P10.9 AN UPDATED WARM-SEASON CONVECTIVE WIND CLIMATOLOGY FOR CAPE CANAVERAL AIR FORCE STATION / KENNEDY SPACE CENTER

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1. INTRODUCTION

Convective wind warnings are the second-most frequent type of weather advisory issued by the 45th Weather Squadron (45 WS) at the Cape Canaveral Air Force Station / Kennedy Space Center (CCAFS/KSC). The 45 WS convective wind warning and related advisory requirements are listed in Table 1. Due to the extreme challenges in the anticipation and detection of these convective wind events, a NASA Space Grant contract was awarded to Plymouth State University to investigate improved methods for forecasting strong convective wind events at the CCAFS/KSC. This paper reports some of the preliminary results from that investigation.

First, an updated warm-season convective wind climatology was developed using CCAFS/KSC wind tower data from May through September of 1995-2003. The resulting climatology includes divisions of convective wind events by year, month, hour, elevation, and by tower. This climatology updated and significantly extended a previous preliminary climatology of convective winds at CCAFS/KSC (Sanger, 1999).

Second, based on this updated climatology, five strong convective wind events and five weaker events that each occurred on days of negligible synoptic-scale pressure gradient were chosen at random for case-study comparisons. A number of thermodynamic parameters, were derived from Skew-T/Log-p thermodynamic diagrams and statistics were computed to show which parameters differentiated the best between strong convective wind outbreaks (≥ 50 knots) with the weaker events that did not meet the convective wind warning criteria (i.e., < 35 knots). Vertical profiles of key parameters were also examined to see if there were correlations between strong and weaker wind cases.

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LOCATION	CRITERIA	DESIRED LEAD-TIME
KSC (surface-300 Ft)	≥ 35 Kt	30 min
	≥ 50 Kt	60 min
	≥ 60 Kt	60 min
CCAFS (surface-200 Ft)	≥ 35 Kt	30 min
	≥ 50 Kt	60 min
Patrick AFB (surface)	> 25 Kt	30 min
	≥ 35 Kt	30 min
	≥ 50 Kt	60 min
	Gust Spread ≥ 20 Kt	Observed
	LLWS < 2,000 Ft	Observed
MELBOURNE (surface)	≥ 50 Kt	60 min

Table 1. Convective wind warning and advisory requirements at 45 WS.

2. DATA AND METHODOLOGY

2.1 Data

Five-minute averaged peak wind speeds were acquired from over 40 wind tower sites sampling up to 10 height levels from the CCAFS/KSC mesonetwork (Case and Bauman, 2004) from May through September of 1995-2003. The tower locations are shown in Figure 1. Lambert (2002) outlined the automated quality-control schemes that were applied to these data. Extensive manual quality control was also used in this study to remove some additional outlier observations that had no meteorological support or corroboration. Data from tower reporting sites that had less than 75% valid reports from all possible 5-minute observations were not included in this study. After this initial processing, the remaining individual tower and elevation reports were merged and then sorted chronologically by date and time for each month.

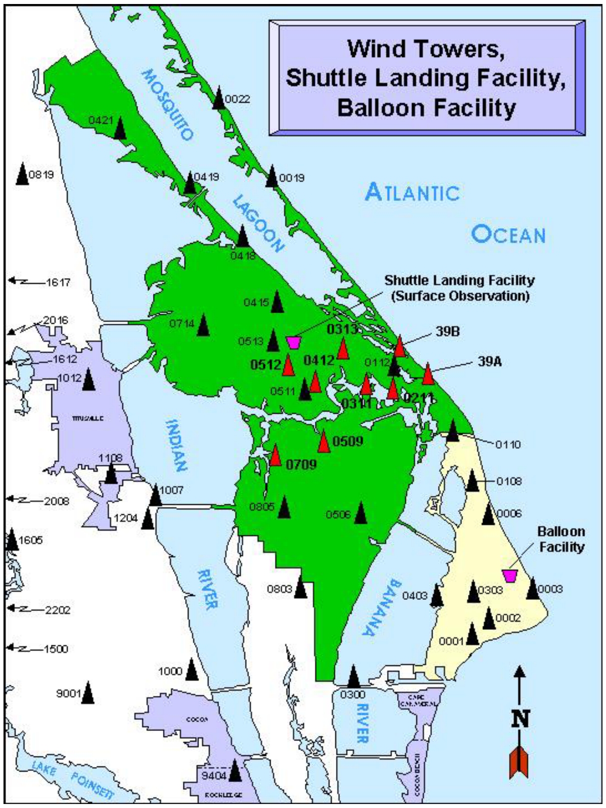

Figure 1. Weather towers at CCAFS/KSC.

