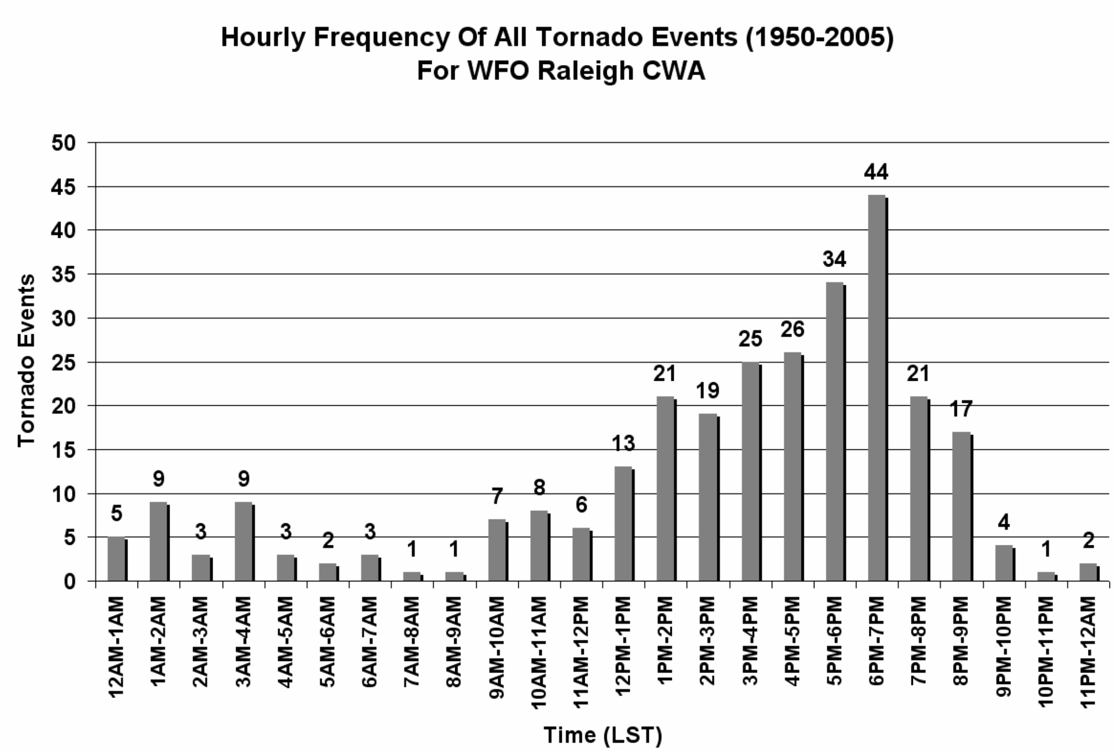

Figure 6. The hourly distribution of tornadoes (1950-2005) in the WFO Raleigh CWA.

