Progress report for year 1 of
National Oceanic and Atmospheric Administration (NOAA)
Joint Hurricane Testbed (JHT) Program

Improved SFMR Surface Wind Measurements in Intense Rain Conditions

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Summary:

The airborne stepped frequency microwave radiometer (SFMR) estimates surface winds and rain rate in all-weather conditions, and particularly in tropical cyclones. 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 two-year 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 year, 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 72%. Additionally, the accuracy (root-mean-squared error) is decreased overall by 31%, and in the wind/rain range of interest, by 51%. All proposed work tasks have been completed as scheduled. This year-1 progress report details all accomplishments thus far.

Proposed Timeline of Accomplishments for Year 1 (August 2011 – August 2012):

1) August - November 2011: Continue further assembly of SFMR and dropwindsonde data, and obtain additional data during hurricane season flights as necessary
2) December 2011: Finalize assembly of full SFMR vs. dropwindsonde database
3) January 2012: Complete statistical wind speed correction algorithm
4) March 2012: Present year-1 results at IHC
5) May 2012: Meet with JHT committee and set-up implementation of correction product in JHT testing environment for parallel SFMR wind speed product

6) June – November 2012: Perform real-time parallel testing of corrected SFMR winds and obtain additional data during season as necessary

7) Summer 2012: Begin development of the coupled wind/rain geophysical model function (GMF)

Progress of Accomplishments (Year 1)

Task 1:

As proposed, an SFMR vs. GPS dropwindsonde database has been expanded to include a more broad 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 heavy precipitation. With our efforts to collect the data, especially during the 2011 season as well as with the addition of data from 1999-2004, this number increased from 103 to 181, which is an increase of over 75%. Although these direct observations were obtained, we feel that these conditions continue to remain relatively under-represented in the overall data sample. 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):

$$U_{WL150} = 2.30\times10^{-3}U_{FL}^{2} + 0.72U_{FL} + 3.21 \ \ (\mathrm{m\,s^{-1}}). \tag{1}$$

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-induced 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 10 mm hr^{-1}.

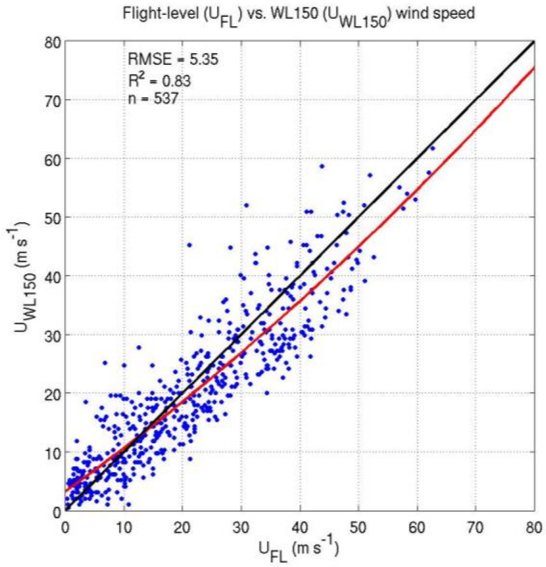

Fig 1: Empirical relationship between 700-mb flight level wind (U_{FL}) and lowest 150-m wind speed (U_{WL150}) developed to provide additional surface wind estimates in conditions under-sampled by direct dropwindsonde observations.

Task 2:

Table 1 summarizes the number of observations (3328 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 observations. The addition of many more observations in heavy precipitation has expectedly degraded relative accuracy and resulted in a significant high bias, which is addressed in the next task.

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

Table 1: Cumulative number of observations within each rain rate and paired wind speed bin. For each bin, the two values are: counts from the original 2005-2010 data plus the additional data from adding years 1999-2004 and 2011, and the total count after adding synthetic data.

Task 3:

With the database sufficiently expanded, a random sample of 2663 observations (80% of the total) was extracted for developing a bias correction model. The remaining 665 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. The closer the synthetic value was to the expected value (based on the least-squares fit), the higher the weight that was 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):

$$\Delta U = 2.853 - 0.070 U_{SFMR} + 0.012 R + 1.019 \times 10^{-3} (U_{SFMR} \cdot R) \quad (\mathrm{m\,s^{-1}}), \tag{2}$$

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 surpasses 30 mm hr^{-1}.

