2.11 STRONG WIND CHARACTERISTICS AND CHANGES DURING THE LAST HALF-CENTURY AT FIVE NWS STATIONS NEAR COASTAL SOUTH CAROLINA

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1. INTRODUCTION

Strong wind events often have dramatic and sometimes long-lasting effects on habitats, agriculture, power-distribution, and industry in the coastal and piedmont areas of South Carolina. The causes of each individual event can vary from tropical weather systems, strong cold fronts, or migratory low pressure systems.

For the purpose of this paper strong winds refer to those greater than or equal to 11.2 mps (25 mph). Two additional categories of wind speed were studied for comparison: weak winds -- 0 to 4.47 mps (0 to 10 mph) and moderate winds -- 4.47 to 11.2 mps (10 to 25 mph). Previous studies of winds in the Southeastern U.S. by the authors have been directed toward mean wind speeds and gusts (Weber, et al.; 2002a, 2002b, and 2004).

Hourly wind speed data were acquired from the National Climatic Data Center (NCDC, 2005) for five National Weather Service (NWS) stations along and near the U.S. Southeast Coast (Table 1) to study strong wind events and to examine how conditions changed during the period of record the 1940s through 2004. The NWS stations selected for these analyses were Charleston and Columbia, South Carolina (CHS and CAE); Wilmington, North Carolina (ILM); Augusta and Savannah, Georgia (AGS and SAV).

Table 1: Stations examined for this study.

Station	Elevation (tower base)	Period of Record (years)	ASOS Start	Periods of 3-hr Observation Intervals†
	(m ASL)	(mo/yr)	(date)	(date)
CHS	12.2	1/45 – 03/05 (60 yrs)	01Oct 1995	1965-69* 1975-77*
ILM	9.1	1/48 – 03/05 (57 yrs)	01Nov 1995	1954-59†† 1965-77*
AGS	40.2	1/49 - 03/05 (56 yrs)	01May 1994	1965-73* 1980-81**
CAE	64.9	1/48 - 03/05 (57 yrs)	01Dec 1995	1965-72*
SAV	14.0	10/50 - 03/05 (55 yrs)	01Apr 1996	1965-77*

†As opposed to the usual 1-hour observation interval.
††Station was down during the nighttime hours including 22:00 -- 05:00 EST from 1954 through ~ first 140 days of 1959.
*Station reported every three hours - 01:00 through 22:00 EST.
** Station reported every three hours - 01:00 through 22:00 EST through half of 1981.

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2. METHOD

Figure 1 shows the U.S. Southeast Coast and the location of the five NWS stations used for the study. Three stations, ILM, CHS, and SAV are within ~16 km (10 mi) of the coast while the remaining two, CAE and AGS are ~200 km (124 mi) inland.

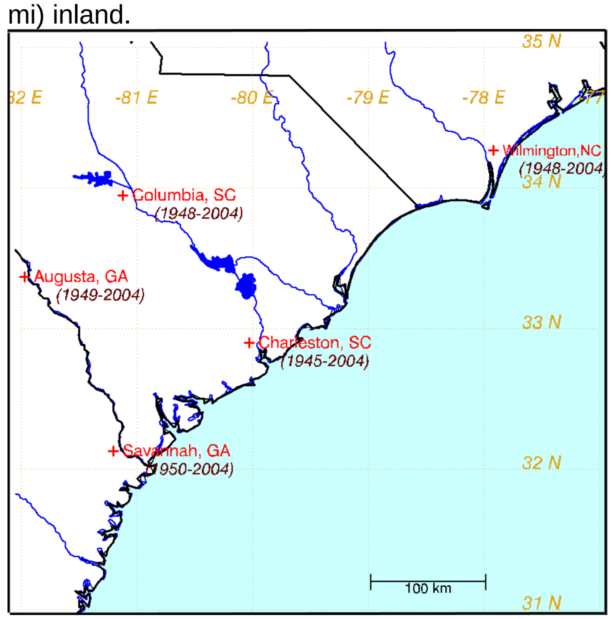

Figure 1: Stations used for studying winds along and near the U.S. Southeast Coast.

