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CHARACTERISTICS OF THE NOCTURNAL LAND BREEZE OVER THE KENNEDY SPACE CENTER, FLORIDA

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1. INTRODUCTION

The onset of the nocturnal land breeze at the Kennedy Space Center (KSC) and Cape Canaveral Air Force Station (CCAFS) is both operationally significant and challenging to forecast. The occurrence and timing of the nocturnal land breeze influence low-level winds and stability, low temperatures, and the development of fog. U.S. Air Force forecasters at KSC/CCAFS can often predict the occurrence of a land breeze for a particular night, but find it challenging to determine the onset time, movement, and strength. Accurate predictions of the land breeze are especially critical for toxic material dispersion forecasts associated with space-launch missions, since wind direction and low-level stability can change dramatically with the passage of a land-breeze front.

Many studies have analyzed the Florida sea-breeze phenomena in great detail; however, limited work has been done in understanding the characteristics, structure, and evolution of the land breeze. As a result, the Applied Meteorology Unit (AMU) at CCAFS developed a land-breeze climatology to examine the characteristics of the land breeze at KSC/CCAFS. The ultimate goal is to develop a set of forecast rules that will improve the reliability of the occurrence forecasts and help determine the timing, duration, speed, and direction of the land breeze.

This paper presents an objective methodology used to generate a seven-year climatology of land-breeze events across east-central Florida. Section 2 describes the objective technique used to identify land breezes over KSC/CCAFS, section 3 presents sample results from the seven-year climatology, and section 4 provides future direction towards developing forecast rules to predict more precisely land-breeze events.

2. MESONET WIND-TOWER DATASET

The data set used to develop this climatology is derived from the KSC/CCAFS mesonet of wind towers, which covers the barrier islands of east-central Florida where all the KSC/CCAFS launch pads are located, as well as adjacent portions of mainland Florida (Fig. 1). The KSC/CCAFS mesonet has an average station spacing of about 5 km and measures temperature, dew point, and winds at various levels ranging from 1.8 m (6 ft) to 150 m (492 ft). The primary measurement levels for most towers are 6 ft (temperature and dew point), 12 ft (winds), and 54 ft (winds and temperature). Tower data are available as often as every minute; however, archived 5-minute data were used for this study.

The period of record of the wind-tower dataset used for this climatology spans from February 1995 to January 2002. For this study, we have excluded the peak convective months of June to September. The starting month of February 1995 was chosen based on a format change in the archived wind-tower data at that time. All KSC/CCAFS wind-tower data were quality controlled prior to processing for the land-breeze climatology. In preparation for the objective technique, the wind-tower observations were objectively analyzed to a grid with 1.25-km horizontal grid spacing using the Barnes (1964) technique. The temperature and dew point temperature at 6 ft, and temperature, and u- and v-wind components at 54 ft were all analyzed to the grid every 5 minutes.

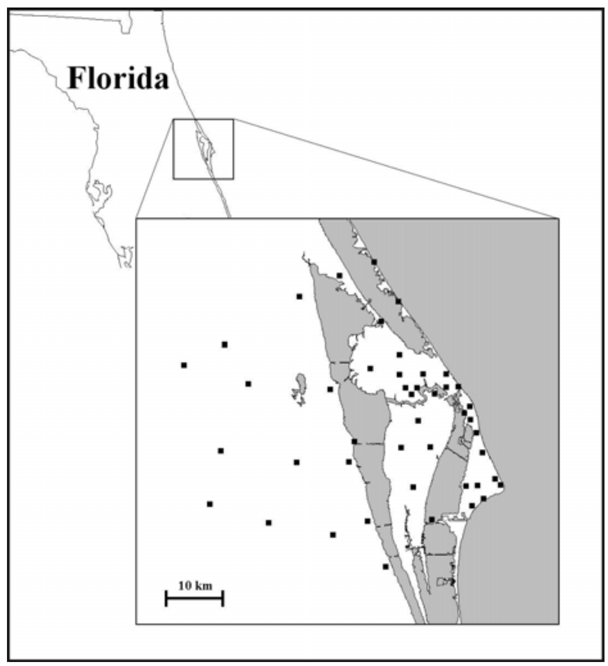

Figure 1. The locations of the 45 KSC/CCAFS mesonet wind towers used to develop the seven-year land-breeze climatology over east-central Florida.

3. OBJECTIVE BOUNDARY IDENTIFICATION

The initial effort towards building the climatology was a subjective classification of events from the 1999 – 2000 cool-season months. Since the subjective, manual classification of all land-breeze events over several years is labor-intensive, the AMU developed an objective, computer-based method that identifies land-breeze boundaries while distinguishing them from other

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features such as fronts or precipitation outflow. This objective technique was then used to build the seven-year land-breeze climatology.