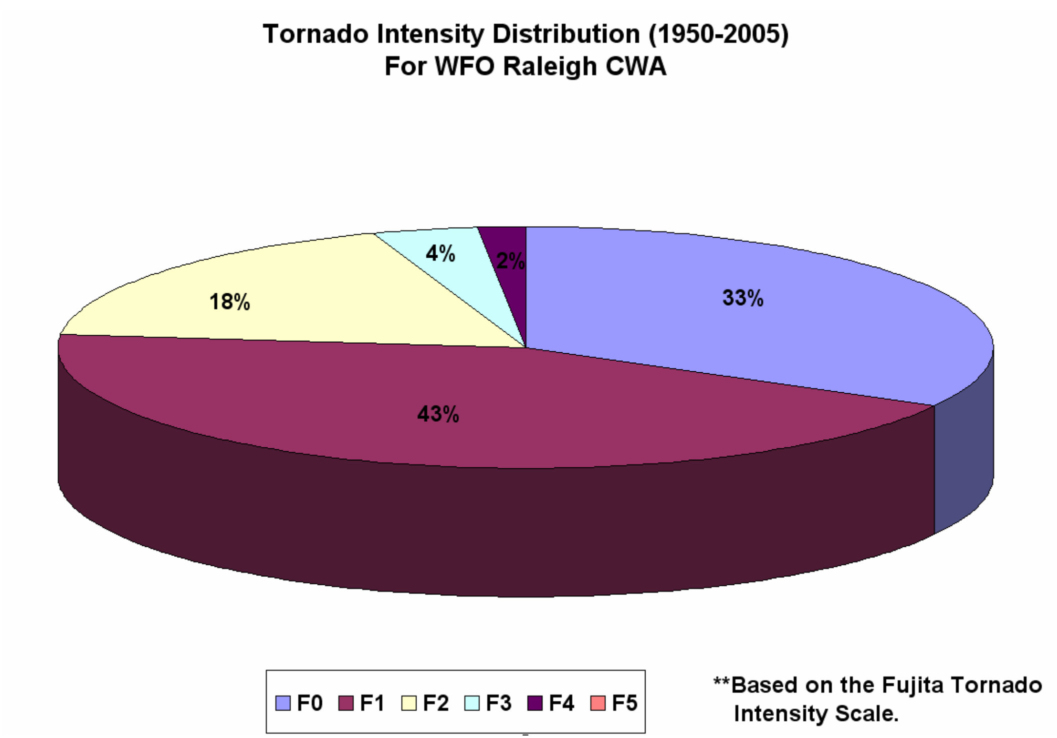

Figure 7. The tornado intensity distribution by Fujita Scale (1950-2005) in the WFO Raleigh CWA.

FUJITA SCALE			DERIVED EF SCALE		OPERATIONAL EF SCALE	
F Number	Fastest 1/4-mile (mph)	3 Second Gust (mph)	EF Number	3 Second Gust (mph)	**EF Number**	**3 Second Gust (mph)**
0	40-72	45-78	0	65-85	**0**	**65-85**
1	73-112	79-117	1	86-109	**1**	**86-110**
2	113-157	118-161	2	110-137	**2**	**111-135**
3	158-207	162-209	3	138-167	**3**	**136-165**
4	208-260	210-261	4	168-199	**4**	**166-200**
5	261-318	262-317	5	200-234	**5**	**Over 200**

Table 1. A comparison of the Fujita Scale and the updated Enhanced Fujita Scale. The Fujita scale was used to assess the intensity of tornadoes prior to February 1, 2007 (Table obtained from the NOAA, Storm Prediction Center on-line at http://spc.noaa.gov/faq/tornado/ef-scale.html).

