10.5

TOWER AND DOPPLER RADAR OBSERVATIONS FROM THE BOUNDARY LAYER OF HURRICANES ISABEL (2003) AND FRANCES (2004)

Sylvie Lorsolo*, John L. Schroeder
Texas Tech University

1. INTRODUCTION

Understanding the structure and behaviour of the hurricane boundary layer (HBL) has been the main focus of the Texas Tech University Hurricane Intercept Team (TTUHIT) for over 8 years. To answer the numerous questions about the HBL, TTUHIT has been conducting field experiments that involve the deployment of instrumented towers and mobile radars in the path of landfalling hurricanes. During the 2003 and 2004 hurricane seasons, one experimental objective was to collect high-resolution data to investigate small-scale linear coherent features present in the HBL. Several past studies have identified linear coherent features in the HBL, but exhibited large differences in resulting wavelength. An early study using the Doppler On Wheels (DOW) (Wurman and Winslow 1998) identified sub-kilometer (∼600 m) HBL rolls, even suggesting features as small as ∼100 m. However, another study (Morrison *et al.* 2005) using WSR-88 data found HBL rolls of average wavelength of ∼1.4 km, with few occurrences below 1 km. A simulation study (Nolan 2005) identified instabilities in the HBL with wavelengths ranging between 3 and 5 km. Another simulation study (Foster 2005) indicated the prevalence of rolls in the HBL, with sub-kilometer wavelengths within the radius of maximum wind (RMW) and 1-2 km wavelengths outside.

Another important aspect of the HBL small-scale features is their potential interaction with the near-surface windfield. Although it has been suggested that these small-scale features could be responsible for irregularities in the the surface windfield and resulting damage, little is known about this interaction. To fully address both the small-scale features' structure and correlation with the near-surface windfield, TTUHIT deployed SMART radars near 10 m-towers. Such an experimental design would allow for the correlation between HBL data observed by the radar with near-surface data acquired from the towers. The radar scanning strategy was designed to collect high temporal and spatial resolution data of the lower HBL.

**Corresponding Author Address*: Sylvie Lorsolo, Texas Tech Univ., Atmospheric Science Group, Lubbock, TX 79409-2101 s.lorsolo@ttu.edu

2. RESULTS

2.1. Radar Data

Because of their finer spatial resolution relative to WSR-88D radars, SMART radars are ideal to investigate the structure of HBL small-scale features. The scanning strategy used for both Hurricane Isabel and Frances deployments provided high-resolution data focused on the lowest portion of the HBL. After performing successive radar data processing, the HBL small-scale features were identified and their wavelength was estimated. The data processing steps were as follows:

1. VAD processing
   The VAD technique (Browning and Wexler 1968) was performed on plan position indicators (PPIs) to obtain the mean wind vector, which was then removed from the original data. Figure 1 shows the resulting residual radial velocity field. The figure exhibits coherent linear features that are approximately aligned with the mean wind direction.

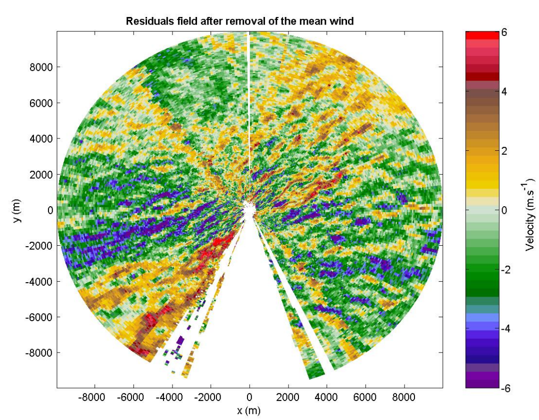

Figure 1: Radar velocity residuals after removing the mean wind filed using the VAD technique for Hurricane Frances.

2. Cartesian Gridding
   A gridding algorithm using the Cressman scheme was applied to individual volume scans to obtain data displayed in a cartesian framework. Figures 2 and 3 represent a three-dimensional view of the small-scale features for Hurricanes Isabel and Frances, respectively. In both cases, the features'

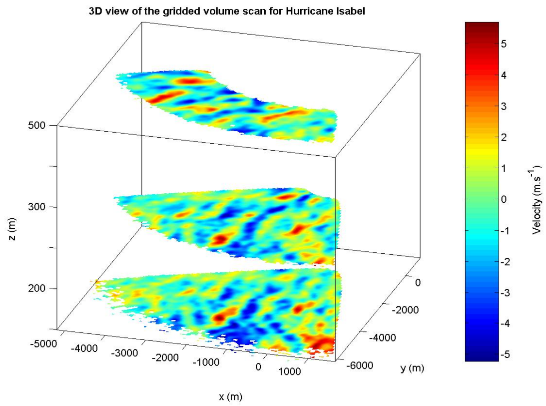

Figure 2: Three-dimensional view of the gridded radial velocity residual data from Hurricane Isabel. The plans are at 200 m, 300 m and 500 m AGL.

