# HURRICANE BOUNDARY LAYER SMALL-SCALE FEATURES OBSERVED USING RHI DATA COUPLED WITH VAD ANALYSIS

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## 1. INTRODUCTION

One focus in hurricane research is to better understand the hurricane boundary layer (HBL) as it is the portion of the storm that affects society. For over eight years, the Texas Tech University Hurricane Intercept Team (TTUHIT) has conducted field experiments to contribute to an improved understanding of hurricanes and more specifically their boundary layer (BL). At first, the experiments consisted of deploying instrumented towers in the path of landfalling hurricanes, allowing the acquisition of high temporal resolution meteorological data. Then, the Shared Mobile Atmospheric Research and Teaching (SMART) radars (Biggerstaff 2005) were added to the equipment to provide high spatial and temporal resolution radar data, which complemented the tower data. Individual deployment methodologies and experimental plans used were specific to the scientific issue being addressed.

One issue addressed by the Texas Tech Atmospheric Group was small-scale features embedded in HBLs. Early observational studies (Wurman and Winslow 1998) suggested that these small-scale features were a significant factor in the vertical transfer of momentum, heat and moisture throughout the HBL. However, little is known about the physical characteristics of these features. In an attempt to provide further understanding of these features, recent TTUHIT deployments have been focused on acquiring high resolution data of HBLs. During the landfall of Hurricanes Isabel (2003) and Frances (2004), high resolution data of the BL were collected using the SMART radars so that the entire depth of the BL could be investigated and documented.

The goal of the present study is to investigate the physical characteristics of the HBL small-scale features in both Hurricanes Isabel and Frances using radar data processing that incorporates the Velocity-Azimuth Display (VAD) technique into the analysis of Range-Height Indicators (RHIs).

## 2. EXPERIMENTS AND INSTRUMENTATION

#### 2.1. HURRICANE ISABEL (2003)

On September 18, 2003 Hurricane Isabel made landfall near Drum Inlet, North Carolina, as a category 2 hurricane. In order to document this event, two teams from TTU and the University of Oklahoma deployed five instrumented towers and the two SMART radars in the path of the hurricane. One SMART radar (SR2) employed scanning strategies dedicated to the acquisition of data to be used in the identification and the analysis of the small-scale features embedded in the HBL. SR2 was located at the Craven Regional Airport in New Bern, NC and the horizontal extent of the scans was almost entirely over land (Figure 1). Because the size of the features is relatively small, a gate spacing of 66.7 m was used, enabling high resolution data collection.

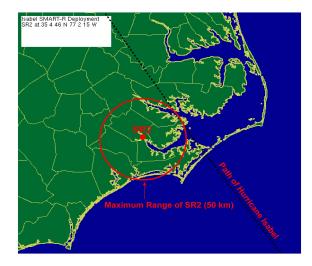


Figure 1: Experimental setup used during Hurricane Isabel's landfall.

Three types of scanning strategies were performed: the first one, using only sector scans of  $80^{\circ}$  and 7 elevation angles up to  $8.25^{\circ}$  was designed to collect data throughout the entire HBL. The limited azimuthal extent of the sector scans allowed for the temporal evolution of the BL to be captured. The second scanning strategy used  $90^{\circ}$  sector scans of 3 elevation angles up to  $1.5^{\circ}$ . The goal of this scanning strategy was to collect data in the HBL at a fast enough rate so that they could be correlated with data from towers deployed in the vicinity of the radar. The third scanning strategy performed RHIs along a fixed azimuth and was created to document the vertical extent of the small-scale features.

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## 2.2. HURRICANE FRANCES (2004)

Hurricane Frances made landfall on September 5th, 2004 on the east coast of the Florida Peninsula as a category 2 hurricane. For this deployment, both radars were used for the small-scale feature experiment. However, the TTUHIT simultaneously conducted other experiments including a dual-Doppler set-up, so the radars were at two different locations, 22 km apart. SR1 was was deployed at the Merritt Island Airport while SR2 was located at the Space Coast Regional Airport in Titusville, Florida (Figure 2).

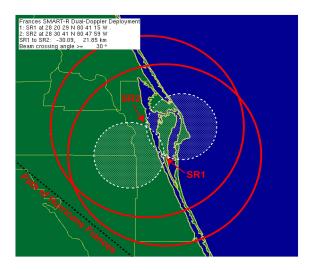


Figure 2: Experimental setup used during Hurricane Frances' landfall.

The scanning strategies used for Hurricane Frances were slightly different relative to those used for Hurricane Isabel. The strategy aimed at the entire HBL investigation was similar, with the exception that the sector scans azimuthal extent was  $140^{\circ}$  instead of  $80^{\circ}$ . The strategy used to document the temporal evolution of the small-scale features used sector scans of  $180^{\circ}$  and were only performed at one elevation angle ( $3^{\circ}$ ). As for the RHI scanning strategy, it was performed along successive azimuths, over  $120^{\circ}$ , so that data from the longitudinal and the lateral directions of the features could be acquired. Data from the dual-Doppler scanning strategies were also added to the analysis.

## 2.3. THE SMART RADARS

As aforementioned, the equipment used to identify and characterize small-scale features located in the HBL was the SMART radars (Figure 3) (Biggerstaff 2005). The SMART radars are mobile radars that are part of a research collaboration between the National Severe Storms Laboratory, Texas A&M University, the University of Oklahoma and Texas Tech University. Both radars are mounted on trucks, have wavelengths of 5 cm, an 8-foot antenna, a beamwidth of  $1.5^{\circ}$  with a gain of approximatively 5 dB and a minimal gate spacing of 62.5 m.



