# CORRESPONDENCE

## Comments on "Estimating Maximum Surface Winds from Hurricane Reconnaissance Measurements"

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Powell et al. (2009, hereafter PUK) investigated the relationship between flight-level and surface winds near the radius of maximum wind (RMW) in tropical cyclones. In their study, the flight-level wind observations were obtained by National Oceanic and Atmospheric Administration (NOAA) WP-3D aircraft between 2- and 4-km altitude while concurrent surface measurements were made by the Stepped Frequency Microwave Radiometer (SFMR; Uhlhorn et al. 2007). PUK found an overall ratio of maximum surface to maximum flight-level wind of 0.84, with the largest ratio on the cyclone's left side (0.89) and the smallest on the right side (0.79). PUK then compared their results to an earlier study by Franklin et al. (2003, hereafter FBV), but did so in a way that overstated the differences between the two studies and, in addition, misrepresented the analysis conducted by FBV.

FBV examined GPS dropwindsonde (Hock and Franklin 1999) observations in tropical cyclones at 700 hPa and the surface, and recommended operational application of a 90% adjustment for estimating a tropical cyclone's maximum surface winds from 700-hPa flight-level data (see Table 2 in FBV). This appears at first glance to be significantly different from the 0.79 right-side ratio found by PUK—a difference that PUK attributed to a sampling bias in the FBV dataset. PUK assert (p. 879) that FBV's "flight-level wind was measured somewhat inward" of the flight-level RMW, implying that FBV's higher recommended adjustment results from a failure to consider the typical outward slope of the eyewall with height. The purpose of this comment is to offer a different perspective on the differences between the two studies' conclusions.

We first address the issue of eyewall slope. Sonde trajectories, of course, are not guaranteed to sample the precise RMW at either 700 hPa or the surface, and it is knowledge of the wind structure along the sloping RMW that is desired. It should be clear from FBV's discussion (p. 39), however, that FBV did account for the eyewall slope in the formulation of their recommended adjustments. Because of eyewall slope, sondes released more than a kilometer or two inward of the flight-level (or 700 hPa) RMW will tend to approach the surface RMW as they fall; for these sondes, the ratio of surface to 700-hPa wind will indeed be higher than the corresponding ratio along the actual sloping RMW. However, the opposite is true for sondes dropped at or a short distance outward of the flight-level RMW; these sondes will be moving farther away from the RMW as they descend, and consequently for this group the ratio of surface to 700-hPa wind will be lower than the corresponding ratio along the sloping RMW.

FBV accounted for eyewall slope by selecting a sample of sondes that would have preferentially encountered the 700-hPa RMW at the expense of the surface RMW. Specifically, the FBV adjustments were based on a sample of sondes near the flight-level RMW for which the mean release point was 0.1 nautical miles (n mi) outside of the flight-level RMW, not inward of it as claimed by PUK. As noted above, sondes released at this location would tend to move away from the sloping RMW as they fall, underestimating the surface wind maximum by a greater margin than the maximum at 700 hPa. It follows, then, that adjustment factors determined from such a sample of sondes would represent a lower bound on the adjustment factor to be applied *at* the sloping RMW.

Given the above, what then explains the difference between FBV's 90% recommended adjustment and the 0.79 ratio found by PUK? In large part, it is not an apples to apples comparison.

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FBV's mean eyewall profile, evaluated at the flight-level RMW, showed a surface to 700-hPa wind speed ratio of 0.88 (p. 39). Thus, for the eyewall as a whole, the two studies' reported adjustment factors differ by only 0.04 (0.84 for PUK versus 0.88 for FBV). In addition, FBV reported a 4% asymmetry between the right and left quadrants, yielding a dropsonde-based ratio of 0.86 for the right quadrant and 0.90 for the left. Thus, the left-side result from FBV is virtually identical to the left-side result reported by PUK (0.90 versus 0.89); however, the right-side ratio from FBV is indeed higher than that of PUK (0.86 versus 0.79).

