Drag Coefficient Distribution and Wind Speed Dependence in Tropical Cyclones

Year 1 Progress Report to the Joint Hurricane Testbed

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Project Abstract

This project will update the most recent measurements of surface drag coefficient (Cd) in hurricanes to extend the measurements to mean boundary layer (MBL) winds over 70 m/s. All available GPS sonde profiles collected in hurricanes from 1997-2004 will be processed, stored in a modern relational database, quality controlled, and organized by mean boundary layer wind speed, storm relative location, and water depth. Profiles will be averaged and analyzed to provide updated values of surface stress, roughness, and Cd as a function of wind speed, storm-relative azimuth, and water depth. These mean profiles and associated derived surface exchange quantities will be made available to modelers to evaluate existing model surface layer momentum flux packages as well as develop new parameterizations for the coupled H-WRF model. The proposed effort is applied towards numerical weather prediction priorities EMC-1 and EMC-2.

A. Progress Report:

During the first year of the project we have focused on database design, sonde inventory, and developing a prototype interface for database queries and organization.

1. The database schema was designed and tested in Oracle 10g and resides on an existing server at HRD.

2. An inventory was assembled to allow the investigators to determine how many sondes have been launched for each research or recon flight, how many were transmitted, and how many were post processed. As of 3-20-2006, the inventory contains 4368 sondes that have been launched since 1997.

3. Post-processed sondes files have been assembled and we are in the process of loading them into the database. So far, 1729 sonde files have been loaded into the database.

4. Storm track files have been constructed for each of the 194 flights in the inventory, which will allow calculation of the radial and azimuthal wind components and storm-relative sonde splash locations.

5. Water depth data have been 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. These data have been added to the database so water depth is associated with each sonde splash location.

6. The large amount of sonde data makes analysis difficult without modern database software. An interface has been constructed to allow examination of the sonde inventory, uploading newly processed files, updating files that have already been processed, and to conduct queries of the sonde data. While this interface and software and been developed specifically for this project to assist in analysis, it is possible that it may be appropriate for more general use after completion of the project. The interface software is not considered a deliverable for this particular project but has been developed to assist in the forthcoming analysis. Screen grabs of the database query interface are available in the mid year report.

7. The interface also allows sorting of sondes according to the criteria of the project, e.g. Date, Storm, radius, azimuth, water depth, MBL wind speed, etc. After conducting the sorting, a metadata file is generated that contains pertinent data consisting of one line per sonde. The metadata file is an ascii column oriented file that can easily be brought into a spreadsheet or other analysis package. After finalizing the metadata, the scientist can then query the database to construct a concatenated file containing all the sonde data that meet the criteria of the query. For example, all sondes for azimuths 340-090 degrees, for MBL wind speeds of 50-59 m/s, in water depths of < 200 m could be combined into one file to construct a mean vertical wind speed profile.

8. One of the more time consuming aspects of the project is to integrate a database of flight-level observations organized by radial flight legs. The scaled radial coordinate will be determined by using the maximum flight level wind speed on the particular radial leg on which a sonde has been launched. It is recognized that sondes launched on non-radial legs would be omitted from this type of analysis. We have begun ingesting the flight level data but do not expect to complete this until the first quarter of the second year.

Out of the 1027 sonde files loaded into the database the data are distributed by mean boundary layer (MBL) wind speed as follows:

Table 1 Number of sonde profiles as a function of MBL wind speed group.

MBL group (m/s)	Sonde profiles in database (3-20-2006)
20-29	226
30-39	294
40-49	255
50-59	162
60-69	123
70-79	94
80-89	26

So far, with about a half of the database loaded, the 20-29 m/s through 60-69 m/s MBL groups meet the target of > 150 profiles needed to investigate azimuthal differences in the boundary layer and surface layer wind profiles. In addition, there are sufficient profile to examine the mean profile for the 70-79 m/s MBL group. This group did not contain sufficient samples to construct a profile in the Powell et al., 2003 study.

B. Hardware / software:

As per the proposal budget, a 1.2 terabyte JBOD hard disk drive was purchased to provide sufficient storage for the database. JMP 6.0 statistical software was also purchased.

C. Preliminary Analysis

1. Quality Control

Metadata files have been examined to look for gross errors in the storm relative position and flow calculations, and the derived quantities have been computed using routines developed by Matt Easton. During QC, errors in storm tracks were found for about 10% of the sondes and these are being investigated. The errors are probably caused by identifying a sonde with another storm on the same date.

Sonde data are binned to provide relatively high vertical resolution near the surface and then lower resolution above the boundary layer. Height bins are identical to those chosen for the Nature paper with 4 m bins near the surface (8-12, 13-16,17-20), ten m bins through the surface layer to 300 m (21-30, 31-40), 20 m bins through 500 m (e.g. 301-320, 501-550), 50 m bins through 1000 m, and 100 m bins above 1000 m. The standard error of the bin averaged mean wind values (ratio of the standard deviation to the square root of the number of samples) is computed for each bin as an indicator of bins with poor estimates of the mean wind speed. Based on preliminary analysis with 1017 profiles we will remove from consideration all bins with < 10 wind samples and/or standard errors > 1.0 m/s. This tends to happen at bins in the lowest 50 m when examining the high wind MBL groups, especially after dividing into azimuth or radial categories within an MBL group. When the database loading through the 2005 season is completed, we will have several hundred more profiles available for analysis so our bin mean estimates should improve due to a larger sample size. Further criteria to be considered in the year 2 analysis include the number of satellites used in the wind calculation and wind processing flags.

