5.6 A COMPARISON OF TROPICAL STORM (TS) AND NON-TS GUST FACTORS FOR ASSESSING PEAK WIND PROBABILITIES AT THE EASTERN RANGE

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1 INTRODUCTION

Peak wind speed is an important forecast element to ensure the safety of personnel and flight hardware at Kennedy Space Center (KSC) and the Cape Canaveral Air Force Station (CCAFS) in East-Central Florida. The 45th Weather Squadron (45 WS), the organization that issues forecasts for the KSC/CCAFS area, finds that peak winds are more difficult to forecast than mean winds. This difficulty motivated the 45 WS to request two independent studies. The first (Merceret 2009) was the development of a reliable model for gust factors (GF) relating the peak to the mean wind speed in tropical storms (TS). The second (Lambert et al. 2008) was a climatological study of non-TS cool season (October-April) mean and peak wind speeds by the Applied Meteorology Unit (AMU; Bauman et al. 2004) without the use of GF. Both studies presented their statistics as functions of mean wind speed and height.

Most of the few comparisons of TS and non-TS GF in the literature suggest that non-TS GF at a given height and mean wind speed are smaller than the corresponding TS GF. The investigation reported here converted the non-TS peak wind statistics calculated by the AMU to the equivalent GF statistics and compared them with the previous TS GF results. The advantage of this effort over all previously reported studies of its kind is that the TS and non-TS data were taken from the same towers in the same locations. This eliminates differing surface attributes, including roughness length and thermal properties, as a major source of variance in the comparison.

The goal of this study is two-fold: to determine the relationship between the non-TS and TS GF and their standard deviations (GFSD) and to determine if models similar to those developed for TS data in Merceret (2009) could be developed for the non-TS environment. The results are consistent with the literature, but include much more detailed, quantitative information on the nature of the relationship between TS and non-TS GF and GFSD as a function of height and mean wind speed.

2 DATA

The wind data used in the comparison are from Towers 2, 6, 110 and 313 on CCAFS and KSC (Figure **1**). They consist of 5-min mean and peak speeds and directions. The mean wind is the average of 300 1-second observations collected over a 5-min period, and the peak is the highest 1-second wind in the period.

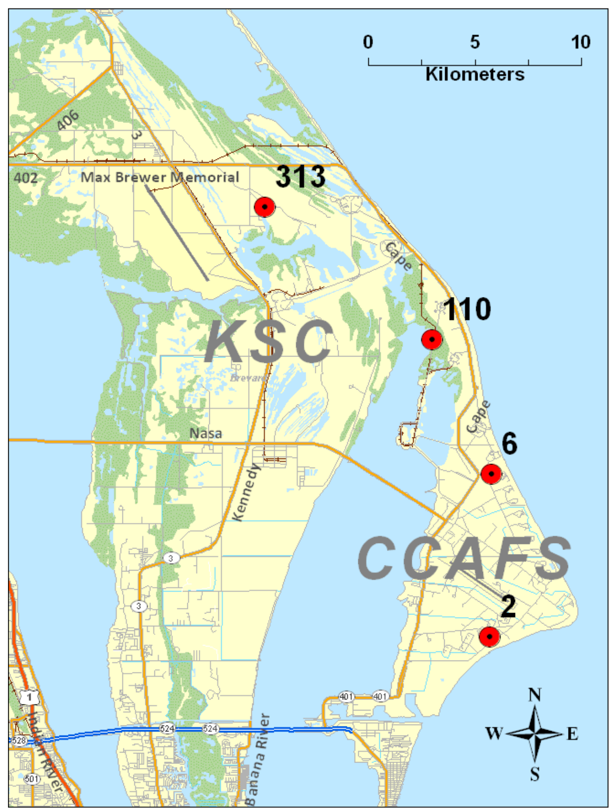

Figure 1. Map of the KSC/CCAFS area showing the locations of the towers used in this study.

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The towers are instrumented on two opposing sides with wind sensors at 12, 54, 90, 145, 162, 204, 295, 394 and 492 ft above ground. Data from the 12-ft sensors were not used because they were likely affected by local surface features (e.g. vegetation). It was unlikely that valid statistics or comparisons could be produced at this level. Not every tower is instrumented at every height and only Tower 313 has heights greater than 204 ft (Table **1**). The data were checked for quality using the algorithms described in Lambert (2002).

