A REANALYSIS OF FIVE 19TH CENTURY SOUTH CAROLINA MAJOR HURRICANES USING LOCAL DATA SOURCES.

by

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Bachelor of Arts
University of Northern Colorado, 1999

Submitted in Partial Fulfillment of the

Requirements for the Degree of Master's of Science

In the Department of Geography

University of South Carolina

2006

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Acknowledgments

I would like to thank my wife, Michele, for her love and support throughout this endeavor.

I would like to thank my advisor, Cary Mock, for introducing me to historical climatology and paleotempestology, for providing strong guidance in my academic endeavors at University of South Carolina, and for steering me through the thesis writing process.

I would also like to thank Dr. Greg Carbone and Dr. Allan James for their feedback and guidance on this project.

Thank you Capers for keeping me straight.

This research was funded through the following grants:

National Science Foundation, "Historical Climatic Reconstructions of the Southeastern United States."

National Science Foundation, "Baseline Methods for Reconstructing United States 19th Century Climate Extremes from Historical Data"

ABSTRACT

Nineteenth century North Atlantic tropical cyclone reconstructions from historical data often are based in urban areas, such as Charleston, South Carolina, which provide the highest temporal and spatial resolution of hurricane damage of all the paleotempestology proxies and allow investigations of their physical impacts. This study approached hurricane reanalysis from the mesoscale perspective utilizing local documentary and instrumental evidence from newspapers, diaries, and journals to analyze regional and local damage caused by five major nineteenth century hurricanes on the South Carolina coast with a focus on Charleston, SC. Wind damage and storm surge reports were classified in accordance with the Saffir-Simpson Scale and mapped at the highest resolution possible, in many cases damage accounts in Charleston could be mapped at the block or parcel level. These maps revealed distinct patterns of damage and flooding at the regional level leading to enhanced regional intensity estimates, refined estimations of landfall location for two hurricanes, and provided unique comparisons of observed storm surge flooding between storms as well as modern storm surge models within the city of Charleston. Results of this research suggest that the major hurricane of 1822 first made landfall at Bull Island, SC, as a major hurricane. The Great Carolina hurricane of 1854 came ashore south of Savannah, GA and was more notable for its size and duration in South Carolina than its intensity. This hurricane blew for nearly 60 hours in Georgetown, SC. Flooding was reported as far north as Georgetown, SC, nearly 150 nm from landfall location. The hurricane of 1885 came ashore between Rockville and Charleston, SC, about 30 nm north of the current estimated landfall location. Documentary and instrumental evidence indicate that this hurricane was a category 2 hurricane at landfall

with wind damage and flooding indicative of a weak Category 2 hurricane in Charleston, which has significant implications for SC and Charleston major hurricane return intervals and vulnerability analysis as well as HURDAT best track and intensity. The hurricane of October 13th, 1893 was a very compact hurricane with very little impact in Charleston. It came ashore as a major hurricane just south of Winyah Bay, SC, with an estimated storm surge of 14 feet (4.25 m) Due to limited data, a great deal of mystery remains regarding the local effects of this hurricane. Charleston storm surge was similar in 3 of the hurricanes studied, limited to Cat 2 type flooding. The approach used in this research adds a mesoscale perspective to HURDAT synoptic storm summaries. Damage mapping at this scale also provides valuable insight about actual damage sustained in different landfall scenarios to local hazard managers and emergency preparedness officials, and provides detailed proxy evidence for paleaotempestologists.

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CHAPTER 1: INTRODUCTION

1.1 Study Area

This study uses local historical data to analyze the regional and local effects of five major nineteenth century hurricanes on the South Carolina coast with a focus on Charleston, SC. Documentary and instrumental data from local sources in South Carolina and neighboring locations were compiled to create regional and local scale damage maps for coastal South Carolina and Charleston, SC, to better understand the intensity of these hurricanes in these locations.

1.2 Objectives

There are three primary objectives of this research:

1. To assess the physical impacts of these hurricanes on the SC Coast based on the type and extent of reported wind damage and storm surge.
2. To assess the physical impacts of these hurricanes within the city of Charleston, SC.
3. To compare the results of these assessments to the official NOAA estimates of intensity and landfall location found in the North Atlantic Hurricane Database (HURDAT) and recommend changes as necessary.

Four of the hurricanes in this study are classified as major hurricanes (Category 3 or greater). The fifth is not officially listed in HURDAT, but Tannehill (1938) indicates that it was a major hurricane and no published evidence has refuted this. All of these hurricanes made landfall between St. Catherine's Sound, GA, and Winyah Bay, SC. These hurricanes are all considered to be historically significant in Charleston and the coastal communities of South Carolina (Edgar 1998). While these hurricanes have great historical significance, the damage caused by these storms was not always representative of a major hurricane.

Our current understanding of these hurricanes is based primarily on HURDAT intensity estimates. However, HURDAT was originally compiled from a synoptic perspective as a statistical forecast aid for tropical cyclones in the Atlantic hurricane basin. This database does not provide appropriate resolution for understanding the intensity or physical impacts of these hurricanes at the local level, which is critically important to coastal interests (Landsea et al. 2004). This study demonstrates how using high-resolution local data can provide a more accurate assessment of hurricane intensity at the regional and local scale.

This research has relevance and implications at multiple spatial scales. Locally, it demonstrates that historical significance does not always directly translate into hurricane intensity. At the mesoscale level, it provides a framework that can be used to study other tropical systems that have impacted South Carolina and other locations, allowing a more detailed assessment of the strength, size, and landfall location of these storms. Utilizing higher resolution local scale data allows for a more complete understanding of the impacts of these hurricanes at or near landfall location. This research clearly demonstrates the value in reanalyzing nineteenth century tropical systems using documentary evidence from local sources and has led to some significant findings. The hurricane of 1885, while historically significant, did not have Category 3 impacts in the city of Charleston, and likely did not reach Category 3 status just prior to landfall. This hurricane also likely made landfall about 30nm (55 km) northeast of the current best track. This research also utilizes a new method of analysis for historical hurricanes. Within the city of Charleston storm surge flooding and wind damage were mapped to the block or parcel level using historic addressing information. The result is a high resolution analysis of impacts in an urban setting. One of the results of this analysis shows that three hurricanes in this study, those of September 1854, August 1885, and August 1893, each with very different size, forward speed, angle of approach, landfall location, and intensity, showed similar patterns of storm surge flooding in Charleston.

CHAPTER 2: LITERATURE REVIEW

2.1 Hurricane Climatology

Tropical cyclone development requires sea surface temperatures (SST) of 26.5° C or greater (Gray 1968; Elsner and Kara 1999). Wendland (1977) suggested a seasonal significant correlation between the aerial extent of warm SSTs and the frequency of tropical cyclone development, but the existence of a near surface disturbance is also necessary to provide the required spin and low-level inflow for cyclogenesis. These surface disturbances have shorter temporal timescales than the SSTs. Vertical wind shear, or horizontal wind speed change with height, is another primary factor in tropical cyclone development. Wind shear values greater than 10 ms^{-1} inhibit tropical cyclone development, and can act to weaken existing storms (Landsea 2000).

North Atlantic tropical cyclones generally form between 5º and 20º Longitude from the Cape Verde Islands, off the west coast of Africa, to the Gulf of Mexico and western Caribbean. The season of hurricane development in the North Atlantic is generally June through November. The regional and seasonal variations in North Atlantic tropical cyclone development are very closely related. Elsner and Kara (1999) plotted the location where tropical cyclones reached hurricane strength for each month of the hurricane season from 1886—1996. Their maps illustrated a strong trend toward early season development in the Gulf of Mexico and the western Caribbean during June and July. The region of development shifted eastward through September, at which time it peaked over the central region of the tropical North Atlantic. It then shifted west during October and November, returning to the Caribbean and Gulf of Mexico. The majority of hurricanes that affect Charleston originate in the tropical North Atlantic. Consequently, the peak season for hurricane activity in this area is August through early October. According to the HURDAT, the hurricanes of 1893, 1885, and 1854 were Category 3 hurricanes at landfall, originating in the tropical North Atlantic in August and September. Track data and intensity estimates for the hurricane of 1822 are not available through HURDAT.

Understanding and identifying historical hurricane damage is important to properly assess the full range of hurricane variability relative to the shorter modern hurricane record. Hurricane intensity is rated on the Saffir-Simpson damage potential scale. The Saffir-Simpson scale takes into account central barometric pressure, maximum sustained 1-minute averaged wind speed, peak wind gust, storm surge height, and the type of damage experienced. The storm is then assigned to the appropriate Category, one through five. Prior to the development of the Saffir-Simpson scale by the National Weather Service in the 1970's, tropical cyclones were simply classed as hurricanes based on the Beaufort scale of wind force. This scale rated wind speeds on a one through twelve scale. A hurricane rates a 12 with sustained winds of 74 mph or greater (Dunn and Miller 1960). Often, in nineteenth century records, a wind speed of 8 to 10 could be a hurricane wind. The only further differentiation made was between a hurricane and a "great hurricane." Tannehill (1938) distinguished between a hurricane and great hurricane by a qualitative assessment of central pressure, diameter, and destruction, which he attributed to Mitchell's 1928 work titled *Hurricanes of the South Atlantic and Gulf States, 1879-1928.*

Hurricanes exhibit temporal variability on annual, decadal, and millennial time scales. Reconstructions of prehistoric hurricanes from sedimentary records indicate variability on decadal, and millennial timescales (Donnelly et al. 2001b; Nott and Haynes 2001; Lui and Fearn 2000); however, these reconstructions are mostly restricted to storms that are Category 3 or higher. The historic record reveals significant temporal variability at annual and decadal timescales, provides greater temporal and spatial resolution, and records storms of lesser intensity. Walsh and Reading (1991) and Caviedes (1991) utilized the existing historical record to investigate tropical cyclone frequency for the period 1500—1990. Walsh and Reading discussed some tentative correlations between hurricane activity and ENSO, SSTs, and atmospheric circulation, and Caviedes correlated decreased Caribbean hurricane activity with ENSO. Both studies, however, suffered from poor data quality for the pre-twentieth-century period. Elsner et al. (2000) examined the cumulative frequency of the annual number of major hurricanes in the North Atlantic between 1900 and 1999. The authors found four distinct periods of activity, which "delineate decadal-scale shifts in North Atlantic hurricane climate." Smith (1999) studied the number of major hurricanes that made landfall on the East Coast for this same time period and also noted significant decadal variability. Others have demonstrated decadal or multi-decadal variability in North Atlantic hurricane activity. Periods of increased activity are positively correlated to the Atlantic Multi-decadal Mode, La Nina, and weak North Atlantic Oscillation values (Goldenberg et al. 2001; Elsner et al. 2001; Landsea et al. 1999). Trenberth (2005) suggested a potential enhancement of tropical convection that could lead to tropical cyclone development; however, direct effects on hurricane frequency were not established. Webster (2005) noted a global increase in frequency and intensity of tropical cyclones over the last 35 years. Linkages of destructive potential of North Atlantic tropical cyclones to global warming (Emanuel 2005) have been much less robust (Landsea 2005; Pielke et al. 2005)

2.2 Paleotempestology

2.2.1 Geologic Record

Through the application of geologic proxy techniques, prehistoric landfall frequencies of intense hurricanes have been reconstructed for various locations along the Atlantic and Gulf coasts (Lui 2004; Donnelly and Webb 2004). These techniques, however, limit reconstructions to hurricanes that are Category 3 or higher. Long-term variability of intense storms can be detected by extracting a series of sediment cores from coastal lakes subject to overwash processes during catastrophic hurricanes. One such study conducted at Western Lake near Pensacola in northwestern Florida revealed significant variability at the millennial timescale with a relatively quiet period between 5000—3400 C^{14} YBP, a period of hyperactivity between 3400—1000 C^{14} YBP, and a return to relatively low frequency after 1000 C^{14} YBP (Liu and Fearn 2000).

Donnelly et al. (2001a) examined stratigraphic evidence of overwash fans in a back barrier marsh at Whale Beach, New Jersey, to reconstruct the history of intense landfalling hurricanes. Three distinct sediment layers were found and ages were calculated based on radiocarbon dates, pollen analysis, and ^{137}Cs. These ages were then compared with historical records of known storms. From this it was determined that the upper-most layer was deposited by the Nor'easter of March 6—8, 1962, the middle layer was deposited by the intense hurricane of 1821, and the lower-most layer was deposited by an intense hurricane that occurred between 1278—1434. The significance of this study was the ability to make a distinction between deposits resulting from Nor'easters and deposits resulting from intense hurricanes. In a similar study, Donnelly et al. (2001b) uncovered evidence of six intense hurricanes in Succotash Marsh, Rhode Island that made landfall in the last 700 years.

Potential uses of coral as a geologic proxy for intense hurricanes have been demonstrated. Nott (2003) examined coral shingle ridges deposited above high tide elevations and eroded gravel terraces in Cairns, Australia, for evidence of prehistoric hurricanes. Through the application of storm surge and wave characteristic models, Nott made estimates of hurricane intensity on the Saffir-Simpson scale. The results of his study suggest that two strong Category 4 or 5 hurricanes struck the Cairns region of Australia between 1815 and 1870. Nott and Haynes (2001) performed a similar study that looked at a greater expanse of coast in northeast Australia and found that Category 5 storms occur every 200-300 years throughout the Great Barrier Reef (GBR). The authors noted that this corresponds to the average lifespan of coral in the GBR, which can only be dislodged by the highest storm waves. This finding suggests a possible application of coral as a proxy in paleotempestology. Frappier and Sahagian (2004) used the isotopic signature in speleothems from Belize to reconstruct hurricane frequencies over several decades. Initial findings indicate that this technique shows strong agreement with modern instrumental records.

Lawrence and Getzelman (1996) examined stable isotope ratios in tropical cyclone precipitation events. Anomalous low $\delta^{18}O$ values were recorded in tropical cyclone rainfall events. These findings are significant because of the possible applications in paleotempestology. Isotopic composition of oxygen in cave deposits and fresh water fossils could reveal changes in past tropical cyclone activity.

Tree ring analysis is also being used to reconstruct high-resolution hurricane records. Miller et al. (2003) and Miller (2005) measured $\delta^{18}O$ in early wood and late wood growth segments in Yellow Pine along the Georgia Coastal Plain. Precipitation from tropical cyclones is distinctly depleted in $\delta^{18}O$, and by comparing $\delta^{18}O$ in early vs. late season growth, the author demonstrated strong agreement between the modern hurricane record, and tree ring $\delta^{18}O$ values in the 1940's thru 1990's. Agreement between this proxy and historical records was established as far back as the late 17th century. In summary, chronological calibration in research utilizing geologic proxies for hurricane reconstruction requires accurate track and intensity data from the historical record. In depth investigations of historic hurricane damages can improve the accuracy of current track and intensity estimates necessary for calibration of the geologic record.

2.2.2 Historic Record

Historical records have yielded the greatest volume of hurricane data. Garcia Herrera et al (2004) identified 127 hurricanes or severe storms from ships logs in Spanish and British historical archives. Millas (1968) compiled a list of hurricanes in the Caribbean as far back as the 15th century. Ramsay (1858) included accounts of some of the more intense hurricanes in his *History of South Carolina.* Barnes published two volumes documenting the hurricane history of Florida (1998) and North Carolina (1998). Sullivan (1986) documented Gulf coast hurricanes as far back as 1717 using newspaper, diary, and oral accounts. These volumes offer an overview of hurricanes that impacted these states, but the record is incomplete. Most storms, especially earlier storms, have little more than a paragraph of description and a very general map of their tracks. Garriott (1900) compiled one of the earliest lists of Atlantic hurricanes. This list contains many errors, including numerous accounts of tropical cyclones occurring between December and March. Tannehill (1938) built on the early work of Garriott. His work includes a list and brief description of all known hurricanes in the North Atlantic beginning in 1494, a chapter that documents the most memorable hurricanes occurring before 1901, and a chapter devoted to the hurricanes of the twentieth century, complete with track maps for each year. The list compiled by Tannehill contains many storms that were not of tropical origin, many from the work of Garriott (1900). A similar approach was taken by Dunn and Miller (1960), who utilized the work of Tannehill and added the storms that occurred through 1959.

The various lists of historical hurricanes were not always consistent with one another and were not all-inclusive. A systematic effort was made by Fernandez-Partagas and Diaz (1995a, 1995b, 1996a, 1996b, 1997, and 1999) to combine the existing published record of late 19th and early 20th century North Atlantic tropical cyclones, to document any storms not included in the previously published lists, and to refine the track for known storms. The authors compiled a much more comprehensive catalogue of North Atlantic tropical cyclones than had previously been available by utilizing newspaper accounts, primarily the *London Times* and *The New York Times*, as their primary data source. The clarification of one hundred-five storms for the period 1851—90 resulted from their efforts, as well as numerous adjustments to the existing track data (Fernandez-Partagas and Diaz 1996c). While that study made significant additions to the existing database, it is not sufficiently detailed to be applicable to local-scale investigations.

The work of Fernandez-Partagas and Diaz illustrated the deficiencies in HURDAT. Partially as a result of their work, in 2000, NOAA's Hurricane Research Division outlined its plans for a three year reanalysis project intended to correct the systematic and random errors included in HURDAT. Where possible, a compilation of six hourly position and intensity estimates for the lifecycle of each storm will be made to compile a "best track." In many cases a closer examination and the use of other sources including the instrumental record and local diaries could potentially enhance the accuracy of estimates of best track and landfall intensity (Sandrik 1998).

Improvements to landfall intensity estimates and extensions of the record for populated locations along the Atlantic and Gulf Coasts are possible. Other studies (Mock 2004, Mock et al. 2004) have extended the hurricane frequency record for Charleston, South Carolina back to 1778. Mock utilized a wide variety of historical documents in his reconstruction including newspapers, plantation diaries, and instrumental weather records. Newspapers, such as the *Charleston Mercury* and *Charleston Courier*, provide detailed information on hurricanes that directly impacted the city center, and more intense hurricanes; plantation diaries provide valuable information on hurricanes that affected more remote locations, and storms of lesser intensity; and the instrumental record provides direct meteorological observations such as barometric pressure, wind speeds, and temperatures, which help determine hurricane intensity and distinguish between hurricanes and mid-latitude cyclones. These records were then connected to the modern record for this region to create the longest continuous time series for any region in the United States. These studies also contributed about 30 newly documented storms between 1778 and 1870 and added specifics on many dozens of storms from earlier databases. Sandrik and Landsea (2003) performed a similar hurricane history for North Florida and Georgia.

2.2.3 Case Studies

Historical reconstructions of individual storm events enable a detailed analysis applicable to specific point locations and smaller spatial scales. Rappaport and Ruffman (1999) recreated the synoptic conditions surrounding the catastrophic hurricane of 1775, which is reported to have killed as many as 4000 people in Newfoundland, Canada. A different application of historical data was presented in a study by Al Sandrik (1998) of the National Weather Service, Jacksonville. Sandrik demonstrated the value of historical records in a reevaluation study of the Georgia hurricane of October 2, 1898. This study utilized similar sources of data, but focused on a single hurricane that made landfall in northeast Florida and Georgia. Sandrik looked at regional damages and storm surge heights to determine hurricane intensity and landfall location. The results of this work included an adjustment of best track by 35 nautical miles (65km) and an upgraded minimum intensity estimate to a strong Category 3 hurricane. Chenoweth and Landsea (2004) utilized local and regional data to reconstruct the California landfalling hurricane of October 2, 1858.

Case studies of 20th century hurricanes have primarily focused on economic aspects of the damage (Janiskee 1990), or meteorological phenomenon (Willoughby et al. 1989). Harden and Pulsipher (1992) examined the physical and socioeconomic response to the damage caused by hurricane Hugo on the island of Montserrat. Lee and Roberts (1992) studied the effect that hurricane Hugo had on the cultural landscape of the Isle of Palms, SC. In this study, the authors mapped damage sustained by individual structures, and the results of reconstruction two years after the storm. A thorough analysis and graphical reconstruction of historical hurricanes and the damage they brought to coastal communities at smaller spatial scales is essential to our understanding of past physical and socio-economic impacts and assessment of future vulnerability to tropical cyclones.

Promising opportunities exist in the historical record for expanding our knowledge of nineteenth century hurricanes and their impacts on coastal communities. Studies utilizing historical records to catalogue and reconstruct tropical cyclone frequency are applicable to Atlantic basin analysis, but are not accurate enough for detailed investigations at smaller spatial extents. Extending the current database into the past and expanding our knowledge of localized damages can improve the understanding of the relationship between tropical cyclones and climate change, as well as the social and economic effects of hurricanes on coastal communities.

CHAPTER 3: DATA AND METHODS

This study utilized documentary evidence as well as instrumental and descriptive accounts of meteorological conditions from a variety of historical sources. This information was classified and mapped using GIS to analyze patterns of damage and weather conditions surrounding each of the hurricanes in this study. Analyses were made at the regional and local scale to assess the impacts of these hurricanes on the South Carolina coast and within the city of Charleston. This chapter explains the types of data and the methods used in this research.

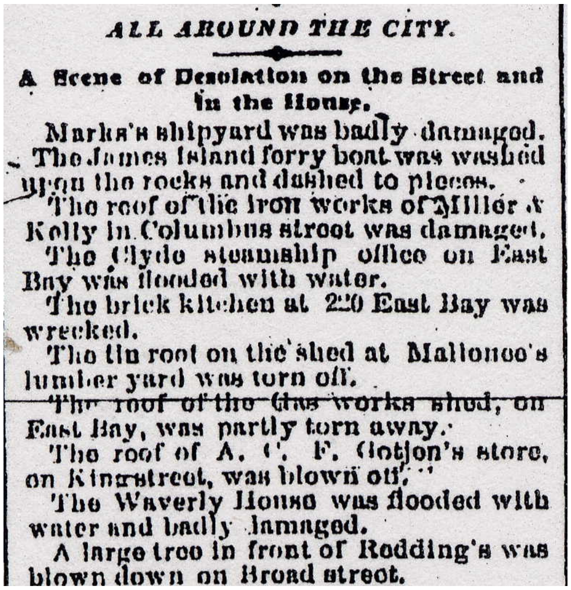
3.1 Newspapers

Newspapers are a very valuable source of information about historical hurricanes (Mock 2004), often providing volumes of information about hurricane damage. Newspapers provide detailed accounts of the events that transpired during and after the passing of a hurricane. This study used data collected from over 20 newspapers covering areas from Savannah, Georgia to Boston, Massachusetts with over 1000 individual accounts of damage. Newspapers collections held at University of South Carolina, University of Georgia, Francis Marion University, Charleston County Public Library and Richland County Public Library were used. All available newspapers with appropriate temporal coverage were examined. Accounts of damage published in newspapers came from a wide variety of sources including ships logs, letters from private citizens, official meteorological observations, interviews and first hand accounts of reporters. Newspaper reports also varied from general accounts of damage to a city or region of the coast to very specific information, including damage sustained by a particular building or plantation. Accounts of major storms often dominate the news for two to three days following landfall. As times passes, reports are often found in the local news section. Accounts can be varied in detail and locational specificity. In larger urban areas like Charleston and Savannah newspapers often contain specific descriptions of both the type of damage and it's location. A typical account in Charleston would read, "On Magazine street a large tree was uprooted at No. 20½ and falling diagonally across the street broke the gate and fence on the premises." (*News and Courier* August 26, 1885, p. 2)

Newspaper accounts often provide block-by-block accounts of storm damage. The *News and Courier* includes specific damage and locational information, often including the business or owners name, which can be accurately located within the city. Figure 3.1 shows an excerpt from the *News and Courier* of August 26, 1885. This is an example of the detailed information about hurricane damages available for the city of Charleston. This particular edition of the *News and Courier* contains three pages of description, and published accounts continued for several days following the storm.