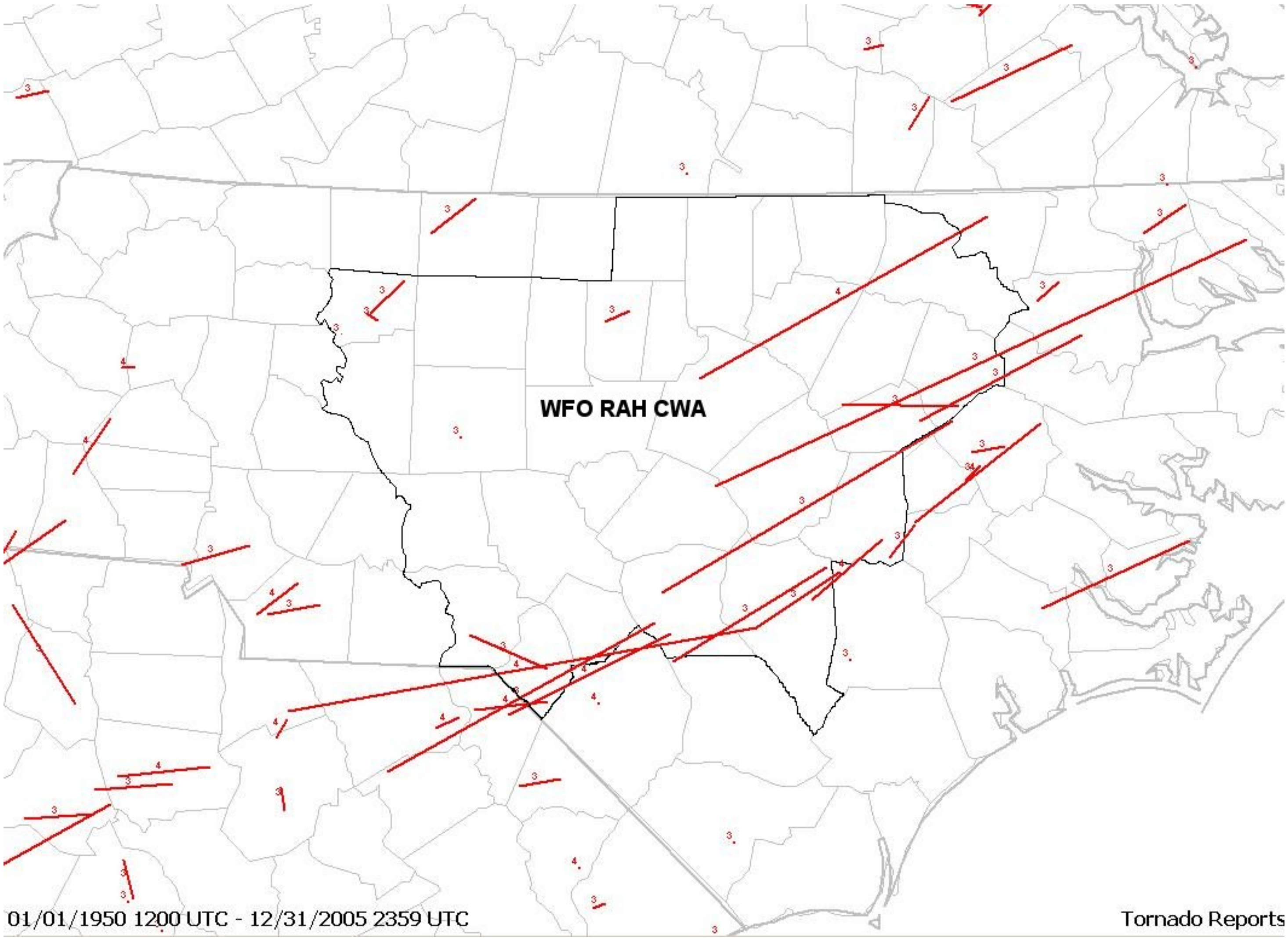

Figure 8. Historical F3-F5 tornado tracks (1950-2005) in the WFO Raleigh CWA. Graphic produced via SVRPLOT software from the Storm Prediction Center, Norman, OK. The SVRPLOT software is available on-line at http://www.spc.noaa.gov/software/svrplot/index.html