The TS data were collected during Hurricanes Frances and Jeanne in September 2004 and are described in more detail in Merceret (2009). The period of the non-TS data includes the cool season months (October–April) 1995-2007.

Table 1. Heights of the wind sensors used in this study for each tower.

Height (ft)	***2***	***6***	***110***	***313***
54	**X**	**X**	**X**	**X**
90	**X**			
145	**X**			
162		**X**	**X**	**X**
204	**X**	**X**	**X**	**X**
295				**X**
394				**X**
492				**X**

3 DATA PROCESSING

The non-TS data were prepared using the same methods as for the TS data in Merceret (2009) to facilitate a direct comparison of the GF and GFSD.

3.1 Stratifications

The non-TS data were first stratified by individual sensor on each tower, height, and side. They were then stratified by three categories: wind direction, wind speed, and time of day.

3.1.1 Direction Sector

The data were stratified into two direction sectors:

- 0° - 60°, or northeast (NE) and
- 180° - 240°, or southwest (SW).

The TS data were not stratified by direction sector, but most of the TS winds were from the NE. Hence, the NE stratification would provide the closest comparison between the TS and non-TS data. For the KSC/CCAFS area, NE is an onshore direction. The SW stratification directly opposes the NE sector and would add effects due to friction from wind flow over land as this is an offshore direction.

3.1.2 Wind Speed Bins

Following the wind speed stratification for the TS data, only mean wind speeds ≥ 15 kt were included in the non-TS data. Instead of stratifying by individual mean speeds, the data were assigned to two bins spanning 10 kt: a 20-kt bin containing mean speeds of 15-24 kt and a 30-kt bin containing mean speeds of 25-34 kt. There were higher speeds in both data sets, but not enough samples in the non-TS data to warrant higher speed bins.

3.1.3 Time of Day

Stability is well known as important in the generation of peak winds. However, the non-TS data were not stratified by any stability parameter. The 45 WS tasked the AMU to use only wind data in the cool season climatology. Temperature data from the towers were not quality controlled since they were not required for that effort. Resources were not available to perform the quality control and analysis needed to generate a stability stratification for this work.

Stability was also not used as a stratification for the TS data, but the TS environment is likely one of near neutral stability because of the strong wind shear and associated production rate of turbulent kinetic energy that drives extensive boundary layer mixing near the surface. This assumption is consistent with Vickery and Skerlj (2005), which found that hurricane GF can be described using models developed for neutral boundary layer flows.

In an attempt to use data from similar neutral stability environments, only data during the daylight hours of 1400 - 2100 UTC (0900 - 1600 EST) were used for the non-TS statistics. All of the non-TS data were collected during the Florida cool season, during which stable conditions occur frequently during hours of darkness. The assumption is that most of the stable cases would be eliminated by limiting the data to daylight hours. The daylight cases likely ranged from near neutral to somewhat unstable.

3.2 GF and GFSD Calculations

The GF is defined here as the ratio of the 1-second peak wind speed in a 5-min period to the mean wind speed over that period. This averaging time was selected based on the data available operationally to the 45 WS (see Section 2).

The GF for each individual mean/peak speed combination were calculated first, followed by the GFSD and average GF for each mean speed. These values were then used to calculate the average GF and average GFSD for each tower/height/speed-bin stratification using a weighted mean based on the number of observations at each mean wind speed. The resulting values were tabulated, plotted and manually examined for outliers. Each outlier case identified during the manual examination was reviewed in detail and kept, revised or eliminated depending on the cause of the anomaly. These final GF and GFSD values formed the basis of the comparison to the TS values and in determining whether a model could be developed to describe the behavior of the non-TS winds.

4 DATA COMPARISON

There are two goals for the GF and GFSD comparisons in this section:

- Determine the relationship between TS and non-TS values, and
- Determine if a TS-like model can be created for non-TS cases.