Not all accounts are highly specific. Some are very general, especially those pertaining to an area that is not as densely populated or is some distance from the newspaper's home city. For example, this description came from the *Savannah Daily Morning News* (August 30, 1893, p. 1): "Raleigh NC, Aug 28—The storm did great damage to the crops all through North Carolina. Tobacco, corn, and cotton were severely injured in the state." While general accounts are valuable and used in analysis, they are generally not mapped in this research. Newspaper accounts are especially valuable because they provide a context in which to analyze the data. Because of the large volume of data published in newspapers, they provide context for analyzing the severity of damage at a regional scale, and for analyzing atypical accounts that are documented at specific location. Newspapers occasionally published side-by-side comparisons of the record from the current hurricane with that of a previous storm believed to be of a similar strength. As an example, the Charleston *News and Courier* reprinted the official meteorological report of the hurricane of August 25, 1885, with the official account of the hurricane of August 28, 1893. These side-by-side comparisons provide valuable insight for analyzing the strength of a storm within the historical context of previous storms. It also enables a more accurate interpretation of damage that occurred in the immediate area.

Newspaper reports can have their drawbacks, however. Newspapers were a business that catered to their audience, focusing on areas within the city or reports from the wealthier citizens scattered through the country and along the coast. Newspapers were not immune from inaccurate or highly suspect reports. One such example came from Kernseville, North Carolina in August of 1893 in which it was reported that winds were blowing at 125 mph (108 knots, 55.5 ms^{-1}) and 100 houses were blown down (*Savannah Daily Morning News*, August 30, 1893, p. 1.) While this account may not be entirely untrue, it is highly improbable that such hurricane winds did this damage. When taken in the context of other regional damage and meteorological reports, it appears that



ALL AROUND THE CITY.

A Scene of Desolation on the Street and in the House.

Marks's shipyard was badly damaged.

The James Island ferry boat was washed upon the rocks and dashed to pieces.

The roof of the iron works of Miller & Kelly in Columbus street was damaged.

The Clyde steamship office on East Bay was flooded with water.

The brick kitchen at 220 East Bay was wrecked.

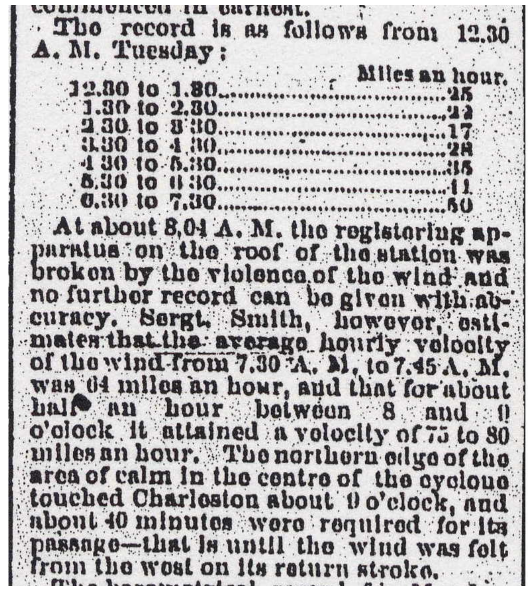
The tin roof on the shed at Mallonee's lumber yard was torn off.

The roof of the Gas works shed, on East Bay, was partly torn away.

The roof of A. C. F. Gotjen's store, on King street, was blown off.

The Waverly House was flooded with water and badly damaged.

A large tree in front of Redding's was blown down on Broad street.



commenced in earnest.

The record is as follows from 12.30 A. M. Tuesday:

	Miles an hour.
12.30 to 1.30	25
1.30 to 2.30	23
2.30 to 3.30	17
3.30 to 4.30	28
4.30 to 5.30	35
5.30 to 6.30	11
6.30 to 7.30	50

At about 8.04 A. M. the registering apparatus on the roof of the station was broken by the violence of the wind and no further record can be given with accuracy. Sergt. Smith, however, estimates that the average hourly velocity of the wind from 7.30 A. M. to 7.45 A. M. was 64 miles an hour, and that for about half an hour between 8 and 9 o'clock it attained a velocity of 75 to 80 miles an hour. The northern edge of the area of calm in the centre of the cyclone touched Charleston about 9 o'clock, and about 40 minutes were required for its passage—that is until the wind was felt from the west on its return stroke.

Figure 3.1 and 3.2: Figure 3.1 (left) is an example account of the damage sustained in the 1885 hurricane in Charleston. Figure 3.2 (right) is an example of the instrumental record from the United States Army Signal Corps just prior to landfall and the accompanying description of the weather conditions during the height of the storm. Instrumental records such as this have great value because they were not restricted to publishing observations at fixed times, as they were in the official record. The information given in the verbal account is often as valuable as the instrumental record. (*News and Courier* August 26, 1885, p. 2.)

this damage was likely the result of a tornado event associated with the hurricane. It cannot reasonably be interpreted as a hurricane wind for the purposes of storm analysis and classification.

3.2 Diaries and Journals

Descriptive accounts were also found in unpublished sources including personal correspondence, diaries, and journals found in local archives including the South Carolina Historical Society and South Caroliniana. Often these were daily journals of farmers and plantation owners that lived in more rural areas of the coast and throughout the state. Information in these sources helped to fill in the geographic gaps between larger urban areas that were covered by newspaper reports. When these unpublished source materials originated in more highly populated areas such as Charleston they are very valuable as an independent source that can be used to verify or call into question information found in other published materials such as newspapers. These descriptions generally went into great detail about the damage that was done to the authors property and surrounding areas. References of a current storm to previous hurricanes were also found at times, which can help understand how different storms had different impacts in different locations.

3.3 Meteorological Data

Meteorological data came from both instrumental and documentary records of weather conditions. Instrumental records were kept by a wide range of observers including: the United States Army Signal Service, which recorded weather observations

(Flemming 1990) at fixed times according to standard procedures; private citizens, who recorded weather observations by standard and non-standard methods at varying times; and ships at sea, whose observations were generally published in newspapers only in the case of extreme weather events.

Official government weather records were recorded at fixed times during a 24 hour period. The number of observations varied from three to five times daily, and the hours of observation varied between records, but generally began in the morning around sunrise and ended between 9:00 PM and 11:00 PM. These instrumental records are of great value because of the regularity with which they were recorded, and the general reliability of the record. One drawback to these records is the lack of coverage of some potentially important times during the height of the storm (e.g., Chenoweth and Landsea 2004). Occasionally the records would include extreme values since the last observation, but not in most cases. The result is that a key barometric pressure value or wind speed may not be included in the record.

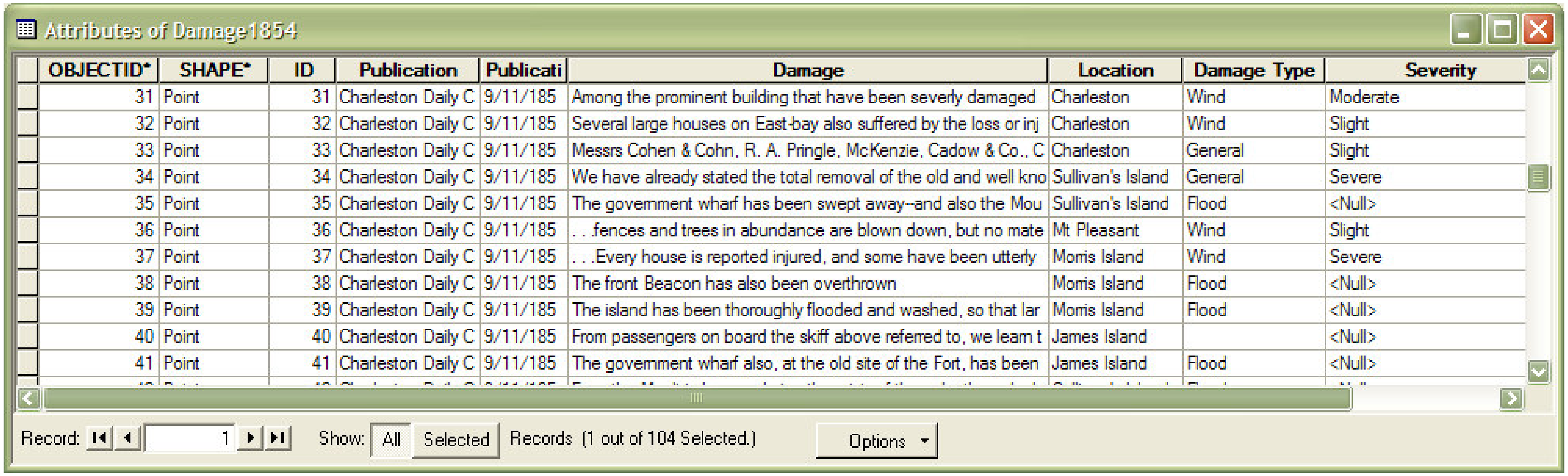
Newspapers occasionally published detailed meteorological records taken by the official weather observer during the storm as shown in Figure 3.2. The published records generally included wind speed and direction, barometric pressure, and occasionally temperature. These reports are a valuable supplement to official records kept by the Signal Service or the Weather Bureau recorders because the newspaper was not restricted to publishing the hourly observations the way the official records are kept.

Specific meteorological descriptions of weather conditions were also found in archival materials such as journals, diaries, and correspondence (Sandrick and Landsea 2003). These sources are very valuable for reconstructing the general path and intensity of hurricanes as they made landfall (e.g., Chenoweth 2003) and traversed the state. These accounts could be as general as giving a wind direction, or as detailed as including information about temperature, precipitation, wind speed and wind direction. The major value in these records is, again, to fill in the geographic gaps in the official and published records and to supplement standard meteorological observations.

Accounts that included wind speeds and directions were valuable in refining current landfall location estimates. Winds generated by tropical cyclones follow a counter-clockwise directional pattern. Hurricanes making landfall on the Atlantic coast typically approach from a direction ranging between the South and East. Based on the forward motion of the storm, higher winds are generally experienced on the right side of the hurricane, while lower winds speeds are generally experienced on the left side, with the overall wind speed increasing closer to the eye wall, and generally calm winds in the eye. It is important to note that these are general conditions and the eye can vary in size and structure and weaker hurricanes may not always have a well defined eye.

3.4 Data Classification

The two primary indicators of the intensity of historical tropical cyclones in a particular region are 1) damage caused by the force of the wind, and 2) coastal flooding associated with storm surge. For analysis, all of the damage accounts had to be classified and standardized before they could be incorporated into a Geographic Information System (Figure 3.3). This proved to be a challenging task because of the varied nature of the accounts of the storm ranging from very broad descriptions covering large geographic areas to very specific accounts of damage done to individual structures or trees.



OBJECTID*	SHAPE*	ID	Publication	Publicati	Damage	Location	Damage Type	Severity
31	Point	31	Charleston Daily C	9/11/185	Among the prominent building that have been severly damaged	Charleston	Wind	Moderate
32	Point	32	Charleston Daily C	9/11/185	Several large houses on East-bay also suffered by the loss or inj	Charleston	Wind	Slight
33	Point	33	Charleston Daily C	9/11/185	Messrs Cohen & Cohn, R. A. Pringle, McKenzie, Cadow & Co., C	Charleston	General	Slight
34	Point	34	Charleston Daily C	9/11/185	We have already stated the total removal of the old and well kno	Sullivan's Island	General	Severe
35	Point	35	Charleston Daily C	9/11/185	The government wharf has been swept away--and also the Mou	Sullivan's Island	Flood	<Null>
36	Point	36	Charleston Daily C	9/11/185	. . .fences and trees in abundance are blown down, but no mate	Mt Pleasant	Wind	Slight
37	Point	37	Charleston Daily C	9/11/185	. . .Every house is reported injured, and some have been utterly	Morris Island	Wind	Severe
38	Point	38	Charleston Daily C	9/11/185	The front Beacon has also been overthrown	Morris Island	Flood	<Null>
39	Point	39	Charleston Daily C	9/11/185	The island has been thoroughly flooded and washed, so that lar	Morris Island	Flood	<Null>
40	Point	40	Charleston Daily C	9/11/185	From passengers on board the skiff above referred to, we learn t	James Island		<Null>
41	Point	41	Charleston Daily C	9/11/185	The government wharf also, at the old site of the Fort, has been	James Island	Flood	<Null>

Figure 3.3: A snapshot showing part of the data structure used in organizing and classifying hurricane damage accounts. Included in the data table is the publication or source of the account, the page and date of publication if applicable, the text (partial or complete) from the publication, the location of the damage, the type of damage, and the severity of damage.

The first step was to classify each account as either relating to storm surge flooding, wind damage, or general damage. The wind damage category included all accounts of damage that could be directly attributed to the force of the wind on a particular object. As an example, the following account was a typical wind damage report, "The fence of Mr. Sinkler, on Tradd street, was blown down." (*News and Courier*, Aug 26, 1885, p. 2). This account clearly attributes the damage that was done to the fence to the force of the wind. Other instances of damage that were not classified as wind damage include those where damage was done to a structure by flying debris or other falling objects. For example, "The kitchen was also badly injured by falling trees and flying projectiles from surrounding houses." (*News and Courier*, Aug 26, 1885, p. 2) This single account documents 2 distinct instances of damage: (1) the falling of trees and (2) the subsequent damage to the kitchen. However, only the falling of the trees can be directly attributed to the force of the wind, therefore the damage to the kitchen would not be classified as wind damage.

The flood category was limited to accounts of storm surge flooding along the coast or coastal creeks and rivers, as well as the damage caused by storm surge to coastal communities and structures. All accounts of flooding were included in this category regardless of the scale or level of detail. This was done because there were generally fewer accounts of coastal flooding, and even general descriptions were useful in understanding the size, strength and track of the tropical cyclone as it moved along the South Carolina Coast. In highly populated areas, such as Charleston, the depth of storm surge was often described in great detail. This information was coupled with published reports that included the time of high and low tide for the region when possible to allow a detailed analysis of actual storm intensity experienced at that location.

The third category of damage that was created was for general descriptions of damage. These descriptions were considered general for the lack of detailed damage information, for the broad geographic area that they described, or damage accounts that could not be clearly attributed to either the wind or storm surge. As an example, the following account comes from the *Georgetown Enquirer* (September 2, 1885, p. 1) "North Island received the full force of the tempest. The house occupied by the pilots went down. . ." This could not be categorized as either wind or flood because of the vague language in the description and the location of the damage. Because the house was on North Island, on Winyah Bay, a place subject to storm surge inundation during past tropical cyclones it is possible that the damage could have been caused by either storm surge or the wind.

All of the accounts that were classified as wind damage were then further analyzed and classified by the severity of damage. Three classifications were used in this content analysis: Slight, Moderate, and Severe (Table 3.1). These classifications are based on the Saffir Simpson hurricane scale and the modified Fujita scale developed by Boose (Boose et al. 2001; Boose et al. 2004). Broader classifications of damage severity were used because the Saffir Simpson scale accounts for the geographic extent of damage in its categories. Individual damage reports cannot be assigned a Saffir Simpson category directly because they only represent a specific instance of damage. Not until multiple reports are classified and mapped can an estimation of the Saffir Simpson category for a region be made.

Table 3.1: This table shows the classification of reported damage into three levels of severity. These damage classifications are not directly comparable to Saffir-Simpson damage potential scale because Saffir Simpson accounts for the spatial extent of damages and cannot be used on single data points. This study classifies individual damage reports into general severity levels.

	Slight	Moderate	Severe
Wind based damage	Includes damage to tree branches, roofing materials, fencing, signs and damage to outbuildings and less substantial structures.	Includes damage to trees, complete removal of roofs, heavy damage to outbuildings and less substantial structures	Includes snapping and uprooting of trees, and significant structural damage to more substantial buildings.

3.5 Mapping

The data collected in this research span 71 years beginning 183 years in the past. In that time, geographic names have changed, communities have moved, been created and destroyed, and addressing systems have undergone numerous changes. Further confusing the situation, many of the small coastal islands and creeks have the same name as others just a few miles away. Some of this has been well documented and some has not. Locating a single account of damage on the map often involved multiple sources and a great deal of time.

Damage accounts at a regional scale were mapped with a very high rate of success. Many places could be located using a standard modern atlas, places like Brunswick, GA, or Conway, SC. The USGS GNIS (http://geonames.usgs.gov/) website was an invaluable tool in locating some of the lesser known or historic areas. The USGS 7.5 minute series of topographic maps was also utilized. Other historical sources of geographic information were utilized for locations that were not found in conventional sources. Regional wind damage and storm surge flooding maps were readily produced for all of the hurricanes investigated in this paper.

Mapping damage that occurred in the city of Charleston at the street level proved to be a significantly challenging task. Sanborn fire insurance maps were used together with published city directories to map accounts of damage and flooding at the street level within the city only for the 1885 hurricane. This storm was chosen for the abundance of damage accounts available, and the availability of Sanborn maps and city directories for that time period. Sanborn insurance maps were available for 1884 and 1888, while city directories were available for Charleston from 1886 and 1892. Even with the combination of in depth descriptions of damage in the newspapers, detailed maps of the city, and city directories, only about 15 to 20 percent of damage accounts could be mapped with confidence.

3.6 Storm Surge Analysis and Model Comparisons

At the regional scale this study focused on the extent of reported flooding and descriptive accounts of flooding along the coast. Rarely were specific descriptions of surge heights reported, with the exception of highly populated areas such as Charleston. Surge heights that were reported in less populated areas typically could not be mapped with a high level of confidence. For this reason specific comparisons of modeled storm surge heights and observed storm surge heights were not performed. Instead, general comparisons were made between SLOSH model output (http://www.cla.sc.edu/geog/hrl/scemd_datadown.htm) and descriptive accounts. Many coastal islands are subject to inundation during Category 1 or 2 hurricanes (based on modern elevations and models). Descriptive accounts from coastal communities often noted if the island was completely or partially submerged. This information could then be used to make general estimations of storm surge heights and the corresponding Saffir Simpson Category.

Flooding in the city of Charleston was mapped for three of the hurricanes included in this study. The September hurricane of 1822, and the October hurricane of 1893 were excluded due to the minimal impacts in the city of Charleston and general lack of storm surge felt in the city. Accounts of flooding for the three hurricanes could be mapped with relative confidence even in the absence of addressing information because of the way that flooding was reported in the newspapers. Typically the accounts of flooding were reported by extent of floodwaters by street or intersection. This allowed flooding to be mapped as accurately as the block level within the city of Charleston. Using GIS the resulting map of flooding in Charleston was then overlaid with the expected flooding based on the SLOSH model (Figure 3.4) and when appropriate the storm surge model more recently developed by the CaroCOOPS project (http://nautilus.baruch.sc.edu/hurricane/latest/). Each of these models depicts the extent of flooding based on different landfall scenarios. This comparison was used to estimate the Saffir Simpson Category that corresponded to the level of flooding within the city.

Table 3.2: Expected storm surge heights above MSL for hurricanes of varying intensity

Saffir Simpson Category	Surge Height in Feet	Surge Height in Meters
Category 1	4-5	1.5
Category 2	6-8	2.0-2.5
Category 3	9-12	2.5-4.0
Category 4	13-18	4.0-5.5
Category 5	> 18	5.5 or greater

3.7 Wind Damage Analysis

Regionally, wind damage reports were mapped throughout South Carolina for all hurricanes in this study. When available reported wind damage from surrounding states

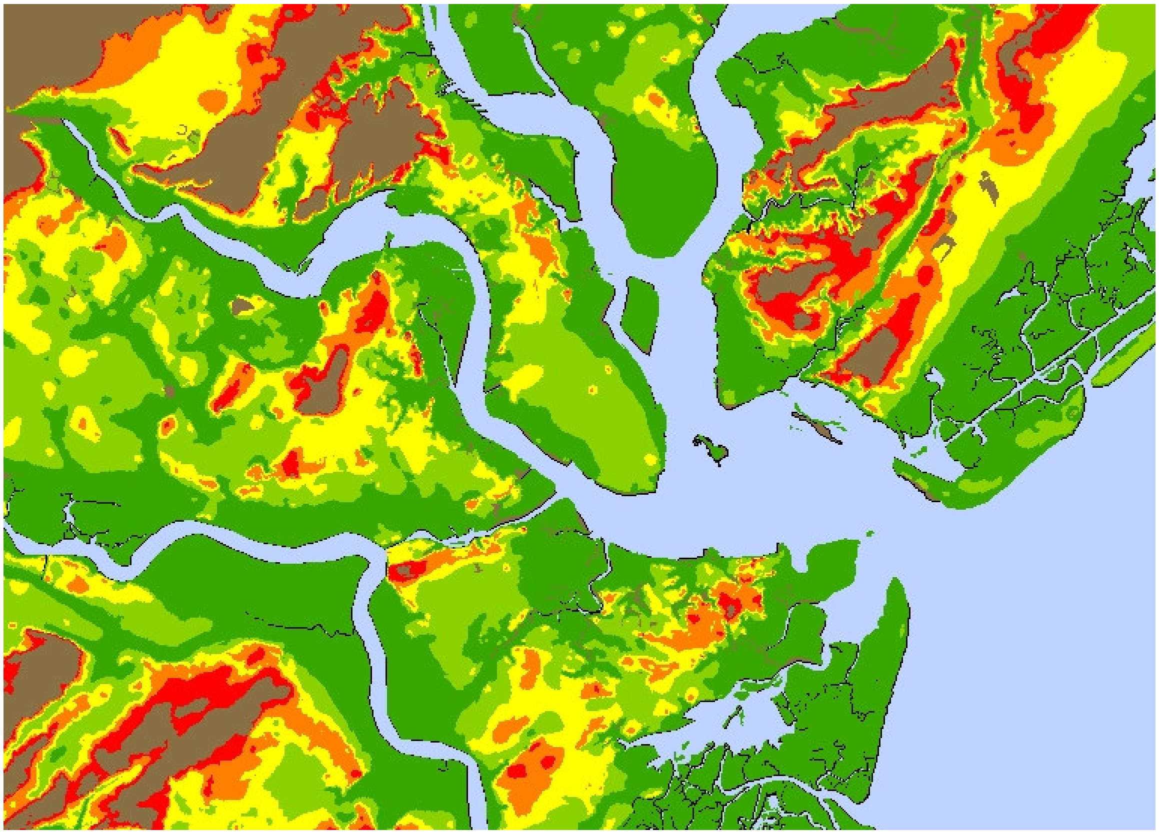


Figure 3.4: Expected storm surge inundation based on hurricane intensity as modeled by the SLOSH model. Dark green areas are those expected to flood during a Category 1 hurricane, Dark brown areas are not expected to flood, even in the event of a Category 5 hurricane.

was also included. The maps generated clearly depicted the spatial distribution of different damage severity levels. Damage severity levels used in this research do not correspond directly with Saffir Simpson expected damages. For example, severe damage does not necessarily mean Category 3 damage, and slight damage does not necessarily mean Category 1 damage. Broad areas of similar damage severity levels were examined more closely to determine the approximate Saffir-Simpson intensity level of damages. This process included re-examination of each damage report within the context of the original source material, and within the context of other damage reports in the area. For example, widespread reports of severe damage were examined to determine if the severe damage was inflicted on both structures and vegetation. The sources of the information were also examined to determine if the reports of severe damage came from a single source, or if corroborating reports came from multiple sources. Generally, if the damage maps showed areas of widespread and severe damage and context analysis indicated that the sources and the damages reported were accurate and reliable, the intensity of that hurricane in that area was determined to be major; that is, Category 3 or greater.

A similar approach was taken within the city of Charleston for local analysis of the 1885 hurricane. Damage was mapped at the block level and symbolized by severity. Damage patterns in the city were analyzed, reports were re examined for content and an estimation of intensity of the wind was made. As with regional analysis, damage to both buildings and vegetation was examined in local analysis.

3.8 Intensity Classification

After analysis, each of these hurricanes was assigned an estimated intensity for different geographic regions along the South Carolina Coast and Charleston. Estimations of intensity were made using all of the information available for each hurricane, including meteorological information, reported flooding, and reported wind damage. Making the determination between areas that experienced major hurricane intensity and non-major hurricane intensity was generally unambiguous. However, determining the difference between strong Category 1 intensity and weak Category 2 intensity or Category 3 versus Category 4 was often unattainable even with multiple data types and sources. Instrumental meteorological data and high-resolution storm surge flooding information in Charleston improved the confidence of intensity estimates for that location and areas in the immediate proximity. Intensity estimates made for other areas along the South Carolina coast were necessarily conservative.