Quality assurance of the hourly data included checking for obvious errors such as a single reported strong wind with no supporting observations such as clouds, storms, or strong winds in current or adjacent hours. The complete hourly observations from the five stations were combined (or “pooled”) to form a regional data set.

Next, the regional data set was examined to select only those observations with wind speeds within the bins described earlier, e.g., • 11.2 mps (25 mph). In the case of a synoptic scale event more than one station could be represented for the same observation time. The final step was to form annual averages of wind speed together with the temperatures and dew points associated with the wind speed observations. Thus, a single annual averaged wind speed represents the averaged speed for any given year; the annual averaged temperatures and dew points are those values associated with the wind speed criterion, e.g., • 11.2 mps (25 mph).

Finally, eight strong wind events during the period of hourly data records are well remembered by the local populace for their regional effects, so those events were examined in detail and compared for their strength and longevity. In addition, these eight events were classified as a tropical system, strong cold front, or winter migratory low pressure system.

3. RESULTS

Figure 2 shows all five NWS stations' wind speeds averaged by year (red solid line). All five stations are included in the pooled average described above; the station with the latest beginning wind observation determines the starting point for the series (1951). The time series shows a fairly uniform decreasing trend in averaged wind speed during the 55 year period except for the beginning six years and perhaps 2004.

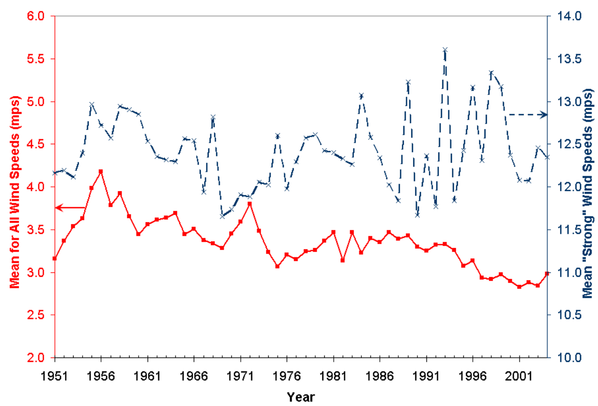

Figure 2: Time series of annual averages of all five stations' (CHS, ILM, AGS, CAE, and SAV) pooled wind speeds. The red solid line denotes the use of all wind speeds (scale to the right), while the blue dashed line indicates speeds restricted to the strong wind category (• 11.2 mps, 25 mph).

Figure 2 also shows the same five NWS stations' averaged wind speeds except that the individual station observations are only included when equal to or greater than 11.2 mps (25 mph) (blue dashed line). The time series for these strong winds has a number of noticeable differences from the time series for all winds. The trends of the strong winds time series are superimposed on higher frequency oscillations. The power spectral density peaks associated with the oscillations occur at 2.4, 5 and 17 years. The trends in this time series for strong winds can be characterized as dropping between 1960 and 1969, then gently rising through the 70s, 80s, and 90s, but dropping again after 1998.

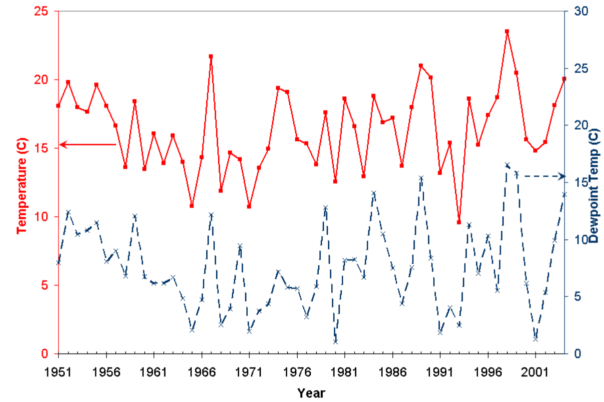

Figure 3: Time series of annual averages of all five stations' (CHS, ILM, AGS, CAE, and SAV) temperatures and dew points associated with wind speeds • 11.2 mps (25 mph). The red solid line denotes the temperatures, while the blue dashed line indicates dew points.

