P7.1 SUMMARY OF TEXAS TECH UNIVERSITY'S HURRICANES AT LANDFALL PROJECT 2005

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1. INTRODUCTION

The primary goal of the Texas Tech University Hurricane Intercept Team (TTUHIT), over the last eight years, has been to collect high-resolution meteorological data from landfalling tropical cyclones by placing instrumented towers in their paths. The project has succeeded in collecting data from 25 tropical cyclones since its inception in 1998.

TTUHIT deployed instrumentation systems for Hurricanes Dennis, Emily, Katrina, and Rita, during the 2005 Atlantic Hurricane Season. In most cases, the data collected has provided a complete record at each deployment location, whereas typical surface observing platforms often fail prior to the peak of the storm. The data obtained from Hurricane Katrina has shed some light on the wind speeds associated with the storm at landfall, which has become a subject of substantial debate. Data was successfully collected at multiple locations during Hurricane Rita as well.

2. INSTRUMENTATION

The 2005 TTUHIT Project deployed five towers for each storm. Two instrument platforms are "ruggedized", trailer mounted towers, known as the Wind Engineering Mobile Instrument Tower Experiment (WEMITE) #1 and WEMITE #2, as shown in Figures 1 and 2. WEMITE #1 is a 10 m tower, collecting wind speed and direction data at three levels, as well as temperature, barometric pressure (BP), and relative humidity (RH). The tower contains a PC-based internal data acquisition system which samples at 10 Hz. WEMITE #2 is a 15.25 m tower with wind instrumentation at five levels, as well as temperature, BP, and RH. WEMITE #2 also samples at 10 Hz.

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Details regarding the WEMITE instrument platforms can be found in Schroeder and Smith (2003). The remaining three portable meteorological towers (PMT) are 10 m masts, which record wind speed and direction at 10 m, as well as the standard meteorological variables. A PMT is shown in Figure 3. Two of the PMTs deployed during the 2005 Atlantic Hurricane Season sample at 10 Hz and one at 2 Hz. The differing sampling rate is due to data storage limitations.

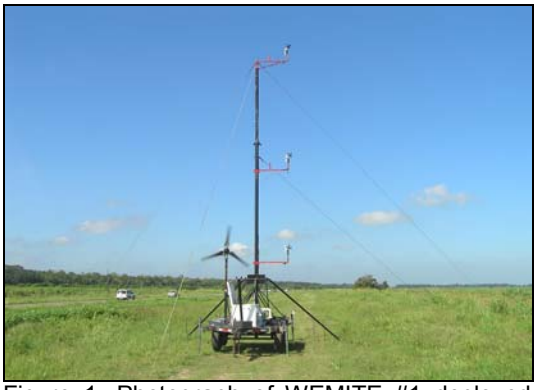

Figure 1. Photograph of WEMITE #1 deployed near Vacherie, LA prior to Hurricane Katrina.

Figure 2. Photograph of WEMITE #2 deployed at Southeast Texas Regional Airport, prior to Hurricane Rita.

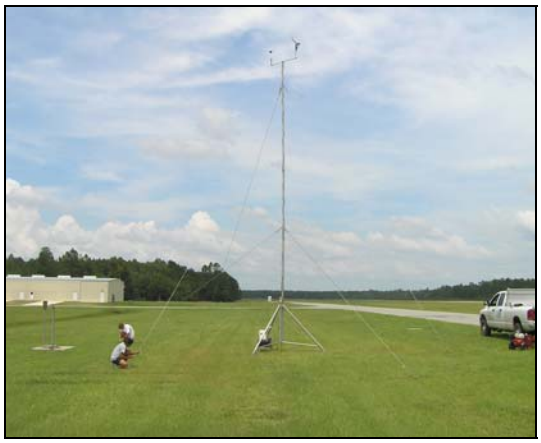

Figure 3. Photograph of the PMT deployed at Slidell Municipal Airport, Slidell, LA prior to Hurricane Katrina.