While there appear to be different asymmetries in the FBV and PUK datasets, there are other differences as well; one of these is the height of the upper-level data used in the analyses. Because the mean wind in the eyewall decreases with height above the boundary layer (FBV Fig. 10), systematic differences in height would produce differences in adjustment factors. PUK included flight-level data taken anywhere between 2 and 4 km, while FBV restricted their analyses to constant pressure levels (e.g., 700 hPa). Since the vast majority of reconnaissance missions in hurricanes are conducted on the 700-hPa surface, this is the more appropriate framework for evaluating operational adjustment ratios. That issue aside, the mean altitude of the PUK sample (2765 m) was about 100 m below that of the FBV sample. While this is not a large difference, FBV's Fig. 10 shows that the PUK ratios should be increased by 0.01 to adjust their findings to the FBV reference level appropriate for operations. This decreases the discrepancy between PUK and FBV to 0.03 for the eyewall overall, to 0.06 for the right quadrant, and to 0.0 for the left quadrant.

Both the dropsonde and SFMR datasets, strictly speaking, directly address only the issue of what local surface wind is associated with a particular wind aloft, as sampled roughly along the aircraft flight track. The National Hurricane Center (NHC), however, is charged with estimating the intensity of the tropical cyclone, that is, the peak 1-min mean surface wind associated with the system, regardless of where it occurs. PUK acknowledge as much (p. 880) when they correctly note that a 90% adjustment has been the basis for NHC best-track tropical cyclone intensity estimates.

Estimating the intensity of a tropical cyclone from widely spaced observations (in this case, azimuthally sparse transects of the eyewall) requires a consideration of undersampling—the notion that the cyclone intensity should generally be higher than the highest observed wind because the actual maximum was almost surely not encountered by the reconnaissance aircraft. PUK make no allowance for undersampling in their recommendations for storm intensity; similarly, H*Wind, the quasi-real-time surface wind analysis developed by the lead author (Powell et al. 1998), also contains no undersampling component.

Although a discussion of undersampling does not explicitly appear in FBV, an undersampling component is implicit in the formulation and operational application of the 90% adjustment and, indeed, was clearly stated in the Landsea et al. (2004) application of FBV to Hurricane Andrew's reanalysis. The maximum flight-level wind is almost always observed on the storm's right-hand side, where FBV's analysis shows that an 86% (or higher) local adjustment applies. FBV acknowledged the right–left asymmetry and pointed out that it was not large enough to invalidate the 90% recommendation (p. 43). In other words, estimating cyclone intensity at 90% of the peak observed 700-hPa wind assumes up to a 4% increase over the FBV local adjustment to account for undersampling. In this regard, it is interesting to note that Uhlhorn et al. (2010) have recently estimated the undersampling of the 1-min mean wind associated with a 6-h reconnaissance pattern to be about 9%, more than double what is currently applied by the NHC.

It is possible, perhaps even likely, that the FBV dropsonde dataset underestimates the degree of asymmetry in the local wind adjustment factors, given the azimuthal translation that occurs as the sondes descend. Or the two samples may contain real differences in asymmetry (the FBV study includes sondes from both U.S. Air Force and NOAA missions while the PUK sample is restricted to NOAA sondes). Differences between the two studies are small enough to even be due to uncertainties in the calibration of the SFMR (the calibration has been updated many times in recent years). However, even if the PUK right-side local ratio of 0.79 turns out to be correct for the 2–4-km layer, Uhlhorn's recent undersampling work would still argue for tropical cyclone intensity estimates being about 87% of the peak observed 700-hPa flight-level wind.

The following key points are offered as a summary:

- PUK's assertion that FBV overestimated the surface to 700-hPa wind ratio through a radial sampling bias is not correct. The FBV adjustments were derived from a sample of sondes specifically designed to provide a lower bound on the adjustment applicable along the sloping RMW.
- When referenced to the same levels, the two studies report surface to flight-level wind ratios for the eyewall overall that are not very different (0.85 for PUK versus 0.88 for FBV). Such differences could easily arise from differences in the two studies' samples or uncertainty in the SFMR calibration. It seems premature to alter the tropical cyclone intensity estimation approach recommended by FBV and currently practiced at the NHC.
- Operational practice for estimating tropical cyclone intensity at the NHC recognizes that typical reconnaissance

patterns, which sample only a tiny fraction of the eyewall, are unlikely to have encountered the cyclone's strongest winds, even on the larger (low wavenumber) scales. Estimating cyclone intensity at 90% of the peak observed 700-hPa wind acknowledges these limitations by including a 4% increase to account for undersampling. When direct surface observations are available from the SFMR, similar reasoning can, and often does, justify estimating cyclone intensity above the highest observed SFMR wind.

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