CHAPTER 4: RESULTS

This chapter examines the regional and local impacts of each of the five hurricanes included in this research. Regional analysis of each hurricane is separated into three sub sections. First the meteorological observations are compared to the official HURDAT estimates of intensity and track, except in the case of 1822, which is not covered in this database. The next subsection examines the documented wind damage and compares observed damage to expected damages based on the Saffir –Simpson scale. The final subsection examines storm surge flooding along the South Carolina Coast and compares the depths and extent to corresponding Saffir-Simpson expected storm surge. This is followed by a "Local Analysis" section that looks at the local impacts of three of these hurricanes within the city of Charleston. All of this information is used to make an assessment of the impacts of each hurricane along the South Carolina Coast and Charleston and an estimation of the level of intensity of the hurricane based on the Saffir-Simpson scale.

4.1 Regional Analysis

4.1.1 September 27th, 1822

4.1.1.1 Meteorological Observations and Storm Track

This storm does not have an official track listed in HURDAT. Ludlam (1963) provides limited information on this storm, suggesting that it made landfall south of the Santee River near Bulls Bay (figure 4.1). This assessment is supported by observed wind

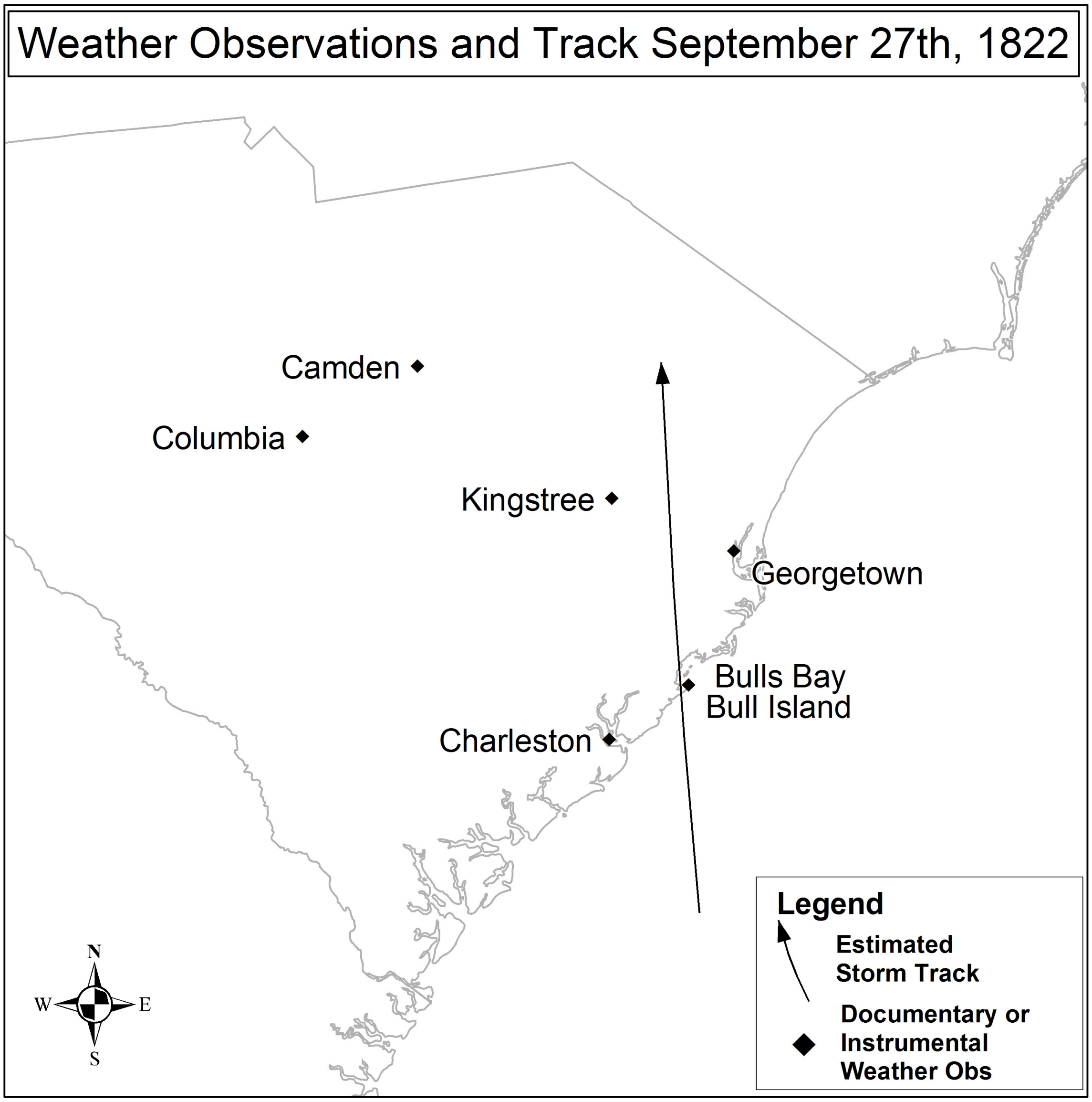


Figure 4.1: Map showing the locations of documentary and instrumental meteorological observations used in this analysis and the estimated storm track of the hurricane of September 27, 1822. Estimated storm track is based on meteorological observations and observed wind and storm surge damage. One account from Bull Island, SC documents the eye passing directly over that location.

directions, patterns of damage and flooding reported in the region. Daily weather observations taken by the US Army Signal Corps at four locations, three in Virginia and one in Florida, recorded meteorological conditions to the north and south of the landfall location of this storm. Conditions at Fort Norfolk, VA, were cloudy and rainy with winds from the southeast on the 26th, 27th, and 28th of September. Similar conditions were reported at Fort Nelson, VA. St Augustine, FL reported north winds and rain on the 25th and 26th, but northeast winds on the 27th and Southeast winds on the 28th. These recorded wind directions suggest that the hurricane likely approached the South Carolina coast from the south-southeast. Its track brought it ashore near the Santee River. It then proceeded north and passed to the west of Richmond, VA.

The wind patterns documented in Charleston and Georgetown are strong evidence supporting a landfall location near the north end of Bulls Bay, SC. Charleston experienced winds from the north, northeast and northwest.

> "About half past ten o'clock the wind commenced blowing from the north and north east with excessive violence and increased till after midnight; it then shifted to the north-west, blowing with still greater fury and continued rage till after two o'clock, when it gradually subsided and ceased about four o'clock."
>
> *Charleston Mercury* Sept 30, 1822 pg2

Georgetown experienced winds that came first from the northeast, east, southeast, and finally from the south:

> "…between ten and eleven o'clock, however, we had a squall from the N. E. from which quarter the wind continued to blow high till about twelve, when we experienced another more violent squall from about E.; the mercury at this hour had risen to 79 and continued to rise for some time after. From 12 the wind continued gradually to change to the S. E. and S. increasing in violence as it shifted; from S. E. it blew with frightful and unprecedented violence; most of the injury caused by the wind must have occurred about two o'clock in the morning and while it blew from this quarter."
>
> *Charleston Mercury* Sept 30, 1822 pg2

Georgetown is approximately 52 nm (96 km) northeast of Charleston on the South Carolina coast. Both cities noted the onset of strong northeasterly winds at around 10:00 PM on the 27th. Around midnight both cities also experienced a directional shift and intensification of the winds. The winds in Charleston shifted to about north, between northeast, and northwest and continued to strengthen. At the same time Georgetown was experiencing a shift in the opposite direction, to the south and southeast, with further strengthening. Charleston and Georgetown both experienced the strongest winds at around 2:00 AM, but blowing from the opposite direction. Nowhere in the accounts from either location was any mention made of a lull, or calming of the winds, to mark a change in wind direction, which would indicate that the eye of the storm passed directly over either city.

There are two documented accounts from locations that were crossed by the eye of the hurricane. On October 2nd, 1822, the *Charleston Courier* published the following:

> "Extract from the Logbook of the U. States revenue schr *Gallatin*, Capt. MATHEWS, at anchor under Bull's Island during the late Gale:--*Friday Evening, Sept. 27th*—At 10 o'clock commenced raining, with fresh breezes—at 11 called all hands to send down yards and top masts; succeeded in getting down the fore yard and housing the main top mast, but in the act of getting the main top sail yard on deck, a whirl of wind snapped the fore top mast short off by the cap; the wreck of the fore top mast and fore top sail yard hung in the rigging for about 25 minutes, when the fore top sail (a new sail) blew from the yard and went to ribbons, wind at this time SW—The wreck was cleared in the course of an hour, but the wind had now increased to a perfect hurricane, the sea making a perfect breach fore and aft; and no one could get from one end of the vessel to the other without crawling.—About half past 1 A.M. began to drag, although there were three anchors ahead (the best howser having been let go at the commencement of the blow) and nearly a whole cable [---] away on each.—At 2 she struck on an oyster bank, where after splitting open the head of the rudder, she brought up. Suddenly the wind, which was now at south died away, and remained calm

> for about 10 minutes.—it then shifted to S. W. and instantly began to roar with full as much , if not more violence than before.—This brought the vessel across the tide, and one hand was stationed at each mast with an axe ready to cut away. . .At 4 A.M. the gale moderated but left us ashore very high up alongside the marsh."
>
> *Charleston Courier* October 2, 1822, p. 2

This account was recorded at Bull Island, SC, which is located on the southern end of Bull's Bay about 17 nm (31 km) north of Charleston Harbor. After passing over Bull Island, the hurricane proceeded north through modern day Williamsburg County. There is evidence that the eye passed directly over the area of Williamsburg County near Kingstree and Indiantown. One published account (McGill 1952) from Williamsburg County has the hurricane coming, "from an eastern direction, continuing for a few hours and then there was a calm, but before the people could kindle up a fire, it returned from the west with greater violence and destruction." The direction of the winds in this area clearly show the hurricane moving in a northerly direction as it passed through central Williamsburg County. Unfortunately no instrumental records were found that document wind speeds or barometric pressure during the height of the hurricane in either Charleston or Georgetown. The descriptive meteorological observations however, are extremely valuable for understanding the general path of this hurricane as it made landfall.

4.1.1.2 Wind Damage

Wind damage was reported along the South Carolina coast from Morris Island to Waccamaw Neck (Figure 4.2). The damage pattern associated with this storm shows the most severe damage occurring between the Santee delta and Waccamaw neck. In this

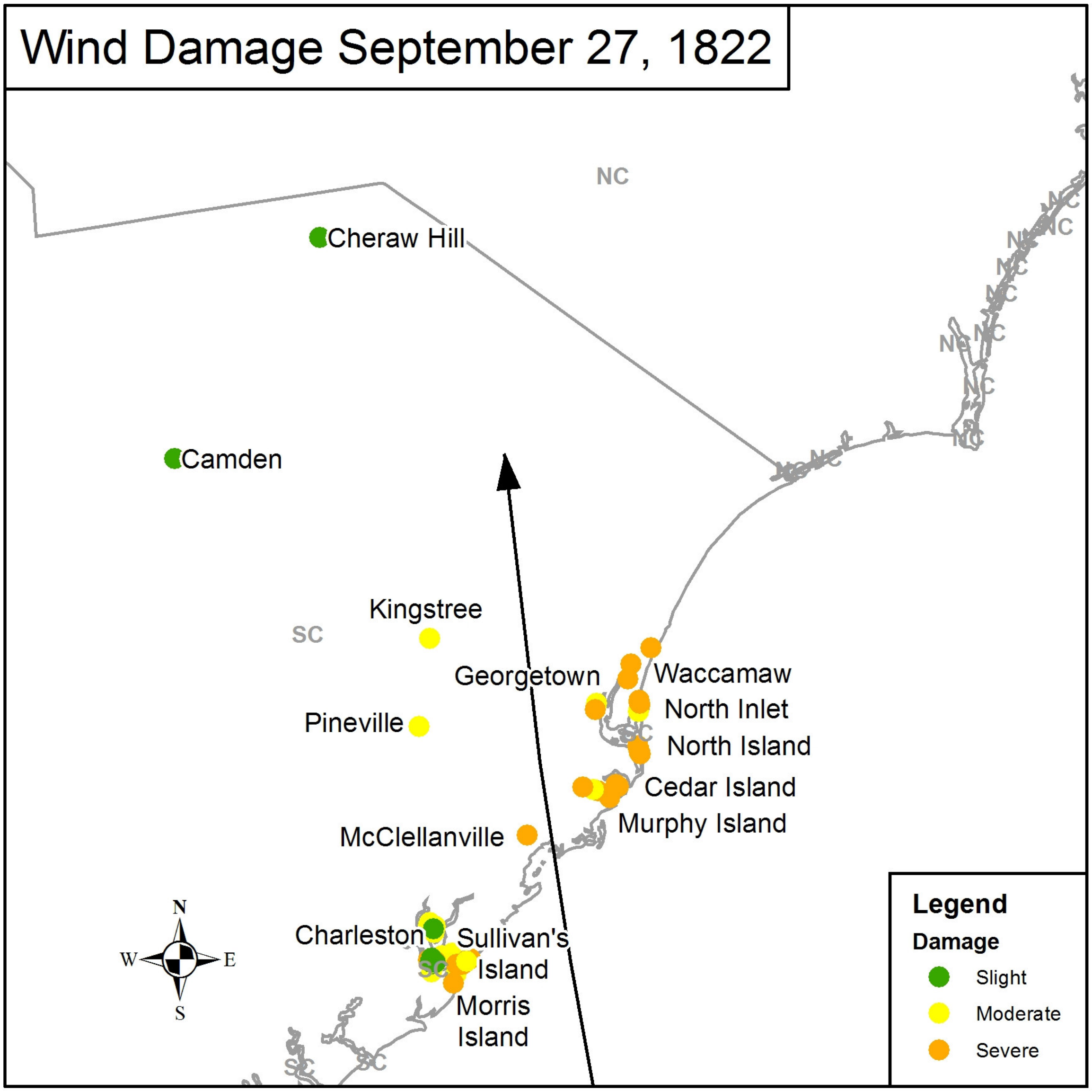


Figure 4.2: Map of documented wind damage during the hurricane of Septemeber 27th, 1822. Mapped wind damage patterns reveal widespread severe damage occurring between Murphy Island and Waccamaw. Less severe damaged occurred to the south around Charleston and further inland. The pattern of wind damage associated with this hurricane was a valuable tool in determining approximate landfall location.

region damage to structures and trees was widespread and severe. Typical damage reports included complete destruction of homes and buildings, and stands of timber blown down completely. Charleston suffered primarily in damage to roofs and chimneys. While some isolated reports of major structural damage were documented in Charleston, the majority of damage reports were non-structural in nature. Five published accounts describe homes in Charleston being severely damaged. Outbuildings, stables and kitchens were the only other structures reported to be destroyed or suffer major structural damage.

Wind damage on Sullivan's Island was severe. On Sullivan's Island more than 10 houses were reported blown down. The majority of other damage reported on Sullivan's Island included the blowing down of kitchens and outbuildings. Of the 41 documented reports of wind damage on Sullivan's Island, only 4 were reports of roof damage. The remaining 37 reports were account of either complete destruction or significant structural damage to houses, buildings and outbuildings. The scene on Sullivan's Island was one of nearly complete destruction:

> ". . .the damage to the houses is very great—many are entirely destroyed—as Mr. A. Tunno's, W. Mason Smith's, A. Robinson's, T. Flemming's, estate of Capt. Dennison's, Mr. L. Fraser's, Col. Johnson's, Mr. Morrison's, the Point House, the small house of Mr. Calder, besides a number of others that are so badly damaged as hardly to be worth repairing—Chimnies are blown down—a great many roofs blown off and Piazzas partly or totally demolished: the whole presenting an appearance of sweeping desolation. Mr. Boyce's house was partly blown away while his family were in it—no one was hurt."
>
> *Charleston Mercury*, Sept 30, 1822, p. 1

The difference in the extent and type of damage that occurred here compared to Charleston likely results from the closer proximity of Sullivan's Island to the center of the hurricane, coupled with the more exposed location at the mouth of Charleston Harbor. Sullivan's Island would have been subjected to significantly higher wind speeds as the hurricane approached and the winds were blowing from the northeast.

Savannah, GA, reported no damage done by the wind. No reports of violent winds or significant damage were found to the south and west of Charleston. Mail carriers from Columbia noted that the damage did not extend more than about 20 nm (37 km) inland from Charleston.

Wind damage patterns indicate that this was likely a compact and intense hurricane. Category 2 impacts were felt in Charleston. Along the coast from Sullivan's Island to Waccamaw the impacts were more indicative of Category 3 winds.

4.1.1.3 Flooding

Storm surge flooding associated with this hurricane was documented from Charleston in the south to Waccamaw in the north (Figure 4.3). Charleston and Sullivan's Island experienced an extreme and rapid rise and fall of the tide around 1:00 AM. The *Charleston Mercury* (September 28, 1822, p. 3) reported in the Weekly Almanac that high tide for Charleston occured at 4:36 PM on Friday, the 27th, and at 5:24 PM on Saturday, the 28th.

Around 1:00 AM the *Charleston Mercury* (September 30, 1822, p. 2) reported, "the tide rose and fell about 6 feet in 45 minutes" in Charleston. On Sullivan's Island "the tide rose and fell with inconceivable rapidity in about three hours from extreme ebb to more than a full sea coming in and going out with prodigious violence." No damage however, was reported in the area of Charleston Harbor as a result of storm surge flooding, with the exception of the displacement of a bridge connecting Fort Johnson to James Island on the south side of the harbor. Caper's Island, 9 nm (17 km) northeast of Sullivan's Island, reported storm surge flooding. Here the sea was several feet higher than had been experienced in previous storms. Two persons were reported to have nearly drowned while attempting to move from one house to another. This indicates that the surge level on Caper's Island was significantly higher than it was on Sullivan's Island to the south, and likely several feet higher than the highest lunar tides. Elevation information could not be obtained for Caper's Island during that time period, but modern elevations generally range from 0 to 3 meters on these coastal islands.

The bulk of the damage resulting from storm surge was reported between Murphy's Island, at the mouth of the Santee River, and Waccamaw Neck, just north of Winyah Bay. In this region over 300 people were reported killed. On Murphy's island alone, entire plantations had been swept away and 50 slaves were killed by drowning or from the falling of buildings. Just north, on Cedar Island a similar scene was reported, with three people drowned and one person swept out into the marsh where he was later rescued.

Farther north at North Island and North Inlet the destruction was described as complete. The *Charleston Mercury* reported (October 3, 1822, p. 2)

> "Mr. R. F. Withers house at North inlet was swept away and all his family except himself lost…Mr. Wither's house was crushed like an eggshell."

The *Charleston Courier* reported (October 3, 1822, p. 2)

> "As soon as the day dawned, on looking around just in my neighborhood, I saw three houses prostrate, and four completely carried away—not a board left to mark the spot on which they stood."

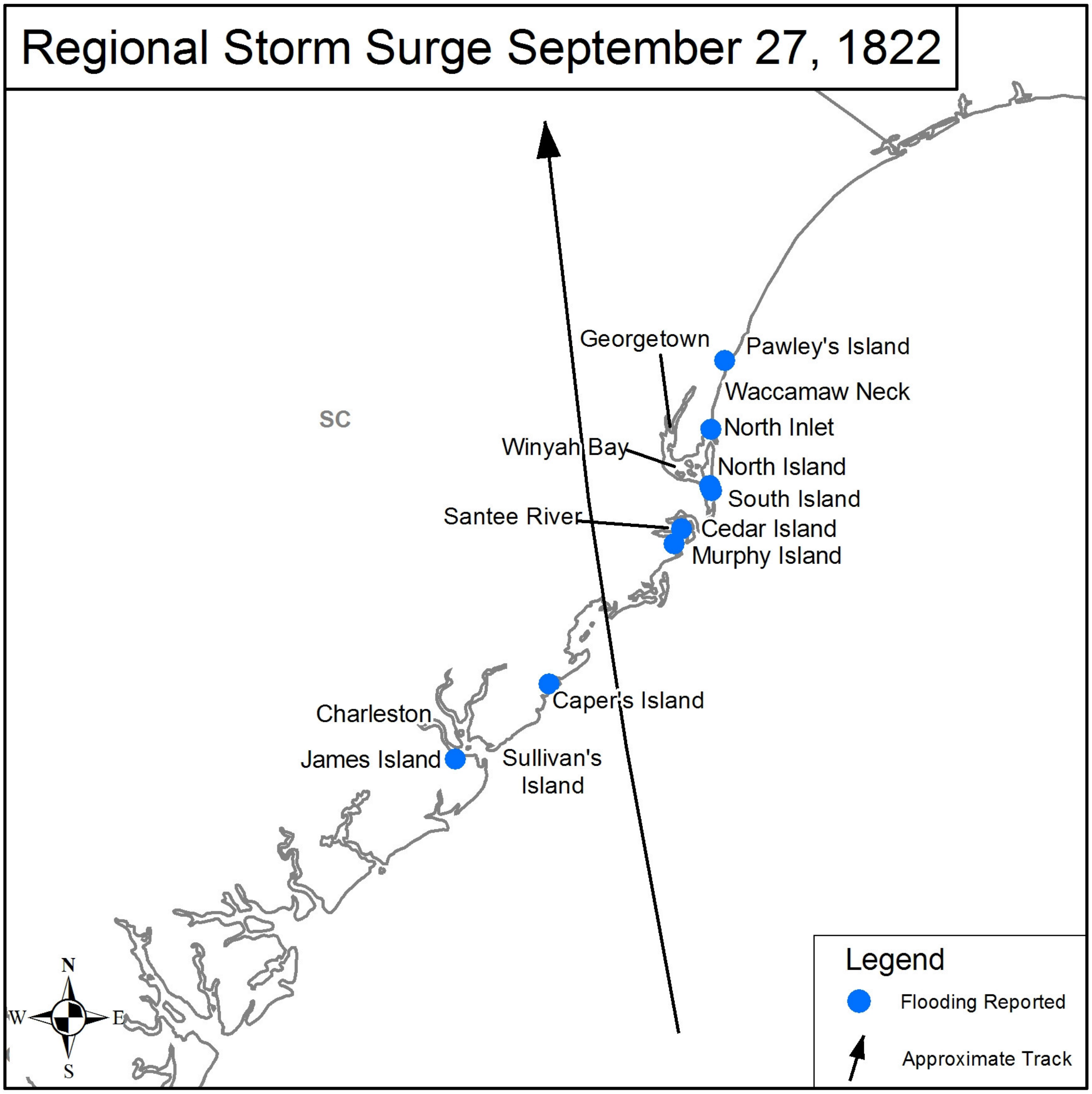


Figure 4.3: Map showing reports of storm surge during the hurricane of September 27th, 1822. Flooding was reported from Charleston Harbor to Waccamaw Neck. Flooding in the Charleston area was minimal with little or no damage resulting. Flooding in the area of the Santee and Winyah Bay was severe resulting is widespread property damage and loss of life.

> "Mr. Robert Taylor's house, strongly built, was thrown some distance from the block, and greater part swept."
>
> Not a shingle from the church to be found, and the whole face of the ground so completely changed, that there is no trace where it stood."

These accounts came from a private letter from a resident of North Island. The writer estimated that at least 30 people were killed at North Island, most as a result of the storm surge.

No reports of surge heights were found in this research, but based on the number of deaths in the region, the amount of damage caused by storm surge, the reports of major beach erosion, all coupled with the fact that this flooding occurred very near low tide indicates that this was a major hurricane with Category 3 impacts in South Carolina around Winyah and the Santee, and Category 2 impacts in the Charleston Harbor region.

4.1.2 September 8, 1854

4.1.2.1 Meteorological Observations and Storm Track

This storm is known as the Great Carolina Hurricane (Tannehill 1938). The current official HURDAT track of this storm shows landfall in the vicinity of St. Catherine Sound, GA. It then traversed inland crossing into South Carolina between Allendale, SC and Augusta, GA. Upon entering South Carolina the storm turned to the northeast and weakened as it passed over Columbia (Figure 4.4). It continued to move northeast through North Carolina and emerged back into the Atlantic Ocean near the Virginia border. This track is supported by numerous instrumental and documentary weather observations.

The following is a newspaper account of the winds experienced in Savannah, GA from September 7th through the 9th.