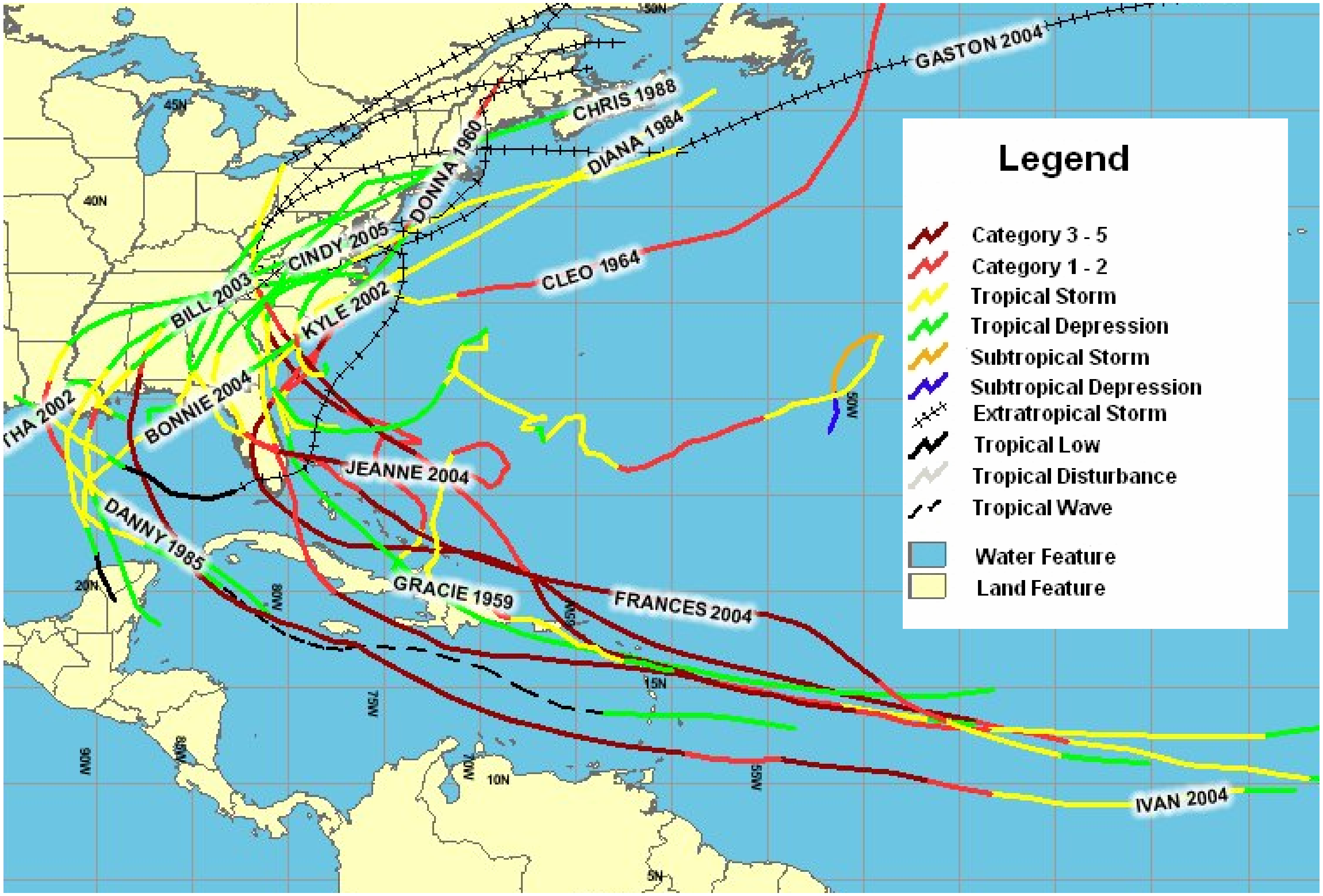

Figure 9. Historical tropical cyclone tracks that produced tornadoes within the WFO Raleigh CWA from 1950-2005. Data courtesy of the NOAA Coastal Services Center [Data is available on-line at http://maps.csc.noaa.gov/hurricanes].