3. EXPERIMENTAL DESIGN

Two experimental designs were developed for use during the 2005 Atlantic Hurricane Season. The first dictated that all five towers be deployed at a single site and aligned in an array paralleling the coastline. Each tower would be spaced approximately 50 m apart. This experimental plan was developed in an effort to document lateral coherency of turbulent structures within the on-shore flow regime of a landfalling tropical cyclone. Figure 4 shows an example of the tower array. The second experimental plan called for each tower to be placed in a different location along the coastline, in an effort to sample the eye or eyewall of a major hurricane.

Figure 4 Photograph of the turbulence array at Wolf Naval Outlying Landing Field, prior to Hurricane Dennis.

4. HURRICANE DENNIS DEPLOYMENT

Hurricane Dennis was the first TTUHIT deployment of the 2005 Atlantic Hurricane Season. All five towers were deployed, utilizing the first experimental plan described in section 3 and illustrated in Figure 4. The tower array was located at the Wolf Naval Outlying Landing Field approximately 4.8 km north of Orange Beach, Alabama and approximately 8 km west of the Florida/Alabama border. Hurricane Dennis made landfall near Navarre Beach, Florida with an official intensity of 105 kts (54 ms^{-1}), placing the tower in an off-shore flow regime. Given the compact nature of Hurricane Dennis and the location of the tower array, which was 64 km west of the point of landfall, hurricane winds were not sampled. The data collected by the array will not be discussed further in this paper.

5. HURRICANE EMILY DEPLOYMENT

The turbulence experimental design was used once again in the second deployment of the 2005 Atlantic Hurricane Season. Although Hurricane Emily made landfall in northern Mexico, the threat existed for extreme south Texas to experience significant hurricane conditions. The tower array was deployed at the Cameron County Municipal Airport near Port Isabel, Texas. Hurricane Emily underwent a southwestward wobble in the track 12 hours prior to landfall. Although in an on-shore flow regime, the tower array, once again, was located outside the region of hurricane winds. Hurricane Emily made landfall near San Fernando in northeast Mexico with an official intensity of 57 ms^{-1}(110 kts). The tower array was located approximately 137 km north of the point of landfall. The data collected during Hurricane Emily will not be discussed further in this paper.

6. HURRICANE KATRINA DEPLOYMENT

The TTUHIT deployed all five towers for Hurricane Katrina, utilizing a modified version of the second experimental design plan described in section 3. Three deployment sites were selected in south Louisiana and along the Mississippi coast. The towers were placed inland from the

immediate coastline due to the potential for catastrophic storm surge flooding. WEMITE #1 was deployed 1.6 km south of Vacherie, Louisiana. This site was approximately 48 km west-northwest of downtown New Orleans. A PMT was deployed at the Slidell Municipal Airport, 8 km west of Slidell, Louisiana, near the National Weather Service New Orleans/Baton Rouge Forecast Office. The remaining three towers were deployed in an array at John C. Stennis International Airport, 4.8 km north of Bay St. Louis, Mississippi. Each tower was spaced 50 m apart. The data collected from each deployment site will be discussed in the following sections. The maximum wind speed data at each location is summarized in Table 1. Figure 5 illustrates the tower locations and observed wind speeds at 1400 UTC 29 August 2004 and the associated KLIX WSR-88D Doppler radar image. The automated surface observing station (ASOS) data is also included at 1400 UTC. Of note is the limited number of operating ASOS stations at 1400 UTC. Roughness lengths were also computed from the data collected at each deployment site. The roughness length (z_o) describes the surface roughness of the surrounding terrain and can be estimated at a single measurement level using the turbulence intensity as indicated in equation 1, and various underlying assumptions (Beljaars, 1987),

$$z_o = \exp [\ln (z) - 1/TI] \qquad (1)$$

where, σ_u is the standard deviation of the observed wind speed, $\bar{U}$ is the mean wind speed, z is the observation height above ground level, z_o is the roughness length, and TI is the turbulence intensity ($\sigma_u/\bar{U}$). Hurricane Katrina made landfall initially along the Mississippi river delta near Buras, Louisiana with an official intensity of 110 kts (57 ms^{-1}). The second landfall occurred near the mouth of the Pearl River or the Mississippi / Louisiana border with an official intensity of 54 ms^{-1} (105 kts).