> "It began to blow on the evening of the 7th and continued throughout the night, but from 10 o'clock on the morning of the 8th until 4 oclock pm it blew a perfect hurrincane. In the evening it changed to the southeast, blew heavily in the quarter for some hours, then toward morning it hauled to the south and southwest where it continues."
>
> *Charleston Mercury* Sept 12, 1854, p 2

Thomas Chaplin (Tombee Plantation journal, 1845-1886), a resident of St. Helena, SC recorded in his journal that winds commenced to blowing from the east on September 7th, continued blowing with increased intensity through the 8th, and did not begin to subside until around noon on Saturday, September 9th. A similar account from the Beaufort district (Gignilliat Family Papers, 1828-1901) indicated high northeast winds on the 7th, increasing to a northeast gale in the 8th that shifted suddenly to the southwest and clearing the following day.

At St John's, SC, the Black Oak Agricultural Society (Black Oak Agricultural Society records, 1842-1925) reported winds from the northeast September 7th, with clouds, wind and rain. September 8th winds remained from the northeast. The remarks read, "Stormy. Gale from NE." Four tenths of an inch of rain was recorded. September 9th the wind came from the SE and shifted to the W, with wind and one inch of rain recorded.

In Charleston, Samuel Wilson recorded his experience (Samuel Wilson 1854) . The rain and high winds from the east began in the forenoon on September 7th, increasing through the day blowing with great violence. The violent winds continued through the night and the next day finally subsiding on the 9th.

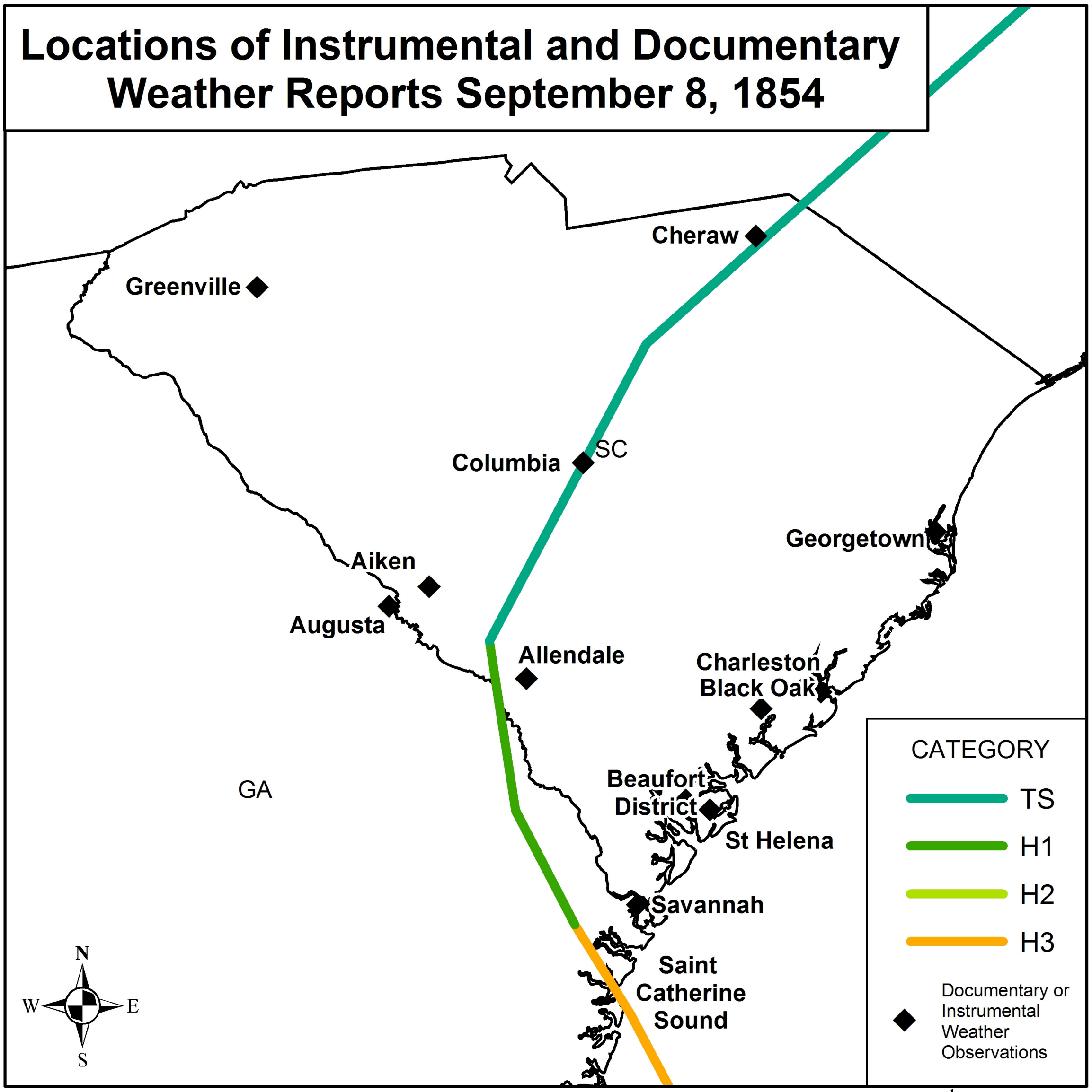


Figure 4.4: Map of HURDAT best track for the hurricane of September 8th, 1854 and location of documentary and instrumental weather observations.

On the 10th Mr. Wilson reported a heavy rain with a gale of short duration. In Georgetown, SC, the *Pee Dee Times* (September 13, 1854, p2) reported the gale at northeast and southeast for 48 hours and then at south-southwest for 12 hrs. It was noted to be the longest duration storm in memory. These observations all support the current best track estimation in HURDAT. These observations also make note of the duration of this hurricane. Every record documents strong wind and rain for nearly three days.

4.1.2.2 Wind Damage

Of importance, wind damage associated with this hurricane was generally not very severe, even as far south as Savannah, GA (Figure 4.5). Newspaper accounts of damage were limited to tree and shrub damage in most cases. This storm seems to have caused very little structural damage. Most damage to buildings was limited to roofing material being stripped. One case of major structural damage was reported in the *Charleston Daily Courier* (September 9, 1854, p. 2): a two story wooden building in King Street, Charleston, was blown down. The remainder of the damage to structures was classified as slight to moderate, limited to damage to roofs and the destruction of fences. Numerous accounts of damage to trees were reported from Savannah to Charleston. The following is a description of the scene in Savannah:

> "We passed through a portion of South Broad street about dusk. It presented a melancholy spectacle. From Abercorn to Bull street nearly every tree is blown down. The few that remain standing are limbless and leafless—nothing but naked trunks remain to tell the effects of the gale. It will take years to replace the beautiful trees which now lie prostrate in that street."
>
> *Savannah Daily Morning News*, September 9th, 1854 p. 2

In St. Helena, SC, winds uprooted trees and blew down fences. In Charleston there were very few trees blown down, but the foliage was stripped from many trees. Inland there were no reports of significant wind damage. In Branchville, SC the effects of the storm were classified as very minimal. In Cheraw there was very little crop damage resulting from this hurricane. Most locations throughout South Carolina indicated high winds, but no notable damage.

Therefore, wind damage in South Carolina was limited at the highest to Category 2 type impacts close to the Georgia and South Carolina border along the coast. In Charleston the foliage was completely stripped from the trees. This type of damage is often associated with more intense winds, however similar damage to other features was not noted in the area. It is likely that the stripping of foliage from vegetation resulted from less intense winds of longer duration rather than more intense winds of shorter duration. Wind damage in Charleston was consistent with Category 1 impacts.

4.1.2.3 Flooding

Storm Surge flooding associated with this storm was extensive. Flooding was reported from Savannah, GA to Georgetown, SC (Figure 4.6). Hutchinson's Island, in the Savannah River just north of Savannah, was completely submerged with only the roofs of houses and trees visible from the city. In the eastern part of Savannah the water was several feet deep in the cotton yards and along the wharves. Farther to the north in Saint Helena Sound, SC much of Warren Island was completely submerged and the Coosaw and Combahee rivers merged to cover Buzzards Island.

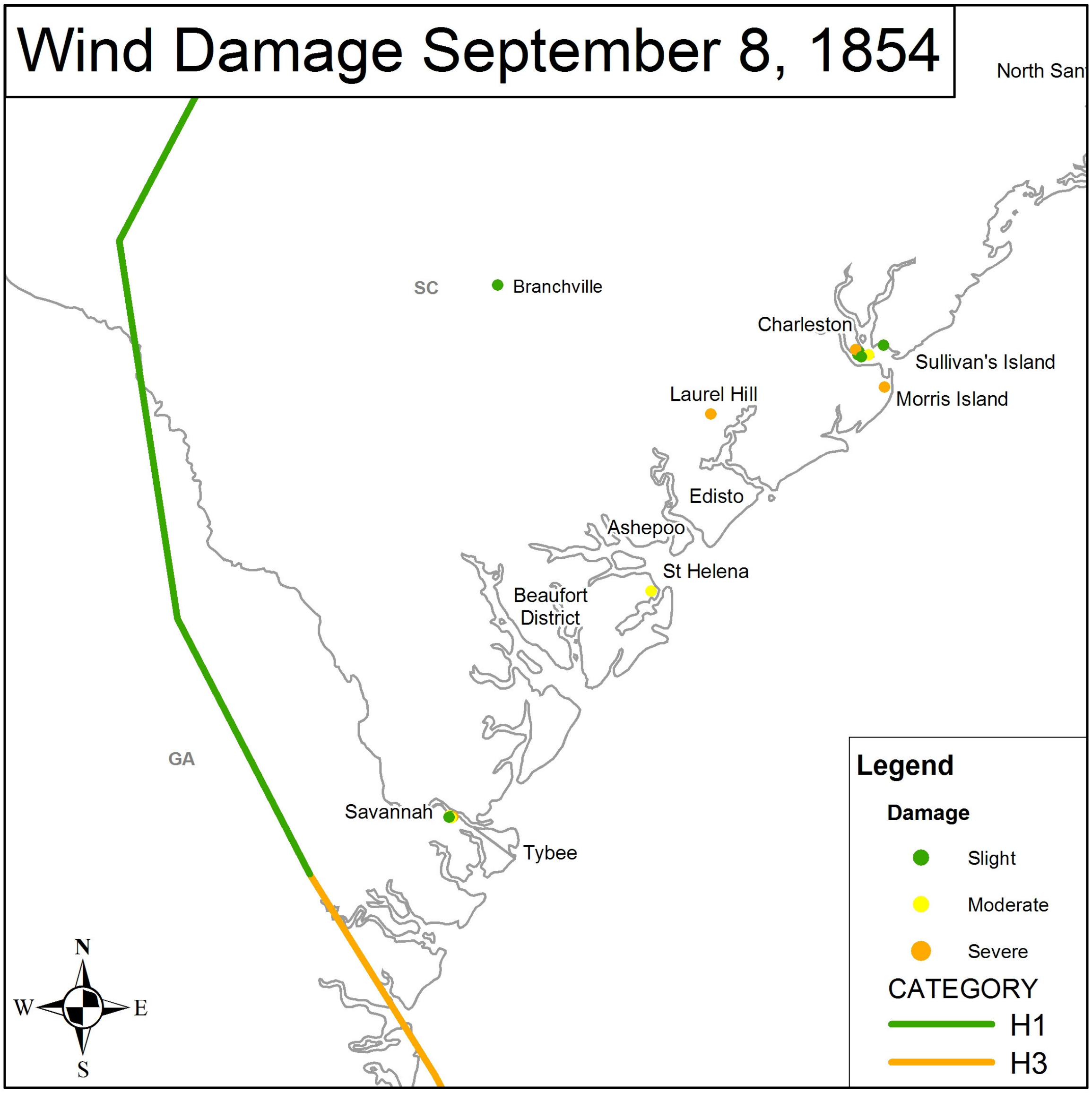


Figure 4.5: Map showing documented wind damage resulting form the hurricane of September 8th 1854. Wind damage resulting from this hurricane was reported from Savannah to Charleston. The duration of high winds caused widespread damage.

Reports from Edisto call this hurricane one of the most terrific in the collective memory of the inhabitants. The surge made a clean sweep over the beachfront in 5 or 6 places inundating hundreds of acres of high ground. The tide is said to have risen higher than in any previous storm including that of 1804.

In Charleston, the water on East Bay Street was up to four feet deep (1.2m) in many places. The water backed up through Atlantic and Water Streets into Meeting Street, parts of which were covered to a depth of two to three feet. The western portion of Sullivan's Island was covered with water on Friday morning when the storm was at its height. On the beach fronting the Atlantic the four cottages that made up "Tennessee Row" were completely swept away, other buildings were swept away or damaged by the storm surge. The *Charleston Mercury* (September 9, 1854, p. 2) reported the appearance of the island as "very dismal" following the storm.

The storm surge was still substantial all along the coast to the mouth of the Santee in the north. Every bridge between South Island and the Santee ferry was carried away by the surge. There was also significant damage to the rice crop along the Santee, Pee Dee, and Waccamaw rivers. In Georgetown, the surge was reported to be as high as that of the hurricane of 1822. Salt water was pushed upriver as far as anyone could remember, doing great damage to the rice crop. Storm surge around Savannah was very likely in the Category 3 range. This hurricane is officially listed in HURDAT as a Category 3 hurricane at landfall in northern GA, and no evidence was found to refute that classification. Surge heights in Charleston were consistent with Category 1 impacts. If reports from Hutchinson's Island and Savannah are accurate, it is very likely that this

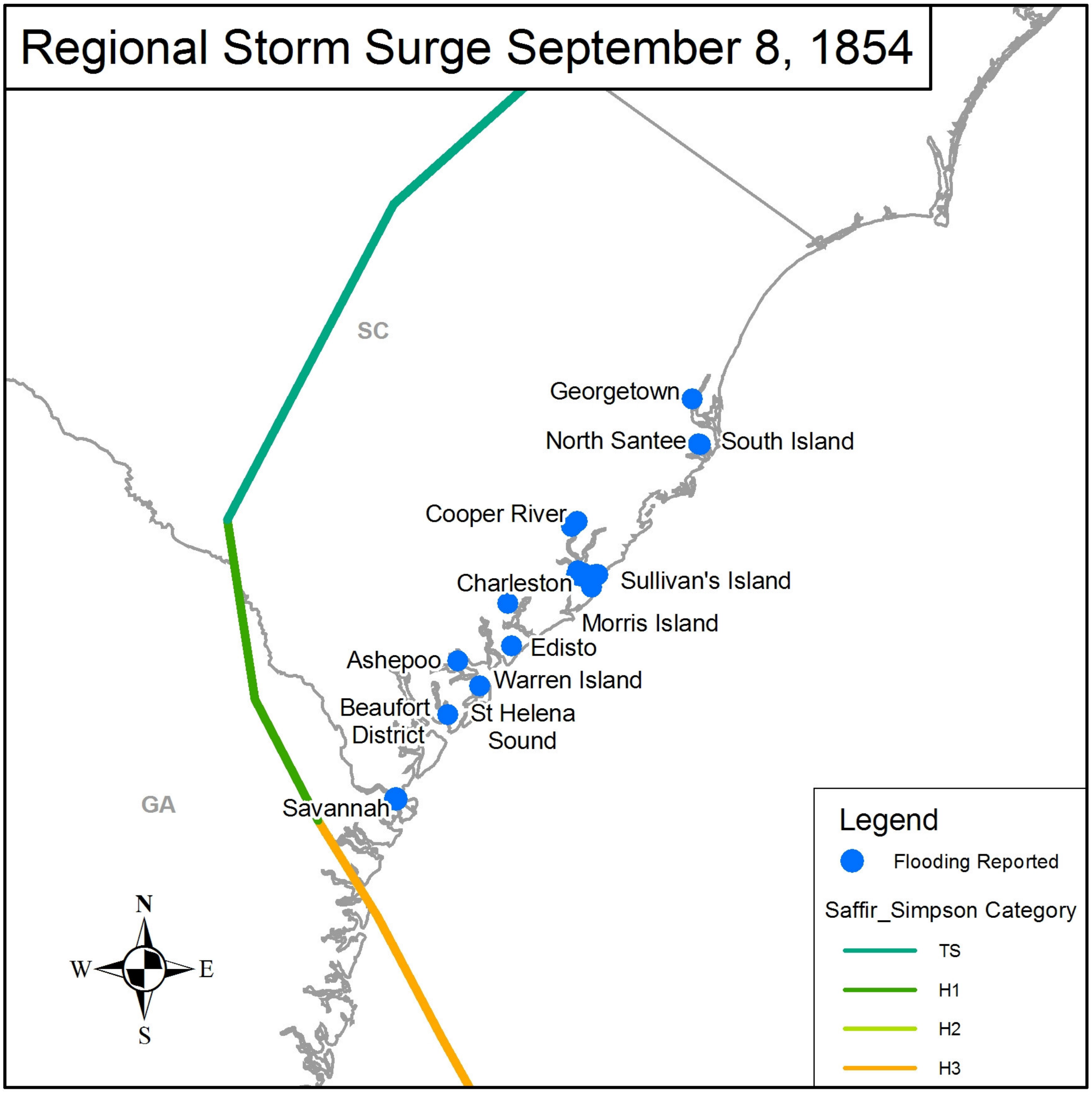


Figure 4.6: Map of reported storm surge flooding. This hurricane brought significant storm surge. Flooding was reported from Savannah to Georgetown. Significant surge was reported as far north as Sullivan's Island. In coastal rivers around Georgetown salt water intrusion was a significant problem that was enhanced by the long duration of this hurricane.

was a Category 3 hurricane with Category 2 impacts in southern coastal South Carolina and Category 1 impacts in Charleston.

4.1.3 August 25th 1885

4.1.3.1 Meteorological Observations and Storm Track

This hurricane is officially listed as a Category 3 hurricane at the time it made landfall near Beaufort, SC. The official best track shows this storm skirting the east coast of Florida in a northwesterly direction and began to curve back to the northeast as it passed the Georgia Coast. The storm made landfall near Beaufort, SC at the mouth of Port Royal Sound traveling north passing over Coosaw near the head of Saint Helen Sound. It turned to the northeast just after landfall and traversed through the Carolinas approximately 16 nm (30 km) west of the coast, until it re-emerged over the Atlantic near Hatteras, NC (figure 4.7). Numerous instrumental observations were taken during this storm, many of which have been previously documented in the *Monthly Weather Review* and by Fernandez-Partagas and Diaz (1996b). The *News and Courier* (August 26, 1885, p. 1) published the official record of the storm as recorded by the US Army Signal Service.

In Charleston the wind began blowing from the east on Monday, August 24th. It continued through the night shifting to the southeast. At daylight on Tuesday morning, August 25th, the wind was coming from the southeast at around 26 kts ($13 ms^{-1}$) with gusts reaching about 44 kts ($22\ ms^{-1}$). At 8:00 AM Tuesday the anemometer was

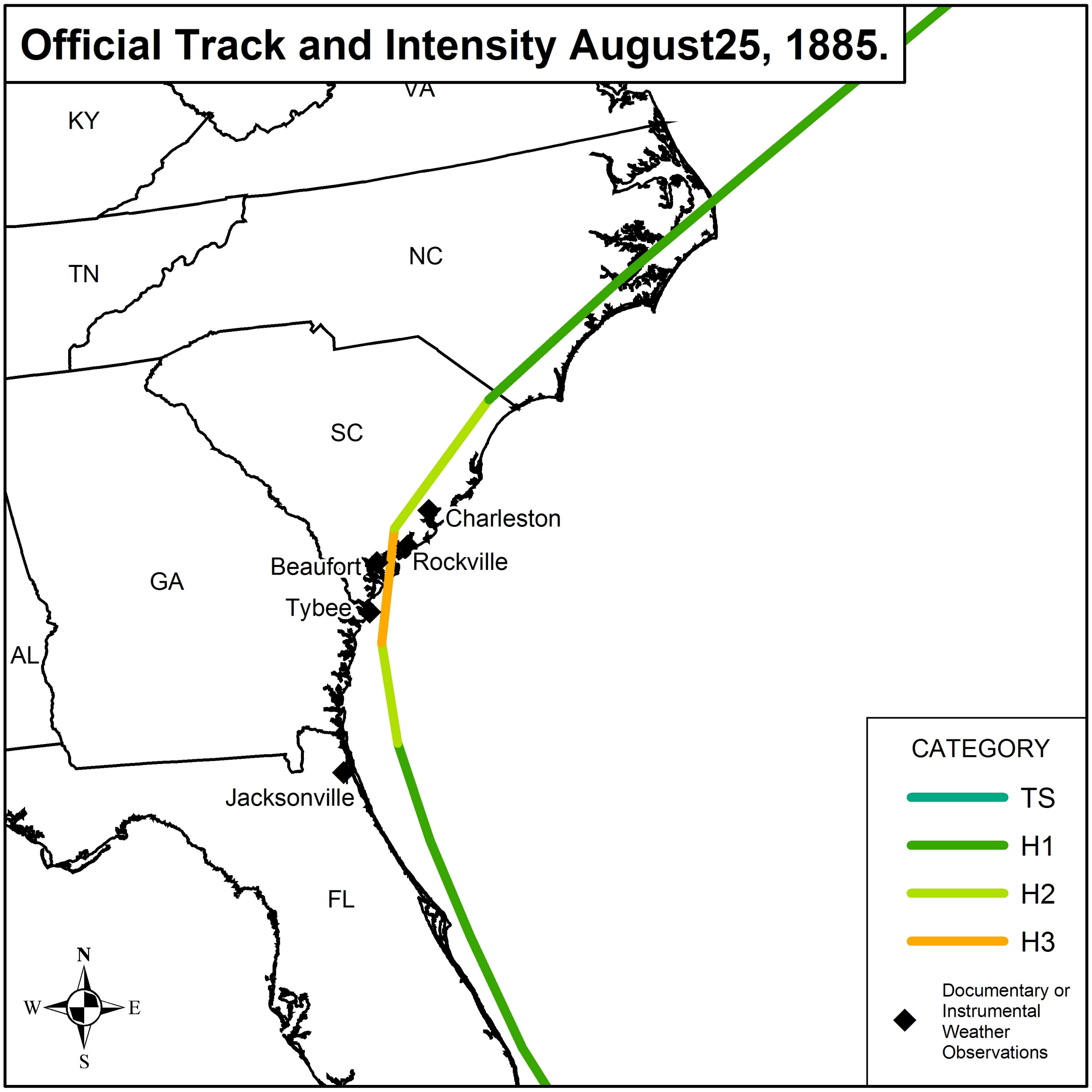


Figure 4.7: Map of selected instrumental and documentary meteorological observations used in this analysis. Based on observations made in Charleston and Rockville it appears that this hurricane made landfall approximately 30 nm (55km) north of the best track and as a significantly weaker storm than its current Category 3 classification.

broken by the wind. The Signal Service observer estimated wind velocities to be about 56 kts (29 ms^{-1}) between 7:30 and 7:45 AM, and 65-70 kts (33-36 ms^{-1}) between 8:00 AM and 9:00 AM. At this time the eye of the hurricane passed over Charleston. The lull lasted approximately 40 minutes. The wind then returned from the west. The lowest barometer reading, 974 mb (28.72 inches), occurred at 9:15 AM. In Beaufort, SC, the winds blew from the northeast and shifted around to the northwest, at which time they were the most intense. At Tybee the velocity of the wind was reported to be 73 kts (37.5 ms^{-1}). Everyone expected to be "blown out to sea," which would indicate a westerly or northwesterly wind.

Residents of Sullivan's Island reported that the wind began to blow from the southeast increasing in strength until around 9:00 AM when it shifted to the southwest and increased to an estimated 60 kts (31 ms^{-1}). No indication was given that the eye passed over Sullivan's Island and no reports of west winds were found, but the highest winds were reported at the time the eastern part of the eye was passing over Charleston. The following observations of wind directions came from the North Edisto River at Rockville, SC:

> **Rockville—Mouth of the Edisto**
> …I went to Edisto and moored in consideration of my passengers. He we felt the full force of the wind, which was blowing great guns. The wind struck us from southeast, and shifting around came on us with ever increasing fury from the east, and then veering again came from the northeast. The heaviest blow was between six and 9 o'clock, when it was blowing at a rate of at least 60 mph. The steamer did not budge from her moorings until the wind shifted to the northwest at 8 o'clock, when we were driven against the wharf, mashing it down…
>
> *News and Courier* Aug 27, 1885, p. 2

This is a report of winds from SE, E, NE, and NW. No indication was given of southwest or west winds, which would have put landfall south of this location. This observer's account of wind direction indicates that the eye of the hurricane passed either to the east or directly over this location. However, given no report of a lull or calming it is unlikely that the eye crossed this location. It was also noted in this account that the wind shifted to the NW at about 8:00 AM. At this time in Charleston the wind was from the southeast and near its maximum velocity. It seems likely that this hurricane made landfall at John's Island between Rockville and Charleston, not at Port Royal Sound as the HURDAT best track suggests (Figure 4.8). The meteorological observations that were found clearly give no indication that this hurricane was a Category 3 storm at landfall. Even in Charleston where HURDAT lists this as a Category 2 storm, the observed wind speeds are well below Category 2 and the barometric pressure values within the eye are only minimal Category 2 values.