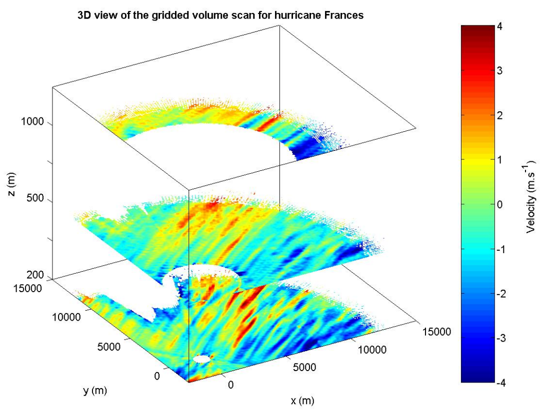

Figure 3: Same as Figure 2, but for Hurricane Frances. The plans are at 200 m, 500 m, 1000 m AGL.

vertical coherency is apparent. In the Isabel case, a veering of the features' orientation is apparent between 300 m and 500 m height. In Hurricane Frances, the veering of the features' orientation is more subtle, but clearly apparent between the lowest and highest cross-sections. It is not clear wether there is an actual veering with height or the features in the lower and upper portions of the HBL are in fact different. Such a veering with height would seem unlikely in the case of features that would span the HBL, with an overall roll-like circulation. It is thus important to anlyze further the upper-level of the HBL using range-height indicators (RHIs). The features seem to loose definition with range. This loss of definition might be attributed to aliasing (due to radar beam spreading) or to the fact that the top of the features has been reached.

3. Wavelength Analysis

Feature wavelength was analyzed using vertical cross-sections normal to the features. The vertical and horizontal coherency of the features was investigated by taking multiple vertical cross-sections normal to the features' orientation, then the residual velocity at each height along the cross-section was extracted and the peak to trough distance measured to estimate the wavelength. The estimates were then compiled and plotted in a histogram form which represents a normalized frequency (percentage of total sample size at each height) of wavelength versus height. Figure 4 is the wavelength distribution for Hurricane Isabel. The histogram reveals that most of the wavelengths are concentrated between 250 m and 550 m, with a maximum around 400 m. The distribution indicates also that the wavelength correlates with height up to 400 m AGL. A lack of data above 400 m AGL impeded the analysis above this level. Figure 5 represents the wavelength distribution for Hurricane Frances. Like in Hurricane Isabel, most wavelengths are localized in a 250-500 m window, with a peak at 400 m. In this case the analysis was conducted up to 550 m AGL, and also shows vertical coherency. The analysis was conducted with samples of approximately 1500-10000 peak to trough measurements at each height for Hurricane Isabel and 3000-5000 for Hurricane Frances. Almost no wavelengths greater that 1 km were found using the methodology discussed.

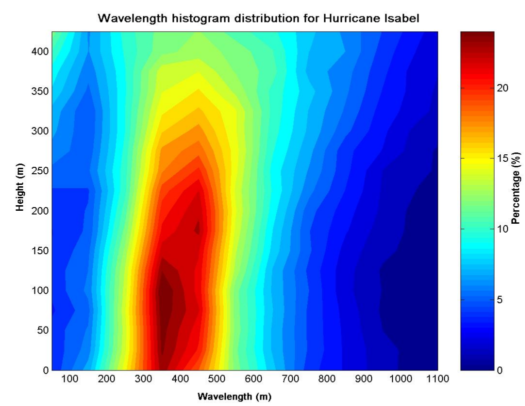

Figure 4: Histogram of wavelength distribution with height for Hurricane Isabel.

