BOUNDARY LAYER WIND PROFILES IN HURRICANE FABIAN

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1. Introduction

On September 5, 2003, the eyewall of Category 3 Hurricane Fabian passed over Bermuda, causing the loss of four lives and extensive damage. Official *in situ* measurements, taken at two sites on Bermuda, will be considered here. Bermuda is an archipelago of volcanic origin, spanning 54 square kilometres and comprised of some 150 islands.

Blackwell (2000), and Powell and Houston (1996) observed low level jet asymmetries in the boundary layers of Hurricanes Danny and Andrew, respectively. Both concluded that the jets were the result of surface friction, and that the speeds of these jets could be enhanced by increased surface roughness. Kepert (2003) discussed some analyses and modelling studies of the boundary layers of landfalling tropical cyclones. Kepert concluded that jet asymmetries and increased convergence in the offshore flow may be induced or enhanced by asymmetric surface roughness.

This preliminary study evaluates whether the local observations taken during Fabian's landfall, in conjunction with remote sensing observations and flight data, are sufficient to perform a similar study to Kepert (2003) and Blackwell (2000). Does a small island, such as Bermuda, satisfy the surface roughness requirement in order to produce asymmetric mesoscale features in the boundary layer of a tropical cyclone, as outlined by Kepert? This has particular relevance for small island states in tropical basins other than the Atlantic, as illustrated by the recent impact of TC Heta on Niue, in January 2004. In the opinion of the author, as both a former operational forecaster in Bermuda and a research meteorologist, this question is pertinent to both real-time operations and tropical cyclone theory.

2. Data Collected

The Bermuda Weather Service (BWS, airfield designation TXKF) recorded surface wind observations (2 minute mean) on a frequency of one hour or less during September 5, 2003. Radiosonde ascent data was also collected at 00 UTC, 11 UTC and 12 UTC, but unfortunately there is no ascent data at 00UTC on the 6th. At 11 and 12 UTC, the outer tropical storm force surface winds of Fabian were beginning to affect the local Bermuda area. Ascent data are instantaneous winds collected at 10-second intervals. The balloon is advected with the flow, rather than ascending directly over TXKF, so without the spatial coordinates of the sonde, it is difficult to determine the specific causes of variability in the data signals, and the spatial and temporal scales of observed features. Calculations using sonde data averaged over time or height should be treated with caution.

Wind data (10-minute mean) in Warwick parish was also collected by the Bermuda Biological Station for Research Inc. (BBSR) at an instrument tower (henceforth labelled Warwick Tower or WT), with rotary anemometers at 87 m and 108 m above mean sea level (MSL), and sonic anemometers at 108 m above MSL. The u, v and w components as well as the actual wind speeds were recorded at this site. Warwick Tower is sited on a hill 40 m above MSL, and forced ascent is a possible factor for updraft enhancement, especially in strong wind events. Additional wind data and traces were available from unofficial weather stations, operated by members of the public, and private companies.

Wind analyses, dropsondes and surface wind products by the Hurricane Research Division (HRD), as well as high resolution wind data from QuikSCAT and SeaWinds scatterometers were examined.

3. Results

Wind data from the WT show 10-minute mean wind speed maxima at 1900 UTC, of 53.75 ms^{-1} at 108 m, and 50.59 ms^{-1} at 87 m. These maxima occurred approximately two hours prior to the time of maximum surface winds reported at TXKF, which is consistent with Fabian's forward speed of 28-31 km hr^{-1} (15-17 knots), from the NHC advisories.

Wind speeds from the 11 and 12 UTC TXKF radiosonde ascents show two wind speed maxima of ~30 m s-1 at 1440 m and 2380 m. This double jet is a notable feature of the low level wind profile from TXKF, which is also evident as early as the 00 UTC ascent (see Figure 1).

Another interesting aspect of the 11 and 12 UTC ascents is the rapid increase in near-surface wind speed between these two observation times. During this period, conditions at the surface rapidly deteriorated. TXKF reported winds at 090°, 13.9 m s^{-1}, with gusts to 17 m s^{-1}, with unobstructed visibility at 11 UTC; by the 13 UTC observation, winds had increased to 120°, 17.5 m s^{-1}, with gusts to 25.3 m s^{-1}, and visibility of 3.2 km, in thunderstorms with moderate rain and blowing spray. Wind gusts at the TXKF airfield are (for operational purposes) assumed to be representative of the mean speed over the open waters of the Bermuda Marine Area (which extends 46 km from the coast). Assuming that this approximation is correct, the time period discussed above was the transitional onset of tropical-storm force winds over the local area.

The ratio of surface to flight level (700 mb or 3050m) wind speed has been dubbed 'surface wind factor' (SWF) by Kepert, 2003. SWF was calculated from the 11 UTC and 12 UTC radiosonde ascents from TXKF to be approximately 0.55. At the time of these balloon ascents, the centre of Fabian was 250 km to the south-southwest (bearing 195°) of TXKF. At that time, Bermuda's marine area was only just beginning to experience tropical storm force winds, which extended out to 320 km north of the storm's centre.

