FROM ALLEN TO JANGMI: 30 YEARS OF AIRBORNE TROPICAL CYCLONE PASSIVE MICROWAVE OBSERVATIONS

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The dawn of a new era in hurricane surface wind observation from Hurricane Hunter aircraft began on August 5, 1980 with a flight into Hurricane Allen at an altitude of 3 km (700 mb) by a NOAA C-130H aircraft equipped with the NASA/ Langley Stepped Frequency Microwave Radiometer (SFMR) operating at C-Band between 4.5 and 6.6 GHz and the Airborne Microwave SCATterometer (AMSCAT) operating in Ku-Band at 14.6 GHz for remotely measuring surface wind speeds and the intervening average rainfall rate. Two NOAA WP-3D aircraft flew beneath the C-130H at altitudes of 450 m and 1.5 km to obtain 'surface truth' in-situ observations used in boundary layer model 10-m wind estimates. The flight sequence was repeated on August 8, resulting in the first-ever series of airborne surface remotely-sensed winds up to 50 m/s documented in a landmark *Science* paper by Jones, et al., 1981, complete with Allen eyewall cover photograph. Fig. 1 illustrates the close comparison of SFMR derived surface wind measurements using a four-frequency algorithm documented by Black and Swift, 1984 with surface winds estimated from the WP-3D boundary layer wind data using a 0.8 reduction factor (Miller, 1958). The figure also shows a close comparison between SFMR rain rates derived from C-band attenuation measurements using the Olsen et al., 1978 attenuation-rainfall rate relationships and rain rates derived from WP-3D lower fuselage radar reflectivity values using the Jorgensen and Willis, 1982 reflectivity-rainfall relationship for hurricanes. These results were reported in detail in Delnore et al., 1985.

The subsequent history of the SFMR development was outlined in Uhlhorn and Black, 2003. A key milestone was achieved in the early 1980's with the redesign of the SFMR system from a reconstituted passive microwave group under the direction of Calvin Swift at the University of Massachusetts, Microwave Remote Sensing Laboratory (MIRSL) following dis-establishment of the NASA Langley group after the successful Allen flights. This system was flown successfully in Hurricane Earl in 1984 and improved upon by Mark Goodberlet in 1986. However, it wasn't until 1997 that the new GPS dropsonde became operational and allowed direct in-situ verification of SFMR surface wind estimates for the first time, such as the example in Hurricane Floyd, 1999 (Fig. 2). This allowed for a modification of the algorithm as outlined in Uhlhorn and Black, 2003.

Further algorithm modification documented in Uhlhorn et al., 2007 was possible based on the large number of CAT 5 winds observed during the Katrina and subsequent Rita flights.

It was the occurrence of Hurricane Katrina in 2005 that produced surface winds showing the storm had suddenly expanded and weakened in less than 18 hr during the night from a tight CAT 5 storm to a broad CAT 3 storm converting Katrina from a wind event to a devastating surge event. This event led to a Congressional appropriation of $10.5M for implementation of SFMR operationally on the WC-130J operational Hurricane Hunter reconnaissance aircraft. Operational SFMR surface wind observations are now a reality for all hurricane reconnaissance missions, a result that lead to the use of the WC-130J and its SWFMR and dropsonde capability by the Office of Naval Research in their latest Western Pacific typhoon investigations in 2008 and shortly again in 2010. Flight into Typhoon Jangmi in Sept 27, 2008 recorded one of the highest SFMR surface winds on record, 80 m/s, not only the first SFMR observations in a WPAC CAT 5 typhoon, but one of the highest surface wind observations on record in any basin.

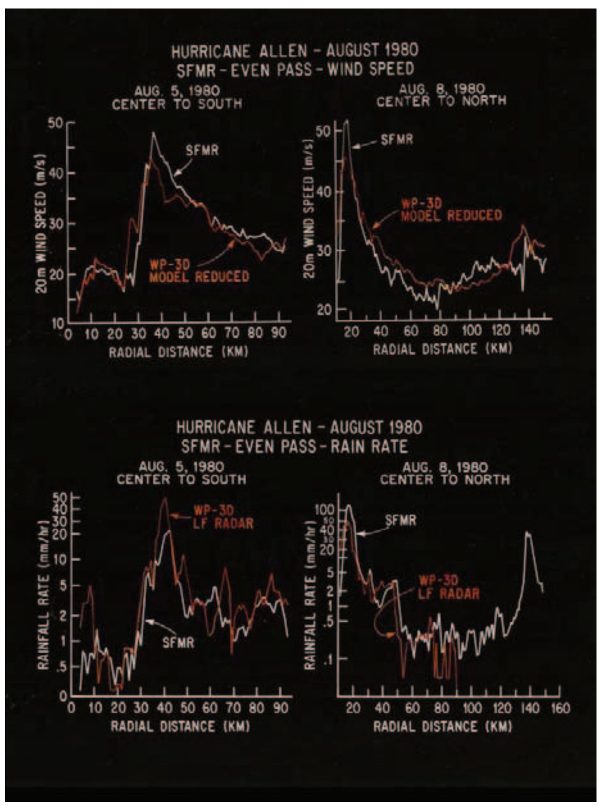

Figure 1. Upper panels show comparison of SFMR derived wind speed in Hurricane Allen on Aug 5 (left) and Aug 8 (right) with surface estimates from WP-3D boundary layer observations. Lower panels show comparison of SFMR derived rain rates in Hurricane Allen on Aug 5 (left) and Aug 8 (right) with estimates from WP-3D lower fuselage radar obtained 5 km in front of the aircraft.

