Modification of local roughness length by advancing storm surge in landfalling tropical cyclones

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INTRODUCTION

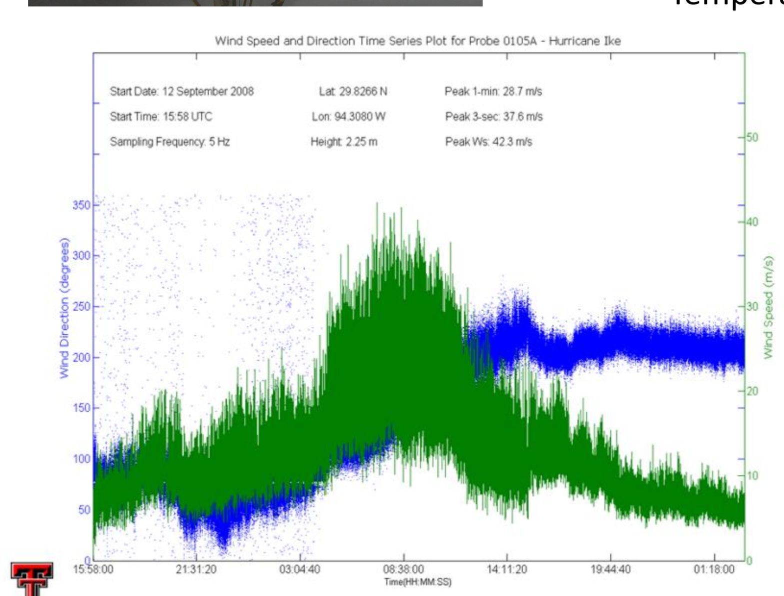
Near-shore ocean conditions have been shown to vary with changing wind speeds (Zachry et al., 2013; Kennedy et al., 2011), which in turn influences the surface roughness (z_o) felt by the wind approaching the coastline. At extreme wind speeds, like those observed in the hurricane environment, shear stress, drag coefficients, and z_os have all been shown to decrease. Once the wind has moved over land its turbulent structure will be governed by the marine-land transition and then the local surface z_o. When storm surge inundates a coastal region a third regime is possible in which underlying surface conditions are obscured by water, leading to an aerodynamically smoother exposure characterized by lower z_os. In such a situation, the reduction in wind speed which would be expected as wind flows from a region of lower- to higher z_o would not be as large, meaning higher wind speeds could potentially penetrate further inland than anticipated. Current coastal building design criteria assign a roughness category to a structure based upon non-storm conditions. However, data collected by Texas Tech University's (TTU) StickNet project in Hurricane Ike suggest that inundation by storm surge may reduce surface z_o locally, which may prompt additional design considerations for structures which are not coastal but may be inundated by storm surge during hurricane passages.

Hypothesis: Inundation by storm surge in landfalling hurricanes causes a local reduction in roughness length

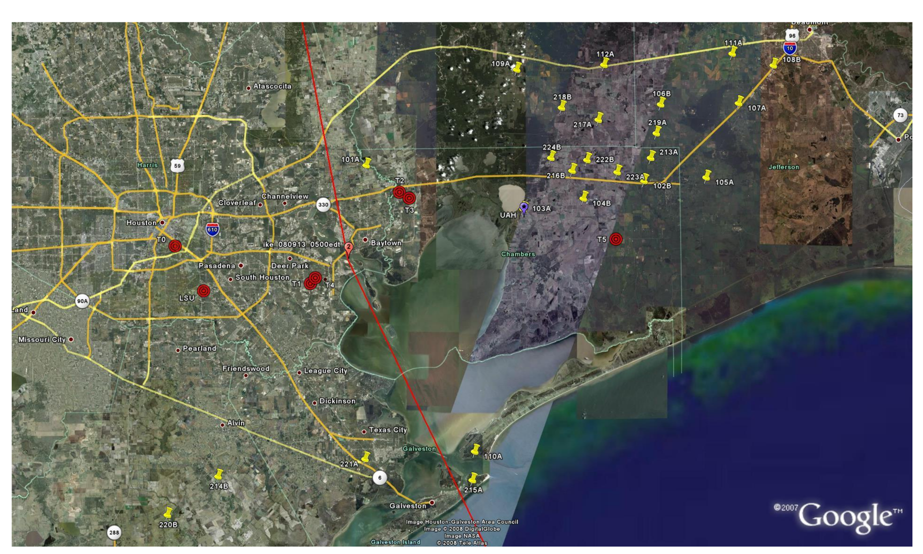
DATA

Twenty ruggedized 2.5 m instrumented probes called "StickNets" capable of withstanding wind speeds up to 60 m s^{-1} were deployed for Hurricane Ike. Designed for use in extreme environments, the StickNet probes have been deployed in seven tropical cyclones and numerous severe storms since 2008. Each probe recorded the following parameters at a sampling rate of 5 Hz.