Table 1. Summary of maximum 10 m wind speed collected during Hurricane Katrina at each deployment location.

Deployment Site	Peak 1-min mean Ws (ms^{-1})	Peak 3-s Gust (ms-1)	Peak Gust (ms^{-1})
*Vacherie, LA	24.7	31.4	32.8
Slidell, LA	31.01	38.5	44.6
Bay St. Louis, MS	30.1	47.1	52.3

*record incomplete

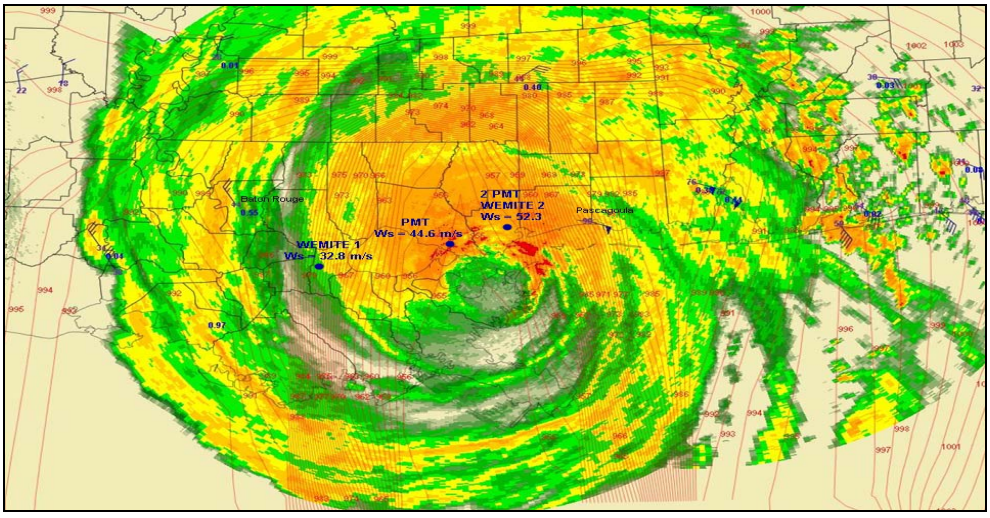

Figure 5. KLIX Doppler radar image from 1400 UTC 29 August 2005. The blue dots represent TTU deployment sites. The wind barbs are functioning ASOS stations at 1400 UTC. The solid red lines are isobars.

6.1 *Vacherie, LA WEMITE #1*

WEMITE #1 was deployed south of Vacherie, Louisiana along state highway 3127. The site was surrounded in all directions by sugar cane fields, with a forested area approximately 6.4 km to the west of the tower location. This deployment location was approximately 129 km west-northwest of the point of landfall. The peak instantaneous wind speed measured by WEMITE #1 was 32.8 ms^{-1}, which occurred near 1130 UTC, 29 August 2005. The one-minute mean peak wind speed measured during the observation period was 24.7 ms^{-1} (Table 1). Figure 6 shows the time history of the instantaneous wind speed and direction. WEMITE #1 suffered an internal power failure at approximately 1300 UTC and did not record data past this time. Hurricane Katrina passed 124 km to the west of the deployment site just prior to 1400 UTC. The roughness lengths calculated for the WEMITE #1 deployment site were relatively constant and below 0.1 m with a mean of 0.08. This represents an open to roughly-open exposure (Davenport, 1960; Paulsen and Schroeder, 2005). Visual observations of the deployment site agree with this exposure classification. The mean wind direction did not change significantly over the observation period, as seen in Figure 6.