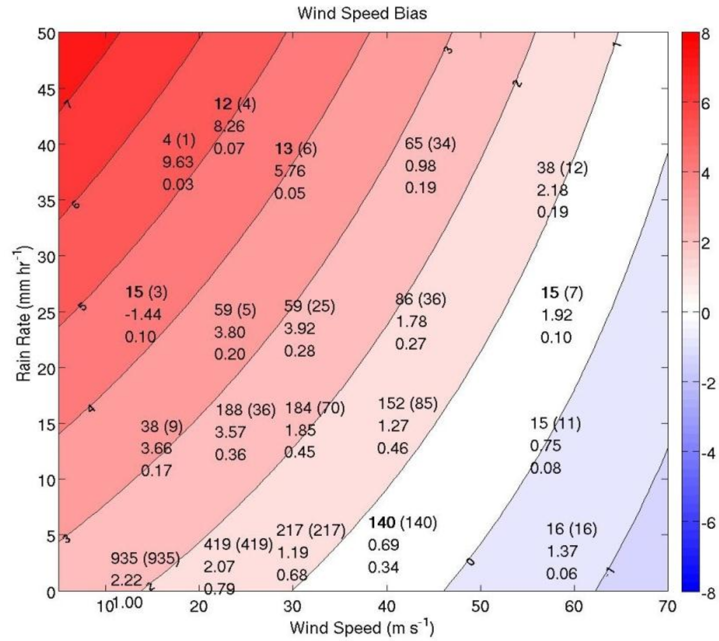

Fig. 2: Fitted wind speed bias (ΔU) function computed from Eq. 2. Contours are every 1 m s^{-1} with warmer colors representing higher biases and colder colors representing lower biases. Values are located at the mean wind speed and rain rate within each bin. The top line of each text field on the figure 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.

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%). The overall bias is reduced to 1.0 m s^{-1}, which is a 50% 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%).

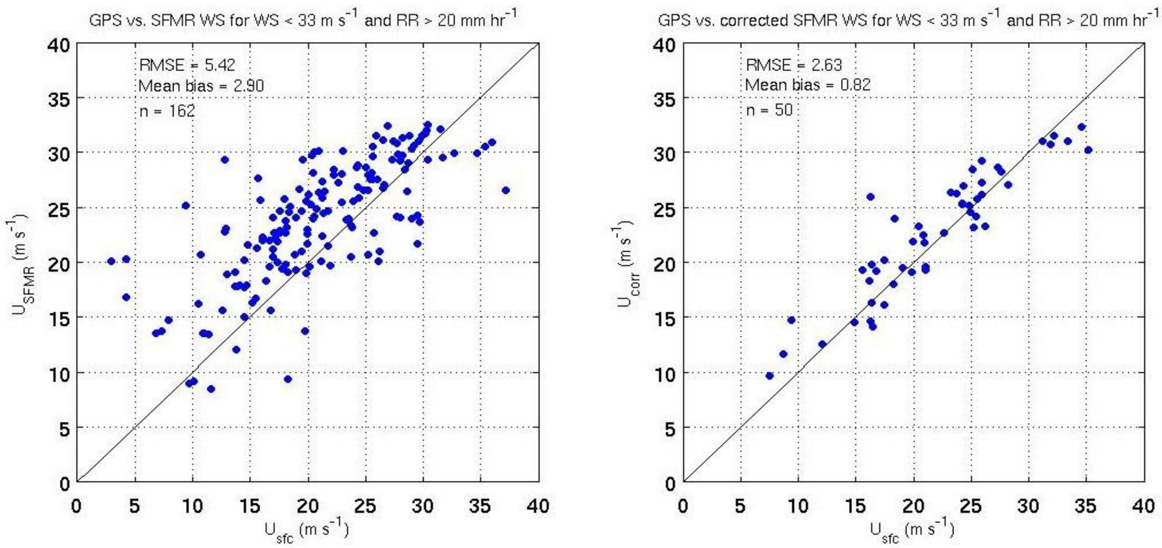

Fig. 3: Comparison of U_{SFMR} vs U_{sfc} for wind speeds < 33 m s^{-1} and R > 20 mm hr^{-1} (left), and comparison for U_{corr} vs. U_{sfc} for same range based on independent observation sample.

Tasks 4-6:

After the described results were found, they were presented at the Interdepartmental Hurricane Conference (IHC) in Charleston, SC. The report was well-received by those in attendance and several important questions were presented by the JHT advisory committee. These questions were addressed after the conference. The PI and Co-I then met with members of the JHT advisory committee to review the results presented at the IHC. The committee determined that applying the wind speed bias correction to an existing National Hurricane Center internal product would help the investigators examine the performance of the correction in semi-realtime during the 2012 hurricane season.

With some developing systems early in the season, the experimental testing was used by some forecasters at the National Hurricane Center in their classification and intensity determination of these tropical cyclones. Overall, the correction product reduced the wind speeds reported by the SFMR and most of these more closely aligned with coincident wind reports from other data sources, such as GPS dropwindsondes and buoys. This experimental product will continue to be tested throughout the season.

