7C.6 IMPROVING SFMR SURFACE WIND MEASUREMENTS IN HEAVY RAIN CONDITIONS

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1. INTRODUCTION

The airborne stepped frequency microwave radiometer (SFMR) estimates surface winds and rain rate in most weather conditions, particularly in tropical cyclones (Uhlhorn and Black, 2003; Jiang et al., 2006; Uhlhorn et al., 2007). However, due to a couple of potential factors, retrieval accuracy has been shown to be degraded in weak-to-moderate winds coupled with strong precipitation. In particular, winds are typically overestimated in such conditions. The objective of this project is to quantify the wind speed errors in such situations and propose a solution that may be implemented for real-time operations. In the first part of the project, the primary goal is to provide an empirically-determined SFMR wind speed correction computed from the wind speed and rain rate reported in the HDOB messages. Preliminary results indicate that over all observed wind speeds and rain rates, the proposed correction reduces the rain-induced high bias by 50%, and in sub-hurricane force winds with heavy precipitation, by 81%. Additionally, the accuracy (root-mean-squared error) is improved overall by 36%, and in the wind/rain range of interest, by 49%.

2. DATA AND RESULTS

The data used throughout this work are from the airborne SFMR as well as the GPS dropwindsondes. Some flight level wind speed data is used as well in the development of some synthetic data.

2.1 Database Expansion

An SFMR vs. GPS dropwindsonde database has been expanded to include a broader distribution of wind speed and rain rate combinations to assess accuracy in all expected conditions. In a previous observational sample, only 103 of the 1591 dropwindsondes were collected in weak-to-moderate winds and moderate-to-heavy precipitation ($U < 33$ m s^{-1}, $R \geq 10$ mm hr^{-1}). With our efforts to collect the data, especially during the 2011 season, this number increased by over 20%. Data were also added for years 1999-2004 to enhance the database in the desired range, and the total number increased by another 77 pairs.

However, a majority of this new data had rain rates less than 20 mm hr^{-1}. Although these direct observations were obtained, we feel that these conditions continue to remain relatively under-represented in the overall data sample, especially within the heavier rain rate bins. To improve the representation, synthetic dropwindsonde surface wind observations were estimated from the observed flight-level wind speeds. First, an average relationship between the "WL150" dropwindsonde wind speed (U_{WL150}) and ~700-mb flight-level wind speed U_{FL} is developed based on observations obtained in 2010-2011 (Eq. 1):

$$U_{WL150} = 2.3\times10^{-3}U_{FL}^{2} + 0.72U_{FL} + 3.21 \qquad (1)$$

The data and functional fit are shown in Fig. 1. Observations are only used radially outward of 2 maximum wind radii to reduce eyewall tilt uncertainties (Dunion et al. 2003). The surface wind speed estimate (U_{sfc}) is then computed from U_{WL150} (Franklin et al. 2003; Uhlhorn et al. 2007). All synthetic data were added for SFMR-observed rain rates greater than 10 mm hr^{-1}.

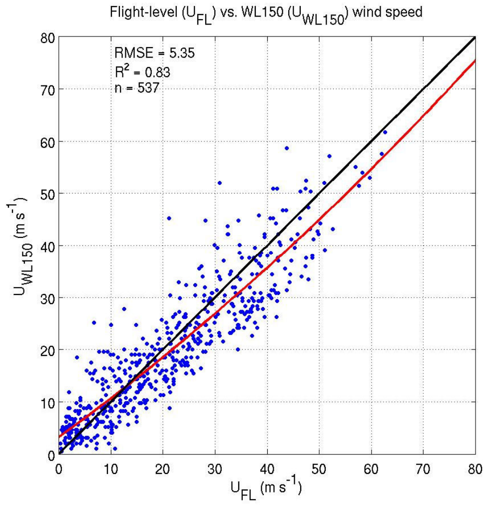

Fig 1: Empirical relationship between 700-mb flight level wind (U_{FL}) and lowest 150-m wind speed (U_{WL150}) developed to provide additional surface wind estimates in conditions under-sampled by direct dropwindsonde observations.

