# Performance of the Revised SFMR Algorithm: 2015 Season in Review

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## Introduction

The Stepped Frequency Microwave Radiometer (SFMR) has been a mainstay on the NOAA WP-3D hurricane hunter aircraft for the past 15+ years and is a unique and reliable operational instrument for observing surface wind speeds in tropical cyclones (TCs). Extensive work to improve the instrument algorithm was completed from the wealth of data collected during the 2004 and 2005 hurricane seasons (Uhlhorn et al. 2007), and because of this improvement, SFMRs were added to all 53rd Air Force Reserve Command (AFRC) WC-130J hurricane hunting aircraft prior to the 2008 season. Over the next several seasons, due to the increased opportunity to obtain data, evidence emerged that the SFMR overestimated surface wind speeds within weaker TCs ($V_{max}$ < 33 m $s^{-1}$), especially within moderate to heavy precipitation.

A recent study examined this SFMR wind speed overestimation to better understand the source of the problem and to propose a method to reduce or eliminate the impacts due to precipitation (Klotz and Uhlhorn 2014). Interestingly, their results indicated that a high bias of ~2 m $s^{-1}$ was present in non-raining conditions and of > 5 m $s^{-1}$ when rain rates exceeded 20 mm $h^{-1}$ at wind speeds below 33 m $s^{-1}$. Based on their examination, one major contributor to the overestimation was an improper application of rain absorption. This issue was remedied in the updated version of the algorithm along with an improvement to the wind portion. The outcome of these updates was a more realistic and larger range of attainable rain rates and a significant reduction of the high bias at low wind speeds within moderate to heavy precipitation.

The Joint Hurricane Testbed approved the transition of this updated algorithm to operations, and it was utilized during the 2015 hurricane season on all NOAA and AFRC aircraft. The purpose of this presentation is to show the collected data and examine the performance of the updated algorithm. An in-depth analysis of an individual case in Joaquin is also presented.

## Data and Methods

During the 2015 hurricane season, a combined 85 TC missions were conducted over the North Atlantic, Northeast Pacific, and Central Pacific basins. SFMR data from these missions were post-processed, quality controlled, and made available on NOAA's Hurricane Research Division data page. For the purposes of evaluation, the 2015 SFMR data are also processed using the previous algorithm. Table 1 below provides a list of the number of NOAA and AFRC flights conducted in each TC along with the overall maximum SFMR wind speed obtained in each TC.

Following the methods described in Uhlhorn et al. (2007) and Klotz and Uhlhorn (2014), the wind speeds and rain rates from each flight are paired with a surface-adjusted wind speed (Franklin et al. 2003) from co-located (based on launch time) GPS dropsondes. These paired samples allow for direct comparison of two independent measurements of wind speed. Additionally, for comparisons regarding rain rate, the previous algorithm rain rates are scaled to the current version using a 3rd order least squares fit.

| | NOAA | AFRC |
|---|---|---|
| ANA | -- | 6 (28 m $s^{-1}$) |
| BILL | -- | 4 (28 m $s^{-1}$) |
| BLANCA | -- | 3 (47 m $s^{-1}$) |
| CARLOS | -- | 2 (44 m $s^{-1}$) |
| DANNY | 5 (53 m $s^{-1}$) | 4 (34 m $s^{-1}$) |
| ERIKA | 5 (29 m $s^{-1}$) | 7 (28 m $s^{-1}$) |
| ELA | -- | 2 (13 m $s^{-1}$) |
| GUILLERMO | -- | 7 (37 m $s^{-1}$) |
| HILDA | -- | 7 (47 m $s^{-1}$) |
| IGNACIO | -- | 6 (62 m $s^{-1}$) |
| JOAQUIN | -- | 11 (65 m $s^{-1}$) |
| KATE | 3 (30 m $s^{-1}$) | 2 (28 m $s^{-1}$) |
| KILO | -- | 4 (17 m $s^{-1}$) |
| MARTY | -- | 1 (36 m $s^{-1}$) |
| OHO | -- | 2 (28 m $s^{-1}$) |
| PATRICIA | 3 (93 m $s^{-1}$) | 1 (94 m $s^{-1}$) |
| TOTAL | 16 | 69 |