4.1 TS and non-TS GF

As noted by Paulsen and Schroeder (2005; hereafter PS05), several studies found non-TS GF to be less than TS GF, but others showed little difference. Sparks and Huang (1999) are reported by PS05 to have suggested that the differences found by others may be due to differences in roughness exposure since the TS and non-TS measurements were made at separate locations. Those studies also used different instrumentation at each location. PS05 conducted their study using two locations but the same instrumentation. Their data clearly showed that the non-TS GF were less than the TS GF. Although the use of common instrumentation was a step in the right direction, their results are still subject to the roughness exposure issue due to different locations. The measurements in this study were made with the same instruments mounted on the same towers at the same locations in both TS and non-TS environments, thereby overcoming this issue.

The non-TS GF were compared with the TS model GF from Merceret (2009). Both were put in tabular form in Microsoft Excel® and the ratio of the non-TS to the TS data was computed for each tower/height/speed bin. Ratios less than 1 indicate the non-TS GF were less than the TS GF. The non-TS data differed sufficiently from tower to tower that it was necessary to treat each tower separately. The TS model is tower-independent and was used for all towers. The results are shown in Table 2. The ratios show that the non-TS GF in this study were less than the TS GF, with one exception. The only stratification with non-TS GF greater than TS GF was Tower 6 at 54 ft and 20 kt (gold shading). The reason for this deviation from the otherwise universal occurrence of ratios less than 1 is unknown.

Table 2. Ratios of non-TS GF to the TS model GF for each tower, height and mean wind speed bin. Empty cells are those for which there was insufficient data for the computation of a valid mean GF. The gold cell highlights the only value ≥ 1.

Tower	*Speed Bin (kt)*	*54 ft*	*90 ft*	*145 ft*	*162 ft*	*204 ft*	*295 ft*	*394 ft*	*492 ft*
2	20	0.951	0.939	0.932		0.940			
	30			0.978		0.970			
6	20	1.010			0.863	0.862			
	30				0.878	0.878			
110	20	0.947			0.915	0.911			
	30				0.917	0.906			
313	20	0.893			0.912	0.919	0.925	0.932	0.934
	30				0.952	0.950	0.928	0.920	0.919

Merceret (2009) established that TS GF decrease systematically with height. This characteristic has long been known to be true of non-TS GF as noted by Davis and Newstein (1968), Deacon (1955), and others. The results of this study confirm this result, and also show that the functional form of this variation is the same in both the TS and non-TS cases.

Figure 2 shows the non-TS and TS model GF values for the 20-kt mean wind speed bin at all levels on Tower 313. Both sets of values decrease with height, and the non-TS values are less than the TS model values as found in Table 2. The curves through each set of values are of the form $GF=aH^b$ given by Merceret (2009). The TS model fit is perfect ($r^2=1$) since the points are derived from the model equation of that form. The fit to the non-TS GF values is excellent ($r^2=0.9998$). The coefficient and exponent values for the TS and non-TS equations are shown in Table 3. The non-TS coefficient, ***a***, is less than ***a*** for the TS model while the power law exponents are both near -0.1. This shows that the non-TS GF are systematically smaller than the TS GF at these wind speeds, confirming the results shown in Table 2 and other studies.

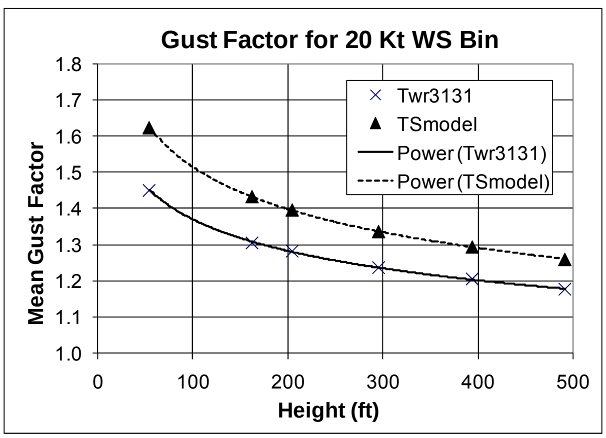

Figure 2. Mean GF from the TS model (Merceret 2009) and Tower 313 non-TS data for the 20 kt mean wind speed bin as a function of height. Both curves are fitted in the form $GF=aH^b$.

Table 3. Regression coefficients for Figure 2.