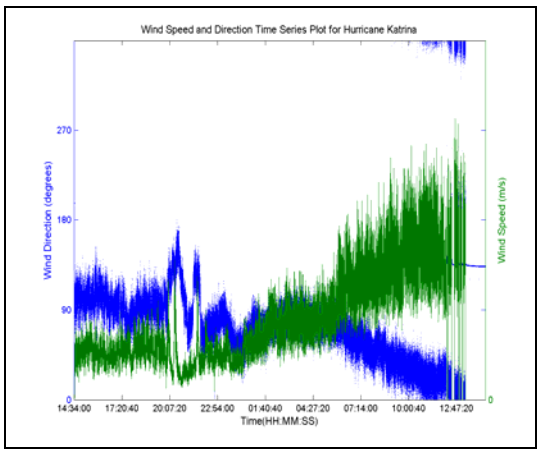

Figure 6. Time history of the 10Hz wind speed and direction observed by WEMITE #1 near Vacherie, LA. The data record is incomplete

6.2 *Slidell, LA PMT*

The portable meteorological tower deployed at Slidell Municipal Airport was located approximately 50 m from the airport ASOS station. The deployment site was located west of Slidell, Louisiana, and most likely sampled the northwest eyewall of Hurricane Katrina. The maximum instantaneous wind speed observed at the deployment site was 44.6 ms^{-1}, with an observed maximum one-minute mean of 31.01 ms-1 (Table 1, Figure 7). The center of Hurricane Katrina passed approximately 4-6 km to the east of the deployment site at 1445 UTC 29 August 2005. The peak wind speed occurred just prior to the center passing the latitude of the deployment site. The calculated z_o, for a tower relative mean wind direction between 0-100 degrees, was 0.14 m. This value is higher than what would typically be observed given an open terrain exposure (Paulsen and Schroeder, 2005). The presence of a forested area surrounding the airport resulted in a higher mean value of z_o. The observations made at the deployment site are not representative of the wind speed values that would have been observed given an open or open to rough terrain exposure (z_o<0.1 m; Davenport, 1960).

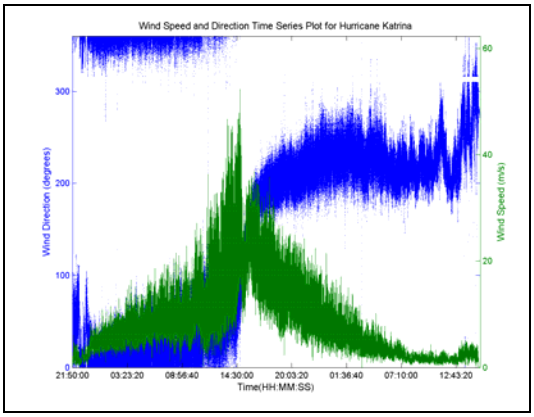

Figure 7. Time history of the 10Hz wind speed and direction observed by the PMT at Slidell Municipal Airport.

6.3 *Bay St. Louis, MS PMT*

Three instrument platforms were deployed at John C. Stennis International Airport. The deployment site was approximately 8 km north of Bay St. Louis, MS and Waveland, MS. This site most likely sampled the northeast eyewall of Hurricane Katrina. The center passed between the Slidell, LA deployment site and the Stennis site. The three towers were oriented in an east-to-west array with 50 m between each platform. WEMITE #2 was the western-most tower. Only data collected from the central platform, a PMT, will be discussed in this

paper. The maximum instantaneous wind speed measured by the PMT was 52.3 ms^{-1}, which occurred at 1440 UTC 29 August 2005, as shown in Figure 8. The peak one-minute mean wind speed observed was 30.1 ms^{-1} (Table 1). The center of Hurricane Katrina passed approximately 4.8 km west of the deployment site at 1500 UTC. The recently reduced official intensity of Hurricane Katrina at the second landfall at the mouth of the Pearl River was sustained winds (one-minute mean) of 105 kts (54 ms^{-1}). The deployment site at Stennis International Airport only measured an instantaneous gust near this value, with a peak 3-second gust of 47.1 ms^{-1} (Table 1). The calculated z_o mean value for the time of the peak wind speed was 0.2. The calculated z_o is significantly higher than the values observed in open terrain, such as the Vacherie, LA deployment site. The observed wind speed values at Stennis International Airport do not represent an open exposure, however the peak one-minute mean wind speed observed by the PMT was 58 kts (30.1 ms^{-1}), which is well below the official intensity of Hurricane Katrina. The Slidell, LA deployment site observed a higher maximum one-minute mean wind speed of 31 ms^{-1} compared to the Stennis site, most likely due to the smaller values of z_o.

