High Wind Drag Coefficient and Sea Surface Roughness in Shallow Water

Mid-term Progress Report to the Joint Hurricane Testbed

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Project Abstract

This project examines how the aerodynamic roughness of the sea surface varies between shallow and deep water. All tropical cyclone GPS sonde data collected and post processed since 1997 will be placed in a modern relational database, organized by water depth, and analyzed to provide values of surface stress, roughness, and drag coefficient Cd as a function of wind speed and water depth. The proposed effort is applied towards numerical weather prediction priorities EMC-1 and EMC-2, and is also related to hurricane forecast improvement needs TPC-5 and TPC-6.

A. Progress Report:

1. Water Depth data

Water depth information were acquired, stored, and indexed to each sonde profile to allow organization by shallow or deep ocean. Water depth data were obtained from the National Geophysical Data Center using the Oct. 2001 version of the 2-minute Gridded Global Relief Data (ETOPO2) from the World Data Center for Marine Geology and Geophysics in Boulder CO. Database queries implemented to organize the profiles and index to ancillary data. Based on observations from Walsh et al., 2002, a water depth threshold of <= 50 m was chosen to indicate shallow water.

2. Queries

The sonde database was updated to accommodate recently processed sondes and the database was queried as follows:

All data since 1997
All radii between 2 km to 300 km
MBL groups: 20-29, 30-39, 40-49, 50-59, 60-69, 70-79, 80-89 m/s

Each MBL group was sorted by water depth and deep water sondes were eliminated. The shallow water dataset as a function of MBL group breaks down as follows:

Table 1 Number of shallow and deep water sonde profiles as a function of MBL wind speed group.

MBL group (m/s)	Sonde profiles in database (3-20-2006)	Sonde profiles in deep water
20-29	32	256
30-39	65	229
40-49	30	207
50-59	18	133
60-69	5	118
70-79	0	94
80-89	0	26
totals	143	1063

3. Upstream fetch

Shallow water sondes are close enough to shore that the mean wind profiles are affected by the upstream fetch. A sonde with an upstream fetch over land (offshore flow) will exhibit more low level wind speed shear than a sonde with an upstream fetch over open water (onshore flow), leading to very different surface layer quantities and different drag coefficients. Therefore sondes within an MBL group were characterized by upstream fetch as follows:

Onshore or open: Sonde splash wind direction or last measured wind direction indicates a flow component that is either onshore or the sonde is in shallow water or shoals but > 50 km offshore from any land mass.

Along-shore: Sonde splash wind direction or last measured wind direction indicates a flow component that is alongshore or within 30 degrees of parallel to shore.

Inland: Sonde splash location indicated the sonde drifted over land inland from the coast.

Sondes within an MBL group were subgrouped into Keyhole Markup Language (KML) files for plotting their location in Google Earth. A JAVA servlet was written to connect to Google Earth and plot the sonde locations and wind barbs as scalable place marks. The wind direction was then examined relative to the coastline to determine the upstream fetch characterization for each shallow water sonde profile.