2.2 Tabulation of Wind Outbreaks

After the chronological datasets were produced, these data were compared to corresponding surface METAR observations from the NASA Shuttle Landing Facility (KTTS); surface or 1000-mb height maps; radar summaries; infrared satellite imagery; and CGLSS lightning climatology from the NASA Applied Meteorology Unit (AMU). This information was used to separate events that were convectively generated from those of non-convective origin. The surface maps—or if none were available, the 1000-mb reanalysis height maps—were also used to classify events according to the magnitude and direction of the synoptic-scale pressure gradient. Potential outbreaks were further segregated according to whether or not a tropical cyclone was associated with their formation.

Convective wind "outbreaks" were defined as "those periods starting with at least one peak wind report of ≥ 35 knots, determined to be convectively driven, for a single tower observation(s) or multiple tower observations that ended when there were no additional convective wind reports ≥ 35 knots from any sites for 6 hours or more." This definition was adopted so as not to exclude other possible convective wind outbreaks that may occur on the same day. Convective winds primarily associated with tropical cyclone activity were not considered. The 35-knot criterion was used, since this is the first threshold in the 45 WS convective wind warnings.

2.3 Thermodynamic Indicators

Ten randomly chosen cases were also selected for further analysis. Five of these events had generated strong convective wind outbreaks ≥ 50 knots, whereas the others did not produce any winds exceeding advisory criteria (i.e. < 35 knots). All events occurred when there were no synoptic-scale pressure gradient contributions evident.

Insight into convectively generated wind events was facilitated by radiosondes, which are released asynoptically from CCAFS during the summer. The 1500 UTC KXMR soundings, which generally preceded convective initiation, were used in this part of the study to gather data on a number of thermodynamic indicators for each of the ten outbreaks. These are listed in Table 2.

Freezing level	CAP Strength
WBZ	LFC height
Precip. Water	Directional shear
Mean RH, sfc-500	EHI
1000-500 thick	BRN
500-hPa temp	Theta-E Index
LCL height	MDPI
Lifted Index	500-700 lapse
Showalter Index	sfc-850 lapse
Total Totals	850-700 lapse
K-Index	Height of min θ_w
SWEAT Index	Vertical Totals
CAPE	Cross Totals
CINH	

Table 2. Thermodynamic indicators from the 1500 UTC KXMR soundings used in the study.

Outbreak values were then sorted by whether or not they were associated with a strong wind gust. The mean, standard deviation, and mean ±1 and ±2 standard deviations were calculated for all events for all thermodynamic indicators. The latter calculations were used to establish a range of values for each parameter. It was deemed that if the range of values of an index for the stronger wind cases was statistically significantly different than for those convective events that generated weaker winds, then the index was considered to be reliable (i.e. differentiated between a strong wind case and weak wind case). In addition, vertical distributions of relative humidity, θ_w and θ_e were developed.

3. Results

3.1 Climatology

Figure 2 shows the annual distribution of convective wind observations ≥ 35 knots. The mean is 460 observations per season with a standard deviation of 317 observations. However, this is because the year 2001 had nearly three times as many convective wind observations as the second-highest year. If 2001 is considered an outlier, then most of the years fall within ±2σ of the annual mean, and so there is little annual variation. Exclusion of the year 2001 yields an appreciable decrease in both the mean and standard deviation of yearly convective wind observations, with a mean of 362 observations per year with a standard deviation of 126. The year 2001 may also reasonably be considered an outlier from the finding that the large number of observations that year were attributable to two major outbreaks on just two separate days in September of that year, with each one having over 300 strong convective wind observations. This lack of inter-annual variability also holds true for the yearly convective wind outbreaks (not shown) with a similar 2001 maxima that again be an outlier.