2.2. Tower Data

As stated previously, one of the goals of this study was to analyze the impact of the small-scale features on the near-surface windfield. Although radar data are useful to study large spatial areas, it is difficult to obtain valuable surface data due to ground clutter and

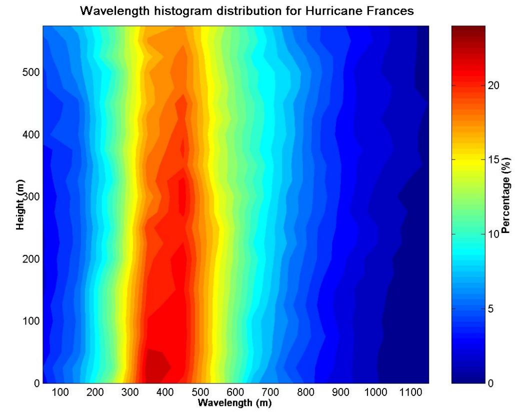

Figure 5: Same as Figure 4, but for Hurricane Frances.

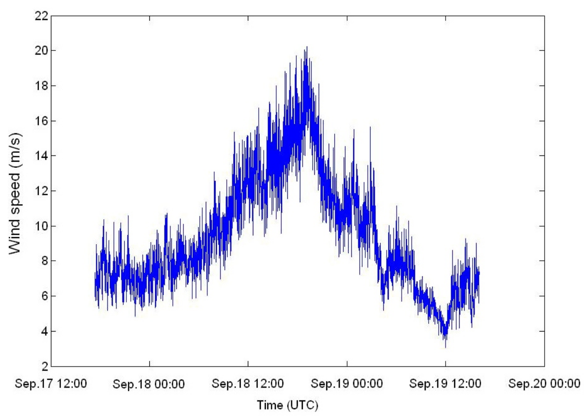

Figure 6: One-minute mean wind speed as recorded at Craven County Airport during the landfall of Hurricane Isabel.

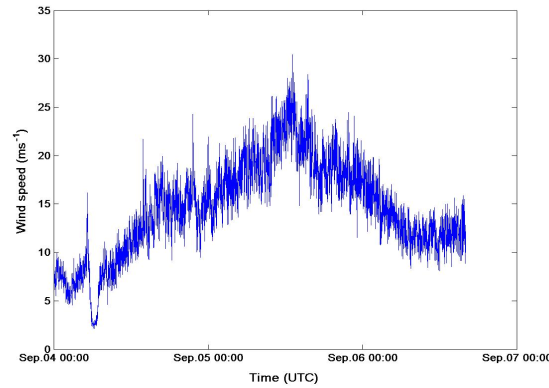

Figure 7: One-minute mean wind speed as recorded at the Space Coast Regional Airport, Titusville, FL during the landfall of Hurricane Frances.

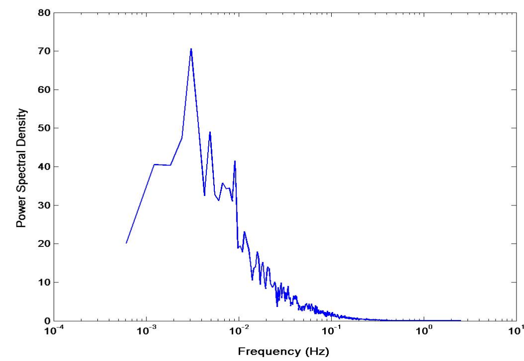

Figure 8: PSD from a 4-hour period of wind speed data collected from Hurricane Isabel.

blockage. Thus, to obtain relevant surface data, instrumented towers were deployed at close range from the radar. In the Hurricane Isabel deployment, three portable mesonet towers sampled data at a rate of 0.5-5 Hz, while in Hurricane Frances, one tower was used with a sampling frequency of 1 Hz. Figures 6 and 7 are time series of tower data from Hurricanes Isabel and Frances, respectively.

To analyze the scales of motion present in the tower records a frequency analysis was performed. This information is necessary to be able to understand the potential impact that the small-scale features have on the near-surface windfield. Figures 8 and 9 are plots of the power spectrum density (PSD) for a time period of four hours. A slidding window of 20 minutes with 50% overlapping was applied. The data were detrended and the PSDs were normalized by the variance. The two PSDs exhibit the same characteristics with most of the energy at low frequency, and little energy above 10^{-2} Hz. Although the features' scale of motion relative to a stationary observer has not yet been identified, it is assumed that any influence on the near-surface windfield would be reflected in such PSDs, but maybe masked by other turbulence. Retrieving the ground relative frequency corresponding to the coherent HBL features, if it exists, is one of the main goals of this study.