- Wind speed
- Wind direction
- Temperature
- Barometric pressure
- Relative humidity



Raw data time history from Probe 105A in Hurricane Ike



Probes deployed in a broad array east of Houston, TX and on Galveston Island and the Bolivar Peninsula

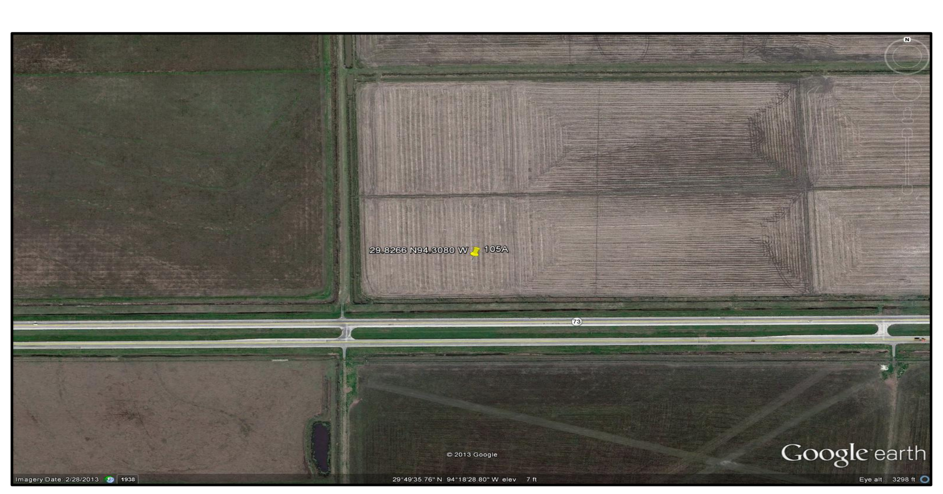
METHOD

- Divide each record into 10 min segments
- Compute mean ws, mean wd
- Calculate sector z_o estimate

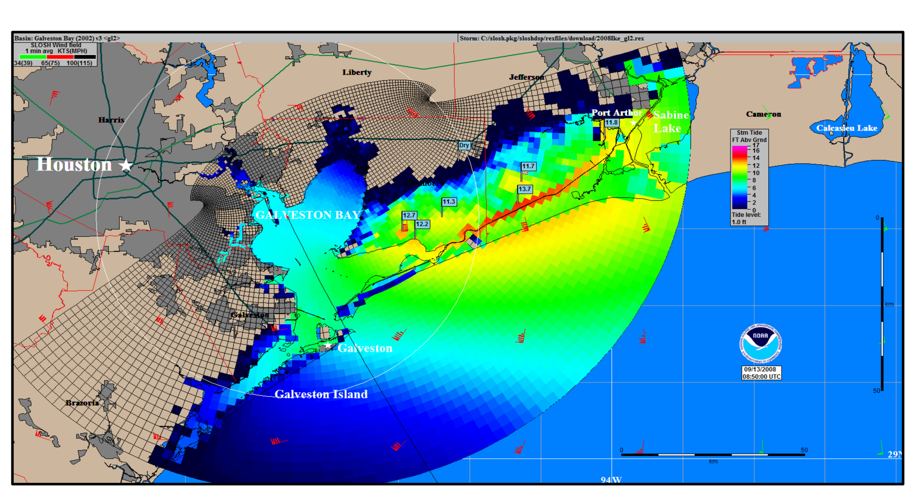
$$z_o = \exp\left[\ln(z) - \frac{1}{TI}\right] \qquad TI = \frac{\sigma}{\bar{u}}$$

- Standardize wind speed to 10 m elevation
- Use zo time histories to identify areas of reduced z_o. Classify z_o using four roughness categories (see table at right)

Name	Roughness Length (m)
Smooth	0.005-0.0199
Open	0.02-0.0499
Open to Roughly Open	0.05-0.0899
Roughly Open to Rough	0.09-0.1899



Aerial and street-level imagery were checked to ensure changes in the zo record were not caused by changes in terrain or upstream obstacles.



