P1.6 A COASTAL INTERNAL BOUNDARY LAYER WITHIN A TROPICAL CYCLONE

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1. INTRODUCTION

With the ever-increasing population along the U.S. Gulf and Atlantic coasts, determining how rapidly the surface layer winds in a tropical cyclone (TC) decrease at the shoreline is of utmost importance. In the immediate vicinity of the coastline, this decrease is governed by the formation of an internal boundary layer (IBL) downwind of the coastal interface as the onshore wind adjusts to the new underlying land surface. Above the IBL, the wind flow characteristics are dominated by the marine roughness, while below it they are transitioning towards equilibrium with the land roughness. A diagram of a typical IBL structure is given in Arya (1988), but is omitted for brevity. IBL formation is not exclusive to the coastline and occurs with any change in roughness regime.

Many of the previous studies of coastal IBL's have been conducted using wind data with 10-minute speeds averaging < 10 m/s (Echols and Wagner-EW, 1972; Raynor et al., 1979). One of the goals of the Texas Tech University Wind Engineering Mobile Instrumented Tower Experiment (WEMITE) over the past two years has been to characterize the coastal hurricane IBL through the collection of high-resolution wind speed (WS) data within landfalling TC's near the coastline . To this end, arrays of instrumented towers were deployed in locations of expected onshore winds generated from Hurricane Gordon (2000) and Tropical Storm Gabrielle (2001). Preliminary analysis of the data collected in Gabrielle will be presented in this report.

2. EXPERIMENTAL SETUP

In order to collect data from a TC coastal IBL, the landfall location must be accurately forecasted and the towers placed in the region of expected onshore winds (usually the right semicircle of a TC) in line with the anticipated wind directions. Optimal spacing of the towers can be estimated using an IBL height model, a set of topographic maps to determine fetches, and a quick pre-deployment site characterization to estimate roughness lengths (z_o). Open exposures within 1 km of the coastline are typically sought. This "ideal" experimental setup is usually not matched in reality as obstacles located near the coastline typically preclude spacing the towers based upon the model.

Two existing IBL models, Elliot (1958) and Arya (1988), were evaluated for use in the experimental setup by testing each with data collected by the University of Texas (UT) from a Gulf coast site near High Island, Texas (EW, 1972). It was determined that the Arya model (equation 1) best fit the UT data and was therefore used in the experimental setup.

$$h_i = a_i z_{or}(x/z_{or})^{0.8} \quad (1)$$

In equation (1), h_i is the height of the IBL, z_{or} is the roughness length of the rougher surface, x is the fetch (downwind distance of anemometer from the roughness change), and a_i is an empirical stability constant taken to be 0.38 for TC winds under neutral conditions.

To sample the TC IBL in Gabrielle, four 10 m instrumented towers, including one instrumented at four levels (WEMITE 2), were deployed on the evening of September 14, 2001 south of Flagler Beach, FL (FB) (roughly 29° 26' 7.3" N, 81° 06' 23.2" W) after Gabrielle made landfall near Venice, FL earlier in the day. Detailed anemometer and sampling rate information is summarized in Table 1. Gabrielle's slow movement over the FL peninsula south and southwest of the FB site provided an extended period of onshore winds on the east coast of FL in the left semicircle of the system. Unfortunately, the site lacked enough area to make an "ideal" deployment, as the towers were not deployed in a linear configuration according to the original experiment design. Normally, an extension to WEMITE 2 with an anemometer located at 15.2 m AGL would also have been deployed, but wind gusts of 20-25 m/s during the deployment made this unfeasible.

Table 1. Anemometer and sampling rate Information

Tower	Anemometer Height(s) (m)	Data Sampling Rate (Hz)
WEMITE 2	2.13, 3.96, 6.1, 10.06	10
Mesonet 1	10	10
Mesonet 2	10	1
Mesonet 3	10	10

The deployment site (Figure 1) was located as close as 26 m from the shoreline. The area between the towers (WEMITE 2 and Mesonet 3) and the shoreline was characterized by approximately 13-16 m of 1 m high grass, a 5/12 sloped escarpment up from the beach, and 12-15 m of gently sloping sandy beach. None of the towers' anemometers were located at a level to be significantly affected by any topographic speed up resulting from the escarpment.

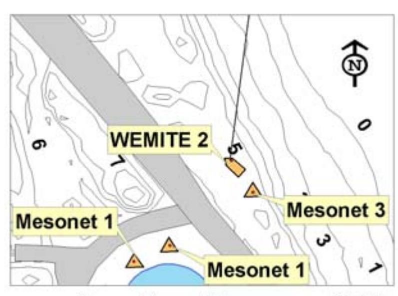

Figure 1. Flagler Beach Deployment Site (Contours in m).

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3. ANALYSES AND DISCUSSION

Each of the wind records (speed and direction) was stratified into 10-minute averaged segments over the length of the entire record. Initially, z_o were determined for the WEMITE 2 location employing all 4-anemometer heights, assuming a logarithmic profile (this assumption, of course, breaks down in the presence of an IBL). When only one anemometer record was available, a log profile was once again assumed, but z_o was determined by direct calculation from the turbulence intensity, assuming the ratio of the standard deviation of the 10-minute WS to the surface stress is 2.2. During several time periods the 6.1 m WEMITE 2 anemometer did not function properly and in these cases z_o was not calculated using the profile method.