The algorithm was designed to identify as many land-breeze events as possible with a near zero false alarm rate (FAR). The algorithm was developed using the 1999 – 2000 cool season data, attempting to match the results of the subjective land-breeze classification. The program was then tested independently on the 1995 – 1996 season data and results were validated by a subjective examination of each day that the program classified a land breeze. Additional adjustments to the algorithm were then made to remove false alarms.

Prior to identifying and determining the movement of land-breeze boundaries, several rules are applied (Table 1) to remove from consideration any nights that experienced meteorological conditions unfavorable for land-breeze development, or had too much missing data. The rules in Table 1 led to a significant reduction in the false alarms caused by fronts or precipitation. The program then reads in the gridded wind data at 54 ft, and computes the wind direction at each grid point in order to define a boundary separating onshore versus offshore winds. The objective algorithm empirically identifies land-breeze boundaries from the analysis grids based on at least a 20° shift between onshore and offshore wind directions across a 2.5-km grid distance. Onshore flow is defined as wind directions from 335° to 180°, based on the geometric orientation of the east-central Florida coastline (Fig. 1). Boundary features are then tracked across the grid at 5-minute intervals.

Once the boundaries are flagged in the analysis grid, the land-breeze start and stop times are identified based on time and space continuity and an eastward movement of the boundary. The start time is considered the onset time of the land breeze, whereas the stop time is the last time when the boundary is identified in the analysis domain. To ensure temporal continuity, the boundary must be present at every 5-minute analysis time between the start and stop times. Finally, the meteorological data are archived for all identified land-breeze events at ± 60 minutes at each wind-tower location.

TABLE 1. A list of the meteorological and data conditions that warrant a night to be removed from consideration for a land breeze in the objective land-breeze identification program.

Condition	***Reason(s) for Rejection***
1) Presence of a trough in archived mean sea level pressure (MSLP) data.	Prevent the identification of a wind shift associated with a frontal or trough passage.
2) Large MSLP changes (> 5.0 mb in 13 hours) at the Shuttle Landing Facility (TTS).	Prevent the identification of a wind shift associated with a frontal or trough passage.
3) Any report of precipitation at TTS between 0000 and 1300 UTC.	a) Avoid the identification of outflow boundaries. b) Occurrence of precipitation is highly unfavorable for land-breeze development.
4) More than 7 out of a possible 14 hourly reports of cloud ceilings at TTS.	Insufficient radiational cooling for a land breeze.
5) More than 5 TTS cloud reports missing.	Prevents the adequate determination of sufficiently clear skies.
6) Mean nighttime, domain-wide 54-ft wind greater than 3.8 m s^{-1}.	Wind speeds too strong for development of a land breeze, based on subjective results of the 1999 – 2000 cool season.
7) More than 4% of 5-minute wind-tower data missing between 0000 and 1300 UTC.	Too much missing data, preventing adequate temporal continuity for tracking boundaries in the program.

4. LAND-BREEZE CLIMATOLOGY RESULTS

The program generally underestimated the total number of land-breeze events on the test season [probability of detection (POD) of 68%] since it was designed to have a near zero FAR. However, the low POD for the 1999 – 2000 developmental season also could have been caused by extensive testing that was performed on the wind tower network during that season, leading to frequent periods of missing data at several sites. The subsequent analyses experienced discontinuities and coverage gaps due to this missing data. As a result, many land-breeze events identified subjectively could not be classified objectively.

The algorithm identified 257 land-breeze events during the 7-year period. The monthly distribution of these events is shown in Fig. 2a. The monthly frequency peaks in April and reaches a minimum in December. The land-breeze frequency likely peaked in April because weather conditions in central Florida are often favorable for land breezes during this month. Florida weather in April typically features the prevalence of a surface high pressure ridge, a decrease in the influence of synoptic-scale frontal systems and subsequent light surface winds, an increase in the frequency of daytime sea breezes, and a relatively large diurnal variation between the high and low temperatures. The smaller number of land breezes during December and January probably results from the high frequency of synoptic-scale fronts and subsequent stronger winds, clouds, and precipitation.

The strength of land breezes varied substantially between events. Based on the subjective analysis prior to program development, “strong” land breezes were those events that had a distinct boundary passage and wind shift across most of the wind-tower network. “Weak” land-breeze events were often slow-moving, with a more subtle or gradual wind shift, and frequently affected only a portion of the wind-tower network. Thus, the percentage of the wind towers that experienced a land-breeze passage in the network is used as a proxy for the strength of an event. In Fig. 2a, the frequency of stronger land-breeze events (> 56% of the tower network experiencing a land-breeze passage) is plotted as a function of month (dark gray bars). Note that the frequency of strongest land-breeze events also peaked in April with the broad maximum extending from February to May. Also note the small number of strong land breezes from October to December.