NOAA SLOSH data were used to estimate times and locations of inundation from storm surge.

CONCLUSIONS

Five TTUHRT StickNet probes experienced a reduction in z_o unrelated to changes in upstream terrain during Hurricane Ike.

Because of the inundation, each probe experienced a period of reduced upstream roughness (z_o)

The reduction in z_o in each case was from the "smooth" and "open" roughness regimes to a regime aerodynamically smoother than the bottom of the "smooth" regime more consistent with marine exposure.

Two of these probes were subject to storm surge flooding, three were believed to have experienced freshwater flooding.

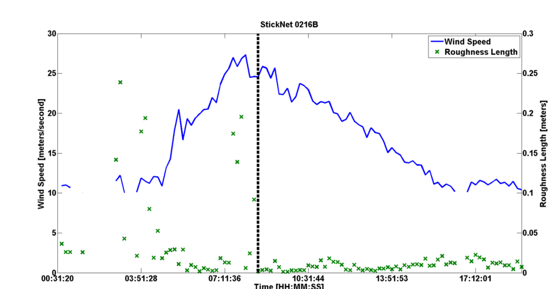
When determining upstream exposure, it is important to consider the possibility of inundation and the resulting smoother exposure

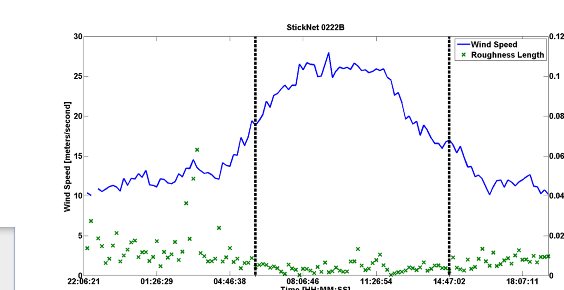
RESULTS

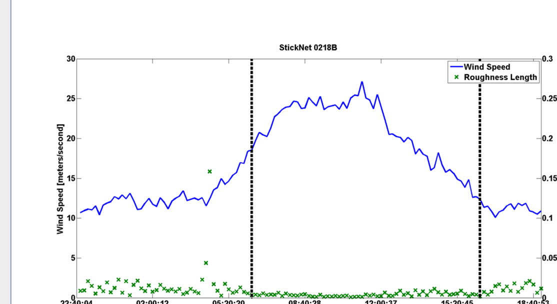
Five probes were chosen for inclusion in the study based upon a period of reduced z_o present in some part of their time histories. In each case, the change in z_o was not caused by a change in exposure with wind direction based upon Google Earth imagery and in-situ observations made by team members. According to SLOSH data, only two of these probes experienced inundation by storm surge. It is thought that the other probes experienced freshwater flooding due to extreme rainrates associated with the hurricane. This hypothesis was confirmed using NEXRAD imagery and observations of TTU personnel who retrieved the probes.