Task 7:

Beginning in the summer of 2012, NOAA Tail Doppler (TA) data and Precipitation Imaging Probe (PIP) data were collected from several past storms, including Hurricanes Katrina, Rita, Earl, and Tomas as well a test mission into day-time convection over the Gulf of Mexico in 2009. The TA radar reflectivity data have been matched in time with the PIP rain-rate data, and a Z-R relationship is in the process of being developed. The two panels in Figure 4 provide an example of the TA radar reflectivity from one center pass from Hurricane Katrina and the comparison between the mean columnar radar reflectivity below the melting layer and the PIP rain rate. As expected, the largest rain rates correspond to the largest TA radar reflectivity values, and from the relationship that is being developed, a more accurate measure of the rain-rate can be obtained and can be used in place of the rain rate determined by the SFMR. The new GMF can then be developed using a more reliable rain measurement.

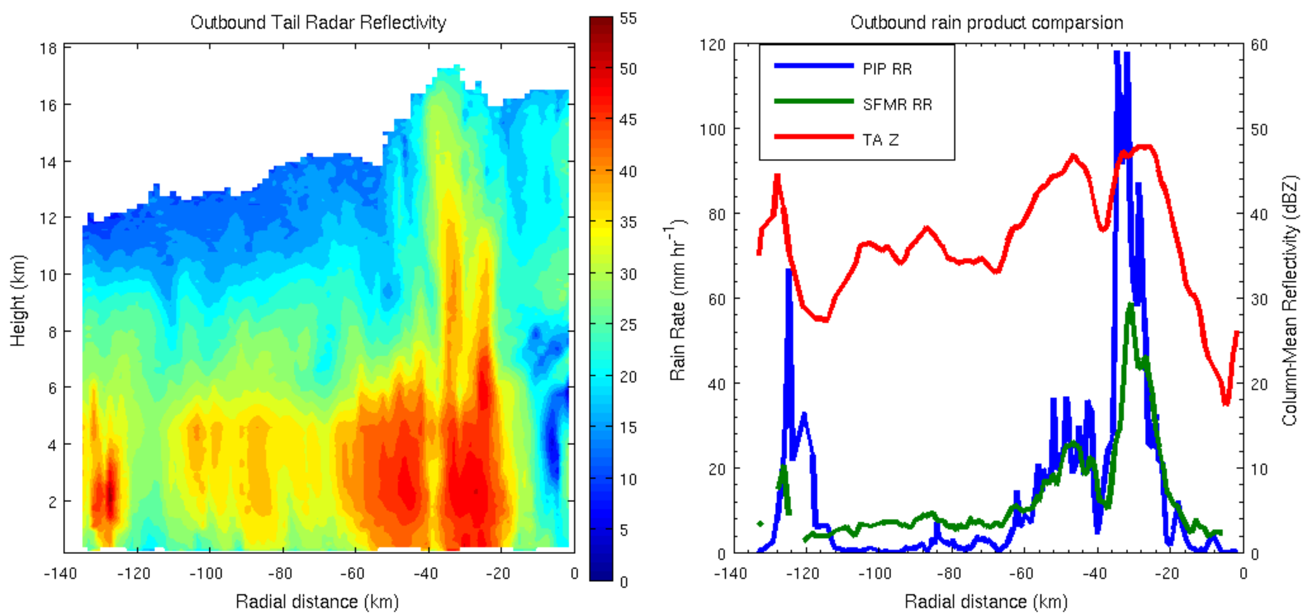

Figure 4: Tail Doppler radar reflectivity values as a function of radial distance and height are shown for an outbound center pass during Hurricane Katrina (left). Coincident PIP and SFMR rain rates (in mm hr^{-1}) are shown as a function of radial distance in comparison with the columnar mean of the Tail Doppler reflectivity below the melting layer (right).

Upcoming Year-2 Tasks:

August-November 2012:	Continue evaluation of real-time parallel testing of corrected SFMR winds and obtain additional data during season as necessary.
August-October 2012:	Continue development of coupled wind/rain GMF using the new determined Z-R relationship.

December 2012: Evaluate the results of the tested statistical bias correction

References:

Dunion, J. P., C. W. Landsea, S. H. Houston, M. D. Powell, 2003: A reanalysis of the surface winds for Hurricane Donna of 1960. *Mon. Wea. Rev*., **131**, 1992-2011.

Franklin, J. L., M. L. Black, K. Valde, 2003: GPS dropwindsonde profiles in hurricanes and their operational implications. *Wea. Forecasting*, **18**, 32-44.

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