Table 1 summarizes the number of observations (2628 total), both real and synthetic obtained thus far, according to wind speed/rain rate bins. The overall accuracy of the SFMR observations relative to dropwindsonde surface measurements is 4.6 m s^{-1} (RMSE) with a bias of +2.0 m s^{-1}. Note that the original SFMR model accuracy was 3.6 m s^{-1} with a statistically-insignificant bias of –0.5 m s^{-1} (Uhlhorn et al. 2007) based on a sample size of ~160

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	U_{SFMR} (m/s)	**<17**	**17 – 25**	**25 – 33**	**33 – 50**	**> 50**
R_{SFMR} (mm/hr)						
< 10		767 – 1201 – 1201	347 – 515 – 515	154 – 262 – 262	90 – 170 – 170	7 – 20- 20
10 – 20		7 – 10 – 53	27 – 46 – 225	36 – 87 – 221	51 – 96 – 185	6 – 13 – 17
20 – 30		2 – 4 – 24	7 – 9 – 76	17 – 30 – 75	17 – 40 – 97	8 – 10 – 22
> 30		0 – 1 – 5	3 – 6 – 15	4 – 9 – 18	21 – 41 – 78	10 – 17 – 49

Table 1: Cumulative number of observations within each rain rate and paired wind speed bin. For each bin, the three values are: counts from the original 2005-2010 data, total after adding 2011 data (NOAA and AFRC) and the 1999-2004 data, and total after adding synthetic data, respectively.

observations. The addition of many more observations in heavy precipitation has expectedly degraded relative accuracy and resulted in a significant high bias.

2.2 Bias correction

With the database sufficiently expanded, a random sample of 2670 observations (80% of the total) was extracted for developing a bias correction model. The remaining 658 paired samples (20%) are subsequently used to evaluate the results of the bias correction. The SFMR surface wind speed and dropwindsonde surface-adjusted wind speed differences were binned into four rain rate (R) bins and five wind speed (U_{SFMR}) bins. Wind speeds are separated into the bins: 0-17 m s^{-1}, 17-25 m s^{-1}, 25-33 m s^{-1}, 33-50 m s^{-1}, and >50 m s^{-1}. Rain rate bins are 0-10 mm hr^{-1}, 10-20 mm hr^{-1}, 20-30 mm hr^{-1}, and >30 mm hr^{-1}. Synthetic dropwindsondes were weighted relative to the real dropwindsonde surface-adjusted wind speed least-squares fit to the SFMR wind speed. As the synthetic values became closer to the expected value (based on the least-squares fit), increased weights were applied to the synthetic wind speed. Lower weights were applied to synthetic wind speeds that deviate more from the relationship. All real data are given the highest weight in this process. Weighted mean differences and error statistics are computed for each bin, and a polynomial function is fit to the bin-averaged differences (Eqn. 2):

$$\Delta U = 2.853 - 0.070U_{SFMR} + 0.120R - 1.019\times10^{-3}(U_{SFMR}\cdot R) \quad (2)$$

where $\Delta U = U_{SFMR} - U_{sfc}$ is the model-estimated surface wind speed bias. Figure 2 shows this relationship graphically and includes the bin averages, counts, and relative weights applied for the calculation of the polynomial fit. These weights are based on the inverse standard deviation of each bin and are not the same weights used in the bin-average calculations. Figure 2 indicates that for low wind speeds and high rain rates, the SFMR wind speed bias is largest, and conversely, the bias is smallest for high winds and low rain rates. In particular, at minimal tropical-storm force winds (~17 m s^{-1}), the SFMR tends to over-estimate the wind speed by at least 4.5 m s^{-1} when the rain rate exceeds 30 mm hr $^{-1}$.