Figure 3 shows the mean temperatures and dew points associated with these strong winds (• 11.2 mps or 25 mph) during the same period. For these cases the strongest spectral peaks are around 5 years and 8 years. The eight year peak is strongest for the temperature. A 2.4 year power spectral density peak can be seen in portions of the time series for temperature and dew point. The calculated mean temperatures and dew points associated with all wind data (not shown) yield time series with decreasing trends from 1951 to 1969 followed by a rising trend from 1970 to present.

Figure 4 shows the averaged wind speeds (red solid line) for the 55 year period by month (January through December) as well as the averaged wind speeds for occasions when the wind was • 11.2 mps (25 mph) (blue dashed line). These two curves are essentially reversed from one another in terms of their maxima and minima. While the average speed for all winds reaches a maximum in March and April and a minimum in August, the strong winds • 11.2 mps (25 mph) reach a maximum in September and minima in May and December. This reversal in the seasonal pattern associated with the strong winds suggests that tropical storm events are contributing the major share of the data entries for the strong winds.

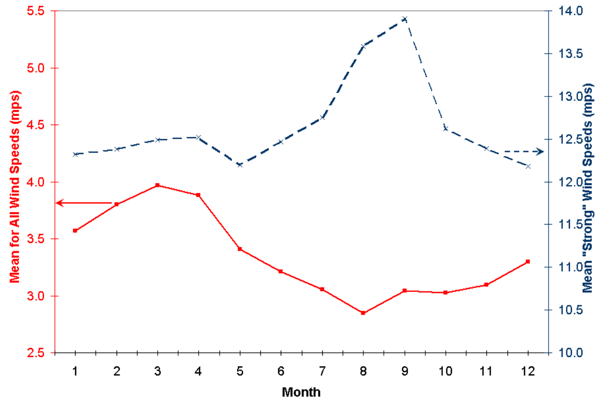

Figure 4: Time series of monthly averages of all five stations' (CHS, ILM, AGS, CAE, and SAV) pooled wind speeds for the 55 year period. The red solid line denotes the use of all wind speeds (scale to the right), while the blue dashed line indicates speeds restricted to the strong wind category (• 11.2 mps, 25 mph).

Next, for comparison, we look at the winds in the remaining two categories. For the middle (moderate) category the winds are in the range 4.47 to 11.2 mps (10 mph • average wind speed < 25 mph). The results shown in Figure 5 for moderate winds (red solid line) resemble all winds (shown in Figure 2). The time series of annual averages for weak winds 0 to 4.47 mps (0 mph < average wind speed < 10 mph) (blue dashed line) indicates there is a plateau between 1955 and 1994 separating two distinct minima before and after those years.

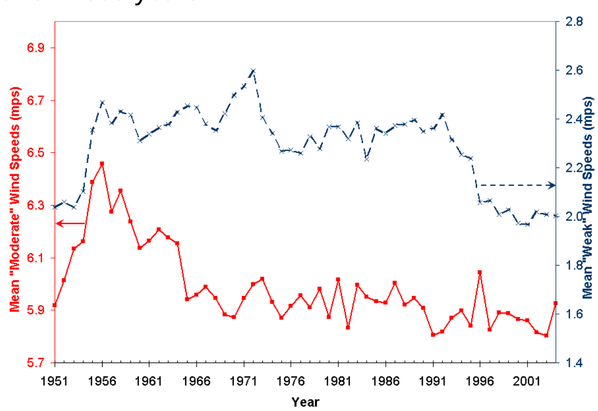

Figure 5: As in Fig. 2 except for moderate wind speeds in the range 4.47 to 11.2 mps (10 to 24 mph) (red solid line) and weak wind speeds in the range 0 to 4.02 mps (0 to 9 mph) (blue dashed line).