Examination of the z_o time histories from WEMITE 2 indicate several distinct roughness regimes associated with shifts in wind direction (WD) (Figure 2). Although the WD is quite variable throughout the first 14.2 hours of the record, all roughness lengths calculated from all instrumentation levels on every tower suggest an extremely smooth terrain (average z_o = 0.0002 m for WEMITE 2), indicative of marine exposure. In the next 4 hours the WD shifted from ~60^o to ~10^o, and the roughness increased only slightly. The WD then stabilized for a 9-10 hour period (~15:17 UTC 9/15 - ~0:47 UTC 9/16), with an average value of 7.79^o as determined from the 10.06 m WEMITE 2 anemometer. During this time period, WEMITE 2 experienced a longer land fetch and as a result, an IBL can be detected in the data. Later, the WD shifted (quite abruptly) once again so that it paralleled the coastline (~320^o) and all instruments saw a lengthy fetch over land. The wind then shifted back towards 0^o for a brief period, but by this time, Gabrielle was well offshore.

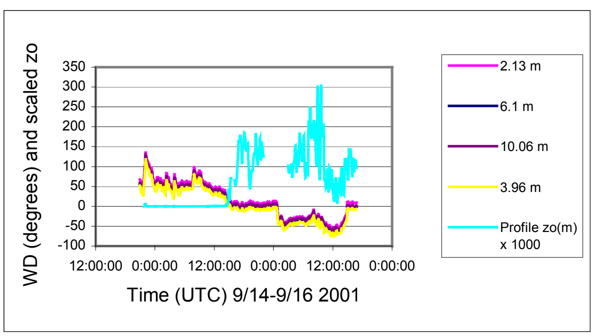

Figure 2. Wind direction and profile derived roughness length time histories for WEMITE 2.

The method for detecting the IBL is similar to that used by EW, but adapted to use the four anemometers located on WEMITE 2 during Gabrielle. Kinks in the 10-minute averaged WS profiles reveal the presence of an IBL associated with the coastal interface. In order to estimate the height of the IBL above the surface, a log profile was assumed for the top three anemometers on WEMITE 2. This log profile was plotted with the corresponding wind profile from all four anemometers on the tower. The intersection point of these two plots yields an estimate for the height of the IBL. To get an exact numerical value for the IBL height in each case, the assumed log profile and actual wind profile were plotted on a semi-log scale so that the log profile is linear and the actual wind profile could be fit to a curve more easily. Finally, the two equations were used to find an exact intersection point and the IBL height.

A scatter plot of the IBL heights determined using this technique is given in Figure 3. The mean IBL height for this case is 7.46 m, which corresponds to a mean slope of ~1/10 from the interface. The mean WS over this time period was 18.44 m/s with an average 10-minute standard deviation of 2.29 m/s.

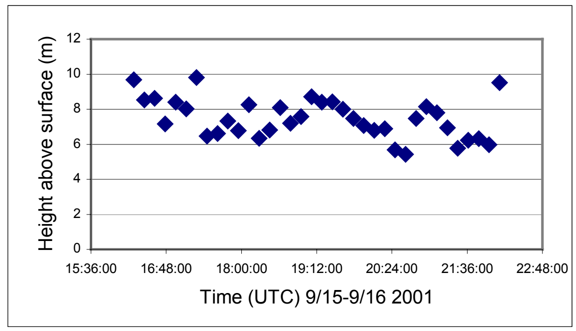

Figure 3. IBL heights determined from WEMITE 2.

In order to further verify the height of the IBL, a fetch of 72.41 m was calculated for the mean WD over the time period of interest by plotting the tower location on a GIS topographic map produced using high-resolution LIDAR data collected via an Airborne Topographic Mapper (NOAA Coastal Services Center Web Site). A value of 7.43^o was used for the average WD to account for missing WS data from the 6.1 m WEMITE 2 anemometer during a portion of this time. Upon application of the fetch value and average z_o = 0.126, the Arya model predicts the IBL height to be 7.7 m, in good agreement with our observations. A more detailed comparison of observations and model predictions using fetches for each 10-minute segment instead of an average fetch will be presented at the conference, as will a similar study for Gordon.

4. ACKNOWLEDGEMENTS

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5. REFERENCES

Arya, S. P., 1988: *Introduction to Micrometeorology*. Academic Press, 307 pp.

Echols, W. T. and N. K. Wagner, 1972: Surface roughness and internal boundary layer near a coastline. *J. Appl. Meteor.*, **11**, 658-662.

Elliot, W. P., 1958: The growth of the atmospheric internal boundary layer. *Trans. Am. Geophys. Union*, **39**, 1048-1054.

NOAA Coastal Services Center Web Site, http://www.csc.noaa.gov/lidar/

Raynor, G. S., S. Sethuraman, and R. M. Brown, 1979: Formation and characteristics of coastal internal boundary layers during onshore flows, *Bound. Layer Meteor.*, **16**, 487-514.