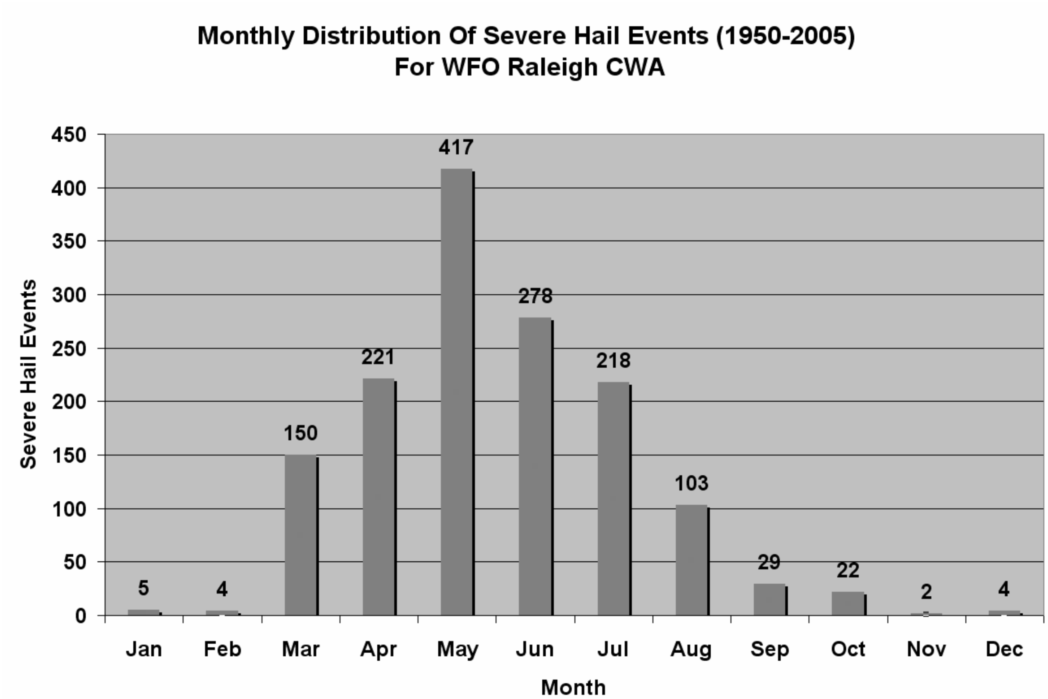

Figure 10. The monthly distribution of severe hail events (1950-2005) in the WFO Raleigh CWA**.**

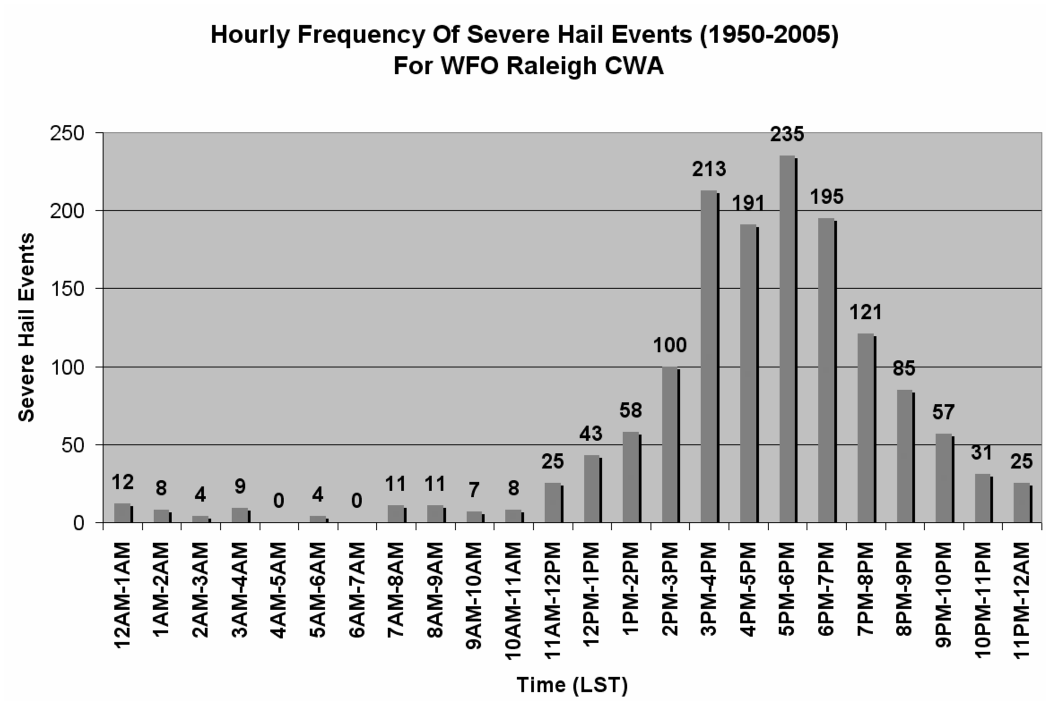

Figure 11. The hourly distribution of severe hail events (1950-2005) in the WFO Raleigh CWA.