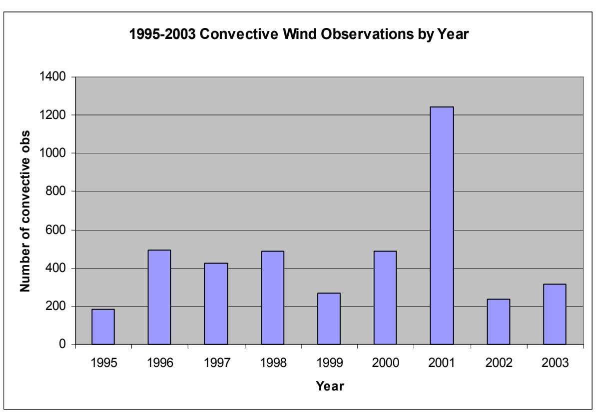

Figure 2. Annual number of convective wind observations(≥ 35 knots) in the CCAFS/KSC mesonetwork.

The monthly climatology of convective wind outbreaks is displayed in Figure 3. The average number of convective wind outbreaks per month shows an approximately normal distribution centered over July (indicated by the purple bars). The maximum number of outbreaks in any month (light blue bars) in any individual year was in June with 13. May and September are tied for having the fewest number of outbreaks in any month in any one year.

Figure 4 shows the hourly climatology of convective wind observations ≥ 35 knots. There is an apparent bimodal distribution in the number of outbreaks. The first of these is the intuitively obvious mid-to-late afternoon peak, but there is also a secondary peak between 0000-0400 UTC. This smaller later peak is presumably due to squall lines moving through the area, which usually happens in the early nighttime. Though fairly infrequent, these mesoscale convective systems tend to be stronger than average and produce more and stronger convective winds. Color-coded on this image are wind speeds in 4-kt increments. Closer inspection of Figure 4 indicates that a large portion of stronger wind observations (≥ 50 knots) occurred during the mid-to-late afternoon maximum.

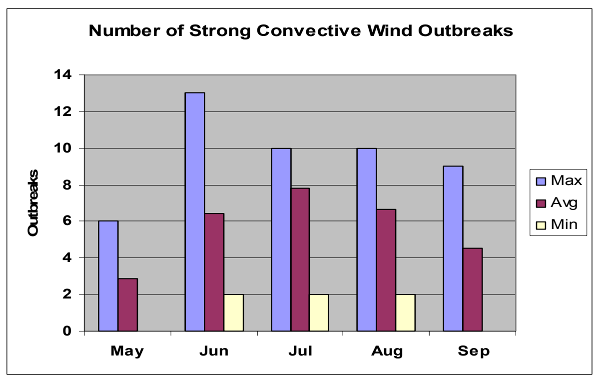

Figure 3. Monthly distribution of convective wind outbreaks.

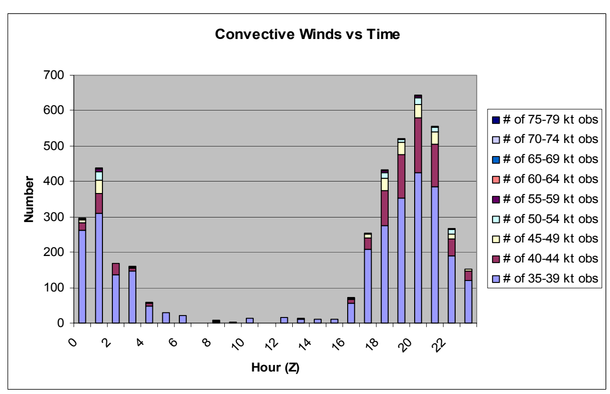

Figure 4. Hourly convective wind observations.

Convective wind observations by elevation, normalized by the number of towers that report winds at each elevation, are shown in Figure 5. The normalization by number of reporting towers is required since there are many more reports at 54 Ft than any other level in the CCAFS/KSC mesonetwork—reporting just the unnormalized number of observations at each level would be highly biased toward the 54 Ft level. While a significant portion of the total number of convective wind observations occurred at lower levels (not shown) this is likely from the fact that many of the mesonet towers report wind speeds at these lower heights. An increase in convective wind observations is noted with increasing elevation. There appears to be a change in the vertical distribution of convective wind speeds around 160 Ft. The number of lighter convective winds seems to be fairly constant above this height and the number of stronger convective winds increases above this height. This suggests a typical frictional and/or turbulent mixing depth of around 160 Ft for this area. The authors have not seen this vertical structure for convective winds previously documented.