The weather conditions conducive to land-breeze development in east-central Florida are also favorable for fog development (Wheeler et al. 1993), and the results of the land-breeze climatology clearly support this statement. The land breeze coincided with a much higher occurrence of fog over east-central Florida, as seen in Fig. 2b. In every month, the mean number of fog observations at the Shuttle Landing Facility (TTS) associated with land breezes was approximately twice that of non-land breeze days. This amount of disparity could be a conservative estimate as well. Among the 12 land-breeze events that the algorithm did not capture from the 1999 – 2000 season, the mean number of hourly TTS fog reports on these days was 4.9 (not shown), considerably higher than most of the monthly means for land-breeze days. Figure 2c also shows that as the strength of a land-breeze event increased (higher percentage of towers experiencing a passage), the propensity to develop fog near TTS also increased. This result agrees well with the timing of the land breeze as shown in Fig. 2d. As the strength of the land breeze increased, the onset time became earlier, thereby providing more time for fog to develop under the favorable offshore wind regime of a land breeze.

The land breeze also had an impact on the low-level temperatures at 6 ft and 54 ft. Figures 3a-b show the mean 6-ft and 54-ft temperature cooling rates within ± 60 minutes of land-breeze passages. Each event was categorized into northwest (NW), west (W), and southwest (SW) land breezes based on the mean wind direction for the hour after passage at all wind towers that experienced the particular land-breeze event. The mean cooling rate was then calculated for the NW, W, SW, and all land-breeze events (ALL).

At 6 ft, the land breeze tended to have a warming effect particularly for land breezes with westerly winds (W) behind the boundary (Fig. 3a). For the hour prior to the land breeze (-60 to 0 minutes), the mean cooling rate at 6 ft was about -1°F h^{-1}. After the boundary passage (given by the bold line at t = 0 minutes), the W land breeze experiences a warming rate of about 0.5°F h^{-1} for approximately 30 minutes. The NW land breeze impact on 6-ft temperatures was slightly less as its passage only slowed the rate of cooling for the first 30 minutes, with a very slight warming rate thereafter. The SW land breeze had the least impact on the mean cooling rate of the 6-ft temperatures (Fig 3a).

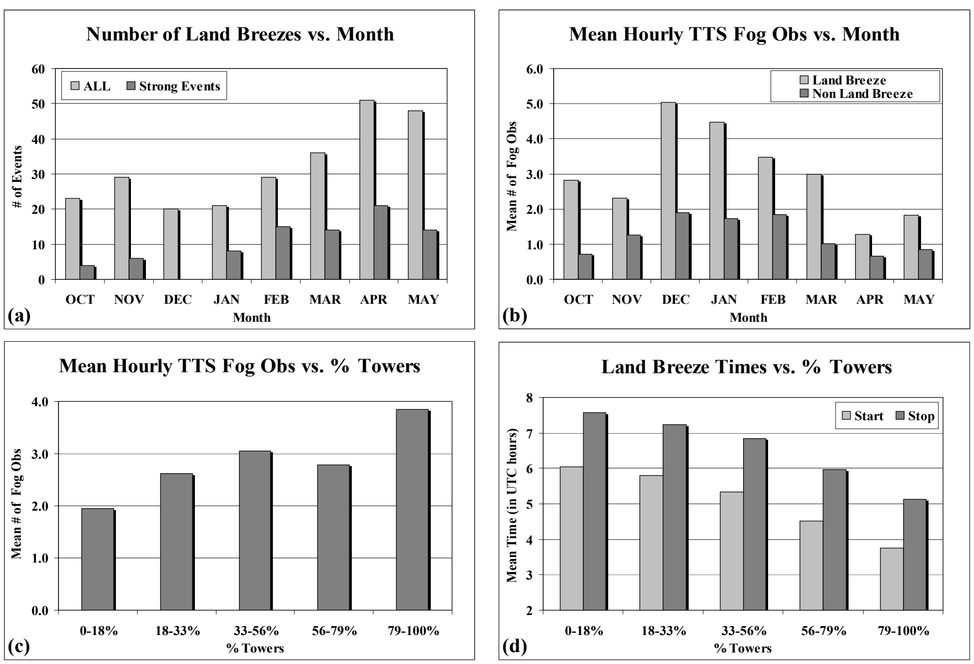

Figure 2. (a) The frequency of land breezes as a function of month for all 257 events (light gray), and for significant events (> 56% of towers, dark gray); (b) The mean number of TTS hourly fog reports per night as a function of month for land breeze (light gray) and non-land breeze days (dark gray); (c) The mean number of TTS hourly fog reports per night as a function of the % of wind towers that experienced a land-breeze passage during an event; (d) The mean start (light gray) and stop times (dark gray) of the land breeze passage as a function of the percentage of towers that experienced a land-breeze passage during an event.