2. Drag coefficient behavior

One of the main interests of this project is to investigate the azimuthal dependence of the drag coefficient. As depicted by this plot from Wright et al and Ed Walsh's scanning radar altimeter wave data (Fig. 1) superimposed on an H*Wind analysis of Hurricane Bonnie of 1998, we can divide the storm into three regions: 1) Left front where the swell travels across the wind, 2) Right side where swell and winds concide, and 3) left rear where the sea is more confused and at times has winds going against the waves.

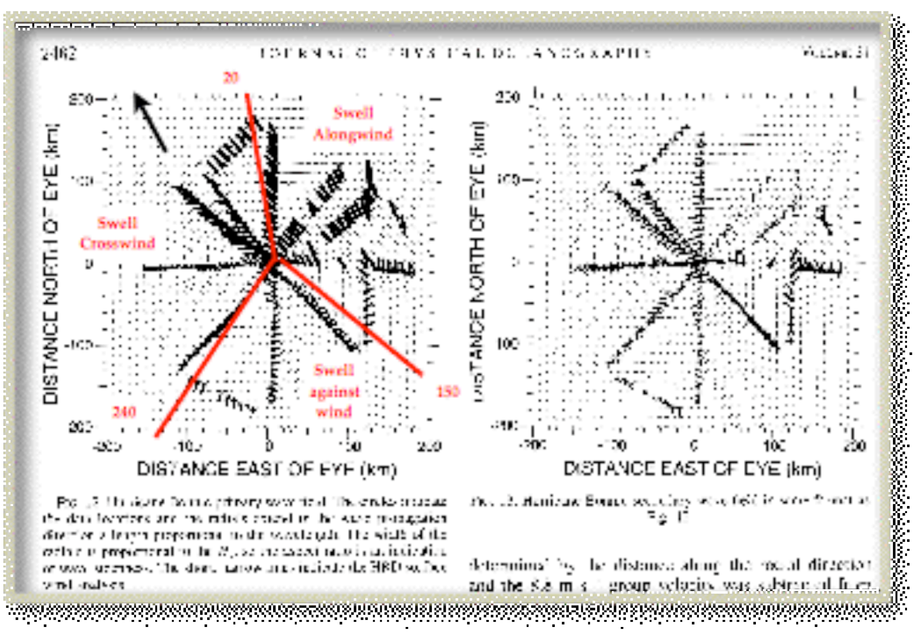

Figure 1. from Wright et al., 2001 showing wave and wind field for Hurricane Bonnie.

Drag coefficient is computed from the bin averaged GPS sonde profiles by fitting the profile of Ln Z (height) vs the mean wind speed (eqns 1, 2).

Profile Method:
Log Law for neutral stability

$U = U_*/k \quad Ln\,(Z / Zo)$ (1)

$Ln\,(Z) = (k / U_*)\, U + Ln\,(Zo)$ (2)

slope intercept

$$\tau = \rho\, U_*^{2} = \rho\, C_d\, U_{10}^{2} \quad (3)$$

The Y intercept is the roughness length and the slope is related to the friction velocity. The drag coefficient may be computed from the roughness length and the ten m neutral stability wind may then be computed from the roughness and friction velocity. A plot of Cd vs. wind speed (Fig. 2) based on 1017 profiles is superimposed on the Powell et al., 2003 results. The plot shows nearly 3 times the number of profile in the original study and suggests slightly smaller values with a similar behavior of an initial increase with wind speed followed by a leveling off at winds of 33 m/s and then a decrease at extreme winds through 60 m/s. Error bars based on the 95% confidence limits of the fit have not been plotted (but are shown for the Nature results).

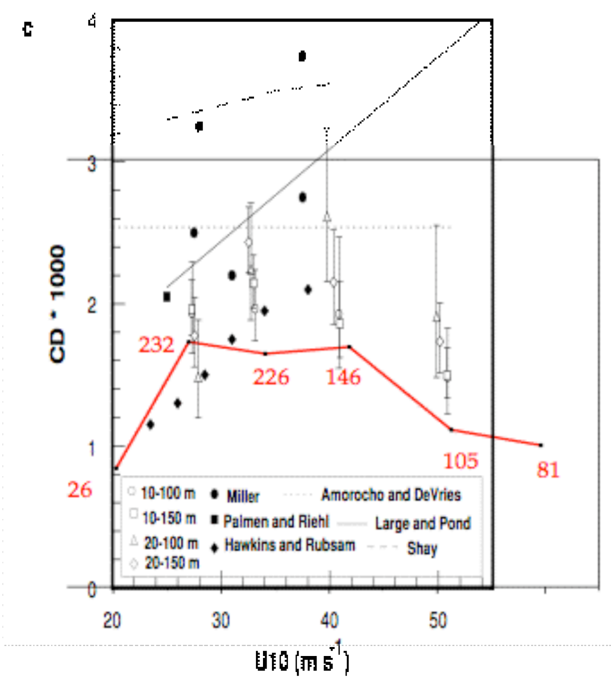

Figure 2. Drag coefficient as a function of wind speed based on 1017 profiles. Number of profiles for each value is shown in red. Open symbols and error bars from Powell et al., 2003.