Figure 6 shows the results of determining the monthly averages for the two categories of moderate and weak wind speeds. The time series for the moderate wind speeds (red solid line) resembles the results from Fig. 4 with a maximum in March and a minimum in August, although the range of wind speeds is restricted to only 0.72 mps (1.6 mph). The time series for weak wind speeds in Fig. 6 (blue dashed line) shows a maximum in April, however the minimum is in November.

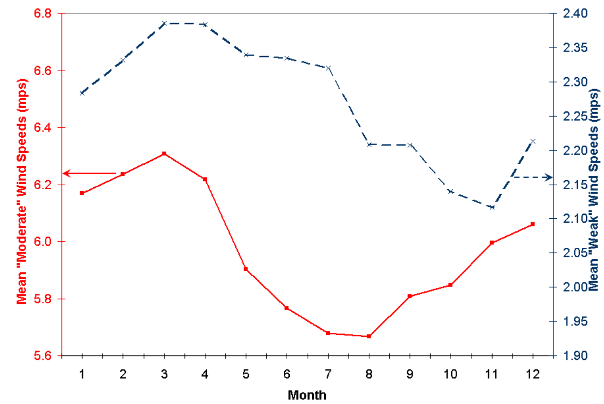

Figure 6: As in Fig. 4 except for moderate wind speeds 4.47 to 11.2 mps (10 to 25 mph) (red solid line) and weak wind speeds less than 4.47 mps (10 mph) (blue dashed line).

*Table 2. Statistical details for strong wind events over the 55-year time period. *Number of events is underestimated since station was closed part of the nighttime hours during 1954-59. (Cf. Table 1.)*

Sta	+N_{1HR} Freq (N_{1HR}/ 1-yr)	$\bar{S}_{1hr}$ mps (mph)	s_{1hr} mps (mph)	S_{MX} mps (mph)	+N_{3HR} Freq (N_{3HR}/ 1-yr)	+N_{5HR} Freq (N_{5HR} / 10-yr)
AGS	573 (10.4)	12.26 (27.43)	1.38 (3.08)	21 (47)	44 (0.8)	13 (2.4)
CAE	716 (13.0)	12.29 (27.49)	1.54 (3.44)	24 (53)	59 (1.1)	18 (3.3)
CHS	1856 (33.7)	12.45 (27.85)	1.62 (3.63)	24 (53)	176 (3.2)	61 (11.1)
ILM	2515 (45.7)	12.89 (28.84)	2.28 (5.10)	38 (85)	231* (4.2)	102* (18.5)
SAV	802 (14.6)	12.37 (27.66)	1.53 (3.43)	23 (52)	74 (1.3)	28 (5.1)

+N_{xHR} = Number of events of duration "x" hours

$\bar{S}_{1hr}$ = Mean wind speed for 1-hr events

s_{1hr} = Standard deviation of wind speed for 1-hr events

$S_{MX,1hr}$ = Maximum wind speed for 1-hr events

Table 2 shows some of the statistical details for the strong winds over the 55 year period. The coastal stations (CHS, ILM, and SAV) had statistically significant larger means and maximum speeds than did the piedmont stations (AGS and CAE). In addition to showing individual strong-speed events, longer duration events of 3 and 5 hours are also given in Table 2. Due to NWS budget constraints, each of the 5 stations experienced periods in the 1960s and 1970s when observations were only available at 3-hr intervals. Thus, during these periods, a 5-hr event was assumed if 3 successive values, i.e., over a 6-hr period, exceeded 11.2 mps (25 mph). Likewise, for a 3-hr event, 2 successive values had to exceed 11.2 mps (25 mph).

The number of occurrences of 1-hr, 3-hr, and 5-hr events was also dominated by the coastal stations. Wilmington significantly dominated all other stations for the number of occurrences for all durations while Augusta had the lowest number.