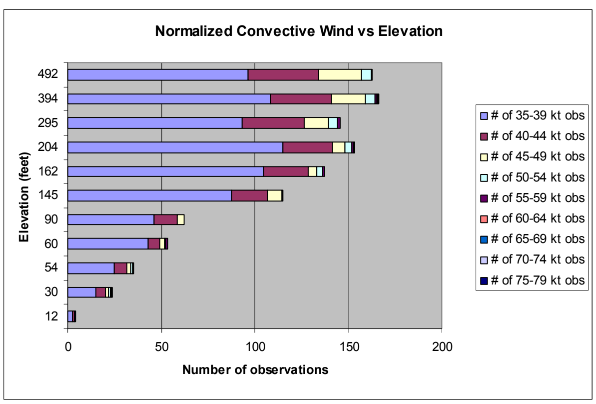

Figure 5. Convective wind obs by elevation normalized by number of towers that report at a particular height.

3.2. Thermodynamic Analysis

Data were computed for all parameters defined in Table 2 for 10 selected strong (≥ 50 Kt) and weak (<35 Kt) wind cases that occurred with no significant pressure gradient. The parameters that showed the greatest differences, i.e. may be the best discriminators between days requiring and not requiring 45 WS convective wind warnings, were precipitable water (PW), mean RH, sfc-500 hPa, LCL height, cap strength, and LFC height (Table 2) In general, Table 3 shows that the stronger wind cases generally were drier overall, had higher CAP strength, and higher LCLs and LFCs, than those associated with weaker convective winds.

3.3 Vertical Profiles

Vertical profiles of relative humidity (RH) and equivalent potential temperature (θ_e) for two cases, one associated with a strong wind convective outbreak and the other not, reveal some interesting results. These events are the July 26, 1999 case (a strong wind outbreak) and the June 21, 2003 case (a weak wind event). Each of the two events occurred at roughly the same time in the day (~18-21Z). Figures 6 and 7 show the vertical changes in relative humidity for the two events. Sharper RH lapse rates are noted in the mid-levels in the strong wind case. This was a common characteristic associated with other strong wind cases and not present in the weak wind cases. Also, there is a pocket of drier near-surface air in the strong wind case.

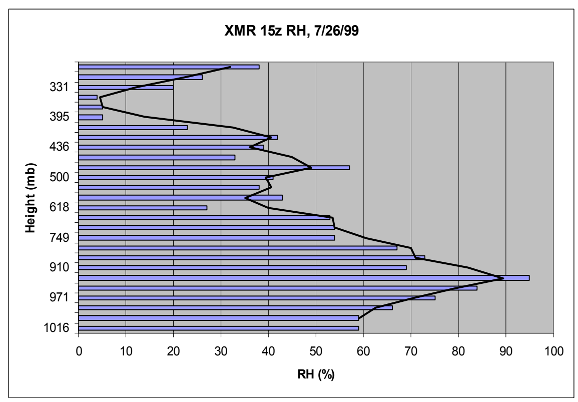

Figure 6. Vertical RH, July 26,1999—a strong convective wind day.

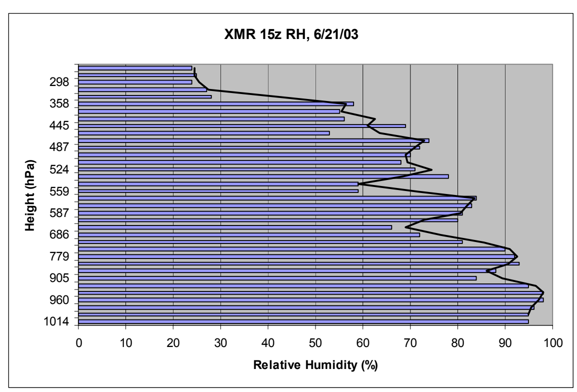

Figure 7. Vertical RH, June 21, 2003--a weak convective wind day.