At 54 ft, all land-breeze passages had a net cooling effect, with the W land breeze having the largest impact in the hour after passage (Fig. 3b). In fact, the mean 54-ft temperature change for each land breeze regime was nearly opposite to the 6-ft temperature change. The W (SW) land breeze had the greatest (least) warming influence at 6 ft, whereas the W (SW) land breeze had the greatest (least) cooling impact at 54 ft. At both heights, the NW land breeze aligned most closely with the overall mean cooling rates (ALL).

The difference between the 54-ft and 6-ft temperatures ($T_{54} - T_6$, representing stability in this layer) also showed some interesting variations between the different land breezes. The near-surface layer was almost always stable during land-breeze events ($T_{54} > T_6$), due to light winds generating conditions favorable for development of a radiational inversion. In addition, the land-breeze passages acted to decrease the 6 to 54-ft stability due to the mechanical mixing associated with the leading edge of the land-breeze front. As seen in Fig. 3c, the near-surface layer was the least stable during nights with SW land breezes, and the SW land-breeze passage also had the least impact on the rate of stability decrease (Fig. 3d). The W land breeze experienced the largest and most sustained rate of decrease in the stability (Fig. 3d). These results suggest that the W land breeze is strongest while the SW land breeze is weakest across east-central Florida.

5. FUTURE DIRECTION

The ultimate goal of this study is to develop a set of comprehensive forecast rules that can be applied to daily land-breeze predictions at KSC/CCAFS during the months when convection is the least frequent (October to May). The knowledge and understanding gained from the seven-year climatology will be utilized for developing such forecast rules. Initially, the AMU is examining several parameters such as the surface geostrophic flow, position and orientation of the surface ridge axis, pressure gradient, and the sea-breeze occurrence/non-occurrence during the previous afternoon as possible predictors of the land breeze onset, timing, strength, and movement. Previous studies over east-central Florida have indicated that the large-scale flow, Coriolis force, and daytime surface heating may be the primary contributors to the initial flow at the beginning of the land-breeze (Zhong and Takle 1992; Zhong and Takle 1993).

6. REFERENCES

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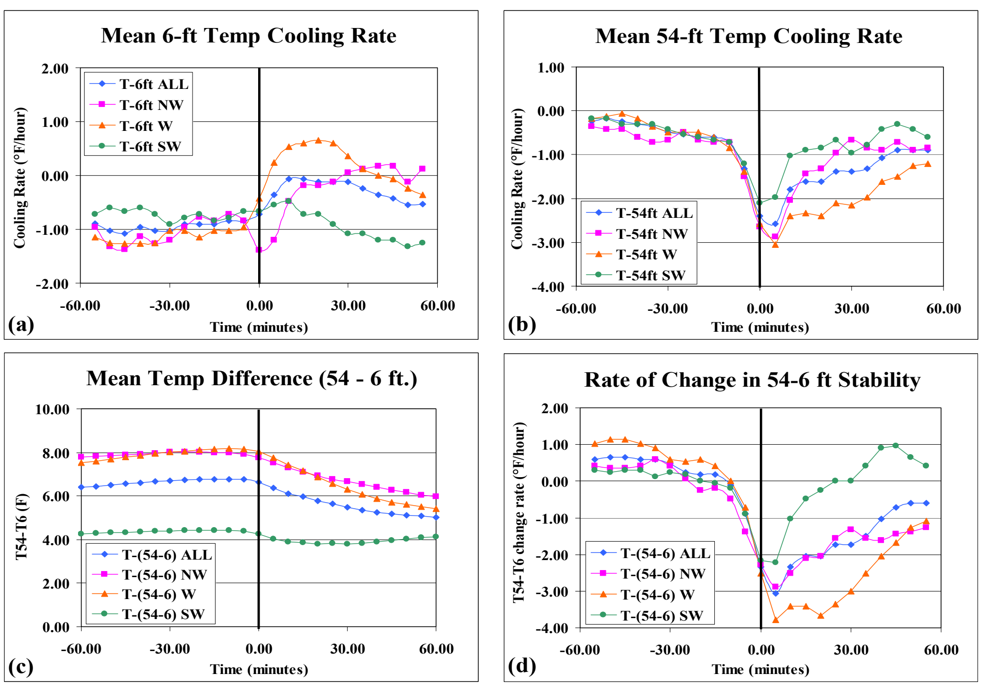

Figure 3. Five-minute mean temperature variations at ± 60 minutes of the land-breeze passage for all land breezes (ALL), and for events with post-land breeze winds from the northwest (NW), west (W), and southwest (SW). (a) 6-ft temperature cooling rate (°F h^{-1}), (b) 54-ft temperature cooling rate (°F h^{-1}), (c) mean layer stability ($T_{54} - T_6$ in °F), and (d) rate of change in the difference between the 54-ft and 6-ft temperatures (rate of change in 54–6 ft stability, °F h^{-1}).