2.3. Radar and Tower Data Comparison

To analyze the potential influence of the small-scale features on the near-surface windfield a one-to-one comparison between tower data and radar data was first made. Because only radial velocities are available in radar data, the comparison required that the tower data were first converted into radial wind speed. Figure 10 shows a comparison between radial velocity from SMART radar 2 (SR-2) at 30.4 m AGL and tower data at 10 m AGL. The time series shows evidence of correlation between the two datasets. Figure 11 shows the one-to-one comparison for Hurricane Frances. This case also indicates that the radial velocities observed by the radar at 20 m AGL have a similar evolution to the tower data. In both cases the magnitudes of radar velocity are greater than the tower data mainly due to the

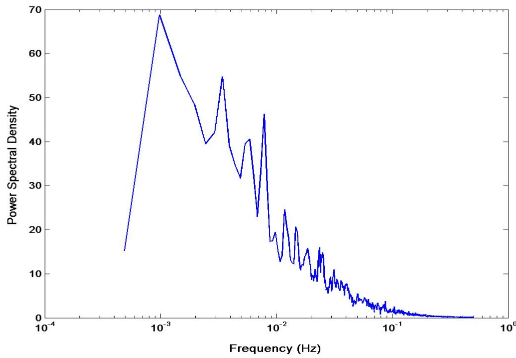

Figure 9: Same as Figure 8, but for Hurricane Frances.

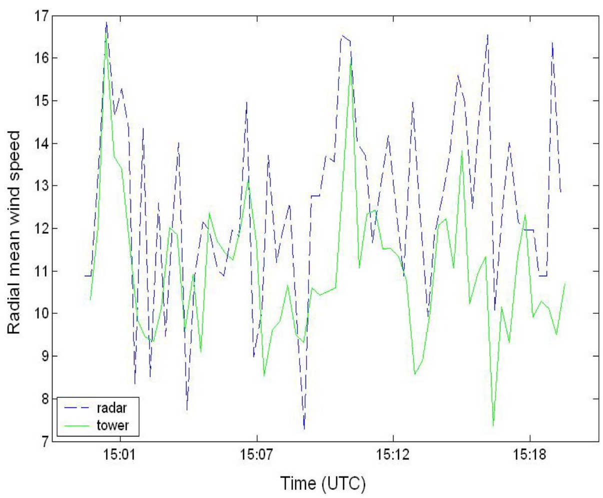

Figure 10: SR-2 and tower radial wind speed comparison collected in Hurricane Isabel. The radar data are located at 30.4 m AGL.

increase of the wind speed with height in the HBL. Although this one-to-one comparison method is valuable and identifies the correlation between data measured by the radar to that measured by the tower, it does not comprehensibly assess the feature's interaction within the general turbulent flow near the surface. Given the identified HBL features are superimposed with other scales of motion, and the fact that they move at a speed close to the mean wind speed, a one-to-one-comparison has limited ability to discriminate the effect of the various scales of motions. Another approach to address the subject of correlation with the surface flow is to identify the features' scale of motion in the frequency domain. The first step in this approach is to retrieve the translational vector of the features. This information, along with the wavelength information, would lead to the ground-relative frequency associated with the features. To estimate the translational vector, a method similar to the tracking reflectivity echoes by correlation (TREC) method (Tuttle and Foote 1990) was applied to the data. In this case, the residual ra-

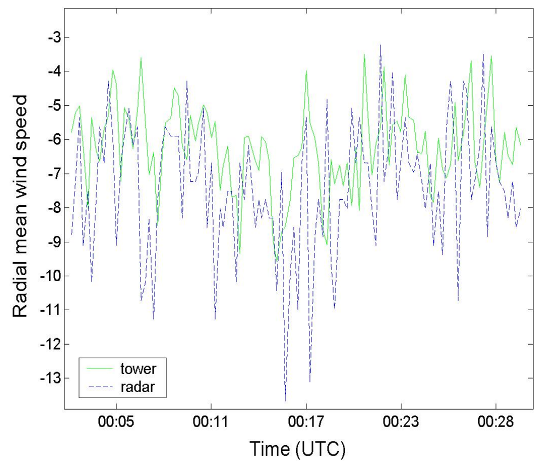

Figure 11: Same as Figure 10, but for Hurricane Frances. The radar data are located at 20.5 m AGL.