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PARAMETER	MEAN	STD. DEV. (σ)	MEAN +/- 1σ	MEAN +/- 2σ
PW (in) (strong winds ($\geq$ 50 kt)	1.70	0.12	1.58 - 1.82	1.47 - 1.94
(weak winds <35 kt)	2.21	0.13~~3~~	2.07 - 2.34	1.94 - 2.47
RH sfc-500 (%)	57.80	6.10	51.70 – 63.80	45.60 - 69.90
	80.90	4.90	75.90 – 85.80	71.00 - 90.80
LCL Height (hPa)	908.59	16.29	892.3 - 924.9	876.0 - 941.2
	942.1	12.9	929.3-955.1	916.4-967.9
CAP Strength (^{o}C)	1.842	0.479	1.400 - 2.320	0.900 - 2.790
	0.360	0.359	0.000 - 0.710	-0.400 - 1.100
LFC Height (hPa)	823.59	25.65	797.90 -849.20	772.30 -874.90
	925.154	25.65	899.50 -950.80	873.90 - 976.40

Table 2. Statistics for parameters showing the greatest distinction between strong/weak wind events.

Figures 8 and 9 display the equivalent potential temperature stratification with height for the same cases. The main difference noted here is the steeper mid-level θ_e lapse rate for the stronger wind case than the weaker wind case. Similar findings hold for the wet-bulb potential temperature stratification in the vertical (not shown).

This possible dependency on lapse rate of θ_e makes good physical sense and suggests a possible improved convective wind index. The steeper lapse rate of θ_e causes a lower average θ_e to be entrained into the convection from the ambient air. In addition, ambient air that is sufficiently dry to cause downbursts via evaporative cooling is entrained at lower altitudes. A downburst that starts at a lower height loses less of its negative buoyancy from compressional heating as it descends and thus arrives at the surface with more of its original velocity. The 45 WS already has a downburst forecast tool that considers the vertical distribution of θ_e. The Microburst-Day Potential Index (MDPI) gives the likelihood of downbursts, assuming deep convection is initiated, via the following equation (Wheeler and Roeder, 1996).

$$\mathrm{MDPI} = \frac{\mathrm{Max}\theta_e(\text{lowest 150 hPA}) - \mathrm{Min}\ \theta_e(\text{650-500hPA})}{30\ \mathrm{K}}$$

The θ_e layers and the normalizing factor of 30K are empirically tuned to the CCAFS/KSC area so that a MDPI $\geq$ 1 means downbursts are likely. However, MDPI does not consider the θ_e lapse rate. The authors speculate that a new 'Modified

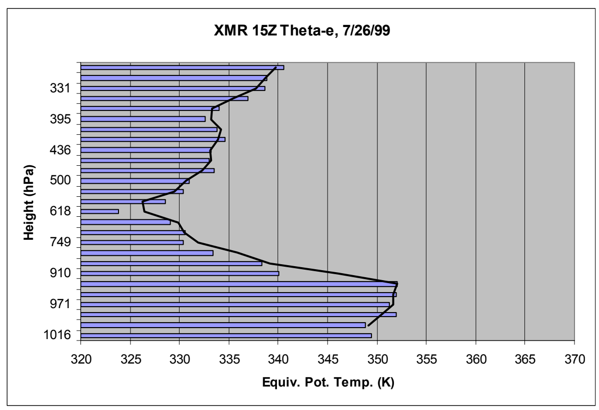

Figure 8. Vertical θ_e, July 26, 1999—a strong convective wind day.

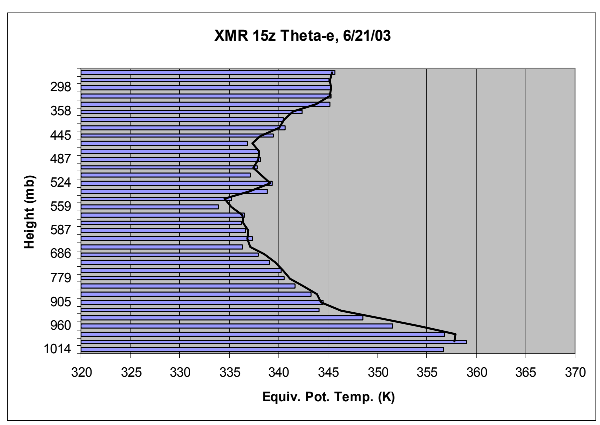

Figure 9. Vertical θ_e, June 21, 2003—a weak convective wind day.