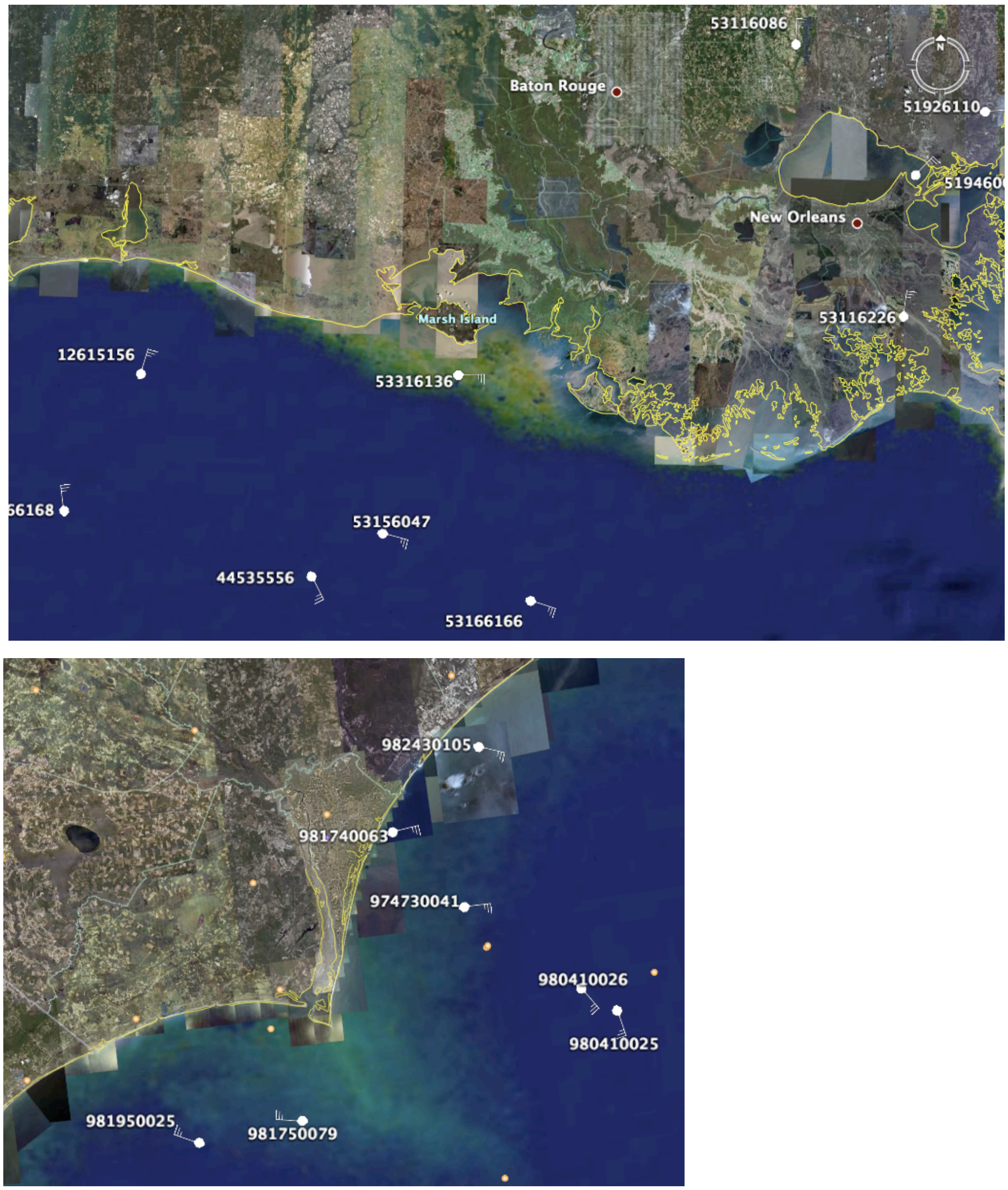

Fig.1 Google Earth images of sondes splash locations and serial numbers in the 40-49 m/s MBL group. Wind barbs show direction last measured wind but speeds are all given a dummy speed of 25. a) Off LA coast (note 3 sondes inland). b) Off Cape Fear NC coast.