4.1.3.2 Wind Damage

The effects of this hurricane along the Atlantic coast were first felt in northeast Florida near Saint Augustine. Damaging winds were reported from Saint Augustine, FL to Wilmington, NC (Figure 4.9). There appears to be a geographic gap in reports of wind damage along the Georgia coast. It is unclear whether this gap is the result of actual lack of wind damage, or simply that wind damage was unreported outside of the local area. The nature of the damage caused by the winds associated with this hurricane is somewhat difficult to assess. Regionally, evidence suggests that the storm made or nearly made landfall near Jacksonville, FL. There was structural damage reported in coastal locations

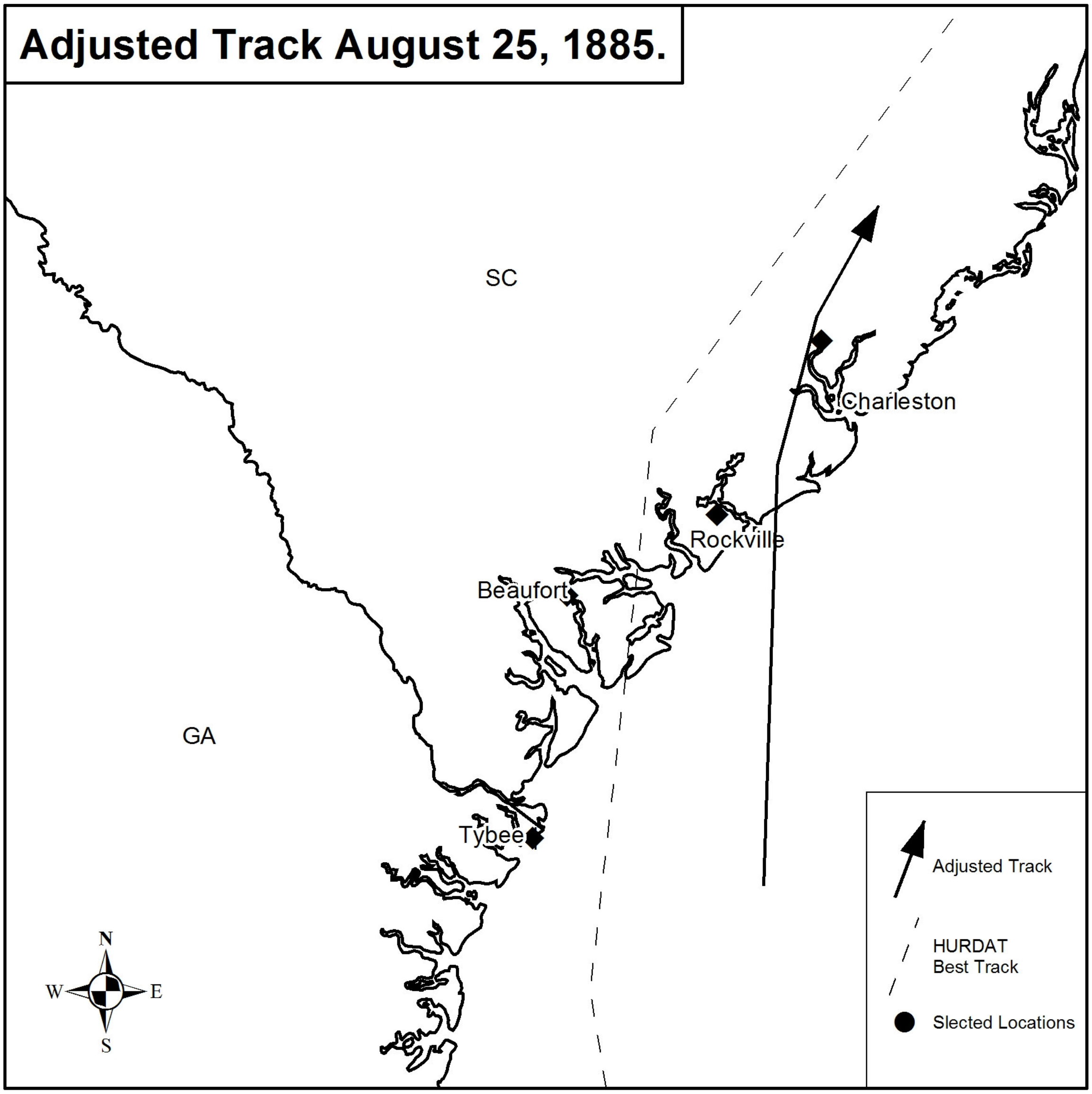


Figure 4.8: Map of suggested landfall location based on instrumental observation in Charleston, SC and descriptive accounts from the mouth of the North Edisto river. This new landfall location is also supported by the lack of severe damage reported in South Carolina south of James Island.

along the north Florida coast. Less significant damage was reported at inland locations, as far west as Lake City and as far south as Palatka.

Isolated severe damage was reported in Saint Augustine, FL. Here the storm was reported to have blown with great fury, turning over a church, blowing a rail car off the tracks and depositing it in the marsh, and littering the streets with sashes, shutters, and doors from houses. In Mayport, one hotel and two houses were blown down and every house was reported to have the roof stripped. The damage at Fernandina was the most severe. Among the damages reported was the destruction of the Colored Man's Hall, a nearly completed residence, a photograph gallery, and a dozen smaller houses. It was also reported that nearly every window on Main street was blown out, and an estimated one hundred small boats in the harbor were destroyed. In contrast to these reports, no damage was reported in the city of Jacksonville, which lies just a few miles inland from Mayport on the St. John's river. The highest wind speed reported in the official record was 35 kts (18 ms^{-1}) from the west. Only a few reports of damage were found for Georgia. The *News and Courier* (August 27, 1885, p 12) reported that there was no damage to shipping or the rice crop in Darien, GA. The first reports of damage in Georgia appear in Savannah, where the damage was slight. In the center of the city little or no damage was done to buildings except in one or two instances. In the outer regions of the city fences were blown down and sheds and outbuildings were unroofed and the siding ripped off. Shrubbery and gardens were broken down, and trees had their branches twisted and snapped. Damage reports from the surrounding communities including Montgomery, Whitebluff and the Isle of Hope were similar to that of Savannah and limited to trees and fences, with no damage to structures reported. At Tybee, where the

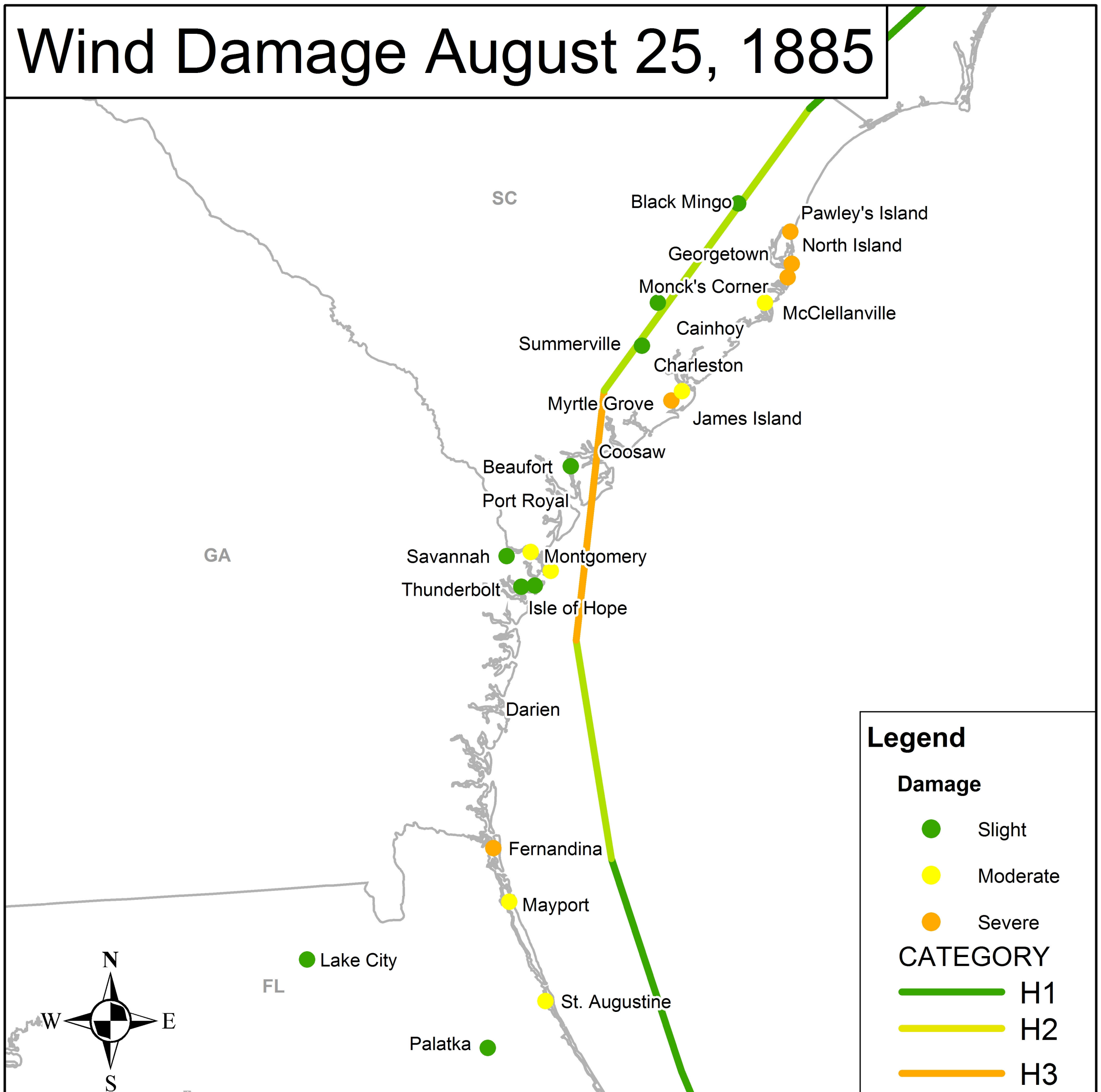


Figure 4.9: Wind damage map from the hurricane of August 25th 1885. Wind damage patterns show a very limited inland extent of damage. The majority of severe and even moderate damage occurred along the coast. No area in the path of this storm suffered widespread damage. Most accounts of severe structural damage were isolated. Evidence of possible tornadic activity was found from Charleston to Georgetown.

wind was reported to have blown at 73 kts (37.5 ms^{-1}), the only report of damage was that of a summer residence being blown down.

In South Carolina wind damage was generally slight south of Charleston Harbor. North of Charleston Harbor the damage reported was more severe, but generally isolated. The majority of reported structural damage occurred in beach front communities or to beach front residences. Damage reports from locations that were not on the beach front were typically less severe. This hurricane also appears to have generated tornadic activity as it traversed the coastline.

In Port Royal and Beaufort wind damage was limited primarily to trees, fences, signs, and fixtures. On James Island, just south of Charleston, the damage was a little more severe. Numerous reports of damage to outbuildings and negro houses came from James Island. There were four reports of damage to houses, including the unroofing of one house in Sessionville and one at the quarantine station, and the loss of piazzas on two other houses in Sessessionville.

In Charleston the damage increased in severity, but was still generally of a non-structural nature, with isolated reports in the city of structural damage. There was widespread damage to trees, fences, and roofs in the city. Charleston is the southern-most location that includes a description of possible tornado damage:

> "Many trees were blown down and snapped off in Charleston. The trees were blown down in opposite directions. Eye witnesses claim the trees blew down at the same time, indicating a rotary motion of the wind."
>
> *News and Courier* Aug 26 p. 2

The reporter also noted that on Beaufain street and others many trees were uprooted and branches snapped, but no material damage was done to the structures lining the street.

Damage on Sullivan's Island was severe. It could not be clearly determined what portion of the damage resulted from the wind and what portion resulted from flooding, as most of the island was flooded at the height of the storm. The wind did inflict significant damage as indicated by reports of piazzas being torn from houses and deposited on the roofs of other structures, windows and sashes being blown out, and one report of the upper story of a house being completely removed. One interesting note is that the *News and Courier* reported that residents of the island claim that all of the wind damage on Sullivan's island was done while the wind was from the southeast. Similar observations were reported in Charleston. At Mount Pleasant, on the north side of Charleston Harbor, the only damage reported was to the shade trees in town. No significant structural damage was reported in this town.

Farther inland at Monck's Corner, Summerville, and Holly Hill, very little damage was reported. These communities lie almost directly in the path of the official best track for this hurricane. All three communities reported some trees and fences blown down, but no damage done to houses.

In McClellanville, about 22 nm (40 km) north of Charleston on Bulls Bay, the damage reported included minimal damage to structures. Two houses were reported to have blown off their blocks. The remaining damage reports included the destruction of outbuildings and fences, and trees being blown down. In this area more accounts of tornado-like damage were reported. All around Bulls Bay, the Santee, and Winyah Bay were reports of significant damage to the turpentine forests.

> "Capt. Leleand says that the damage done to the turpentine business is of incalculable extent. The pine forests around Mclellenville section have suffered severely and thousands upon thousands of trees have been prostrated, and in one place a track was cleared out through the woods like the path of a tornado."
>
> *News and Courier* Aug 28th, 1885, pg 2

> "On the Santee the turpentine forests were in some places entirely destroyed. I am told in some places that a person can walk five miles from tree to tree without stepping on the ground.
>
> *Georgetown Enquirer* Sept 16th, 1885, pg 2

In the city of Georgetown, the damage was minimal. Damage reports were limited to the peeling of tin off roofs and to trees and fences being blown down. The *Georgetown Enquirer* focused most of its reports on Charleston, with very little mention of damage in Georgetown. One correspondent to the *News and Courier* (August 28, 1885, p. 2) reporting from Georgetown remarked that there was no damage done to any of the islands in the area, and doubted that much crop damage had occurred. The lack of severe damage that occurred in Georgetown and the contrasting reports of severe damage done to parts of the forest suggest that there was a possible outbreak of tornadoes associated with this hurricane. Significant damage was noted only in coastal areas in the quadrant of the storm that produced on shore winds. Wind damage analysis supports Category 2 impacts in South Carolina and low Category 2 or high Category 1 impacts in Charleston. Wind Damage patterns associated with this storm generally support a more northerly landfall location as suggested by the accounts from Rockville and Charleston.

4.1.3.3 Flooding

The only location that reported significant flooding was the area around Charleston Harbor (Figure 4.10). Flooding is this area was more notable because it came during high tide. Even coupled with high tide, the extent of flooding was indicative of minimal to moderate Category 2 storm surge values. Regionally, flooding was of very little significance.

Fernandina, FL reported high tides with waves crashing over the beach. Savannah reported water running over the wharves at around 4:00 AM. Flooding was reported in and around Port Royal Sound, including Beaufort, Port Royal, and Coosaw. Beaufort was the only community that reported damage to houses caused by flooding. All reports of flooding south of Port Royal Sound were limited to wharf damage and the grounding of boats in surrounding marshes.

On James Island, just south of Charleston, all of the bridges and connections were washed out during the storm and the cotton crop on the farm of Henry Grimball was damaged by salt water (News and Courier August 28, 1885, p. 2). In Charleston, the water in the harbor was almost level with the wall of the battery allowing the waves to flow over the wall. Several houses along the water front were flooded and most of the wharves and piers were damaged. At Sullivan's Island during the height of the storm most of the island was under water. Farther north between McClellanville and Georgetown reports of flood damage included a few sloops driven ashore and many bridges being swept away. No other flood damage was reported, indicating minimal

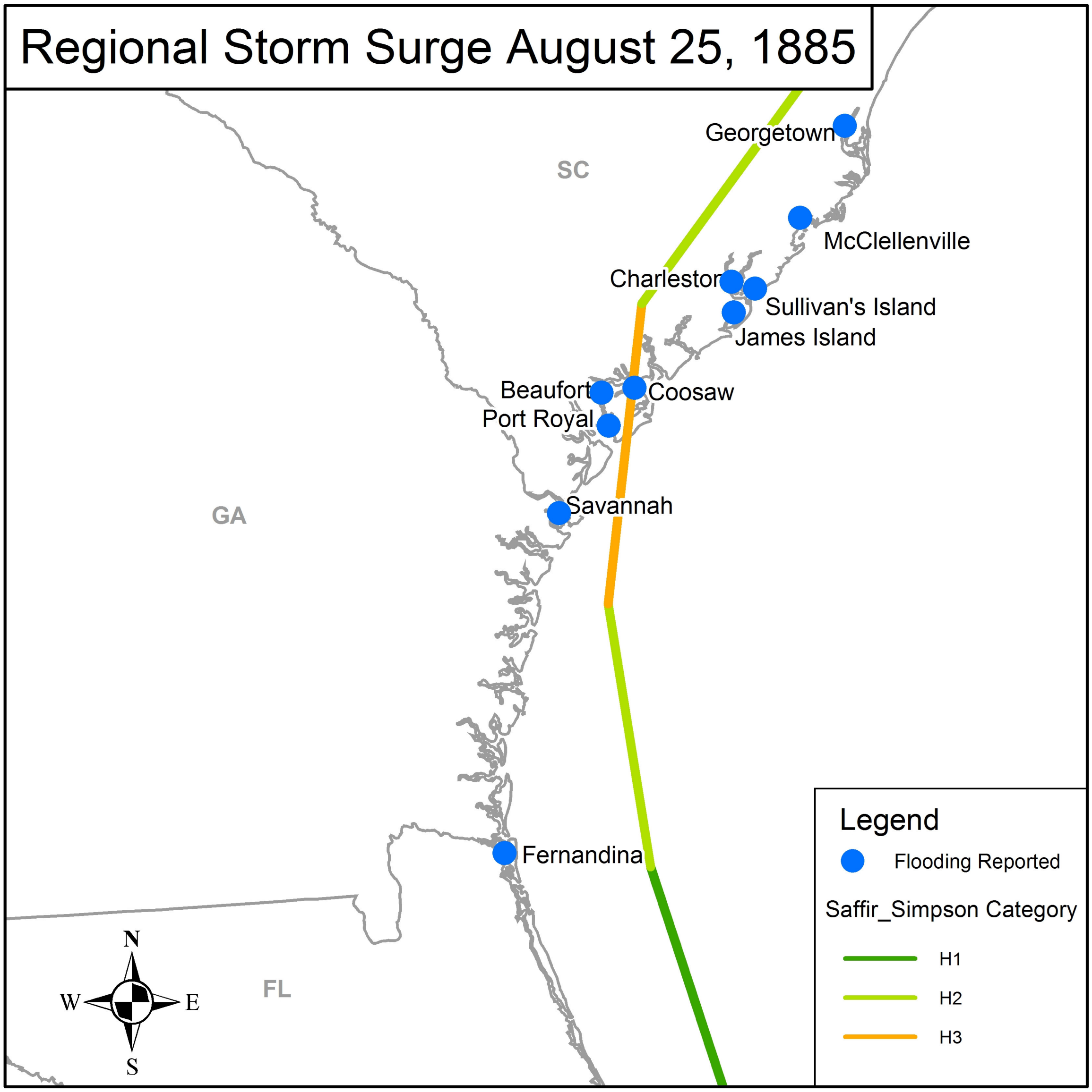


Figure 4.10: This hurricane produce minimal flooding from Florida to South Carolina. Most significant flooding was reported around Charleston Harbor on James Island, Sullivan's Island, and in Charleston. Maximum flooding reported was consistent with a weak Category 2 hurricane.

storm surge between Charleston and Georgetown. Of particular note in this hurricane was the absence of damage reported to the rice crop. In many nineteenth century hurricanes, typically damage to the rice crop occurs when there is widespread flooding and salt water penetrates coastal rivers and creeks (Rogers 1970). The lack of significant coastal flooding supports the notion that this hurricane was not a Category 3 storm at the time of landfall. Unfortunately, historical elevations for Sullivan's Island and other coastal communities were not located, but modern surge models (based on modern bathymetry and topography) predict that Sullivan's Island would be entirely underwater in a Category 2 storm surge.

4.1.4 August 28th, 1893

4.1.4.1 Weather Observations

This hurricane is known as the Great Sea Islands hurricane. Officially listed as a Category 3 hurricane at landfall, this storm has great historical significance on the state of South Carolina (Edgar 1998). The official track shows this storm making landfall just south of Savannah, GA (Figure 4.11). Damaging winds were felt along the entire southeastern coast from central Florida to Wilmington, NC. Storm surge flooding was reported from Saint Augustine, FL, to Georgetown, SC. This hurricane killed over 1000 people and left 30,000 more homeless on the Sea Islands of Georgia and South Carolina. Damaging winds were experienced throughout the entire state of South Carolina as this storm traversed a path from south to north through the center of the state. This storm was still strong enough to cause tree damage as it passed near Washington, DC. The

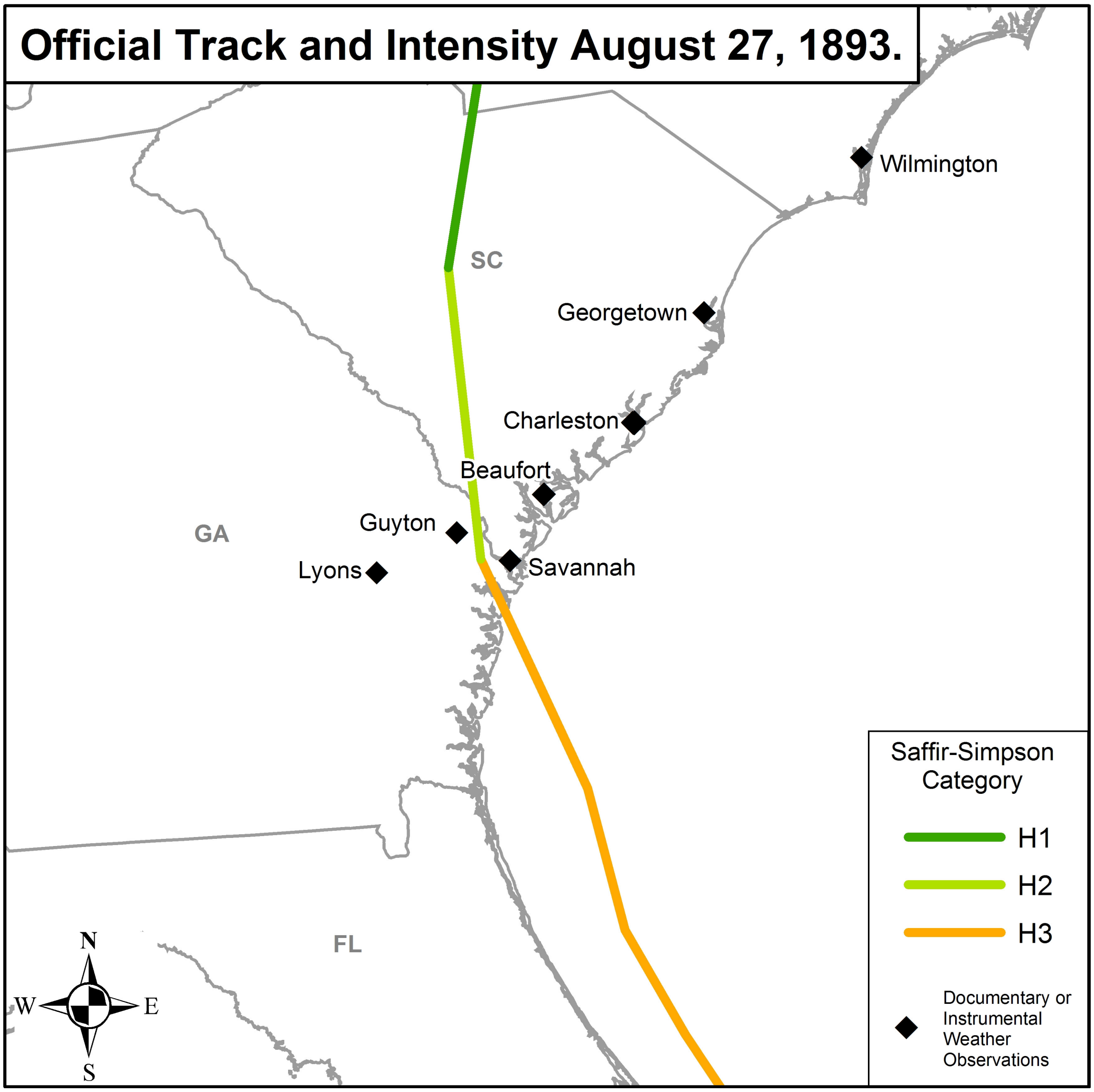


Figure 4.11: Map of official HURDAT storm track and intensity and selected locations reporting meteorological conditions during the hurricane of August 27th 1893.