Source	***a***	***b***
Tower 313 non-TS	2.1096	-0.0941
TS Model	2.5668	-0.1148

4.2 TS and non-TS GFSD

In Merceret (2009), the TS GFSD exhibited consistent changes with speed and height among the towers. This allowed development of a model to calculate the GFSD in addition to a GF model. The value of being able to model the GFSD is that, along with a model for the mean GF and an assumption about the shape of the distribution, the probability of exceeding any specified peak wind at a given mean wind speed can be computed. This is extremely important for operational weather forecasting for aerospace applications. Merceret (2009) developed two such probability models assuming a Gaussian distribution for one and a lognormal distribution for the other. Both models verified well using an independent data set. A comparison between the non-TS and TS GFSD values was done to determine if the non-TS GFSD patterns were such that a model could be developed for the non-TS environment. Such a comparison does not appear to have been addressed in the literature.

The ratios of the non-TS to TS model GFSD are presented in Table **4**. The results are not as clear as for the mean GF shown in Table 2. Although most of the ratios are greater than 1, five are less than 1 (blue shading) with four of the five from Tower 313. Unlike the TS data, there was not a consistent pattern of increasing, decreasing, or steady GFSD values with height or speed among the towers for the non-TS data.

Given the limited range of wind speeds and the differences within and among the towers, no general conclusions can be made beyond noting that the non-TS GFSD do not differ by more than 30% in either direction from the TS model for the heights and wind speed ranges examined here. This result suggests that a model cannot be developed for the non-TS GFSD at this time.

Table 4. Ratios of non-TS GFSD to the TS model GFSD for each tower, height and mean wind speed bin. Empty cells are those for which there was insufficient data for the computation of a valid mean GF. The blue cells highlight the values < 1.

Tower	*Speed Bin (kt)*	*54 ft*	*90 ft*	*145 ft*	*162 ft*	*204 ft*	*295 ft*	*394 ft*	*492 ft*
2	20	1.233	1.159	1.116		1.154			
	30			1.202		1.259			
6	20	1.075			1.223	1.215			
	30				1.292	1.220			
110	20	0.970			1.090	1.218			
	30				1.159	1.289			
313	20	0.873			0.957	0.979	1.083	1.226	1.289
	30				1.061	1.037	0.989	1.004	1.180

5 CONCLUSIONS

A comparison of GF and GFSD between TS and non-TS environments was conducted and the variation of non-TS GF and GFSD values with speed and height were analyzed. The goals were to determine if there were differences between non-TS and TS GF and GFSD, and if a model could be developed for the non-TS environment in which the probability of exceeding a specific peak value can be calculated.

Studies similar to this exist in the literature, some with conflicting results. The conflicts could be attributed to the fact that these studies collected their TS and non-TS data from different locations, and some even used different instrumentation. The benefit of this study is that the TS and non-TS data were collected at the same location, the KSC/CCAFS area, using the same instruments. This prevented differing surface attributes and instrument characteristics from affecting the comparison.

5.1 Results

The results of the GF comparison are consistent with those found in previous studies:

- Non-TS GF are less than TS GF, and
- Non-TS GF decrease systematically with height in the same functional form as the TS GF in Merceret (2009).

These results indicate that a non-TS GF model could be developed whose output would depend on the mean wind speed and sensor height.

The results from the GFSD comparison are less clear. Most of the ratios of non-TS to TS GFSD were greater than one, but five were less than one. There was also no consistent variation of non-TS GFSD with speed or height among the towers. This does not allow development of a model for the non-TS GFSD. Consequently, a model to determine the probability of exceeding specific peak speeds cannot be developed.

5.2 Stability

As stated previously, the TS data in Merceret (2009) were likely from neutral environments. The non-TS data were not stratified by stability, but rather time of day with the assumption that stability differs between day and night hours. Using data collected during daylight hours only likely filtered out mostly stable cases, leaving neutral and unstable cases. Although unstable cases could not be removed, they are likely to have higher GF than neutral cases as shown by Monahan and Armendariz (1971). Since the results in Table 2 show that the non-TS GF are smaller than the TS GF, the inclusion of unstable cases makes stronger the result of non-TS GF being less than TS GF.

Inclusion of unstable cases could be a cause of the rogue GF ratio greater than 1 in Table 2, and also the inconsistent trends in the non-TS GFSD values. Any future work in this area will require the calculation of stability parameters to stratify the data into stable, neutral, and unstable environments.

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