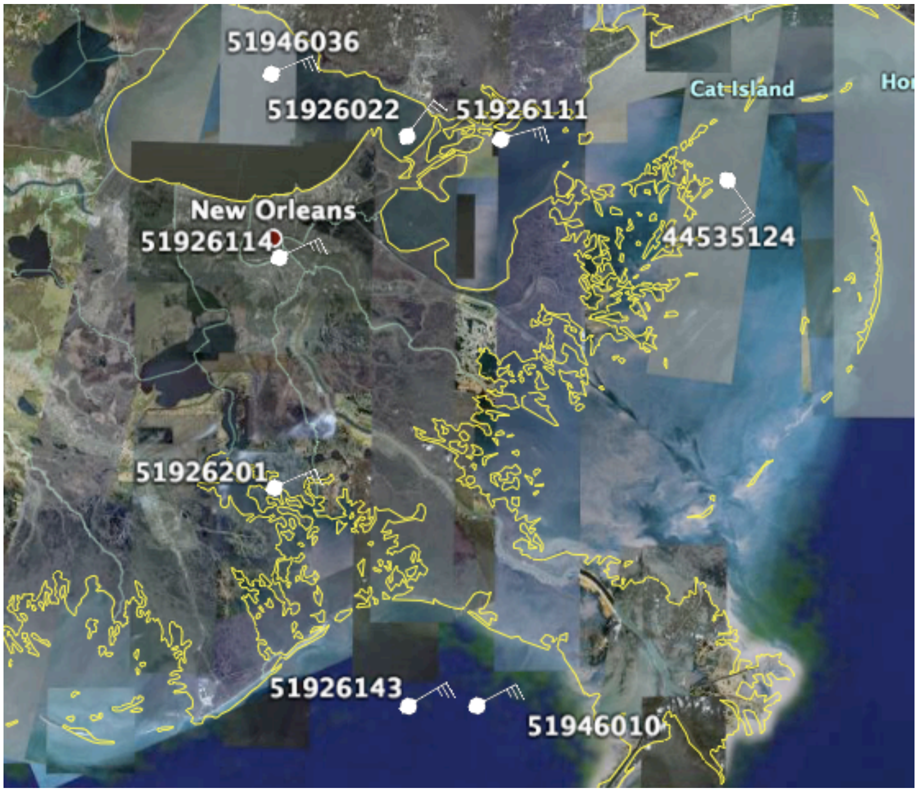

Fig. 2. As in Fig. 1 but for 50-59 m/s MBL group from Hurricane Katrina in 2005. Sonde serial numbers are shown adjacent to the splash location.

4. Preliminary analysis

Exploratory analysis was conducted on the 30-39 m/s MBL group since this contains the largest number of shallow water sondes.

Offshore flow

For offshore flow 10 sonde profiles were available. A log Z vs wind speed plot (Fig. 3a) indicates that for several sondes, the lower 50 m of the wind profile shows near constant wind speed profiles with height characteristic of internal boundary layer development. This behavior suggests non stationary conditions associated with the lower levels of the offshore flow accelerating due to a new (sea) underlying surface, whereas the upper levels of the boundary layer are characterized by higher shear associated with flow over land. The specific humidity (Fig. 3b) also show evidence of an internal boundary layer development with relatively sharp decreases above 50-100 m. Such non stationarity makes the offshore flow profiles unsuitable for estimating surface layer quantities.

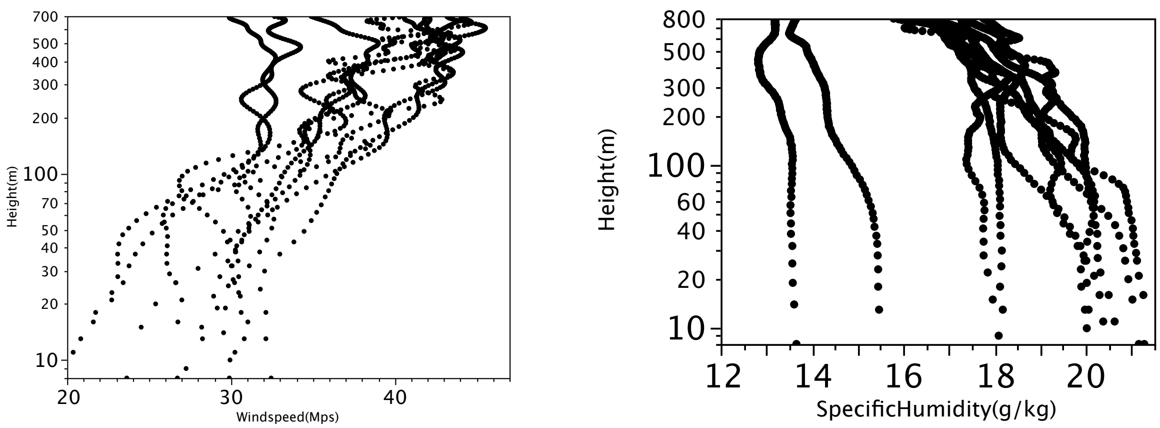

Fig. 3 a) Height vs. Wind speed for offshore sondes showing low shear or near constant wind speed below 50m. b) Height vs. Specific humidity showing a relatively shallow internal boundary layer with a decrease above the lowest 50 m layer.

Onshore flow

For shallow water onshore flow 42 sonde profiles are available (Fig 4a) and a mean profile fit suggests a roughness length of about 0.7 mm. A mean profile constructed from all 294 sondes in the 30-39 MBL group (Fig. 5) suggests a smaller roughness length of about 0.3 mm. However this plot includes all the shallow water sondes. The differences should be larger once we separate out the shallow water sondes. However, another factor to consider will be the storm relative azimuth of the deep water sondes since in our April 2007 JHT report we indicated enhanced roughness in the storm-relative, left-front portion of the storm. By separating the shallow water profiles from the deep ones, we should be able to determine whether the higher roughness values observed to the front left are associated with shallow water or interaction between the flow and the wave motion. Furthermore we hope to determine whether onshore flow in shallow water exhibits different surface layer characteristics than open ocean flow over deep water.