Dropsonde data from September 4th show that boundary layer jets were present in the eyewall region. Observations at 2022 UTC and 2216 UTC show jets of

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74.6 m s^{-1} and 42.1 m s^{-1} respectively, both between 790 and 840 m above MSL. Surface wind factor was calculated as 0.92 for the 2022 UTC dropsonde, and 0.57 and 0.63 for two dropsondes at 2216 UTC. Figure 2 shows storm-relative positions of dropsondes, plotted on the 12 UTC position for Fabian.

4. Discussion

Unfortunately (but understandably), there were no radiosonde ascents during the period that Fabian's eyewall passed over the island, nor were many dropsonde or flight data recorded near to landfall. In order to determine the temporal and spatial variability of jets in the tropical cyclone boundary layer (TCBL), as the TC passes over a small island, one would require multiple wind profiles from before, during, and after passage of the TC. In the case of Fabian's landfall, these observations were unavailable. As a result, any comments regarding the affect of surface roughness are speculative. However, some conclusions can be made regarding the presence of jets in the TCBL, based upon observations made in Fabian's outer region and dropsonde data from the eyewall region.

The SWF calculated from the 11 and 12 UTC ascents and dropsondes provide additional data for comparison with Kepert's work, especially useful to those attempting to forecast the surface winds in different regions of a tropical cyclone. Surface wind factors, and therefore surface wind forecasts, may be affected by low level jets detected in both the outer and eyewall regions of TCs such as Fabian. A SWF of 0.92 was calculated from the 2022 UTC dropsonde, which supports the Kepert's data of SWF approaching unity towards the eyewall. The lower wind speeds evident in the 2216 UTC wind profiles (nearer Fabian's centre) indicate that the dropsonde positions were in the transition zone between the eyewall and the eye. The surface wind factors for those sondes are calculated at 0.57 and 0.63, which is consistent with a rapid decrease of lower-tropospheric winds in the eye.

Despite the variable nature of the wind profiles, the jets were coherent features in and near the eyewall. This suggests a well-established symmetric structure in Fabian's sub-flight level turbulence, near the top of the TCBL. Jets were measured by the TXKF ascents, at similar altitudes in the outer region. However, the nature and origin of these outer region jets is ambiguous, as they were measured as far as 250 km from the central position. Two possible explanations are: a) the jets measured in the eyewall are maintained to large radial distances away from the centre, or b) the jets in the outer region may have been induced by other factors, such as convection, or increased surface roughness over Bermuda. In the absence of more wind profile data, characteristics of the outer region jets remain unclear.

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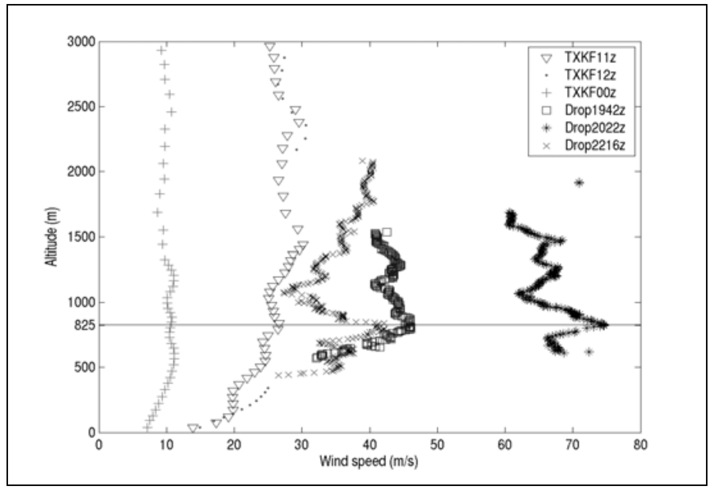

Figure 1: Selected vertical wind profiles during Fabian.

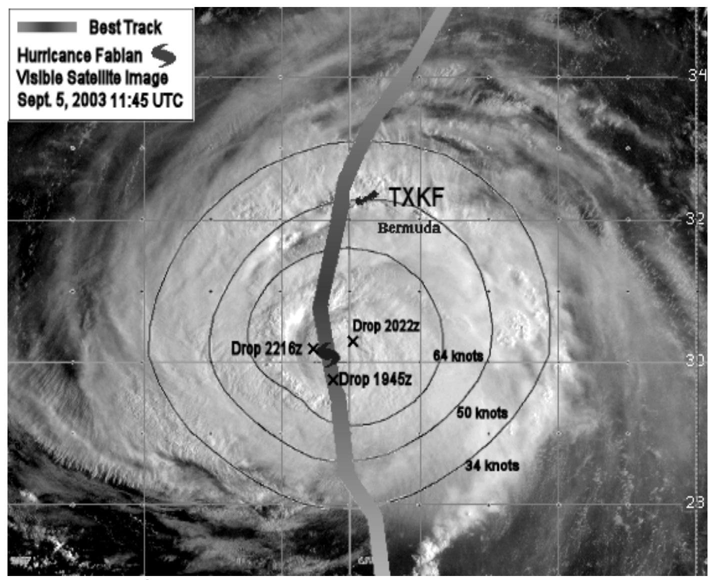

Figure 2: Storm-relative dropsonde positions (x), wind speed radii and best track, overlaid on a visible satellite image of Fabian on Sept 5, 2003.

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