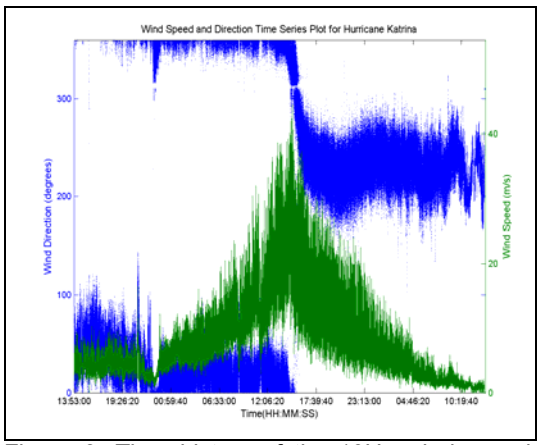

Figure 8. Time history of the 10Hz wind speed and direction from the central PMT at Stennis International, Airport, Bay St. Louis, MS.

7. HURRICANE RITA DEPLOYMENT

The TTUHIT once again, deployed all five instrument towers at 4 different locations, utilizing the eyewall experimental plan described in section 3. All four deployments sites were located in Texas. The towers were placed slightly inland due to the concern for storm surge flooding along the immediate coastline. Hurricane Rita made landfall just east of Sabine Pass in extreme southwest Louisiana. The official intensity at landfall was 105 kts (54 ms^{-1}). PMTs were deployed at the Chambers County Municipal Airport near Anuhuac, Texas and the Winnie-Stowell Municipal Airport near Winnie, Texas. WEMITE #2 was deployed at the Southeast Texas Regional Airport in Port Arthur. WEMITE #1 and a PMT were both deployed at Orange County Municipal Airport in Orange, Texas. The deployment locations are shown in Figure 9. The WEMITE #1 platform suffered an internal power failure shortly after deployment and did not record data through the peak of Hurricane Rita. The PMT co-located, with WEMITE #1, at the Orange County Municipal Airport suffered a catastrophic failure due to debris impact. The tower was sheared into two pieces by a 6 m by 3.5 m hangar door, originating from approximately 300 m away from the deployment site. The damaged tower is shown in Figure 10. The platform collected data until the tower failed. The recorded data will be included in this paper. The maximum wind speed recorded at the Winnie, Port Arthur and Orange deployment sites is shown in Table 2.

Table 2. Summary of maximum 10m wind speed collected during Hurricane Rita at each deployment location

Deployment Site	Max 1-min mean Ws (ms^{-1})	Peak 3-s Gust (ms-1)	Peak Gust (ms^{-1})
Anuhuac, TX	27.8	37.9	40.5
Winnie, TX	31.4	38.6	40.7
Port Arthur, TX	41.8	51.9	53.8
*Orange, TX	29.2 *(prior to debris impact)*	39.3 *(prior to debris impact)*	42.1 *(prior to debris impact)*