Georgetown Semi-Weekly Times (September 2, 1893, p. 1) reported that the wind reached 66 kts (34 ms^{-1}) in Savannah. The weather Bureau observer in Savannah reported that the wind attained a maximum velocity of 63 kts (32.5 ms^{-1}) from the northeast between 11:37 PM and 11:42 PM and the barometer dropped to 959.8 mb (28.31 inches) at midnight. The center of the storm passed over Savannah taking approximately one hour. When the winds returned, they came from the south. At Lyons, GA the winds began from the northeast and shifted to the north where they blew with great intensity until about 1:00 AM. In Guyton, GA the winds increased in intensity until around midnight. They subsided for a short time and then returned with similar intensity. These two accounts support the current best track estimate.

One account from Beaufort was published in *The State* that reported a wind velocity of 113 kts (58 ms^{-1}) at around 3:00 AM. In Charleston the Weather Bureau weather record that was published in the *News and Courier* reported that the wind blew at a velocity of at least 56 kts (29 ms^{-1}) for about 4 hours from 8:30 PM until just after 12:30 AM when the winds reached a velocity of 83 kts (42.5 ms^{-1}) and gusted to 104 kts (53.5 ms^{-1}). The barometer reached a low of 985.7 mb (29.076 inches) at 1:50 AM. A reporter for the *News and Courier* who was out at the height of the storm stated that at 12:45 AM a person could not stand at all if they were exposed to the winds off the bay.

Georgetown first experienced winds from the northeast that shifted to the south at about 5:00 AM. From that point it slowly changed to southwest as the hurricane traversed north into North Carolina. All of the observations generally support the information in HURDAT. The 113 kt (58 ms^{-1}) wind speed in Beaufort and 104 kts (53.5 ms^{-1}) in Charleston are most likely wind gusts, and were not sustained winds. However, 113 knots is a maximum velocity for a Category 3 hurricane, and it was noted in Charleston that the winds were greater than in 1885, even though the damage was not nearly as great.

4.1.4.2 Wind damage

Wind damage associated with this hurricane was widespread and severe (Figure 4.12). As far south as Saint Augustine there were reports that roofs were stripped, in Mayport, FL it was reported that many of the buildings were damaged, and from Jacksonville came reports of roofs being stripped, and trees and signs being blown down.

In Georgia, damage was reported as far west as Waycross, where several small buildings were blown down, and as far inland as Midville and Augusta, GA. In Midville damage included blowing down of trees, fences and small outbuildings. In Georgia moderate damage was generally reported within 50 nm (93 km) of the current best track. All of the accounts of major damage in Georgia came from the Savannah area, including Tybee Island. In both locations buildings were blown down and great numbers of trees were uprooted.

In South Carolina damaging winds were experienced from Beaufort to Horry county along the coast and as far inland as Greenville and Spartanburg. Severe damage was experienced in coastal communities as far north as Sullivan's Island. Moderate damage was experienced along the coast from around Charleston Harbor to Long Bay and along the path of the hurricane as far inland as Orangeburg and Elloree, SC. In Beaufort and Port Royal few houses were left undamaged. Both brick and wooden houses were unroofed and demolished. Further west in Ridgeland houses and

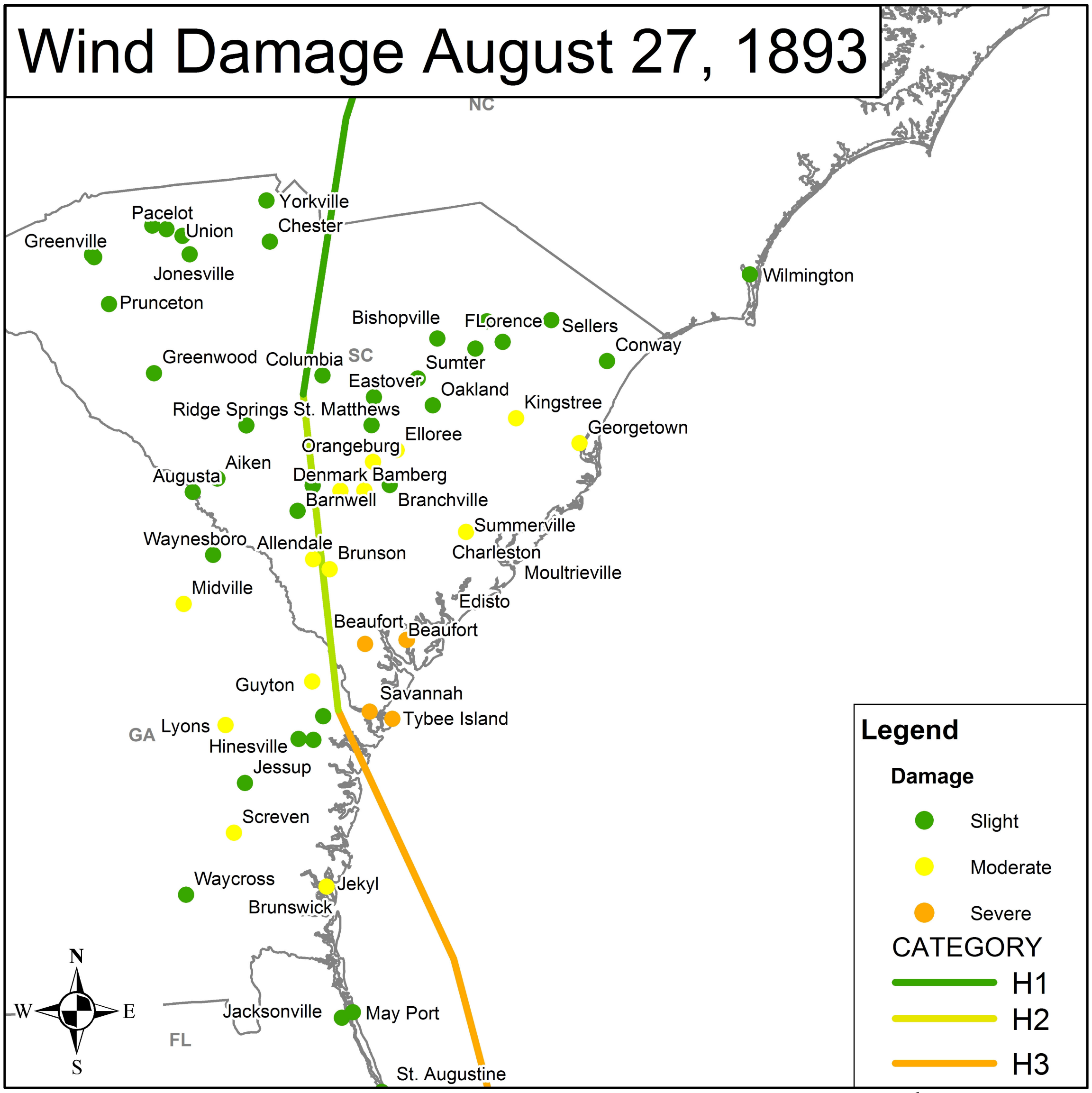


Figure 4.12: Map of winds damage caused by the hurricane of August 27th, 1893. This hurricane brought widespread damage to the entire state of South Carolina. Widespread severe wind damage was found just north of the landfall location. A wide belt of moderate damage extends along the Carolina coast to Georgetown and inland along the storm track to near Orangeburg. Slight damage was experienced throughout the State.

outbuildings were blown down. On Edisto Island, houses, outbuildings, and trees were all blown down. The damage caused by the force of the winds in this region was clearly in the Category 3 range.

In the vicinity of Charleston harbor the wind damage was less extensive and less severe than along the southern coast. On Sullivan's Island, there was limited reporting of damage attributed to the wind. This is likely due to the extensive damage that resulted from storm surge. Charleston reported trees blown down and branches broken. Damage to structures was generally confined to roof damage. In Mount Pleasant, the damage back from the water was slight and limited to the overthrow of trees and fences.

Along the track of this hurricane, as far inland as Orangeburg, SC there were reports of severe damage. In Brunson, trees, fences and outbuildings were blown down; in Allendale a large number of shade trees were blown down; in Denmark, a large number of pine trees was blown down and many farmhouses were destroyed; in Bamberg, a large number of trees were blown down and structures were damaged; and in Orangeburg, winds leveled trees, fences, outbuildings and some houses.

Slight damage was reported across the entire state, from Conway in the east to Spartanburg in the west. These reports included damage to crops and some outbuildings and trees being blown down. The overall pattern of damage associated with this hurricane supports current Category 3 classification at landfall. A large area of widespread severe damage is evident in the right front quadrant of the storm. Severe wind damage occurred in coastal areas up to about 45 nm (84 km) from the estimated storm center at landfall. The area with widespread moderate damage extends about 85 nm (157 km)from the storm center in the right front quadrant, on the back side of this hurricane areas of widespread moderate damage are limited to about 40 nm (74 km). These damage reports suggest that this was a very large and intense hurricane. Damaging winds were reported as far away as Wilmington, NC, which was never closer than 140 nm (260 km) from the storm center.

4.1.4.3 Flooding

The storm surge associated with this hurricane was wide spread. Storm surge flooding was reported for 232 nm (430 km) from Georgetown, SC, to Saint Augustine, FL (Figure 4.13). Over 1000 people were drowned in the storm surge on the Sea Islands of South Carolina.

Flooding south of Savannah was generally slight. St. Augustine reported water coming over the sea wall. In Brunswick, the streets were flooded and several boats were reported beached on Jeckyl Island. No significant damage was reported as a result of flooding on this side of the storm.

Accounts become much more severe around Savannah. At Tybee during the height of the storm the water was six feet deep on the island. On Hutchinson island, opposite Savannah in the Savannah River, the water was seven feet deep. In parts of Savannah near the wharves the water was 6-8 feet (2-2.5 m) deep. Throughout this area were reports of houses being washed away, piers and wharves being destroyed and ships driven ashore.

Flooding in the Port Royal Sound covered Parris Island, Warsaw Island, Coosaw Island, and Lady’s Island. In Beaufort, the wharves and waterfront areas were badly damaged or destroyed. One account estimated the tides to be greater than 8 feet above

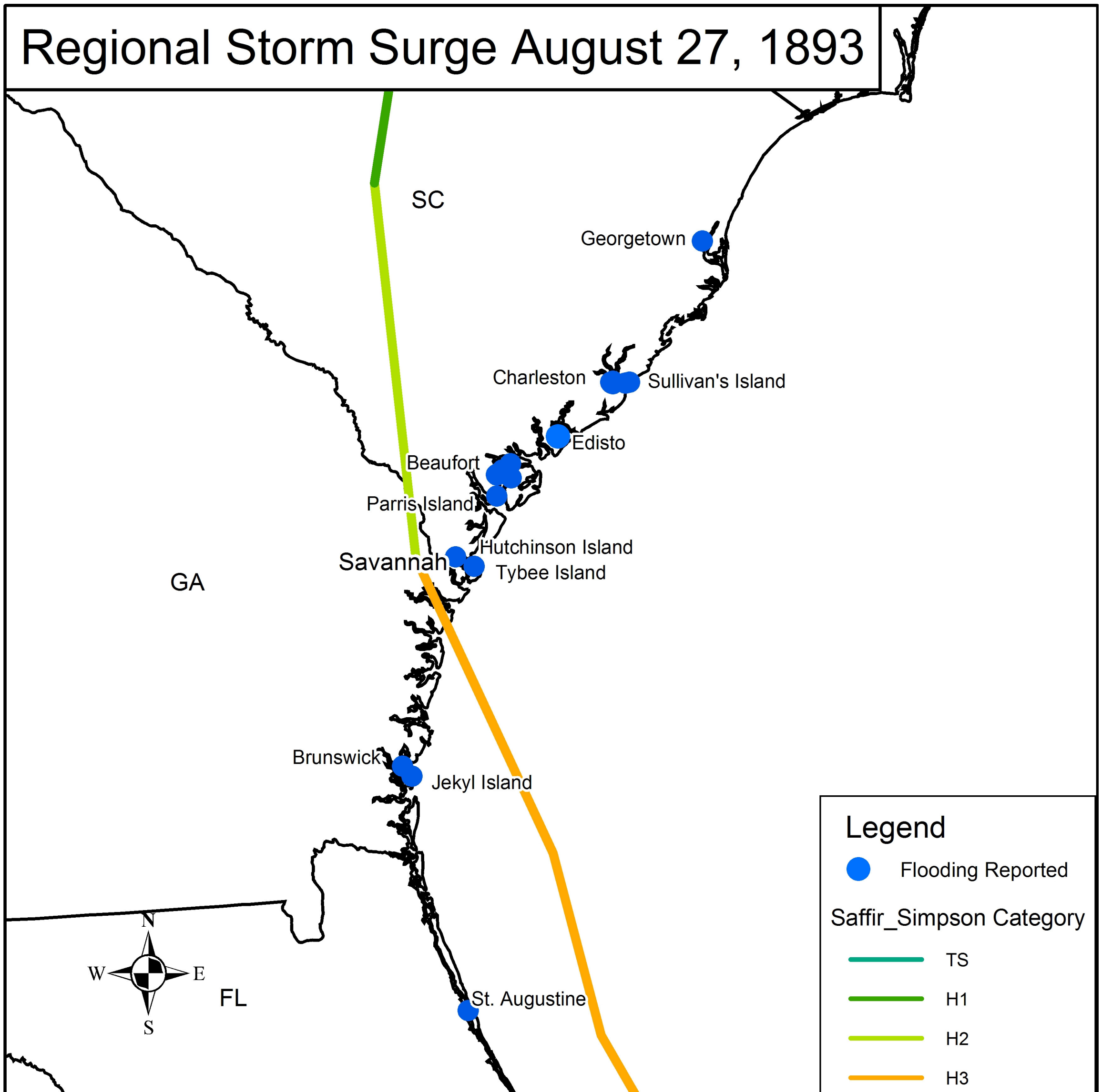


Figure 4.13: Map of regional flooding associated with the hurricane of August 27th 1893. Significant flooding was caused by this hurricane. Along the coast just north of Savannah over 1000 resident were killed in the flooding that accompanied this hurricane. Some reports from Edisto had the water as high as 18 feet (5.5 m) above normal.

Spring tide level, another estimated that the tide rose six or seven feet. The majority of the islands in this region are subject to inundation in the event of Category 2 storm surge, a fact that contributed to the great loss of life that occurred here.

On Edisto Island the agricultural land was submerged. Reports from the Wappoo cut estimated that the storm surge in this area was 18 feet (5.5 m):

> "The water in Wappoo cut is said to have reached all points eighteen feet above water mark and spread itself over the surrounding country like an endless inland lake. For two days communication between the island and the mainland was practically suspended. . ."
>
> *News and Courier*, August 30, 1893 pg 2

If accurate, this could mean that this hurricane was closer to a Category 4 hurricane. Similar maximum values for storm surge were calculated by the Army Corps of Engineers around Savannah Beach (Fernandez-Partagas and Diaz 1996). However, in light of central pressure reading taken by the weather bureau in Savannah, which was in the center of the storm, it is unlikely that storm surge was in the high Category 4 range.

Charleston reported significant flooding in the city. During the height of this storm much of the western portion of the city was under water. On the battery the water was over the sea wall leaving just the railing exposed. It was mentioned that the wall was rebuilt following the 1885 hurricane to withstand similar storms, and the surge in 1893 overtopped the wall.

In Winyah Bay, salt water was pushed 24 nm (45 km) up the Waccamaw river and 22 nm (41 km) up the Pee Dee River. In Georgetown, the tide flowed into some buildings along the water front damaging some merchandise. The peninsula opposite the town was entirely under water.

Storm surge reports and damage clearly support this storm being classified as a major hurricane with Category 3 impacts in South Carolina and it is possible that some areas in coastal South Carolina between the Savannah River and Edisto Island experienced Category 4 impacts. Category 2 impacts were experienced farther north along the coast to about Sullivan's Island, and Category 1 impacts were experienced through Georgetown and Horry counties.

4.1.5 October 13th 1893

4.1.5.1 Meteorological Observations and Storm Track

Very little is known about the Category 3 hurricane that made landfall on the central south Carolina coast on October 13th, 1893. The southern coast had been devastated 6 weeks previous by the Sea Islands hurricane, and recovery and relief efforts were still underway. Local sources published limited information about this powerful hurricane. Officially listed as a Category 3 storm in HURDAT, this storm moved toward the South Atlantic coast from the southeast passing just north of the Bahamas. It proceeded on a northwestern path that brought it within 40 nm (75 km) of the central Florida coast. It curved to the north following the contour of the coast until making landfall near the north end of Bull's Bay (Figure 4.14). From that point it traveled nearly due north through NC, VA, and PA.

The limited meteorological information available for this storm suggests that it was a very compact hurricane. The lowest pressure recorded at Charleston was 996 mb (29.43 inches), and at Savannah it was 1002 mb (29.60 inches). Wind speeds in Charleston did not exceed 56 kts ($29 ms^{-1}$) and shifted between the north and east. In

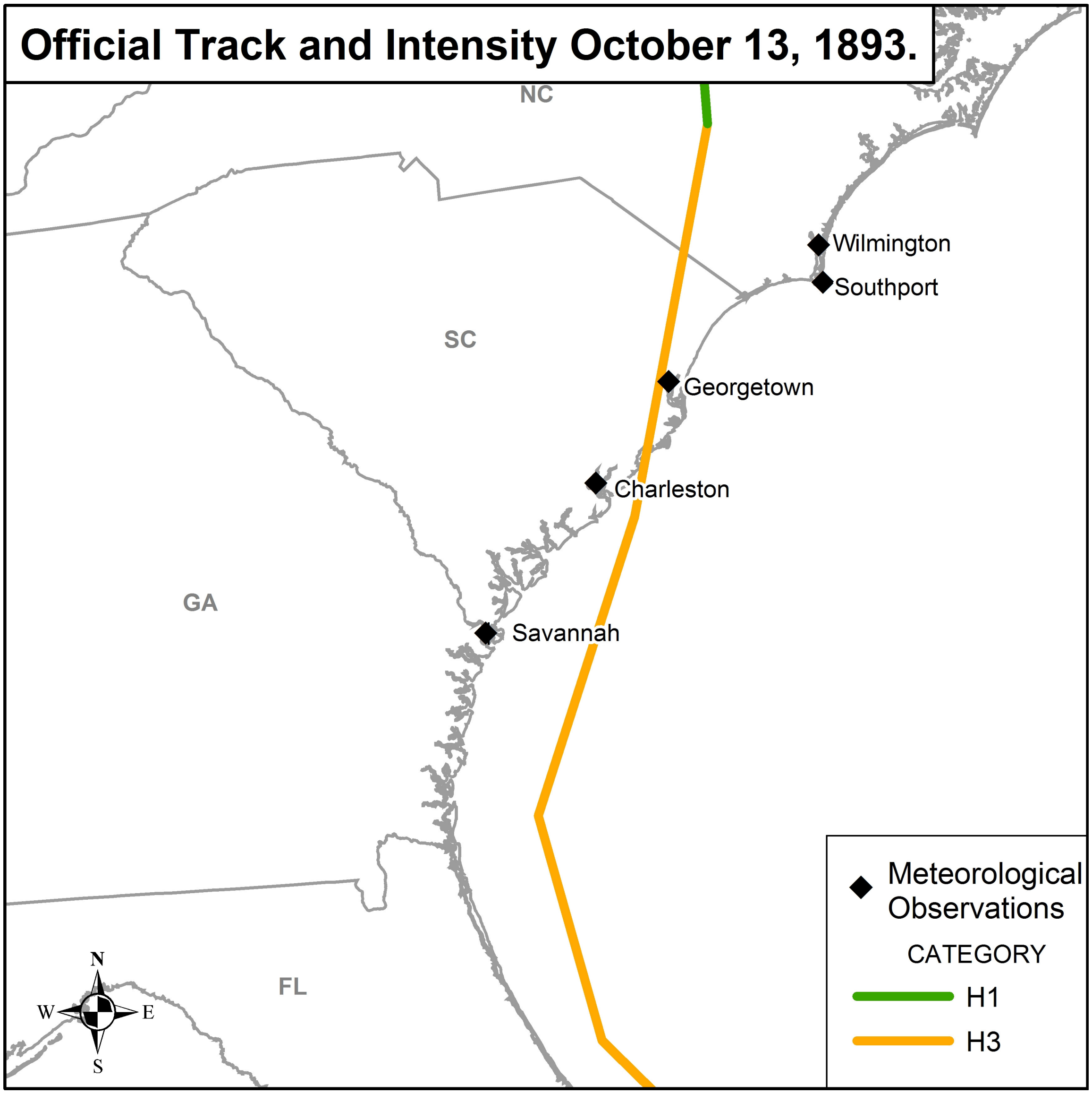


Figure 4.14 : Map of official hurricane track and intensity from HURDAT and locations of meteorological observations.

Savannah the highest winds were out of the east at about 35 kts (18ms^{-1}); in Wilmington 33 kts (17ms^{-1}). No official record was available from Georgetown, however the newspaper reported that the wind blew with great intensity from the northeast for a while followed by a calm period. After a short time the winds came back out of the southwest. However, another account from Georgetown published in *The State* (October 16, 1893, p. 1) has the wind coming first from the northeast, then calming for about 15 minutes and returning with equal velocity from the northwest. Because the exact location that each of these observers witnessed the storm is unknown, both accounts could support the best track estimation in HURDAT. In South Port, NC the wind attained its greatest velocity when at the south. The velocity that was reported by the *Southport Ledger* and reprinted in the *Horry Herald* (October 26, 1893, p. 1) was 82 kts (42ms^{-1})with gusts of 100 kts (51ms^{-1}). The lowest barometer reading in Southport was 981mb (28.96 inches). The wind observations from South Port appear to be anomalously high in light of the published wind observation from Wilmington. Unfortunately, no record from Georgetown was located and wind speeds and barometric pressure from this location are unknown. This information would be very valuable because the eye passed directly over this city.