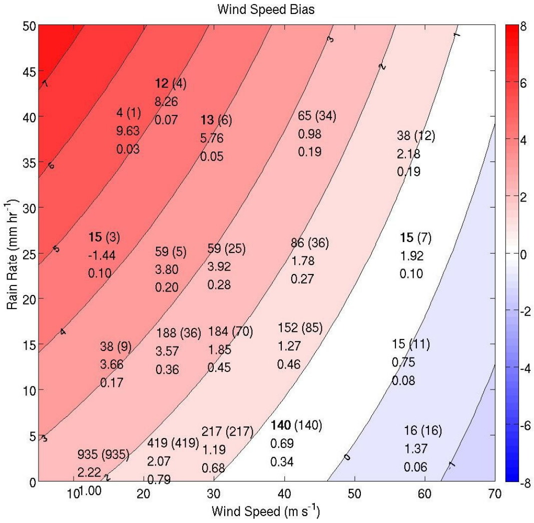

Fig. 2: Fitted wind speed bias (ΔU) function computed from Eq. 2. Contours are every 1 m s^{-1} with warmer colors representing higher biases and colder colors representing lower biases. Values are located at the mean wind speed and rain rate within each bin. The top line of each text field on the figure is the pair count with the number of real data in parentheses. The second line is the weighted mean difference for each bin, and the third line is the weight applied to the particular bin.

2.3 Independent Bias Correction Validation

The improvement in the SFMR surface wind estimate by applying the bias model (Eq. 2) is evaluated using the remaining 20% of the sample not used for model development. For each paired U_{sfc} vs. U_{SFMR} sample, the ΔU is computed from U_{SFMR} and R, and is then subtracted from U_{SFMR} to obtain a “corrected” SFMR surface wind (U_{corr}). The overall accuracy of corrected observations relative to U_{sfc} data is found to be within 3.2 m s^{-1}, or an improvement of 1.4 m s^{-1} (31%).

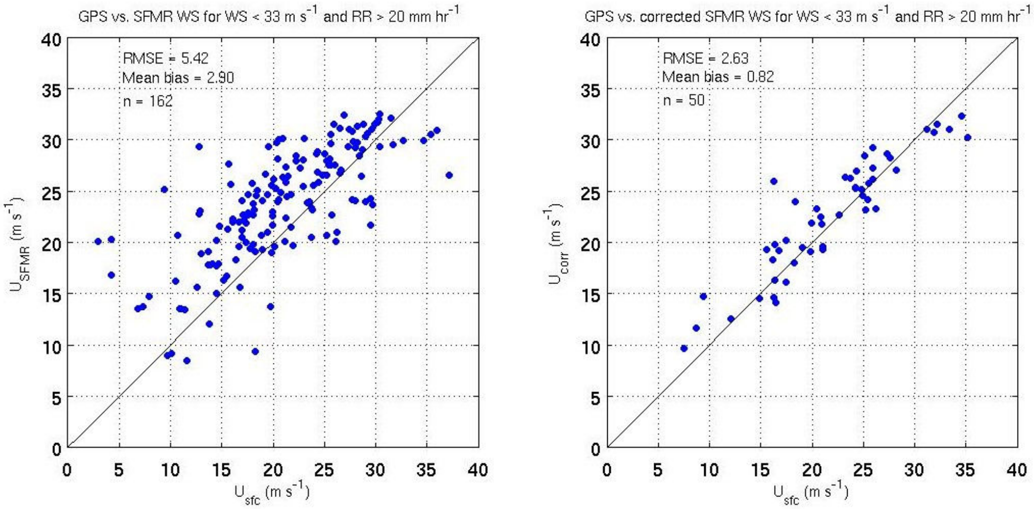

Fig. 3: Comparison of U_{SFMR} vs U_{sfc} for wind speeds < 33 m/s and R > 20 mm/hr (left), and comparison for U_{corr} vs. U_{sfc} for same range based on independent observation sample.

The overall bias is reduced to 1.0 m s^{-1}, which is a 48% improvement. Since we are specifically interested in improving the wind speed estimate at weak-to-moderate winds and heavy precipitation, we have examined the improvement where $U_{SFMR} < 33$ m s^{-1} and $R > 20$ mm hr^{-1} (Fig. 3). In this particular range, the accuracy improves from 5.4 m s^{-1} to 2.6 m s^{-1} (51%), and the bias is reduced from 2.9 to 0.8 m s^{-1} (72%).

3. CONCLUSIONS AND FUTURE WORK

Based on these preliminary results, we are encouraged that SFMR surface wind observations could be significantly improved in the upcoming 2012 hurricane season, and hope to test these results experimentally for real-time operations in the Joint Hurricane Testbed environment.

The work presented is merely the start of the process of updating the SFMR algorithm, especially with the weak wind and heavy rain scenarios. After the real-time experimental testing of the bias correction, the hope is to begin work on an updated, coupled wind/rain geophysical model function.

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