*incomplete record

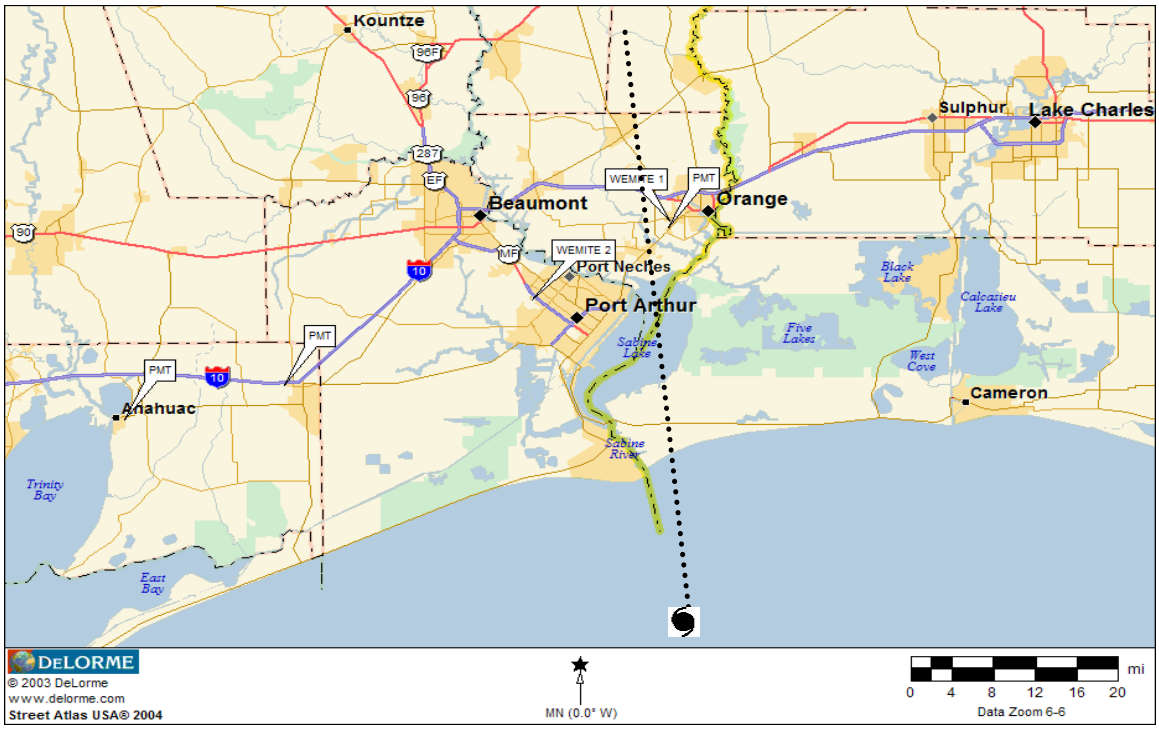

Figure 9. Map of the TTU deployment locations for Hurricane Rita. The dashed line is the approximate track of the center of Hurricane Rita.

Figure 10. Photograph of the damaged PMT at Orange County Municipal Airport, Orange, TX.

7.1 *Anuhuac, TX PMT*

The PMT at Chambers County Municipal Airport was located approximately 72 km west-northwest of the point of landfall. This deployment site was the furthest from the landfall location. Hurricane Rita passed the latitude of the deployment site just after 0745 UTC 29 September 2005. The maximum instantaneous wind speed recorded by the PMT was 40.5 ms^{-1}, which occurred near 0905 UTC 24 September 2005. The maximum one-minute mean wind speed observed at the deployment site was 27.8 ms^{-1} (Table 2). The time history of wind speed and direction from the PMT is shown in Figure 11. The mean z_o for the deployment site prior to Rita's passage was 0.05 m, which indicated that the data recorded was representative of an open exposure. Visual observations of the deployment site suggested an open or open-to-rough terrain exposure in all directions. The airport terrain was flat in elevation with native grasses surrounding the deployment site.

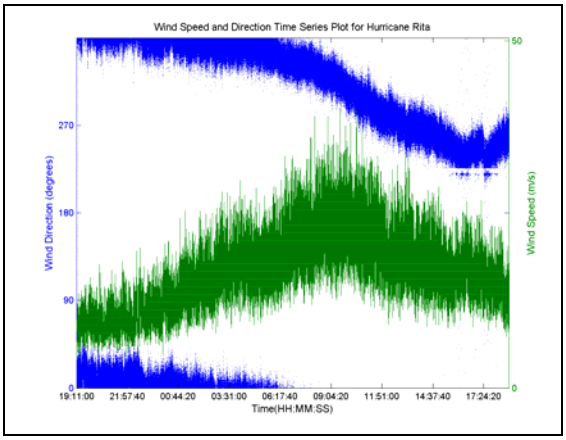

Figure 11. Time history of the 10Hz wind speed and direction observed at Chambers County Municipal Airport, Anuhuac, TX.