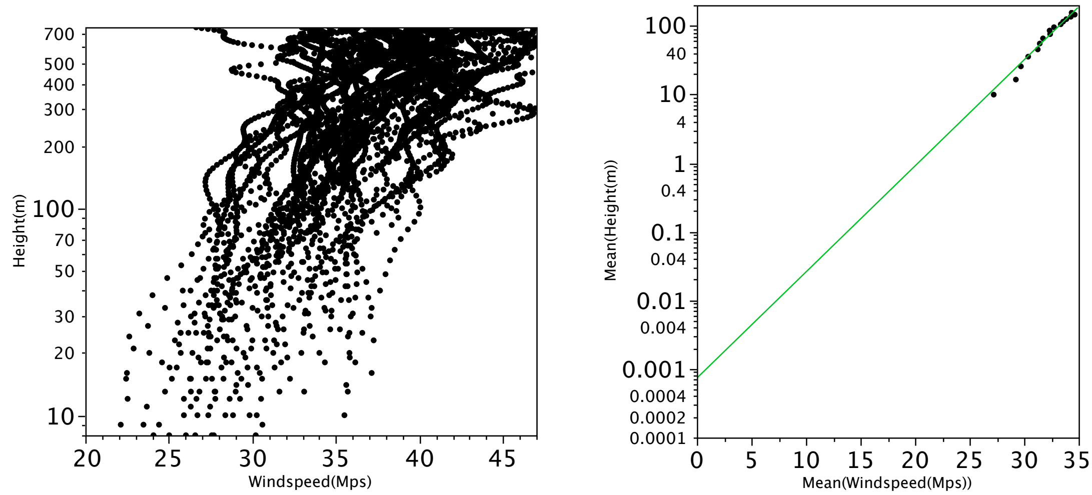

Fig. 4 a) Height vs. Wind speed for onshore flow sondes in the 30-39 m/s MBL group. b) Log fit to the bin mean wind profile in the lowest 20-160 m (lowest two points not used in the fit). Intersection with the height axis determines the roughness length (~ 0.7 mm).

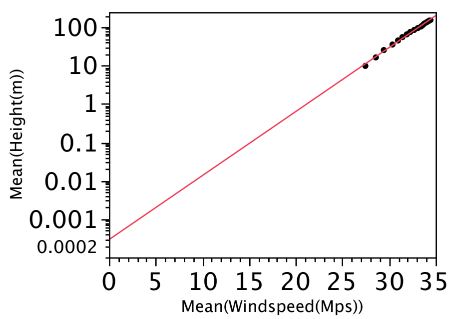

Fig. 5 As in 4b but mean profile for 20-160 m layer from all sondes in the 30-39 MBL group.

Along shore flow

For along shore flow in the 30-39 m/s MBL group, eight sonde profiles are available. Examination of individual plots (Fig. 6) indicates profiles with characteristics of the offshore flow as well as onshore flow. These profiles may be examined more closely to see if some can be associated with the onshore and offshore profile categories.

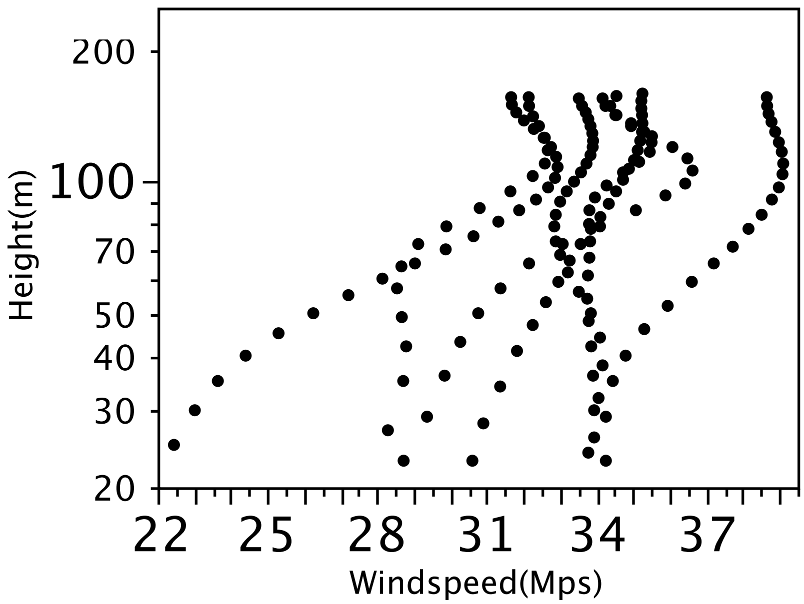

Fig. 6 Height vs. Wind speed for Along-shore flow sondes in the 30-39 m/s MBL group.

