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UNCERTAINTY IN HURRICANE WINDS: WHAT DO NEW MEASUREMENTS AND SIMULATIONS TELL US ABOUT HURRICANE ANDREW

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1. INTRODUCTION

The Best Track committtee of the Tropical Prediction Center recently reclassifed Hurricane Andrew as a Category 5 storm at landfall in South Florida, based on an interpretation (that peak surface winds are ~ 90% of the flight-level winds at the 700 mb level) of open ocean GPS sonde measurements made since 1997.

2. VARIABILITY OF REDUCTION FACTORS

The uncertainty of applying a single mean flight-level wind reduction factor (R) is high, as evidenced by the large standard deviation of 0.19 (Franklin et al 2003). When the reduction factor distribution is further constrained to represent 700 mb winds above 50 m/s, there are only 30 samples and R falls to 77% with a 15% standard deviation. R is known to vary radially within a storm (Franklin et al 2003) in agreement with other observations (Mitsuda 1988, Powell et al., 1996), theory (Kepert 2001) and idealized modeling (Shapiro 1983, Kepert and Wang 2001). Theory and models show a motion-induced left-right asymmetry, with higher SWF on the weak (left) side of the storm. Franklin at al (2003) also noted that R on the left side was on average 4% larger than the right; remarkable considering that 439 eyewall profiles in 17 storms were considered. This behavior was observed in Keperts (2002a,b) analyses of R in Andrew and Georges but is not present in all cases, possibly because other sources of asymmetry (e.g. shear) can dominate at times. Kepert (2001) shows a 10% variation in R dependent on inertial stability in the eyewall, which can vary greatly between storms, and may be the reason for the variability depicted in Fig. 11 of Franklin et al., (2003).

Recent measurements from the Stepped Frequency Microwave Radiometer (SFMR) suggest that in individual storms, R may follow an asymmetric pattern influenced by relative flow patterns associated with a storm passing through a sheared environment. Near peak intensity, Hurricane Isabel of 2003 provided evidence of this feature (700 mb winds of 70-75 m/s approached those measured in Andrew. A research flight on the 12th encountered low (0.75) reduction factors, with the W side slightly higher than the E side, the S side higher than the N side, and later in the flight the E and W sides about the same. Measurements 24 h later showed similar R ahead and behind the storm but higher factors to the left (SW) and lower to the right (NE) side.

3. CHARACTERISTICS OF INTENSE HURRICANES

Unfortunately, none of the storms in the GPS sonde database, including Mitch when a Cat 5, show 700 mb winds as high as Andrew (~82 m/s). Earlier storms showing 700 mb winds similar to Andrew include Inez (Hawkins 1969), Allen in 1980 (on Aug 8th after an eyewall contraction, Jorgensen 1984), Gloria 1985 at peak intensity (peak tangential winds at 550 mb although the distribution of convection in Gloria was asymmetric due to shear of the environmental flow (Franklin et al., 1993)), Gilbert of 1988 near peak intensity (Dodge at al.,1991), and Hugo in 1989 (Black and Marks 1991). Characteristics of such Intense hurricanes include a contracting eyewall process and winds at 700 mb that are as strong as winds at 500 m. This is in contrast to the usual situation where the winds at 700 mb are of the order of 10 - 30% lighter than those at 500 m (e. g. Franklin et al's fig 11). An eyewall with little vertical shear below flight level would thus contribute to smaller values of R.

4. COMPARISON OF 0.9 RULE TO SURFACE WIND OBSERVATIONS IN ANDREWÕS EYEWALL

Anemometers in Andrews eyewall failed to sample complete records but provide a valuable opportunity to validate the 0.9 rule. At 0759 UTC, 24 August 1992, the Fowey Rocks C-MAN station measured a maximum

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sustained surface wind of 108 kts (Powell et al., 1996). The data transmission system failed soon afterwards, followed by the instrument mast (Personal communication, Doug Scally 2002). An objective analysis of the North-South and East-West legs of the 700 mb flight-level observations from 0410-0830 UTC adjusted using the 0.9 rule results in ~140 kt winds at Fowey Rocks, over 30 kts higher than observed. The highest surface wind measurement in Andrew, 119 kts (Powell et al., 1996) came from a Perrine homeowner, using a 10 m mast attached mounted near the side of his house. The mast failed at the time of this measurement consistent with an east (Mayfiield et al., 1994) or eastnortheast wind direction. As discussed in Powell et al., 1996, the most likely time of this observation was ~ 0900 UTC. The 0.9 R objective analysis at 0900 UTC shows ~ 142 kts in Perrine, over 20 kts higher than observed. These comparisons indicate that the 0.9 method used to adjust the 700 mb flight-level winds to the surface overestimated winds in these locations by ~29% and 19%, respectively. If we use the 0.9 rule to estimate flight-level winds from the surface measurement, the 700 mb winds would be ~120 and 132 kts above Fowey Rocks and Perrine, respectively compared to actual flight-level measurements of 156 kts and 162 kts at the same radius. Using an R of .77 yields a 700 mb wind estimate of 140 kts and 155 kts above Fowey and Perrine, respectively which compares much better with the observations.

5. INSURANCE INDUSTRY SIMULATIONS

From an insurance industry point of view, the maximum wind speed alone may not be the best measure of risk or damage potential; the spatial wind hazard impact on properties is much more important. However, models typical of those used by the insurance industry (Vickery et al 2000) attempt to reproduce hurricane surface wind fields with published accuracies of within 15%. With input parameters based on Hurricane Andrews observed minimum pressure (922 mb), radius of maximum wind (19 km), translation speed (10 m/s), and pressure profile (derived from Fig. 4 of Mayfield et al., 1994), such a model is able to reproduce a maximum wind speed range of 118-123 kts. It is not possible to reproduce a wind speed of 150 kts without using unrealistic values for the pressure profile.

6. COASTAL ROUGHNESS

Another plausible reason for the overestimate of the 90% rule may have to do with the exposures of the GPS sonde surface wind measurements upon which it is based. As discussed in Powell et al (2003), nearly all the sondes were launched in deep-water, open-ocean conditions. The aerodynamic roughness of the sea in such conditions was shown to have very small values ~ 1 mm. Near the coast, recent observations in Hurricane Bonnie (Walsh et al., 2002) document shorter and steeper swell, and other researchers have noted larger roughness lengths due to shoaling wave conditions. Unfortunately there are too few GPS sonde wind profiles near the coast to make this distinction. However, university teams have participated with the annual HRD field program and have begun to collect detailed wind measurements from instrumented coastal towers deployed ahead of hurricanes. A particularly interesting set of measurements was collected by Reinhold and Gurley (2003) as part of Clemson and the University of Floridas participation in the Florida Coastal Monitoring Program (http://www.ce.ufl.edu/~fcmp). Onshore flow roughness measurements within 200 m of the (prestorm) shoreline were recently obtained at Cape Hatteras, NC during the landfall of Hurricane Isabel. These measurements document roughness more than an order of magnitude larger than open ocean roughness in similar wind speeds. Further measurements are needed to see if this behavior persists for winds greater than a Saffir-Simpson category two hurricane, but these data suggest that coastal roughness is similar to open terrain conditions over land (~ 30 mm) and much rougher than open ocean conditions. A rougher surface near the coast would contribute to weaker surface winds and smaller values of R.

7. CONCLUSION

Observations, theory and modelling studies support the fact that the surface wind reduction factor varies both within, and between, storms. Careful analysis of the observations in Andrew suggests that R near the right eyewall lies at the lower end of the possible eyewall range suggested by these studies. Thus, Andrew was most probably not a cat 5 at landfall.

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