Figure 3: SMART radars.

#### 3. RADAR PROCESSING AND RESULTS

#### 3.1. VAD ANALYSIS

The small-scale features embedded in the HBL were easily identified in the radar data. In the Doppler velocity images, they appear as fine linear features superimposed on the overall hurricane mean wind field and could be interpreted as perturbations of the mean wind field (Figure 4).

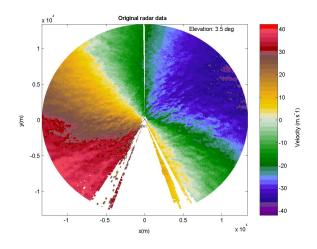


Figure 4: Original radial velocity data of Hurricane Frances collected using the SMART radars.

Thus, in order to analyze these features more closely, a VAD technique (Browning, 1968) was applied on the data to retrieve the mean wind speed and direction; the mean wind was then removed from the original data. Although the majority of the employed scanning strategies used sector scans instead of the full Plan Position Indicators (PPIs), the VAD technique was successfully applied by including a fitting algorithm into the original VAD technique. All the computation was completed with MAT-LAB. Once the mean was removed from the original velocity field, the small-scale features clearly emerged from the resulting field of residuals. Figure 5 shows the resulting field after removing the mean wind from the original data. The small-scale features appear clearly as linear features, almost aligned with the mean wind direction.

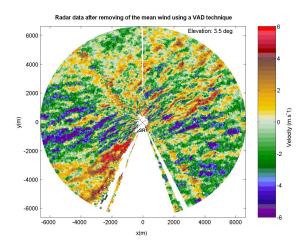


Figure 5: Radial velocity residual field after removing the mean using the VAD technique.

#### 3.2. RHI ANALYSIS

Although the VAD technique used on PPIs gives satisfactory results of the horizontal structure of the smallscale features, information on their vertical structure is not as straightforward to obtain. One way of gathering information on these small-scale features' vertical structure is to perform cross-sections throughout the volume scans of the data from which the mean has been removed. A steady state assumption is required for the results to be valid. This method gives fairly good results. Figure 6 shows a cross-section from Hurricane Isabel. The vertical structure is obvious, however, because it is a cross-section from a volume scan of vertical resolution of 1.5°, the resulting data can be noisy.

The RHIs were analyzed to remedy the problem and better analyze the vertical structure of the BL features. The mean wind speed was removed from the RHIs using the mean wind field retrieved from the VAD method. Because the mean wind field did not change noticeably over time periods as short as 30 minutes, quasistationarity was assumed for data within a 30-minute window. Thus, the mean wind retrieved from PPIs was assumed to be the same for RHIs that were acquired within 30 minutes of the considered PPIs. Typically, for each datum retrieved from the VAD technique corresponding to a wind direction and speed at a particular height, the wind vector was projected onto the azimuth on which the RHI was realized and subtracted from the bin that corresponds to the particular height that was considered. All the heights for which VAD data were un-

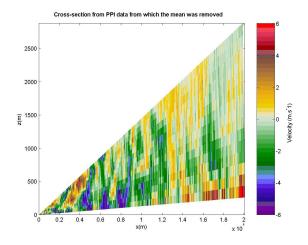


Figure 6: Cross-section of radial velocity residuals after removing the mean using the VAD data from PPIs.

available were then interpolated. Figure 7 shows the resulting image after the mean was removed from an RHI. The linear features are more obvious than for Figure 6. From a rough assessment of the data, it seems that the vertical extent of the small-scale features found in Hurricane Frances at that time period is limited to the lowest kilometer of the HBL, with a wavelength on the order of 1km. Further processing and analysis will be necessary to obtain more accurate results. Figure 8 shows an

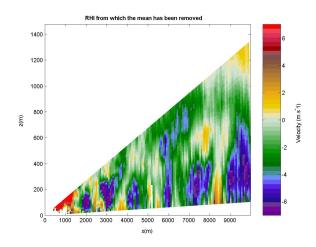


Figure 7: RHI from which the mean has been removed using VAD data.

RHI image from which the mean has been removed a few minutes after the data from Figure 6 were acquired. Similarities between Figure 6 and Figure 8 show that the method using VAD data to remove the mean from RHIs gives fairly good results.

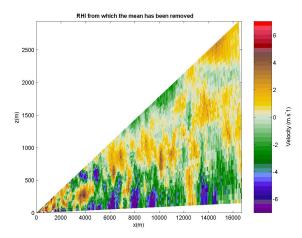


Figure 8: Same as Figure 7 but for an earlier time close to Figure 6.

## 4. CONCLUSIONS

The TTUHIT successfully acquired HBL data that allowed for an identification of embedded small-scale features. A VAD technique used on PPIs was very useful to identify and qualitatively analyze the horizontal structure of the features. The results obtained from the VAD method were also used on RHI data, which led to a representation of the vertical structure of the small-scale features. All the results presented here are qualitative and the data will require further processing to give valuable quantitative results. Some FFT analysis and image processing will be performed for a more complete analysis of these BL features.

## ACKNOWLEDGMENTS

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# REFERENCES

Biggerstaff, M. I., L. J. Wicker, J. Guynes, C. Ziegler, J.
M. Straka, E. Rasmussen, A. L. Doggett, L. D. Carey, J.
L. Schroeder and C. Weiss, 2005: The Shared Mobile Atmospheric Research and Teaching (SMART) Radar:
A Collaboration to Enhance Research and Teaching. Bulletin of the American Meteorological Society, 86, 1263-1274.

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.

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