MDPI' might perform better and might also provide maximum likely wind gust, in addition to downburst likelihood. The Modified MDPI might parameterize the θ_e lapse rate by incorporating the pressure at which the minimum θ_e aloft occurs and the surface pressure. The Modified MDPPI might have the following form:

$$\text{Modified MDPI} = C_i[\Delta\theta_e]\left[\frac{psfc}{psfc - p(\min \theta_e \text{ aloft})}\right]$$

where $\Delta\theta_e$ is the difference from the maximum value in the boundary layer to the minimum value aloft. The C_i is a local empirically tuned scale constant to convert Modified MDPI into a downburst probability for C_1, and perhaps a different conversion constant C_2 could provide the expected maximum convective wind gust for C_2. The C_1 would have units of hPa/K and C_2 would have units of ms^{-1}hPa/K. There are several alternative methods to incorporate the θ_e lapse rate. Yet another alternative is to derive the expected maximum gust directly from the vertical equation of motion—given this much original negative buoyancy at the pressure of minimum θ_e aloft, and this much compressional heating as the parcel descends to the ground, the parcel should have this much velocity remaining when it reaches the surface pressure.

4. Future Work

This paper has reported just the preliminary results of this investigation. Much more work is planned. For example, the authors certainly want to significantly increase the sample sizes. The two large outbreak days in September 2001 should be investigated further and perhaps excluded from the analysis as outliers. The frequency distribution of convective winds and best-fit equation with probabilities of exceeding the 45 WS warning thresholds will be developed. Hypothesis testing will be used to better select the variables that discriminate between strong and weak convective wind days. The performance of the standard convective wind Skew-T/Log-p indexes will be documented, to include T1, T2, Synder Method, MDPI, WINDEX, and the relatively new Wet Microburst Severity Index. Also, the role of the θ_e lapse rate will be investigated further, perhaps via a Modified MDPI, as discussed at the end of section 3.2.

Other possible follow-on projects may be the development of improved displays of the GOES sounder downburst products. For example, a bivariate statistical interpolation scheme, such as a Barnes Analysis, may allow filling in missing values when clouds interfere with the GOES sounder. The display of isoplethed and/or color-coded values across an area at a single time ma help find areas of strong gradients, which may be areas of more likely and/or stronger downbursts. The display of time-series of the GOES sounder downburst indexes at a point may help identify if the downburst behavior of the atmosphere is modifying, especially if the expected diurnal variation is either displayed or correction factors are applied. A different study could investigate how downburst speeds decay with distance. Tools already exist to aid warning decisions for if downbursts are occurring and how intense they may be. But no guidance exists for what wind gust is expected for a point of interest given the distance to the center of the cell. This could be very important to point operations that are sensitive to winds, such as airports and space launch complexes. Finally, a last possible future project is a divergence-based definition of downbursts may be developed for use with weather tower mesonetworks, such as at CCAFS/KSC. Such a divergence-based definition could help future research by providing a better tool to identify candidate downbursts. This divergence-based definition might supplement or even replace the single tower automated downburst algorithm proposed by Fujita and used since 1985.

5. Summary

An updated climatology was developed for strong convective winds for the CCAFS/KSC range complex. The frequency of convective winds appears to usually varies only slightly year to year. On average, July has the most convective events during the warm season. There are two distinct diurnal maxima—one in the afternoon and the other before midnight. Additional work is being completed to categorize winds that are slightly less than advisory criteria.

Initial case studies have been completed to distinguish thermodynamic differences between strong and weak convective wind events. From the preliminary results, the moisture content and vertical distributions appear to be key differentiating features. Other thermodynamic variables also show promise by having significant contrasts for the different kind of events. Many more case studies are in the process of being completed to confirm these preliminary findings.

6. Acknowledgements

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7. References

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