7.2 *Winnie, TX PMT*

The deployment site was located just west of Winnie, Texas at the Winnie-Stowell Municipal Airport. The location was approximately 48 km west-northwest of the point of landfall. The maximum instantaneous gust recorded by the PMT was 40.7 ms^{-1} just after 1300 UTC 29 September 2005. The maximum one-minute mean wind speed was 31.4 ms^{-1} (Table 2). The wind speed and direction time history are seen in Figure 12. The z_o values prior to the center of Hurricane Rita passing the tower's latitude, were typically less than 0.1 m with a mean value of approximately 0.05 m. This result suggested an open terrain exposure and thus the recorded wind speed data was representative of an open exposure (Davenport, 1960). Following the peak in wind speed and subsequent wind direction change as Hurricane Rita passed the tower's latitude, the calculated values of z_o increased slightly with a mean of approximately 0.1 m, but still remained in the open-to-rough exposure category (Davenport, 1960).

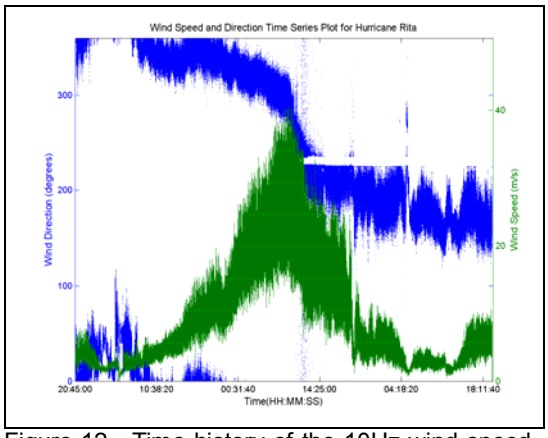

Figure 12. Time history of the 10Hz wind speed and direction from the Winnie, TX PMT.

7.3 *Port Arthur, TX WEMITE #2*

The WEMITE #2 platform was deployed at Southeast Texas Regional Airport in Port Arthur, Texas. The tower most likely sampled the western eyewall, although analysis of the KLCH Doppler radar data showed a deteriorated western semicircle as Hurricane Rita made landfall. The most intense convection appeared to be confined to the northern portions of the eyewall, the observations revealed evidence of an eyewall replacement cycle had begun to take place just prior to landfall. The peak instantaneous wind gust observed by WEMITE #2 was 53.8 ms^{-1}, which occurred just after 0915 UTC 24 September 2005. The degraded center of Hurricane Rita passed approximately 24 km east of the deployment location at 0945 UTC. The maximum one-minute mean wind speed observed was 41.8 ms^{-1} (Table 2). The time history of the instantaneous wind speed and direction is shown in Figure 13. As seen with Hurricane Katrina, the observed peak one-minute mean wind speed was significantly less than the official intensity at landfall, however instantaneous gusts approached the official intensity value of 105 kts (54 ms^{-1}). The dominant mode of the calculated values of z_o prior to Hurricane Rita passing the deployment site was from 0.01 – 0.07 m. The computed values suggested that the data collected was representative of an open or open-to-rough exposure (Davenport, 1960).