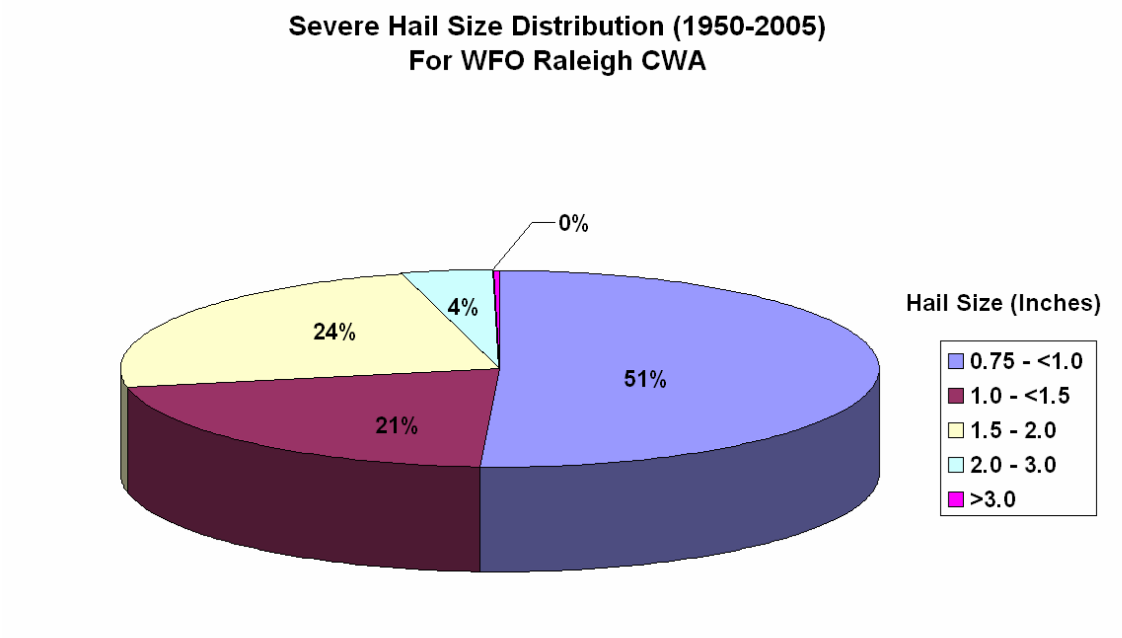

Figure 12. The distribution of hail size for severe hail events (1950-2005) in the WFO Raleigh CWA.