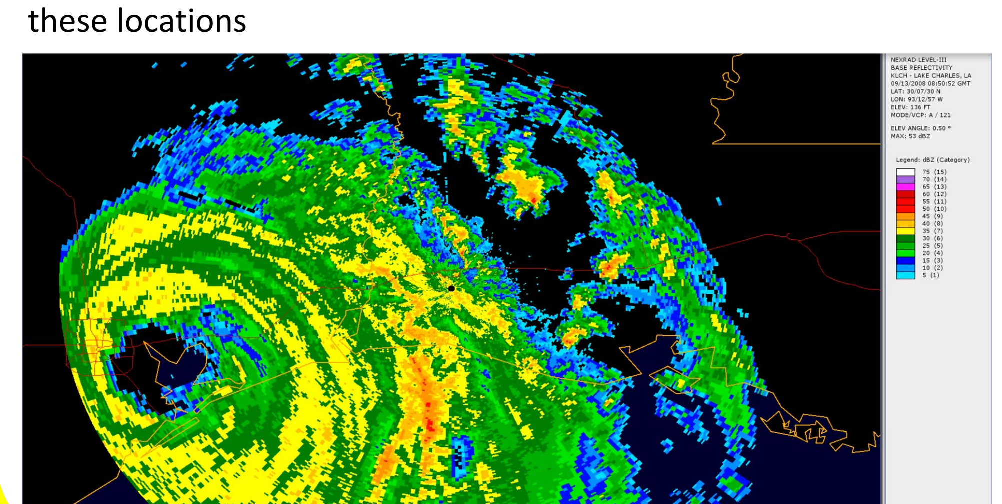
FRESHWATER-FLOODED PROBES

Probes 216B, 218 B, and 222B were not inundated by storm surge, but did exhibit a reduction in z_o in their time histories. The reduction began with the arrival of the maximum winds and ended as storm winds receded at the deployment location. Based upon qualitative analysis of NEXRAD imagery, the drop in z_o and timing of the increase in wind speed occur at the same time as the arrival of the core of Hurricane Ike just after 7:00 UTC on 13 September 2008. The portion of the storm that impacted these probes brought an approximate six-hour period of torrential rain with reflectivities of 35 DbZ and greater, which paired with the exceptionally flat topography in the area would support the hypothesis that freshwater flooding occurred at these locations

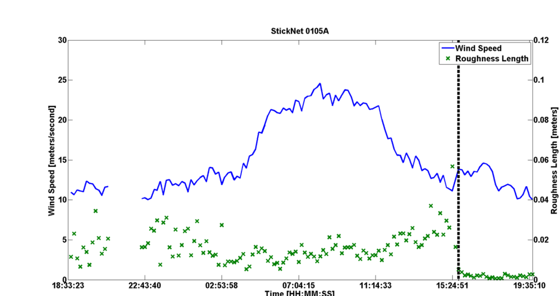




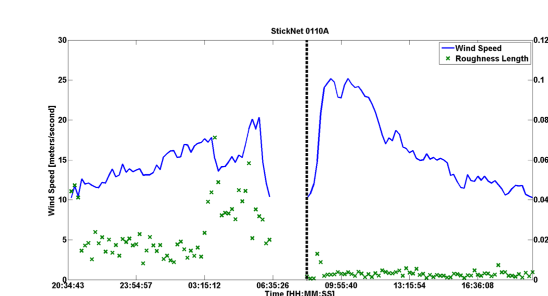




SURGE-INUNDATED PROBES

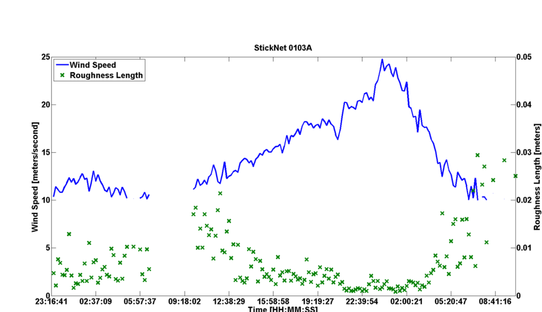


Probe 105A was in an area of significant storm surge flooding. It was located to the east of the track of Hurricane Ike and did not experience an eyewall passage. The area of reduced z_os in this case appears several hours after the bulk of the storm surge arrived at the location at 10:00 UTC on 13 September, 2008

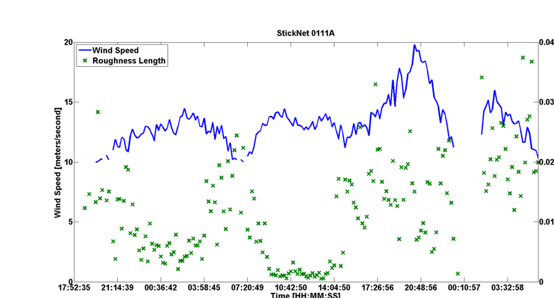


Storm surge reached Probe 110A with the passage of the center of circulation at approximately 05:00 UTC on September 13, 2008. A decrease in z_o occurs with the arrival of high wind speeds. Prior to inundation, z_os fell into the "smooth" and "open" regimes. z_os for the reduced period fall below the "smooth" regime.

FUTURE WORK



Preliminary analysis of coastal wind data taken during Hurricane Sandy by Texas Tech University reveals two types of wind regimes: Protected, in which zo gets lower with increased wind speed, and Open Ocean, where zo has a more complex relationship with wind speed, indicating the presence of large waves. The next phase of this work will be to closely examine these two regimes and seek relationships between sea-surface or overland inundation state and boundary layer turbulence.



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