Inland Wind Profiles

Four sondes in the 30-39 m/s MBL group drifted inland and were characterized by large wind speed shear over the lowest 150 m, resulting in a roughness length near that associated with open terrain (15 mm).

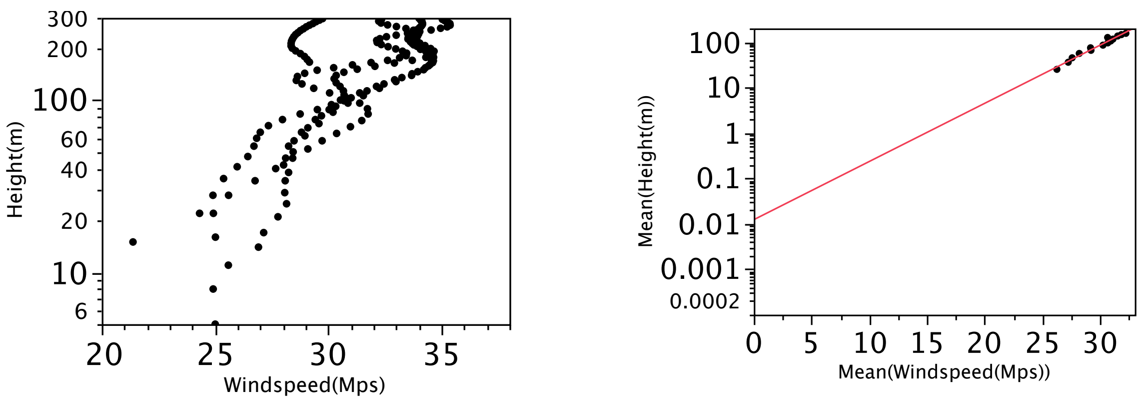

Fig. 7 Wind profiles over land from the 30-39 m/s MBL group. a) individual profiles. b) Bin-mean profiles and log fit over the 20-260 m layer.

We would hope to obtain > 10 profiles over land to substantiate the differences with onshore flow over shallow water and open ocean flow over deep water in the MBL group. However, sondes are not permitted to be launched over land so it is rare that such profiles are available (apparently the inland sondes shown here were advected inland from offshore or from a bay/ sound (e.g. Onslow Bay, Pamlico Sound, Lake Ponchartrain).

C. Remaining work

1. Open-ocean deep water profiles

The database will be queried to remove the shallow water data from the open ocean profiles to better contrast the differences between onshore flow over shallow water and open ocean flow over deep water. Data will be QC's according to processing QC flags, number of samples per bin, standard error of the bin mean, and outliers.

2. Shallow water profiles

The remainder of the shallow water MBL groups will be analyzed to develop mean wind profiles. Data will be QC's according to processing QC flags, number of samples per bin, standard error of the bin mean, and outliers. Based on experience with the 30-39 m/s MBL group, only the 20-29 and 40-49 MBL groups are expected to have sufficient data to construct mean profiles to determine surface layer roughness length, friction velocity, and drag coefficient.

3. Analysis

Student's t tests will be conducted to determine whether the bin means of the shallow and deep water profiles come from different populations. Surface layer parameters and associated error bars will be computed from least squares fits of the profiles and compared as a function of wind speed for deep and shallow water. Analysis of covariance will be used to examine the slopes and intercepts of the mean log wind profiles and determine whether differences exist between the shallow and deep water profiles. Preliminary results will be presented at the Interdepartmental Hurricane Conference in March 2008.

References:

Powell, M. D., 2007: Drag Coefficient Distribution and Wind Speed Dependence in Tropical Cyclones. Final report to the JHT, April 2007, 26 pp.

Walsh, E. J., others, M. D. Powell, Black, and F. D Marks, Jr., 2002: Hurricane directional wave spectrum spatial variation at landfall. *J. Physical Ocean*., **32**, 1667-1684.