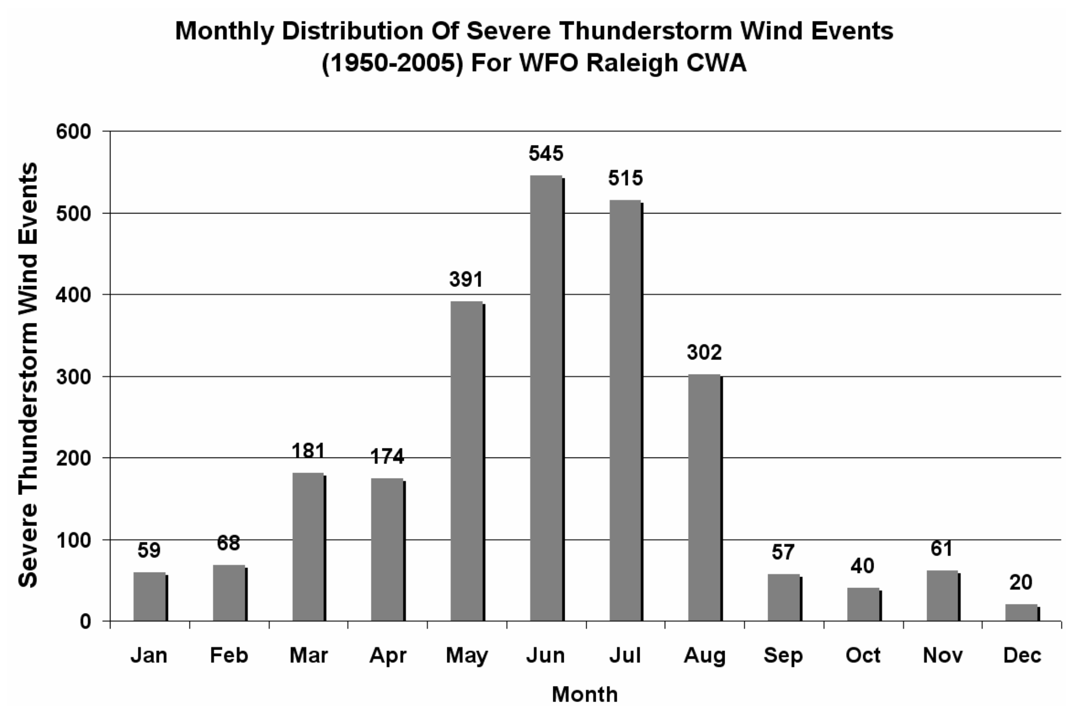

Figure 13. The monthly distribution of severe convective wind events (1950-2005) in the WFO Raleigh CWA.

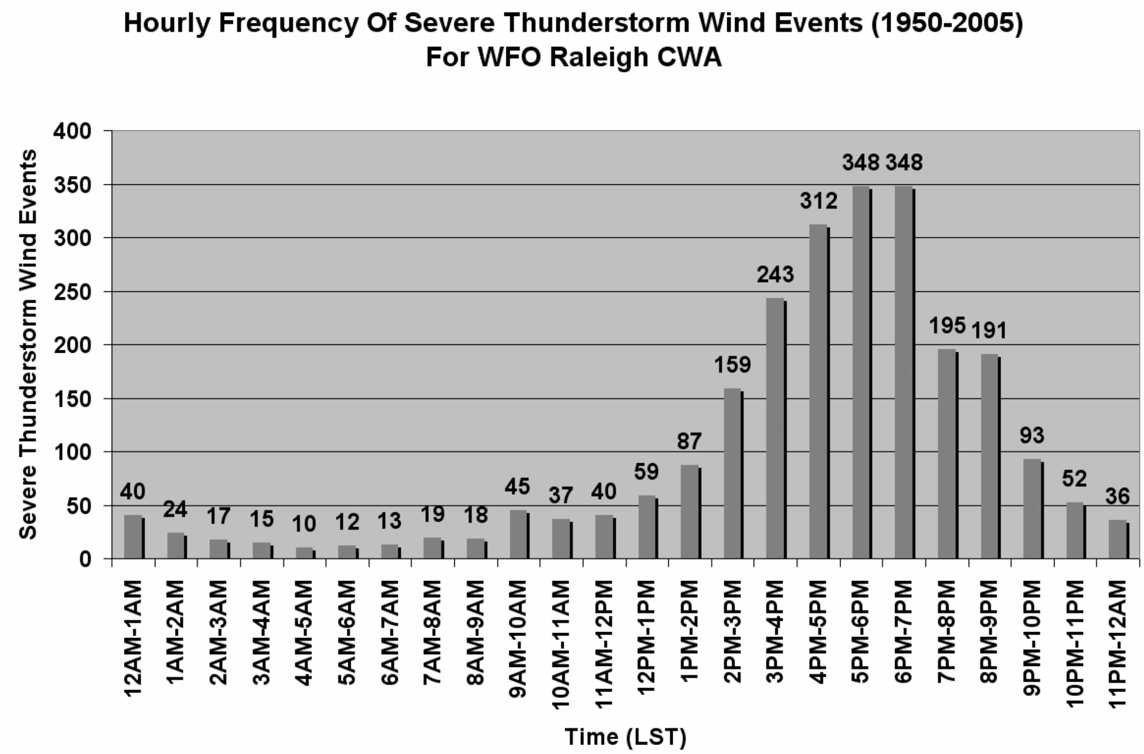

Figure 14. The hourly distribution of severe convective wind events (1950-2005) in the WFO Raleigh CWA.

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