4.1.5.2 Wind Damage

Specific accounts of wind damage associated with this hurricane were very few. In Charleston, electric, telephone and telegraph lines were blown down, and one tree was blown down across Water street (Figure 4.15). Damage in Charleston was very minimal. In Conway, several shade trees were blown down and one building

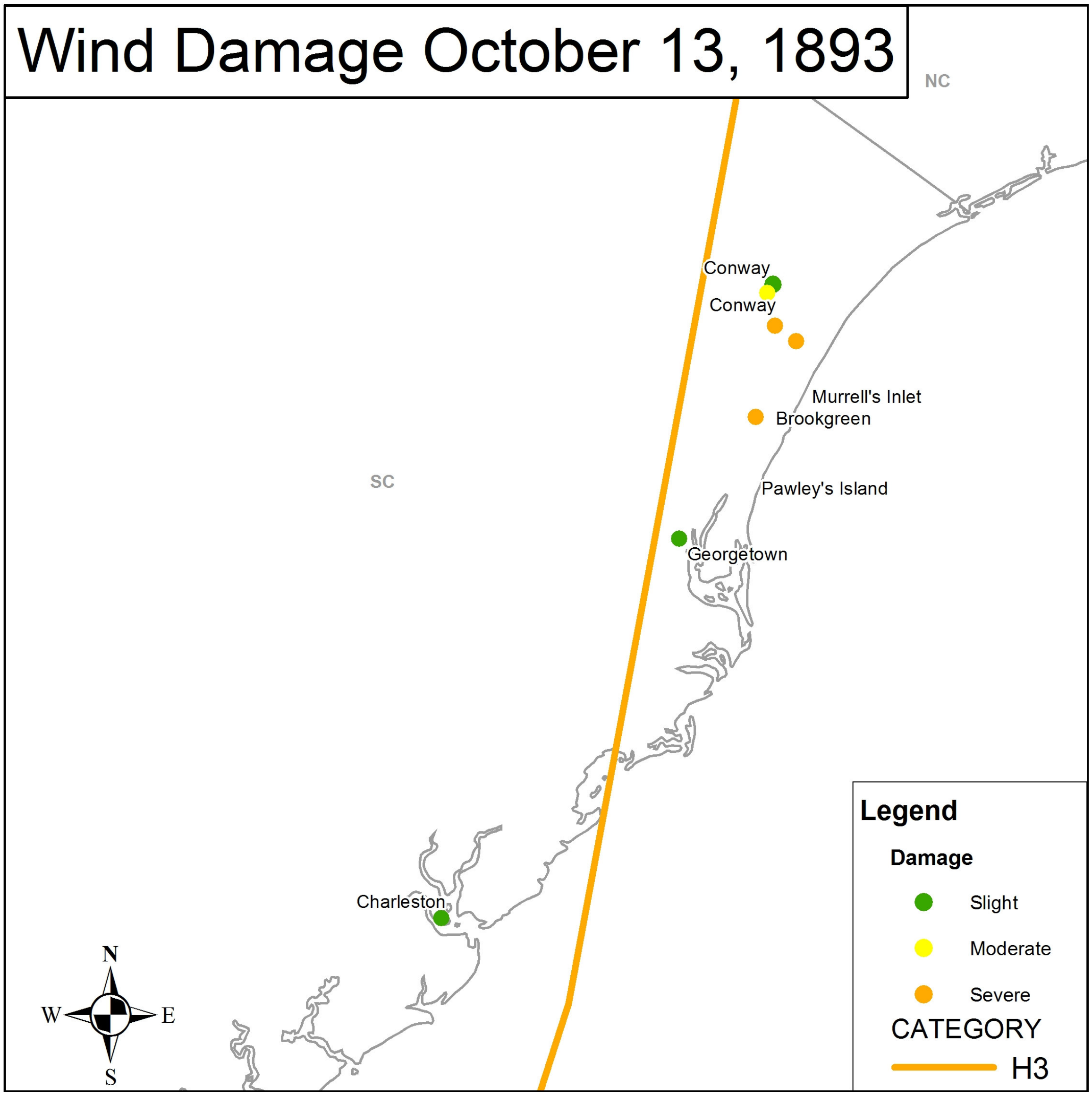


Figure 4.15: Map of wind damage during the hurricane of October 1893. Very little wind damage was reported from this hurricane and no accounts of widespread damage were given. Damage that was documented was generally isolated and severe.

was blown off its blocks. Between Conway and Murrell's Inlet, five churches were destroyed by the wind.

In Georgetown, the *Georgetown Semi Weekley Times* (October 14, 1893, p. 1) reported only that two stills on the peninsula were badly damaged and trees and fences were blown down throughout the region. Many accounts of this storm compare the winds of the October hurricane with those of the August hurricane. There seems to be very little evidence supporting a Category 3 classification of this storm however, based on the wind damage. The effects of this storm in Charleston do not appear to be much greater than tropical storm status.

4.1.5.3 Flooding

Flooding was reported from Charleston to Wilmington (Figure 4.16). In Charleston flooding was generally slight with the part of town around the battery and the western parts of the city had about one to two feet of water in the streets. These areas and water depths are typical of Category 1 impacts. In the city of Georgetown, the water was deep enough to flood stores and businesses on the opposite side of the street from the water front. In general, flooding in Georgetown was not considered to be very bad at the time with estimated water depths to be in the 1 to 4 feet (1 m) range along the waterfront. Newspaper reports compared flooding that occurred during the October hurricane to the flooding that occurred during the August hurricane when the water was 1 to 2 feet deep in the streets along the water front.

Major damage was caused by the storm surge from South Island to Magnolia Beach and Murrells Inlet. Nineteen people were drowned in these coastal communities.

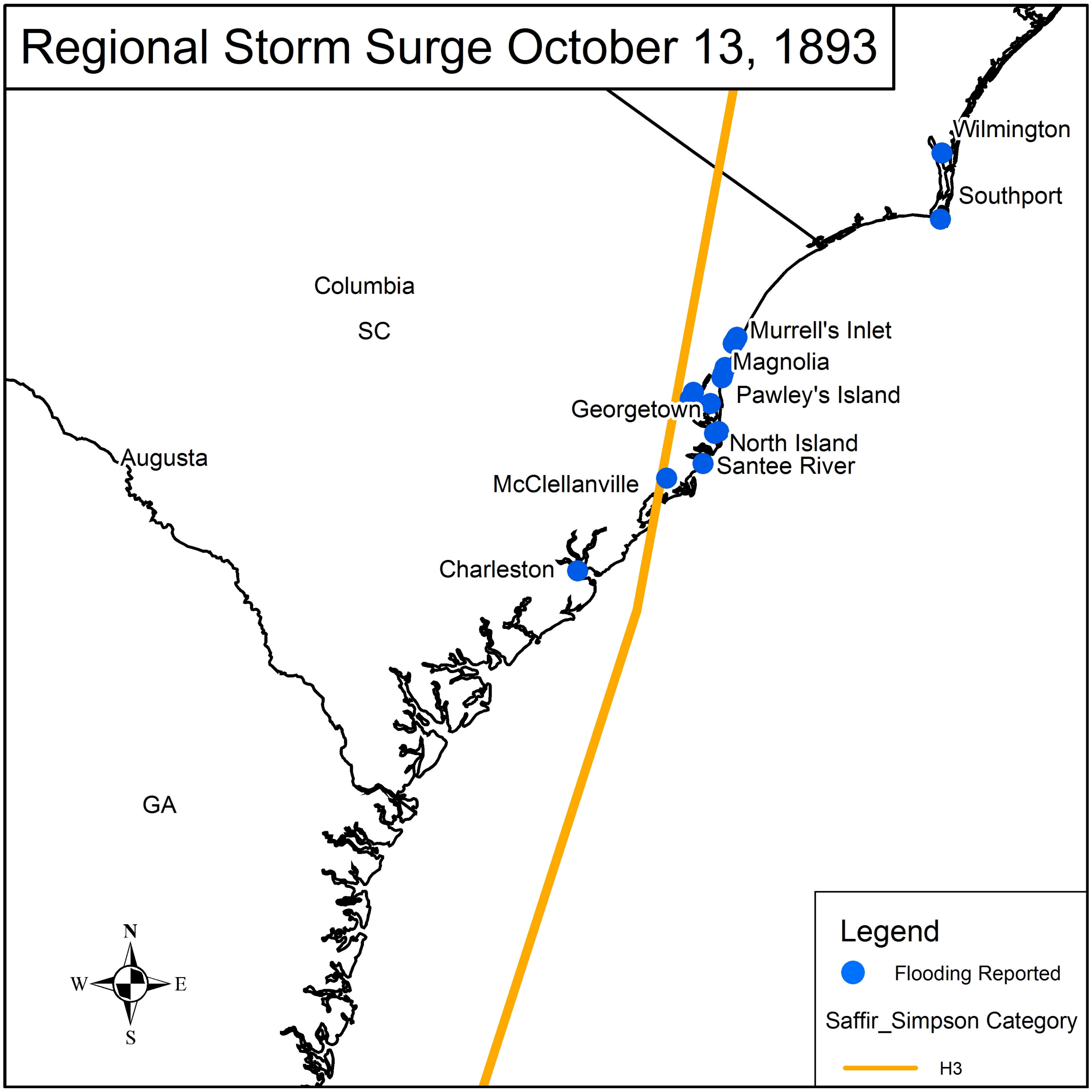


Figure 4.16: Map showing locations where storm surge flooding was reported during the hurricane of October 1893.

On Pawley's Island one survivor's account estimated that the water on the north end of the island was 14 feet above the ordinary tide. However, another correspondent to the *Georgetown Semi-Weekely Times* (October 14, 1893, p. 1) estimates that the water had risen just 5 feet (1.5 m) and stood 2 feet (.6 m) deep in many homes. Another account from Pawley's Island estimates the surge to have been 5.75 (1.75 m) feet higher than it was in August. At Magnolia, near Murrells Inlet the tide was 6 feet (2 m) higher than during the August hurricane. This is where the greatest loss of life and property occurred. Most of the beach front houses were swept away entirely and the few that were left were very badly damaged. One story published in *The State* (October 16, 1893, p. 1) stated that the general elevation of this beach is only about 1 foot (.3 m) above high water level. It is difficult to determine the actual height of storm surge associated with this storm, however most accounts suggest that it was somewhere around 2 meters. The surge did cause significant damage to beach front structures from Winyah Bay to Murrells Inlet, and caused significant coastal erosion in this area.

Overall it appears that this storm was a Category 3 hurricane in light of the Category 3 type surge heights that were reported. There are several possible reasons that this storm did not appear to cause significant wind damage: it struck a portion of the coast that is generally less populated; or the structures and vegetation that was subject to damage by strong winds had already been damaged or blown down during the August hurricane. However, this storm likely had Category 3 impacts on a very small portion of the coast. In Charleston the impacts were consistent with a Category 1 or weaker tropical cyclone.

4.2 Local Analysis

This section examines the extent of flooding in the city of Charleston, SC during three of the hurricanes in this study and wind damage from the hurricane of 1885. The hurricanes of September, 1822 and October, 1893 were not included in local analysis because of the very limited flooding reported in Charleston during these hurricanes. This part of the research used higher resolution data from the city of Charleston that could be mapped at the block level. By working at this scale, highly accurate maps depicting observed flooding in Charleston were generated. These maps were then overlaid and compared to storm surge models for the Charleston area. This chapter shows the results of these comparisons for the hurricanes of September, 1854, August 1885, and August, 1893. Examining storm surge at the local scale also illustrates how hurricanes of different intensities and sizes that come ashore over a large geographic area can have similar and significant impacts at the local level.

4.2.1 *September 8th, 1854*

Flooding in the city of Charleston during the hurricane of September 8, 1854 was significant. Extensive damage was done to the wharfs, piers, and the accompanying store houses along East and South Bay streets. The Battery sea wall also suffered significantly with much of the structure being completely washed away. Floodwaters were about level with the top of the wall, and estimated to be 4 feet (1.25 m) deep in East Bay street. The location of many of the reports of flooding came from areas that were near the border of expected Category 1 and 2 storm surge. Two reports, however, are strong evidence of Category 2 flooding within the city. The floodwaters were uninterrupted to the west and

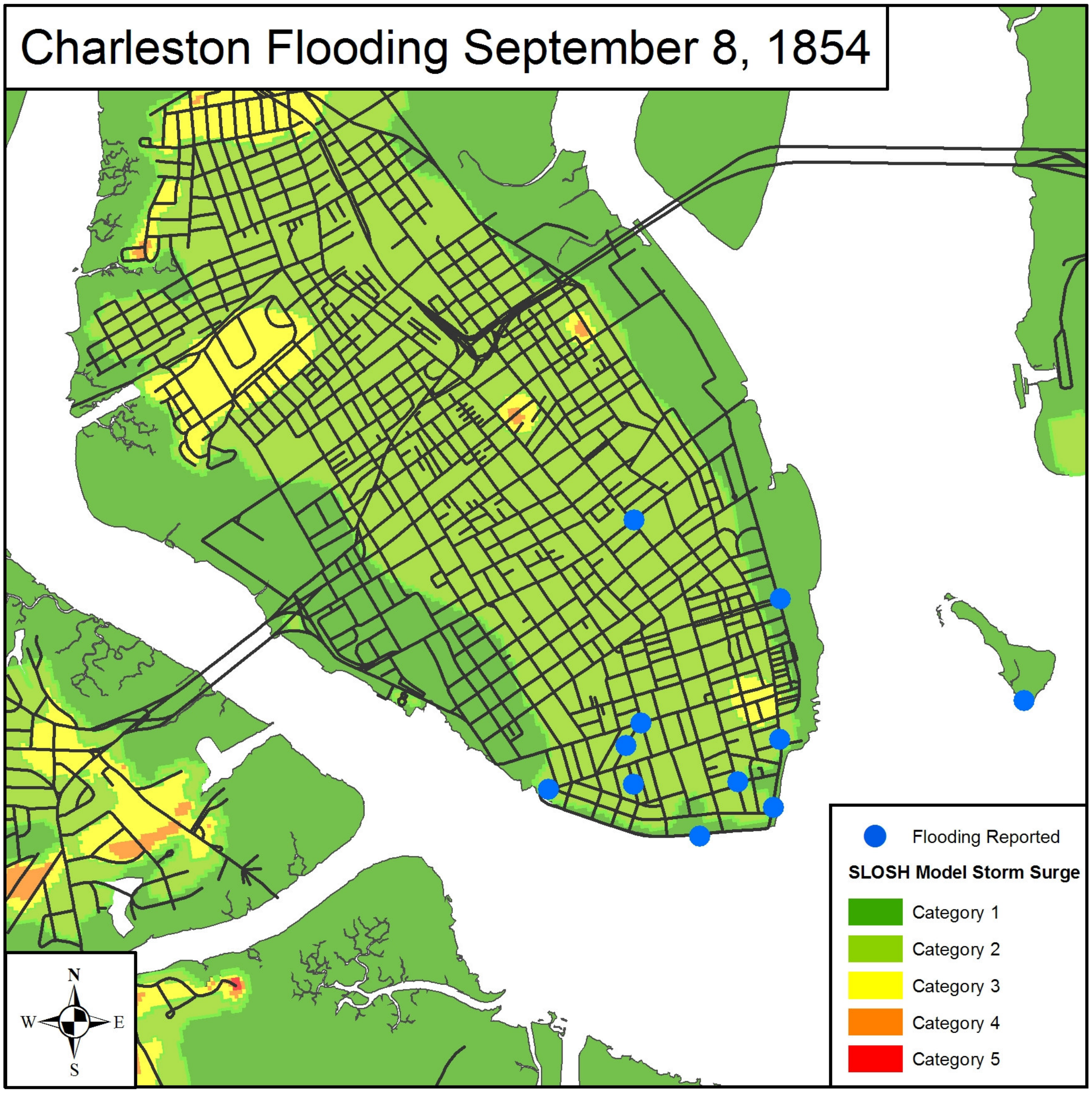


Figure 4.17: Map showing reported locations and extent of storm surge flooding within the city of Charleston compared to expected storm surge flooding based on modern SLOSH model. Location 1) shows the furthest extent of flood waters reported on the southern and western side of the city. Location 2) shows where the flood waters extended up Calhoun street to Meeting street.

south of location 1 (Figure 4.17). On the opposite side of Charleston neck, location 2 (Figure 4.17) shows where the flood waters extended up Calhoun street to Meeting street. These two reports show that the storm surge associated with this hurricane was clearly in the Category 2 range in the city of Charleston.

4.2.2 *August 25th, 1885*

A great deal of damage resulted from the storm surge during the hurricane of August 25th, 1885. Wharves and piers were badly damaged along the waterfront. Waves crashed onto water front houses causing significant damage to these structures. The surge associated with this hurricane however, was not extensive in this city. The pattern of flooding that was documented (Figure 4.18) shows the extent of flooding. During the height of the storm the water in the bay was almost level with the top of the East Battery Sea wall, while the water on the inside was just a few inches lower. The water in the yard of the residence at 5 East Battery was 5 feet (1.5 m) deep. Much of the city west of Rutledge Ave was under water during the height of the hurricane. Within the city the storm surge flooding was similar to what would be expected with a minimal Category 2 hurricane. Of the three hurricanes that were used in this analysis, this hurricane showed the smallest extent of flooding within the city, but the most damage as a result. One of the major differences between this hurricane and the others was the speed at which the storm surge came ashore.

CaroCOOPS has developed an additional storm surge model for the South Carolina coast. A series of maps is available for download from the website. These maps depict modeled storm surge for Charleston Harbor based on different hurricane

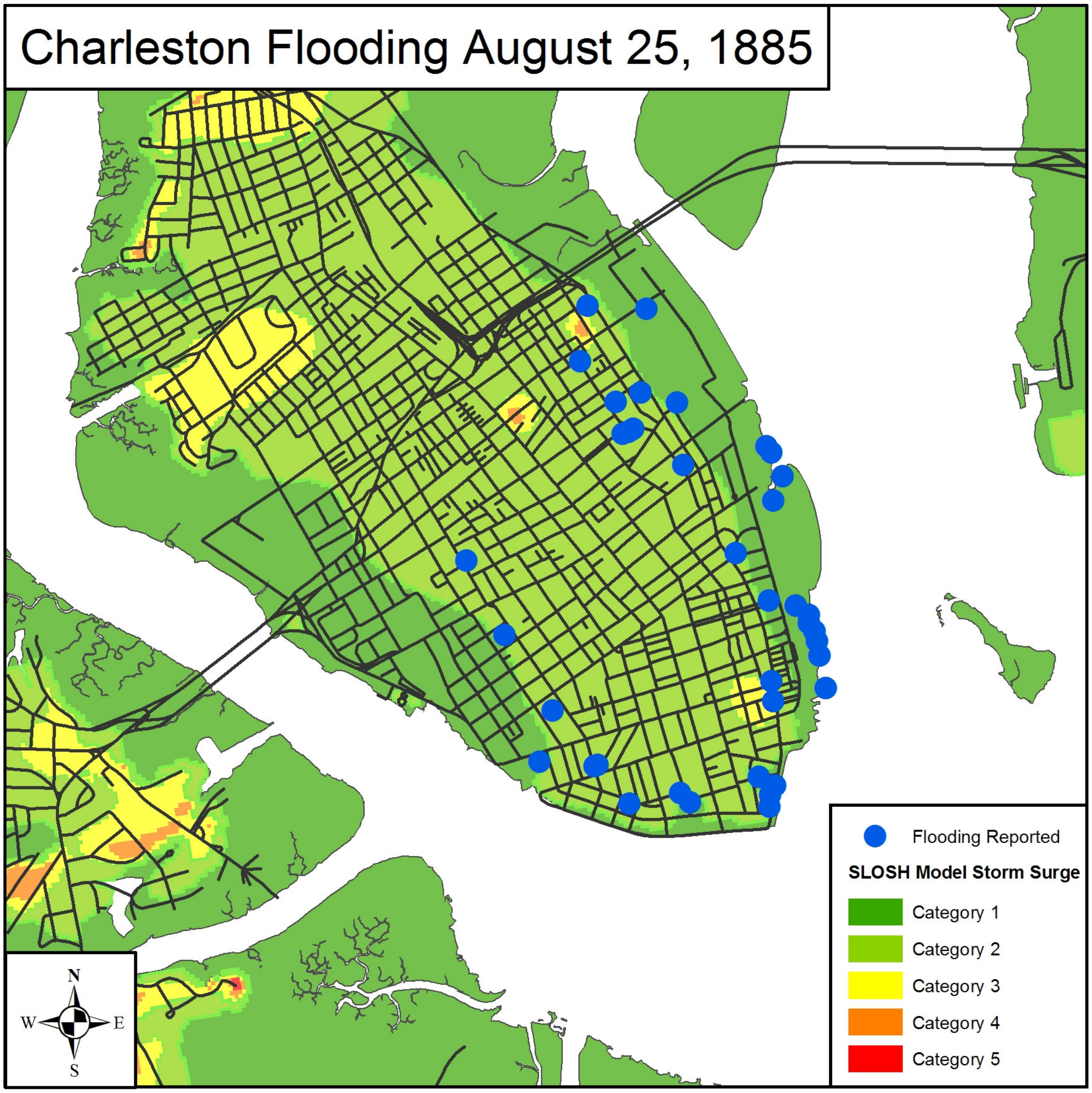


Figure 4.18: Map showing reported locations and extent of storm surge flooding within the city of Charleston compared to expected storm surge flooding based on modern SLOSH model. The pattern of flooding shown in the map is consistent with a minimal Category 2 hurricane.

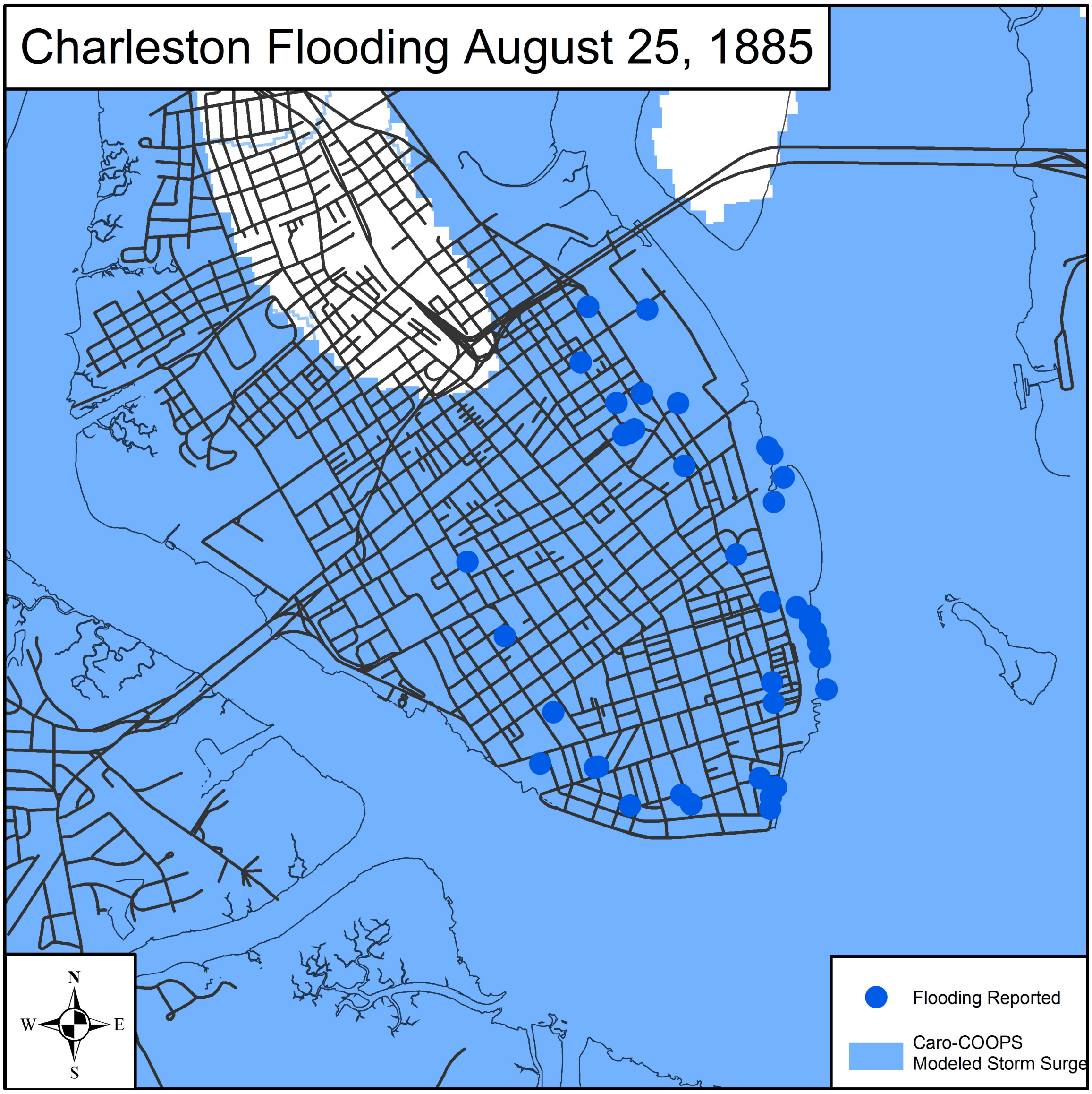


Figure 4.19: Observed flooding in Charleston compared to the CaroCOOPS modeled flooding for a Category 2 hurricane making landfall near Edisto approaching from the SSW at 11 kts (5.5 ms^{-1}).