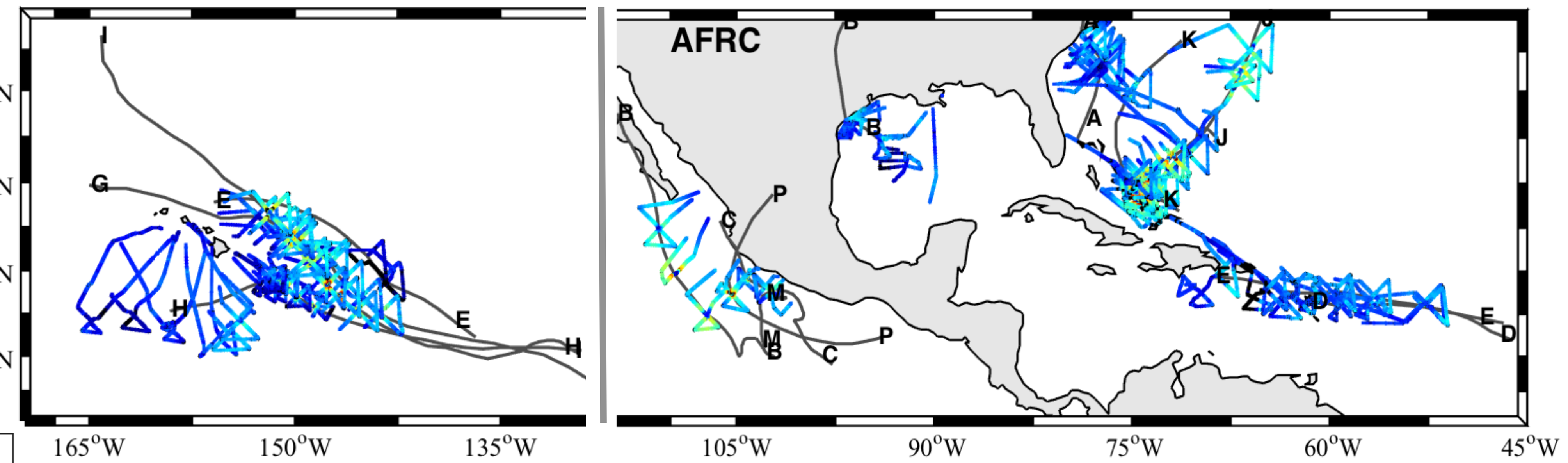
North Atlantic

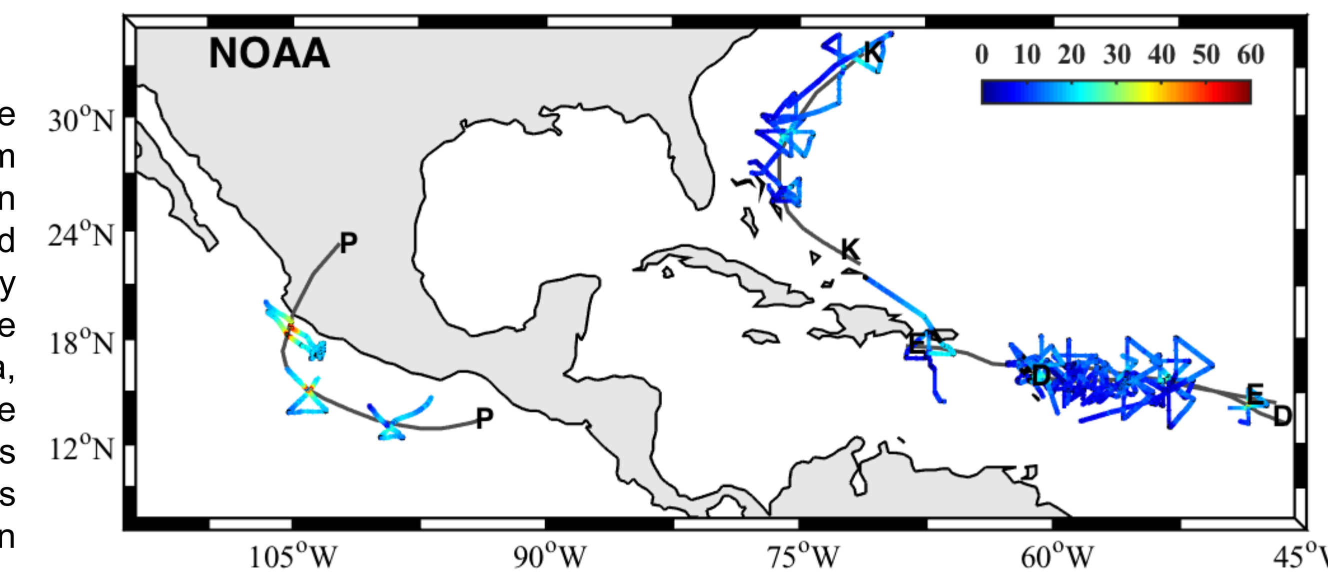
Northeast/Central Pacific

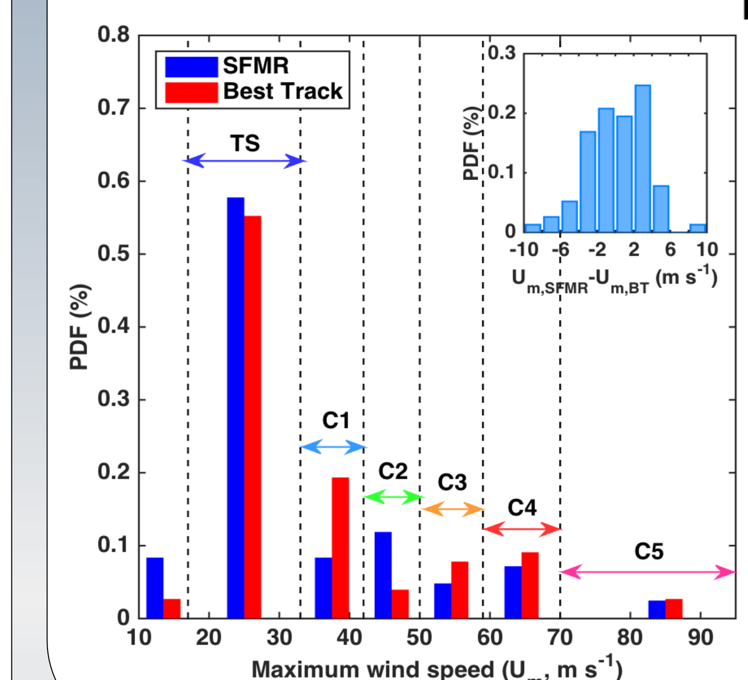
**Left (Table1):** Listed are the number of cases for NOAA and AFRC TC missions during 2015. The value in parentheses is the maximum surface wind speed observed by SFMR at any point during the missions for a particular storm.

## *Overview of the 2015 SFMR cases*

**Right (*Figure 1*):** Maps displaying the flight tracks for AFRC and NOAA aircraft are shaded based on the SFMR wind speed along the track. Additionally, the best track positions are plotted as gray lines with each track labeled with the first letter of the respective storm in Table 1. Also note that TCs Oho and Kilo do not presently have official best track records in HURDAT and are therefore not included in the figure.