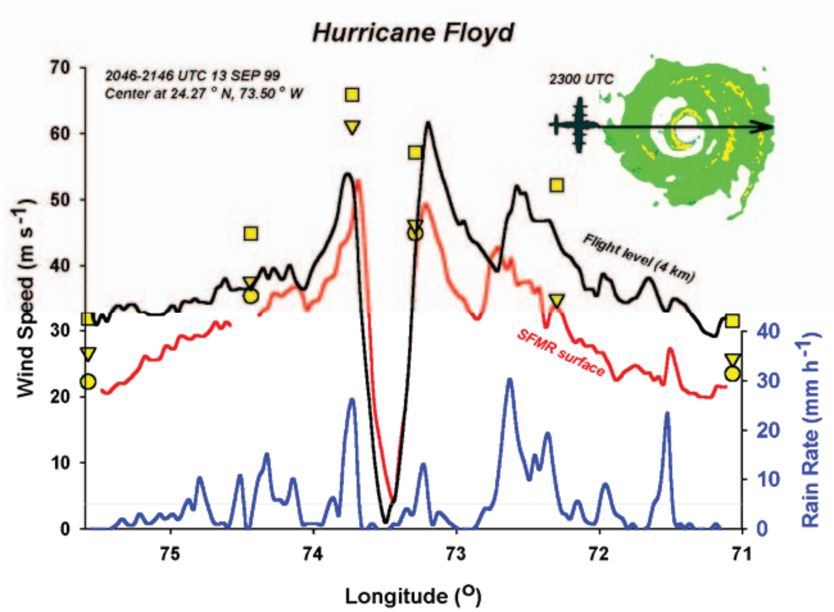

Figure 2. Comparison of SFMR surface 10-m winds (red) and 4-km flight level (black) winds along a north-south pass in Hurricane Floyd, Sept 13, 1999 with new GPS dropsonde observations. Squares indicate dropsonde observation just below flight level, triangles are 10-m surface wind derived from mean 150-m layer average winds and circles are observed 10-m GPS dropsonde winds. Blue line indicates SFMR derived rain rate showing location of eyewall and principal outer rainbands.

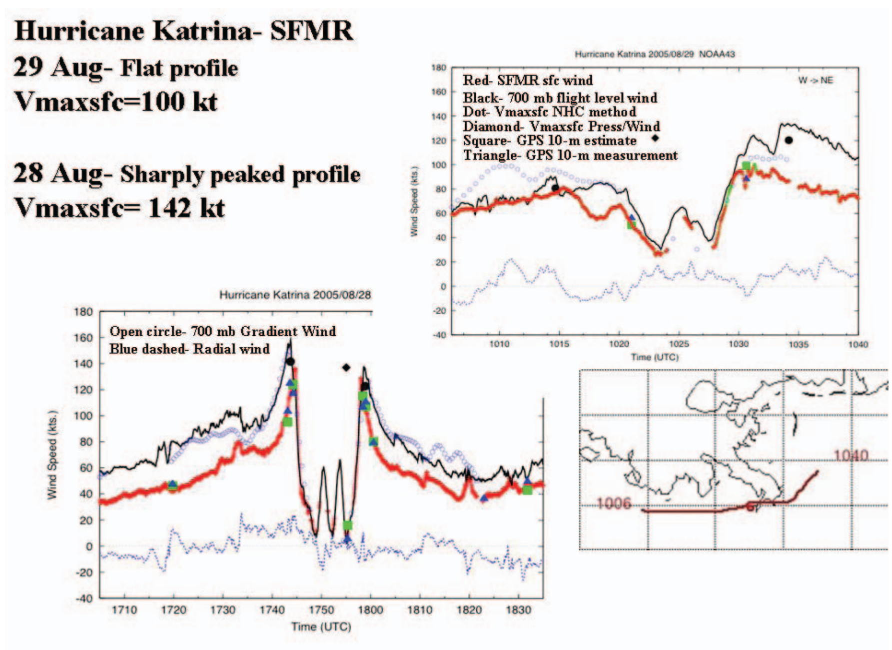

Figure 3. SFMR measurements in Hurricane Katrina, 2005 with flight level wind in black, flight level gradient wind computed from the radial 700 mb height gradient and SFMR surface winds in red for the two days just prior to landfall illustrating the dramatic change in structure from CAT 5 on Sept 28 (lower left) to CAT 3 on Sept 29 (upper right), just prior to landfall.

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