dial velocity data were used instead of reflectivity. Typically, the features's radar signature is tracked between two sector scans taken seconds apart by finding the maximum correlation between the two sweeps. The translational vector is then computed by retrieving the features' displacement during this time in the X and Y direction. In practice, samples of radar data covering approximately 3 km^2 were taken and were correlated with subsequent sector scans observed no more than one minute later. Only data with a correlation coefficient greater than 0.6 were included in the analysis. Preliminary results of this method are presented in Figures 12 and 13. The figures represent histograms of the translational wind speed and direction retrieve from a 30-minute period from Hurricane Frances. The results show that for both the translational speed and direction the standard deviation is very small, suggesting little variation of the translational vector during this time period. The mean translational speed and direction were respectively 25.3 ms^{-1} and 40.1°, very close to the VAD-retrieved mean wind speed and direction (25.8 ms^{-1} and 39.6°).

3. CONCLUSION AND FUTURE WORK

The preliminary results of this study indicate that the small-scale features identified in the BL of Hurricanes Isabel and Frances possess an average wavelength of 400 m. They maintain vertical and horizontal coherency and are approximately aligned with the mean wind direction. They also indicate that the windfield recorded from higher elevations in the HBL by the radar was correlated with the surface windfield recorded by the towers. A preliminary analysis of features' translational vector suggests that the features move at a fairly constant speed and direction. The next

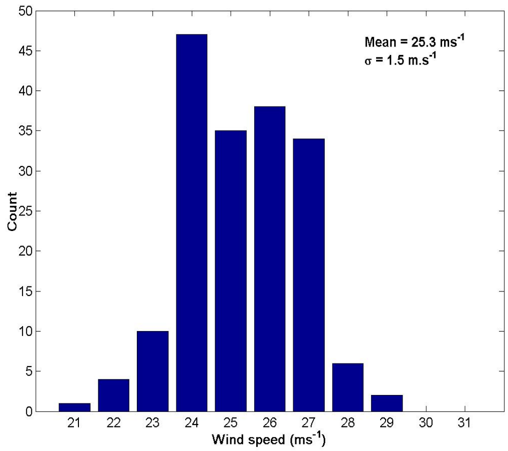

Figure 12: Translational wind speed distribution of the small-scale features in Hurricane Frances.

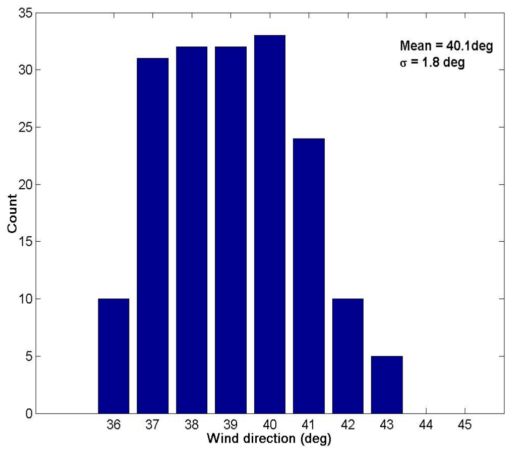

Figure 13: Translational wind direction distribution of the small-scale features in Hurricane Frances.

objective is to retrieve the ground-relative frequency associated with the features. This frequency will then be compared to PSDs from the tower time series.

ACKNOWLEDGMENTS

This research is supported by NIST (Department of Commerce NIST/TTU Cooperative Agreement Award 70NANB8H0059) and NSF Award ATM-0134188. The lead author is also funded by the Conseil Regional de la Martinique.

REFERENCES

Browning, K. A. and R. Wexler, 1968: The determination of kinematic properties of a wind field using Doppler radar. *J. Appl Meteor.*, **7**, 105-113.

Foster, R. C., 2005: Why rolls are prevalent in the hurricane boundary layer. *J. Atmos. Sci.*, **62**, 26472661.

Morrison, I., S. Businger, F. Marks, P. Dodge and J. A. Businger, 2005: An observational case for the prevalence of roll vortices in the hurricane boundary layer. *J. Atmos. Sci.*, **62**, 2662-2673.

Nolan, D. S., 2005: Instabilities in hurricane-like boundary layers. *Dyn. Atmos. Oceans*, **40**, 209-236.

Tuttle J. D. and G. B. Foote, 1990: Determination of the boundary layer airflow from a single Doppler radar. *J. Atmos. Oceanic Technol.*, **7**, 218-232.

Wurman, J., J. Winslow, 1998: Intense sub-kilometer-scale boundary layer rolls observed in Hurricane Fran. *Science*, **280**, 555-557.