A similar plot showing Cd computed using profiles within or outside the median sonde splash radius (~ 32 km for MBL winds above 40 m/s) indicate a radial dependence on the drag which was not expected. We should mention that about 10% of the sondes attributed to the outer region were associated with errors in radial position due to storm track errors (we are in the process of correcting these). We hypothesize that the inertial stability becomes an important consideration and may relate to the depth of the boundary layer wind maximum as recently suggested by Kepert 2001. In year 2 we will investigate this dependence and also examine dependence on a scaled radial coordinate using the flight level radius of maximum wind speed.

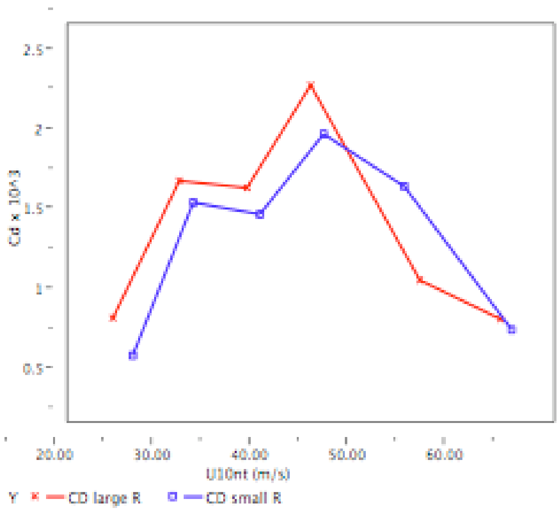

Figure 3. Dependence of Cd on radial distance from the storm center.

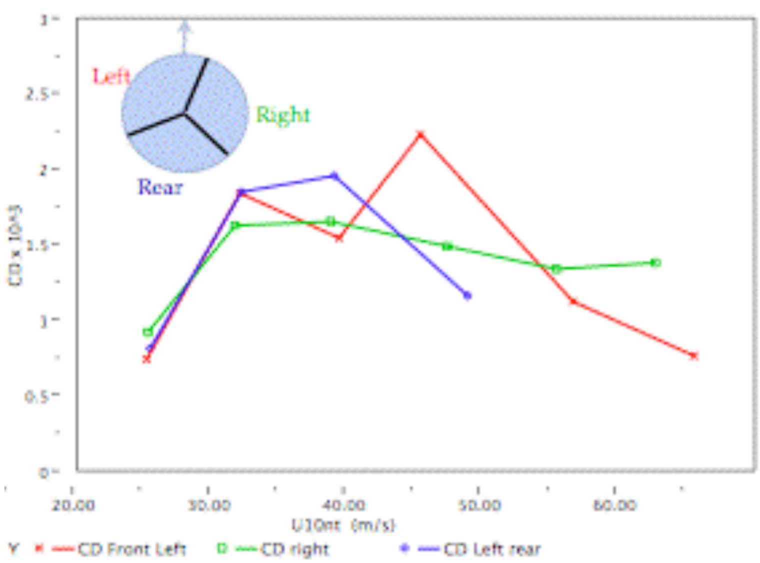

Figure 4. Dependence of Cd on the azimuthal sector relative to the direction of storm motion.

Preliminary investigation of azimuthal dependence based on hypothesized wave, swell, and wind interactions depicted in Fig 1 were hypothesized to show smaller Cd in the right sector where the winds and waves tend to travel in the same direction and larger values where the waves travel across or against the wind. No well defined signal is shown although the right side profiles suggest a smaller Cd than the left rear side at 30-40 m/s. These results are very preliminary and MBL groups did not undergo uniform QC procedures to remove poor estimates. Based on the radial dependence shown in Fig. 3, in Year 2 we will explore ways to simultaneously examine the radial and azimuthal dependence of the drag coefficient.

D. Summary and plans for Year 2

The project is progressing well. The extraordinary 2005 season has lead to many more sonde launches that we hope to be able to load into the database. The first half of 2006 will focus on loading as many of these sondes as possible, including the associated storm track data, water depth information, and indexing the information with the flight-level observations. At the same time we will conduct analysis on the existing available profiles to look for signals associated with storm relative position and water depth. By September 1, we will complete the database loads and focus on final analysis of the mean profiles. We will discuss our analysis results with CBLAST investigators and modelers contributing to the surface layer parameterizations for the HWRF and GFDL models.

References

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