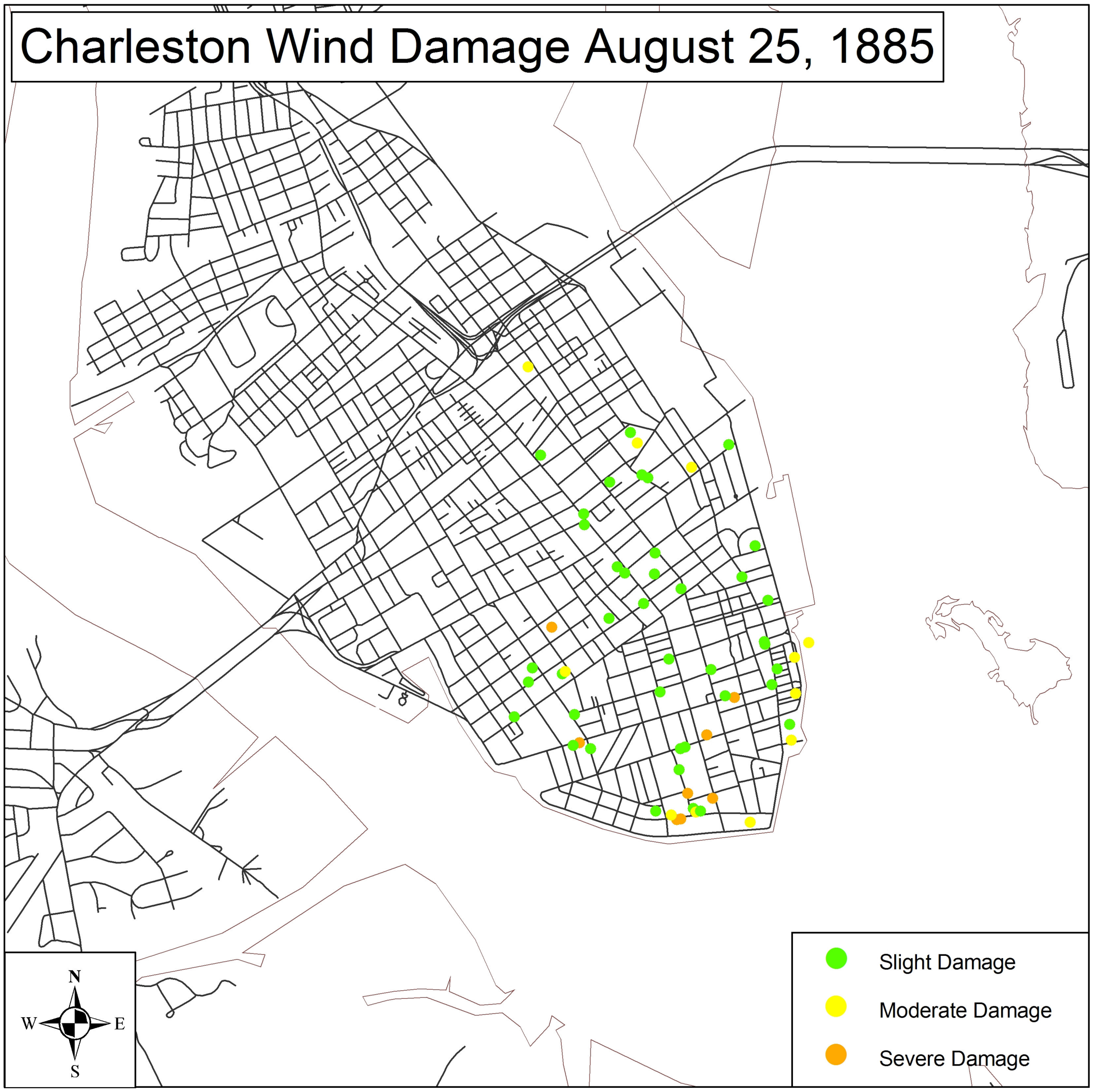


Figure 4.20: Map depicting wind damage in the city of Charleston, SC. The majority of damage in the city was slight, being limited to roofs, fences, and outbuildings. More significant damage occurred along the outer edges of the peninsula especially to the buildings on the wharves along the waterfront.

scenarios that account for varying landfall location, forward speed, angle of approach and Saffir-Simpson Category. Figure 4.19 shows a comparison between observed flooding in the city of Charleston and the CaroCOOPS modeled storm surge for a Category 2 hurricane making landfall near Edisto with a forward velocity of 11 kts (5.5 ms^{-1}) approaching the coast from the SSW (195 degrees). This model predicts flooding to occur throughout nearly the entire peninsula leaving only the northern and central part above water. This scenario is similar to flooding depicted by the SLOSH model. Observed flooding on the northeastern side of the city corresponds very closely with the model. On the southwestern side of the city the observed flooding is less extensive than modeled, however the overall pattern of inundation is similar. Both models indicate that storm surge was likely in the mid to low Category 2 range during this hurricane. The model developed by the CaroCOOPS project appears slightly closer to observed values in this case. It is important to note that these modeled scenarios cannot account for every variable and we should not expect that the two match exactly. This does illustrate the value of mapping observed storm surge at this scale for the purpose of comparison and verification of storm surge models.

Wind damage was also mapped in the city of Charleston (Figure 4.20). Below is a map of 63 data points from within the city of Charleston. The pattern of damage shows that the majority of damage that occurred in the central part of the peninsula was classified as slight. Damage reports from this portion of the city were generally limited to roof and fence damage with some reports of trees being blown down. The majority of the moderate to severe damage that was done occurred in more exposed parts of town along the waterfront. These damages included the destruction of sheds and warehouses along the waterfront. The isolated reports of severe damage on the inner parts of the peninsula were primarily reports of uprooted trees. Within the city the majority of damage was sustained by roofs, fences, and chimneys. Trees throughout the city were uprooted during this hurricane, but widespread structural damage associated with major hurricanes should accompany these reports if this was a major hurricane.

4.2.3 August 28th, 1893

Storm surge in Charleston during the hurricane of August 28th, 1893 was very similar in extent to the storm surge during the hurricane of 1885. Figure 4.21 shows that the general extent of storm surge corresponds with expected storm surge from a minimal Category 2 hurricane. Very little damage was reported that resulted from storm surge in Charleston. The weather observer in Charleston during the hurricane, Mr. Jesunofsky, measured the storm surge in a protected area within the city during the storm. He reported that the official height was 5.5 feet (1.7 m) above mean high tide, which is consistent with the reported flooding and Category 2 storm surge. It is interesting that these hurricanes all showed very similar patterns of flooding in the city of Charleston even thought they were very different storms. The hurricane of 1885 was most likely a Category 2 hurricane that made landfall 15 nm (28 km) south of Charleston. This hurricane was relatively compact and somewhat faster moving. The hurricane of 1854 was a massive Category 3 hurricane that made landfall 100 nm (185 km) south, but was moving very slowly and subjected the coast to hurricane conditions for over 48 hours in most places. Finally, the hurricane of 1893 which came ashore about 100 nm (185 km)

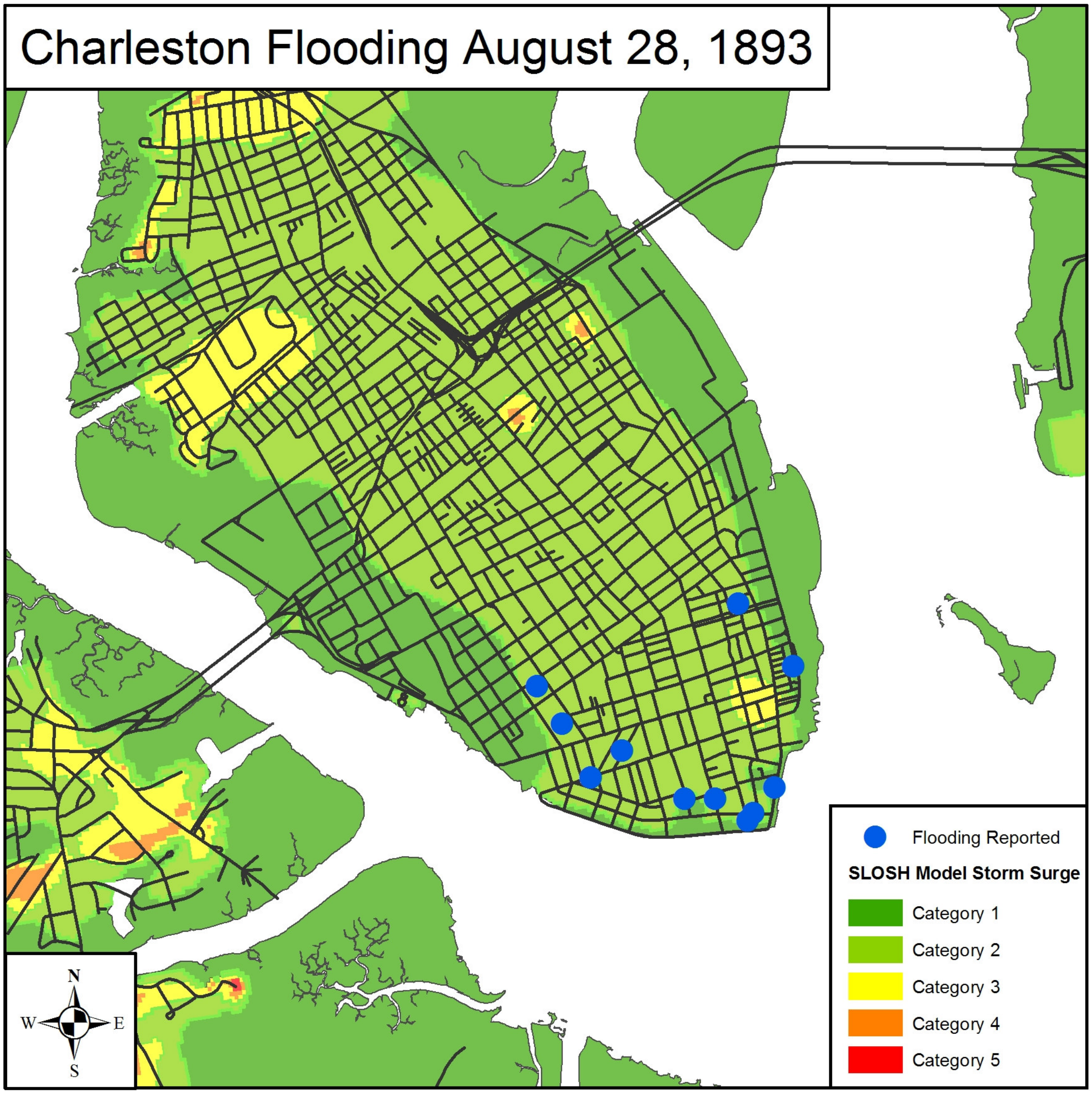


Figure 4.21: Map showing reported locations and extent of storm surge flooding within the city of Charleston compared to expected storm surge flooding based on modern SLOSH model. The pattern of flooding shown in the map is consistent with a minimal Category 2 hurricane.

south of Charleston as a Category 3 hurricane officially. All of these hurricanes had similar storm surge in Charleston.

CHAPTER 5: DISCUSSION AND CONCLUSIONS

5.1 Results

The hurricane of September 27th, 1822 was a relatively compact hurricane making landfall near the north end of Bulls Bay, SC. This assessment is based on published observations of wind speeds and directions from a United States Navy vessel that experienced the hurricane while anchored in this location. The size of this hurricane is evidenced by the lack of reported wind or wind damage from areas south of Morris Island. Storm surge was not reported south of Charleston Harbor and the greatest flooding reported in the coastal islands between the Santee River and North Inlet, just north of Winyah Bay. Overall this hurricane showed Category 3-type impacts along the South Carolina coast between the Santee River and North Inlet. In this region typical damage reports included complete destruction of buildings, major erosion of barrier islands, and storm surge flooding that killed hundreds of people. Within the city of Charleston this hurricane exhibited Category 1 type impacts. Storm surge flooding was minimal in and around Charleston harbor and wind damage reports within the city were primarily limited to the stripping of roofing material and the toppling of chimneys. The documentary data supports classifying this hurricane as a major hurricane at landfall with Category 3 type impacts in South Carolina, and Category 1 type impacts in the city of Charleston.

The hurricane of September 8th, 1854 was a very large very long duration hurricane. As far north as Georgetown, SC, strong winds were reported for nearly 60 hours. Ironically, this storm was known as the Great Carolina Hurricane, even though it made landfall near St Catherine's sound, GA. Impacts from this storm in South Carolina were limited to Category 2 impacts. One likely factor contributing to the severe damage reports that came from as far north as Morris Island, SC was the duration of the high winds. In Charleston, the impacts were generally limited to Category 1. Damage to buildings included stripping of roof material and blowing down of fences. Storm surge was extensive, although not severe. Flooding in Charleston was consistent with Category 1 or 2 type impacts. Storm surge flooding was prolonged in many areas because of the slow forward motion of this hurricane. Documentary evidence supports Category 2 impacts in South Carolina and Category 1 impacts in Charleston. In South Carolina this hurricane was significant for its size and duration, more than the damage that it caused.

Weather Bureau reports from the previous day indicate that the hurricane of August 25th, 1885 may have made landfall in northern Florida before going back out to sea and then coming ashore farther north. This hurricane did follow the contour of the Atlantic coast, at least from central South Carolina through North Carolina. High winds were reported in coastal Florida, however, weather reports from Jacksonville do not indicate that this hurricane came ashore in that vicinity. There was a report published in the Charletson *News and Courier* (August 27, 1885, p. 2) from a ship at Rockville, SC on the Edisto River. The captain of the ship never reported winds from the west or southwest, which would indicate that the storm center passed to the west of his location.

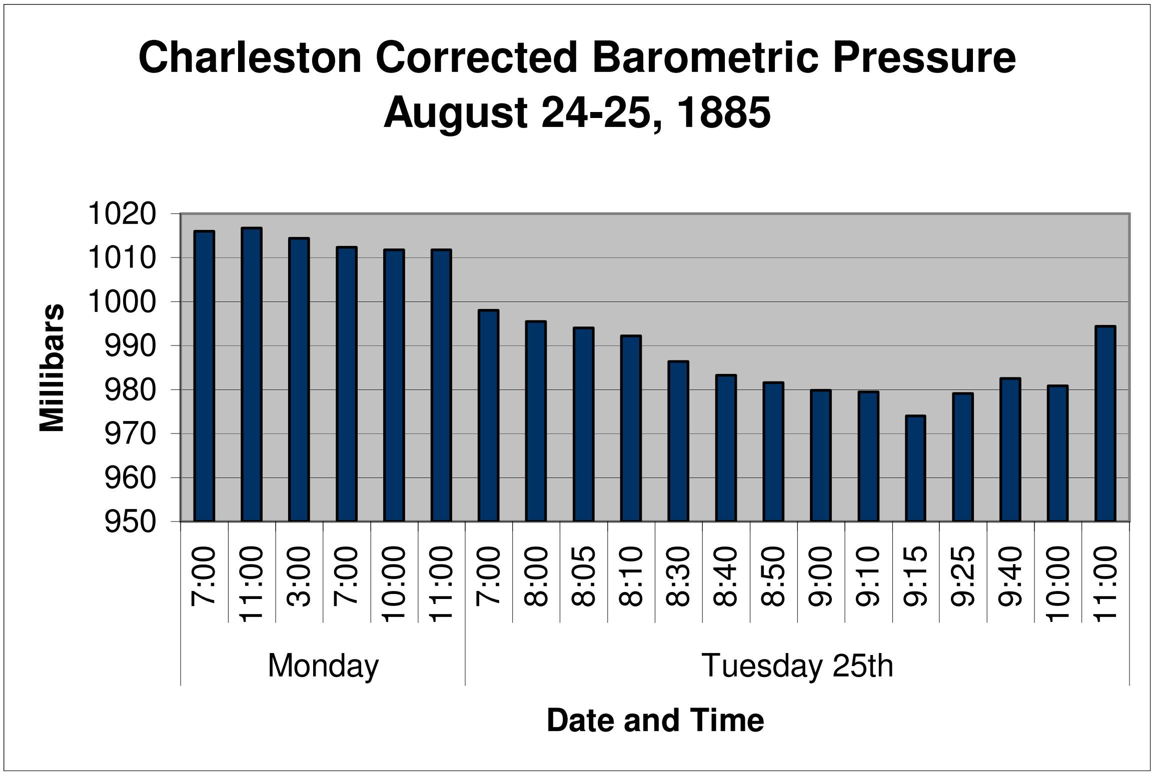


Figure 5.1: Graph of corrected barometric pressure values from Charleston, SC during the hurricane of 1885. Recordings from Monday, August 24th were taken at standard observation times. Recordings from Tuesday, August 25th were taken at non standard times during the height of the hurricane. Lowest corrected value was 937.99 mb at 9:15 AM when the eye of the hurricane was directly over the city. (*News and Courier* August 26, 1885, p. 1)

It was also noted that the highest winds occurred at this location at the same time of the highest winds in Charleston from the opposite direction, which would place the center of this hurricane between Edisto and Charleston on the South Carolina coast. The eye of this hurricane passed directly over Charleston where a corrected central pressure of 974 mb (28.728 inches) was recorded (Figure 5.1). This coupled with the documentary evidence clearly demonstrated that this hurricane was not a major hurricane at landfall and only a minimal Category 2 as it passed over Charleston. Based on documentary and instrumental evidence, it is very likely that this hurricane came ashore about 30 nm (55 km) north of the current best track, which would place landfall on John's Island, SC, and it is very unlikely that this hurricane was a major hurricane at the time it made landfall. This hurricane did exhibit some interesting features after landfall. To the north of landfall location there were several damage reports that indicated possible tornadic activity from Charleston to Georgetown, including swaths of trees in the coastal turpentine forests being cleared. However, no eyewitness accounts of tornados were reported.

The hurricane of August 28th, 1893 was a major hurricane that made landfall near Savannah, GA. This hurricane caused significant and widespread wind damage and flooding in South Carolina, and was clearly a major hurricane with Category 3 impacts in South Carolina. In Charleston, this hurricane caused significant flooding indicative of a Category 2 hurricane. Reported flooding was actually more extensive, albeit slightly, than flooding during the hurricane of 1885. Wind damage in the city was less extensive, but similar in nature to that of the 1885 hurricane. Observed winds during this hurricane were higher than those observed in 1885, however, the anemometer was destroyed during the 1885 hurricane, leaving no official value for the maximum wind speed for that storm. Those who experienced both hurricanes suggested that the hurricane of 1893 was worse in Charleston than the hurricane of 1885. One possible factor contributing to the apparently greater wind velocities and fewer reports of wind damage during the 1893 hurricane compared to the 1885 hurricane was the relative state of disrepair of the city in 1885. Charleston had been weakened during the civil war and had not fully recovered due to economic depression before the hurricane of 1885. After this hurricane, many roofs were re-tinned according to newspaper reports. Then the city was struck by an earthquake in 1886, which demolished many buildings completely. The city under went a significant rebuilding process following these two events resulting in a structurally stronger city that was better able to withstand the winds of the August 1893 hurricane. The data collected supports similar impacts for this hurricane as the hurricane in 1885 in Charleston. One major difference was the barometric pressure reading in Charleston during the height of these storms. In August of 1893, the pressure only got down to 984 mb (29.06 inches), which is in the Category 1 range. Because of this and in light of the type of reported wind damage the impacts from this hurricane in Charleston were classified as Category 1.

The final hurricane in this study made landfall near Winyah Bay, SC on August 13th, 1893. Coastal storm surge reports indicate that this hurricane was a major hurricane at landfall. Damage reports from coastal and inland Georgetown and Horry county were isolated, but do support classifying the impacts as Category 3 for this portion of the South Carolina coast. Impacts farther inland near Conway seem to be significantly less, probably in the low Category 2 range. In Charleston the impacts were minimal Category

1, which indicates that this hurricane was another very compact major hurricane, similar to that of 1822. Unfortunately, there was very little information published about this hurricane. There was almost no mention of this storm in the Charleston newspapers, except to say that minimal flooding occurred in the city and a couple of trees blew down. This hurricane warrants further investigation, due to the minimal number of data points that were found in this research. HURDAT currently lists this hurricane as Category 3 for 11 days, and as far inland as Fayetteville, NC. It seems more likely that this storm diminished in strength rather quickly as it came inland, based on reports in Conway. However, this study focused on South Carolina data sources and therefore cannot speculate on the intensity of this storm beyond Horry county.

5.2 Benefits of this Study

This research plays a valuable role in supplementing our understanding of these tropical cyclones currently found in HURDAT and their physical impacts on coastal communities. This research focused on South Carolina, but a similar approach can be taken for numerous regions of the Atlantic and Gulf Coasts. Hurricanes can have significant social and economic impacts on coastal populations, and by understanding the physical impacts different hurricanes in the past have had we can better understand the historical role of tropical cyclones, as well as incorporate this knowledge into practical and theoretical planning applications including storm surge models such as the one developed by the CaroCOOPS project, and coastal vulnerability studies (Cutter et al 2000; Purvis and McNab 1985). As an illustration, the hurricanes of September 1854, August 1885, and August 1893 all showed very similar flooding in Charleston, even though they varied in intensity from Category 2 to Category 3, made landfall more than 70 nm (130 km) apart, and had very different levels of reported wind damage in the city.

This research also demonstrates the value of incorporating higher resolution local level data into the analysis of historical hurricanes. This type of analysis is invaluable in determining hurricane intensity at landfall and it can often provide more precise information about landfall location, as in the case of the August, 1885 hurricane. There are also implications for the hurricane history of a particular region. For example, the hurricane of September, 1854 has commonly been referred to as the "Great Carolina Hurricane." The evidence suggests, however, that the impacts of this hurricane were less than Category 3 in South Carolina. The August 1885 hurricane has been classified as a major hurricane at landfall, but a closer examination of the local documentary and instrumental evidence suggest that this hurricane was a Category 2 hurricane at landfall.

5.3 Limitations of this Study

This type of research does have some limiting factors that must be acknowledged. The first is the geographic coverage of the data. Often the bulk of the reports come from highly populated areas. Hurricanes often come ashore in less populated areas resulting in uncertainty about exact location of landfall, as well as the intensity of the hurricane. This leads right into the next problem, which is the lack of good instrumental evidence for these hurricanes. There were very few highly reliable weather observers collecting meteorological data at the time. This makes the task of assigning these hurricanes a Saffir Simpson Intensity classification more difficult. One other problem with relying on documentary evidence alone is the subjective nature of these accounts. Often, with the exception of newspapers, those that documented these events did not have a large volume of writing to use as context an analyzing the reports of hurricane weather or damage. Similarly reports of damage to individual structures could relate more to the relative strength or weakness of a given structure than the force of the wind, necessarily. All of these potential problems illustrate the importance of performing analysis like this study that includes different types of information in different forms from different sources. When all available types of information are utilized, anomalous values or reports are more easily identified and can be more appropriately analyzed.

5.4 Future Work

This research helps to lay the ground work for future reanalysis efforts of other landfalling hurricanes in this and other regions. Potential efforts include Hurricane Hazel, which made landfall on October 15th, 1954 near Little River, South Carolina; the hurricane that made landfall near Beaufort, SC, on August 11th, 1940, and the hurricane that made landfall near St. Catherine Sound, GA, on August 28th, 1881. This research also highlights the need to further investigate the October 13th, 1893 hurricane. Exhaustive searches of libraries and archives in South Carolina netted very little detailed information about this hurricane. A better understanding of this hurricane may be achieved through synoptic mapping of basin wide meteorological data. Other potential data sources that were not utilized in this study including ships logbooks from the National Archives, COADS data, may help to refine our current knowledge of this and other Atlantic Tropical Cyclones. Utilizing higher resolution data from local sources in reanalysis and reconstruction provides a level of detail that is necessary for historians, emergency planners, model comparisons, calibration of other paleaotemestology techniques (Liu, In Press), and refinement of HURDAT landfall and intensity estimates. Undertaking this type of research requires a great deal of time and meticulous efforts to perform the necessary exhaustive data searches that assure quality results. The results of this study illustrate that Charleston has been very fortunate in the past, enduring several near misses, but no Category 3 type impacts from these 19th century hurricanes, a trend which will eventually end.

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