Table 3. Statistical details for moderate wind events over the 55-year time period.

Station	N (N_{1HR}/ 1-yr)	$\overline{S}$ mps (mph)	$\overline{s}$ mps (mph)
AGS	80420 (1462)	5.91 (13.21)	1.27 (2.85)
CAE	94356 (1716)	5.95 (13.30)	1.26 (2.82)
CHS	146628 (2665)	6.05 (13.53)	1.31 (2.94)
ILM	140254 (2550)	6.17 (13.80)	1.70 (3.08)
SAV	110773 (2014)	5.91 (13.23)	1.26 (2.82)

N = Number of occurrences

$\overline{S}$ = Mean speed

$\overline{s}$ = Standard deviation about mean speed

Table 4. Statistical details for weak wind events over the 55-year time period.

Station	N (N_{1HR}/ 1-yr)	$\overline{S}$ mps (mph)	$\overline{s}$ mps (mph)
AGS	327886 (5961)	1.96 (4.38)	1.36 (3.05)
CAE	331234 (6022)	2.12 (4.74)	1.33 (2.97)
CHS	277828 (5051)	2.57 (5.75)	1.22 (2.74)
ILM	243076 (4420)	2.36 (5.28)	1.36 (3.05)
SAV	285403 (5189)	2.40 (5.37)	1.28 (2.87)

Tables 3 and 4 show the number of occurrences, mean speeds, and standard deviation of mean speed for moderate and weak winds, respectively. As expected the piedmont stations dominate the weak winds and the coastal stations dominate the moderate wind statistics.

The North Atlantic Oscillation (NAO) and El Niño Southern Oscillation (ENSO) indexes were used to determine if there was any relationship to the strong wind events. To our disappointment, the Pearson correlation coefficients were both less than |0.06| showing no correlation whatsoever between either index and the strong wind events.

In order to assess the frequency of additional strong wind events, periods where wind speeds exceeded 11.2 mps (25 mph) for 3 and 5 successive hours at CHS (as in Table 2) were examined over the 1945-2004 period and are shown in Table 5. The total number of storm events as defined by these criteria during this 60-year period is 209 for events of 3 hours or longer, and 75 for events of 5 hours or longer. A summary by decade is given in Table 5. Note that the decades of the late 40s and 50s contained significantly more strong wind events than any of the decades to present. Note that the total number of times over the 60 year period in which Charleston registered at least 11.2 mps wind speeds is 2181, or about 3 events per month.

Table 5. Decadal periods containing strong wind speeds • 11.2 mps for CHS.

Decade	*N_{Rec}	+N_{1HR} (N_{1HR}/ 1-yr)	+N_{3HR} (N_{3HR}/ 1-yr)	+N_{5HR} (N_{5HR} / 10-yr)
1945-1949	43786	267 (53.4)	26 (5.2)	11 (22)
1950-1959	87594	1030 (103)	102 (10.2)	40 (40)
1960-1969	58455	220 (22)	23 (2.3)	5 (5)
1970-1979	70112	219 (22)	20 (2.0)	8 (8)
1980-1989	87862	134 (13)	15 (1.5)	3 (3)
1990-1999	87696	229 (23)	19 (1.9)	7 (7)
2000-2004	41740	82 (16)	4 (0.8)	1 (2.5)
TOTALS	477245	***2181***	***209***	***75***

*N_{Rec} = Total number of records for the period

+N_{xHR} = Number of events of duration "x" hours

Eight intense storms (1948, 1965, 1978, and 1993 winter storms; and Hurricanes Gracie, Hugo, Floyd, and Gaston) affected this region and are noteworthy since they are familiar to most long-time residents because of the wind destruction produced. These eight storms were studied in detail for the time history of their winds. Figure 7 shows the time series of hourly wind speeds for the four winter events (half of the total). Three of these storms were classified as strong fronts/front from a distant low and the remaining one was a winter migratory low pressure system affecting the entire region. Data shown are for Columbia, SC (CAE), Charleston, SC (CHS), and Wilmington, NC (ILM). Also shown are lines demarking 8.94 and 13.4 mps (20 and 30 mph) speed thresholds. Note that the observations were only available at 3-hr intervals in 1965.