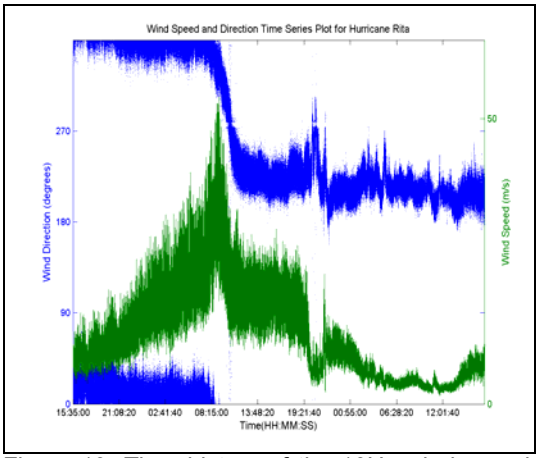

Figure 13. Time history of the 10Hz wind speed and direction observed by WEMITE #2 at Port Arthur,TX.

7.4 *Orange, TX PMT*

The PMT deployed at the Orange County Municipal Airport, as discussed previously in section 7, suffered a complete failure due to the impact from a hangar door, as shown in Figure 10. WEMITE #1, which was located approximately 400 m from the PMT, failed to collect data during Hurricane Rita. The final observation recorded by the PMT was an instantaneous wind speed of 42.1 ms^{-1}. The time history is shown in Figure 14. The deployment location possibly sampled the eastern eyewall but given the deteriorated inner structure of Hurricane Rita

it is difficult to make this claim. The official center of the cyclone passed approximately 9.6 km west of the deployment site just prior to 1030 UTC. Data at this time was not collected.

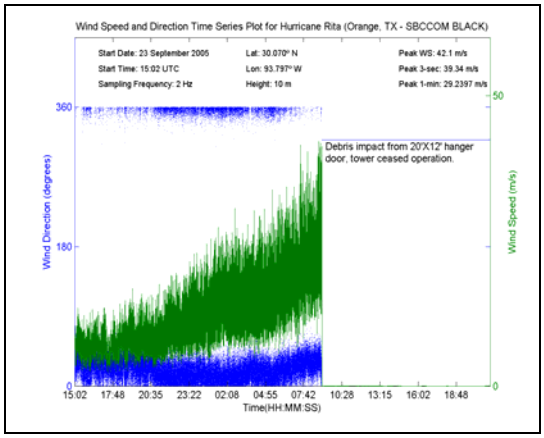

Figure 14. Time history of the 10Hz wind speed and direction prior to failure of the PMT at Orange, TX.

8. SUMMARY AND CONCLUSIONS

The 2005 TTUHIT Project succeeded in collecting high-resolution datasets from Hurricanes Katrina and Rita. The data obtained from these two cyclones represent a high percentage of the complete wind records from each storm, as conventional observation platforms typically failed. The implementation of the turbulence experimental plan, as discussed in section 3, was not successful in sampling hurricane winds. On each occasion, the tower array was located outside the radius of maximum winds. The eyewall experimental plan was used with success for Hurricanes Katrina and Rita, although with some modifications in each case. Technical problems did not allow for a complete data record to be obtained from Vacherie, LA during Hurricane Katrina and Orange, Texas during Hurricane Rita.

The successful deployments during Hurricanes Katrina and Rita yielded interesting results regarding the intensity of each storm. The wind speed data collected from each storm revealed a similar wind field. Although Hurricane Katrina resulted in much more significant damage and loss of life, mainly due to catastrophic storm surge flooding, the observed peak wind speeds were quite similar to Hurricane Rita. It should be noted that the Hurricane Rita deployment sites each exhibited a roughness length near the open exposure classification (Davenport, 1960). The observed peak one-minute sustained wind in each case was substantially lower than the official landfall intensity, however the data collected during Hurricane Katrina at the Slidell and Stennis locations are not necessarily representative of an open exposure. Direct measurements were not made along the immediate coastline, all deployment sites were at least 5 km inland for both Hurricane Katrina and Hurricane Rita. Peak instantaneous gusts during each storm however, did approach the official landfall intensity.

The 2005 Atlantic Hurricane Season shattered all known historical records and given the increase in tropical activity the likelihood of landfalls in the continental United States will increase as well. The need exists for continued collection of complete meteorological data records from landfalling tropical cyclones.

9. ACKNOWLEGEMENTS

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