Figure 8 shows the time series of hourly wind speeds for the tropical events for the same three stations (the remaining half of the eight storms). All four of these tropical events have been classified as hurricanes (Gracie, Hugo, Floyd, and Gaston). Note that the duration of strong winds • 11.2 mps (25 mph) extended over many hours.

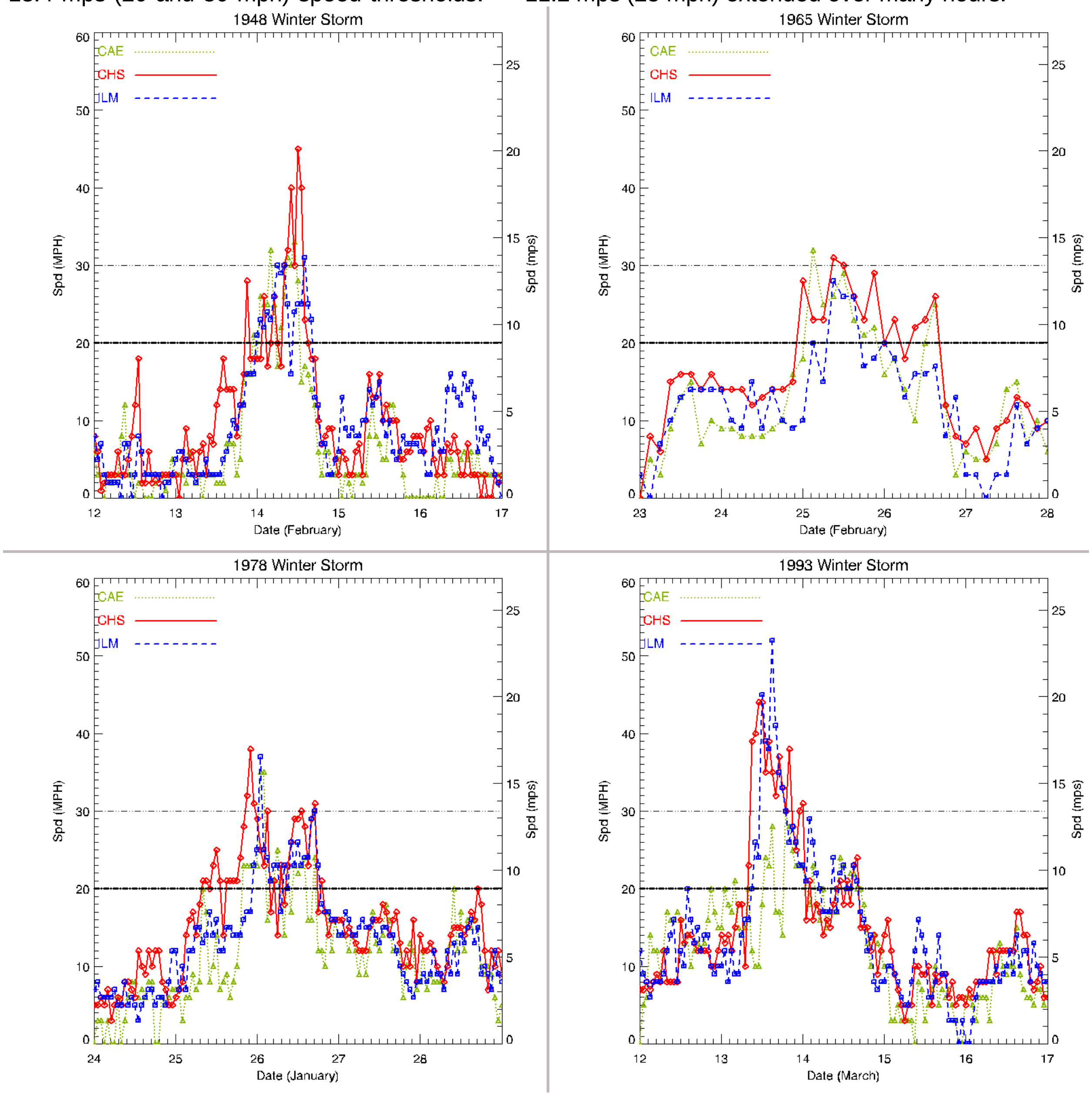

Figure 7: Time series of hourly wind speeds of significant winter events. Data shown are for Columbia, SC (CAE), Charleston, SC (CHS), and Wilmington, NC (ILM). Also shown are lines demarking 8.94 and 13.4 mps (20 and 30 mph) speed thresholds. Note that data were only available at 3-hr intervals in 1965.

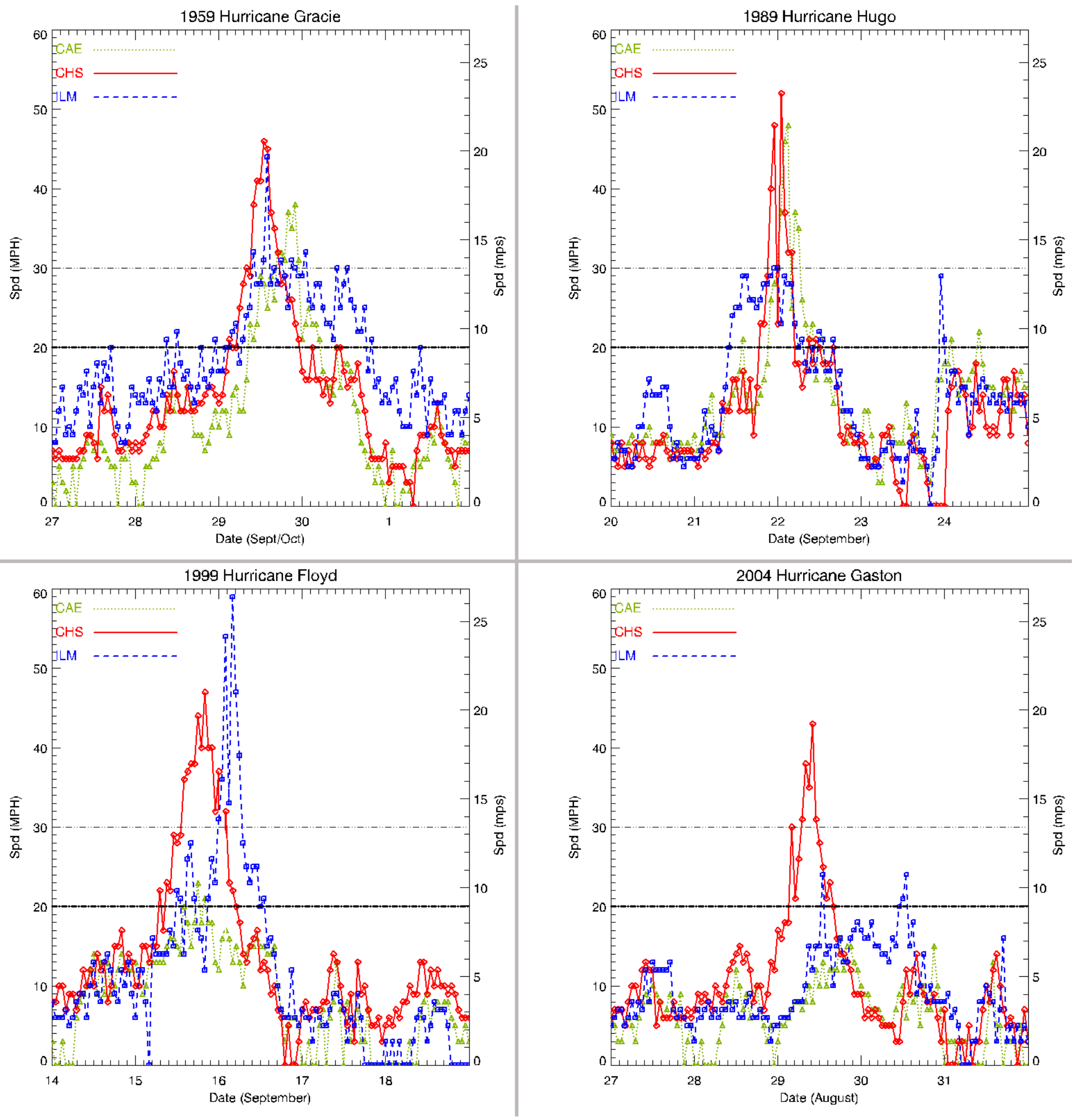

Figure 8: Time series of hourly wind speeds of significant tropical events. Data shown are for Columbia, SC (CAE), Charleston, SC (CHS), and Wilmington, NC (ILM). Also shown are lines demarking 8.94 and 13.4 mps (20 and 30 mph) speed thresholds.

4. DISCUSSION/CONCLUSIONS

The strong winds being discussed here are those capable of causing damage to structures as opposed to being personally uncomfortable, so some might argue that the strong wind threshold is too high, however the authors chose to focus their efforts on events capable of causing considerable damage.

From the results of examining the trends of the time series in Fig. 2 (mean and strong winds), there does not seem to be a uniform trend that can be used to extrapolate strong wind events in the future.

The spectral peaks at 2.4 and 5 years (associated with the strong winds) in Fig. 2 are manifestations of the well-known quasi-biennial oscillation (QBO) and quasi-quadrennial oscillation (QQO) discussed by Burroughs (2003). The QBO is especially evident during the last 20 years of the series. The QBO and QQO can also be seen in the temperature and dew point time series of Fig. 3. However, neither of these two periodic components of the wind speed spectrum seem to provide a reliable means for climate forecasting. For more information on this topic, consult the in-depth discussion by Burroughs (2004).

As expected, the coastal stations (CHS, ILM and SAV) dominated in the number of strong wind events during the 55-year period; among these stations ILM was affected by strong winds the most often. The order of the high wind incidence from greatest to least for the stations was ILM, CHS, SAV, CAE, and AGS. The order of weak wind incidence from greatest to least among the stations is almost opposite the previous order, i.e., CAE, AGS, SAV, CHS, and ILM. The strong winds showed no correlation to the NAO nor ENSO indices.

Of the eight memorable events, four were hurricanes and the others were winter storms occurring from January through March. While the tropical storms had the strongest winds overall, the winter storms generally persisted for a longer period of time (~1.2 days above 8.9 m/s (20 mph) versus ~0.7 day for the hurricanes).

One of the most striking results from this study is the number of strong wind events during the 15 year period between 1945 and 1959 as compared to the number of events in the remaining years. Table 5 (for CHS) shows that in the mid-1940s and 1950s there were 51 occurrences of 5-hr strong wind events as compared to 24 events for the remaining 45 years. This translates into more than 3 strong wind events per year in the early period as compared to one event every 2 years in the most recent period. Similarly, there were 128 three-hour events (8.5 per year) in the early period and 81 (1.8 per year) in the remaining years. There were 1279 one-hour events (85.3 per year) in the early period and 884 (19.6 per year) in the most recent period.

The seasonal preference of strong winds (Fig. 4) has potential useful applications. Since the maximum for strong winds is in the autumn, and for all winds is in the spring, the optimum time for most wind-sensitive construction or repair activities is in summer.

The minima in the weak wind speed averages beginning the mid 1990s (Fig. 5) may be instrument/data-processing related since the Automated Surface Observation System (ASOS) was implemented during the mid 1990s.

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