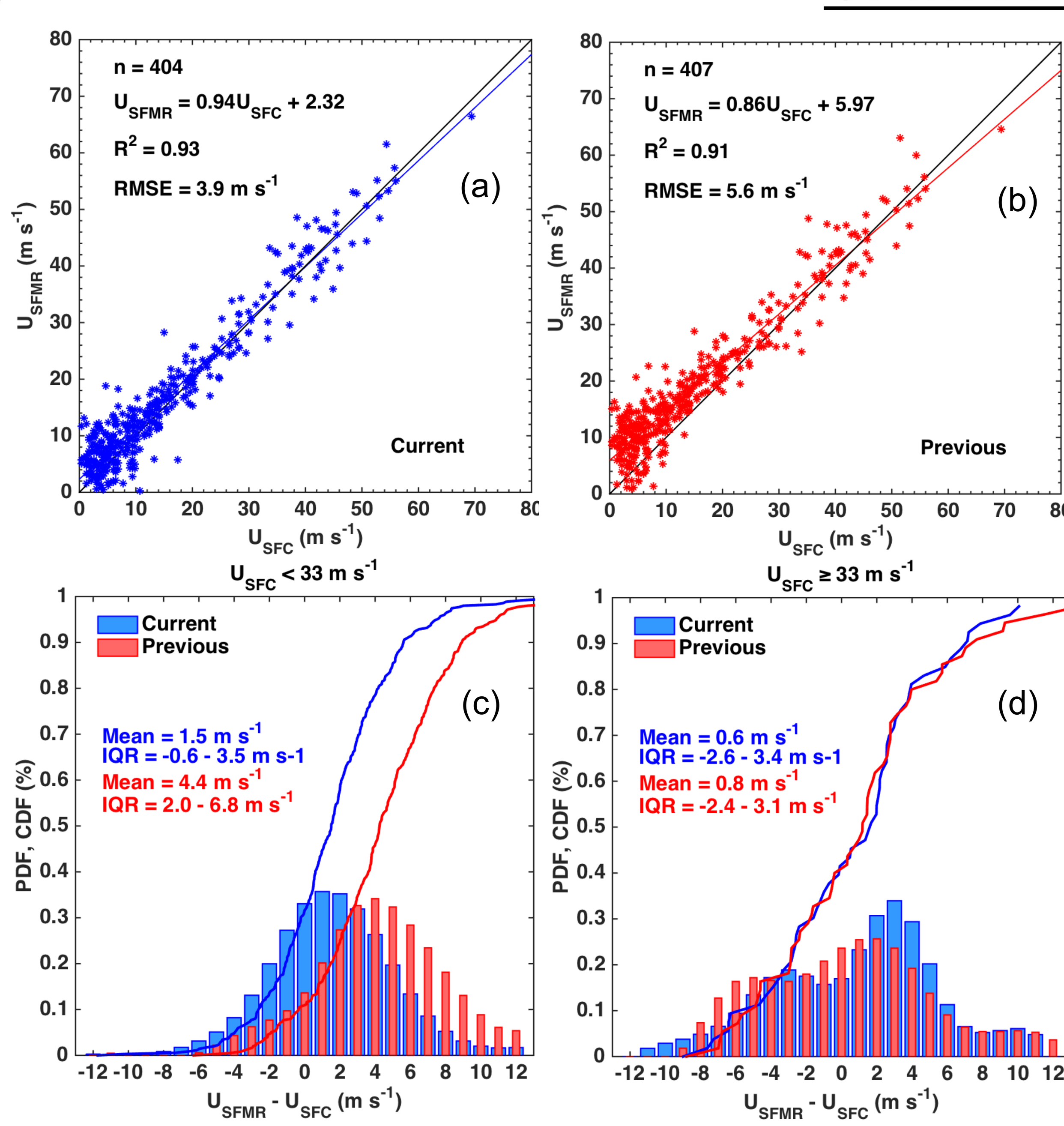


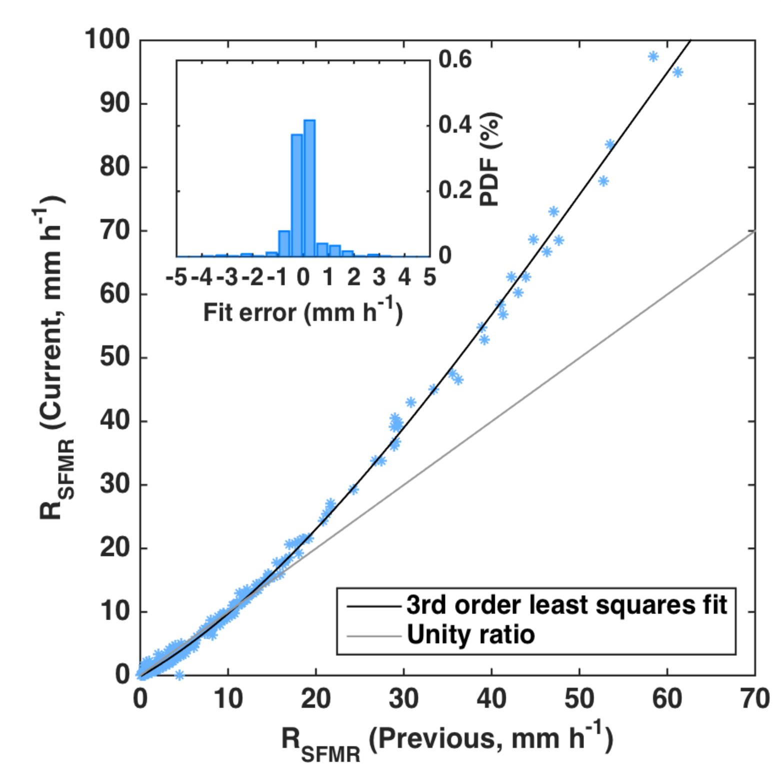

**Left (Figure 2):** PDFs (%) of the maximum SFMR wind speed from each flight as well as the closest (in time) best track maximum wind speed as a function of TC intensity category are shown. The inset PDF provides the difference between the two maxima, where a majority of the cases have maxima ± 5 m $s^{-1}$ of each other. This falls within the expected error as described in Landsea and Franklin (2013).

## *SFMR Performance*

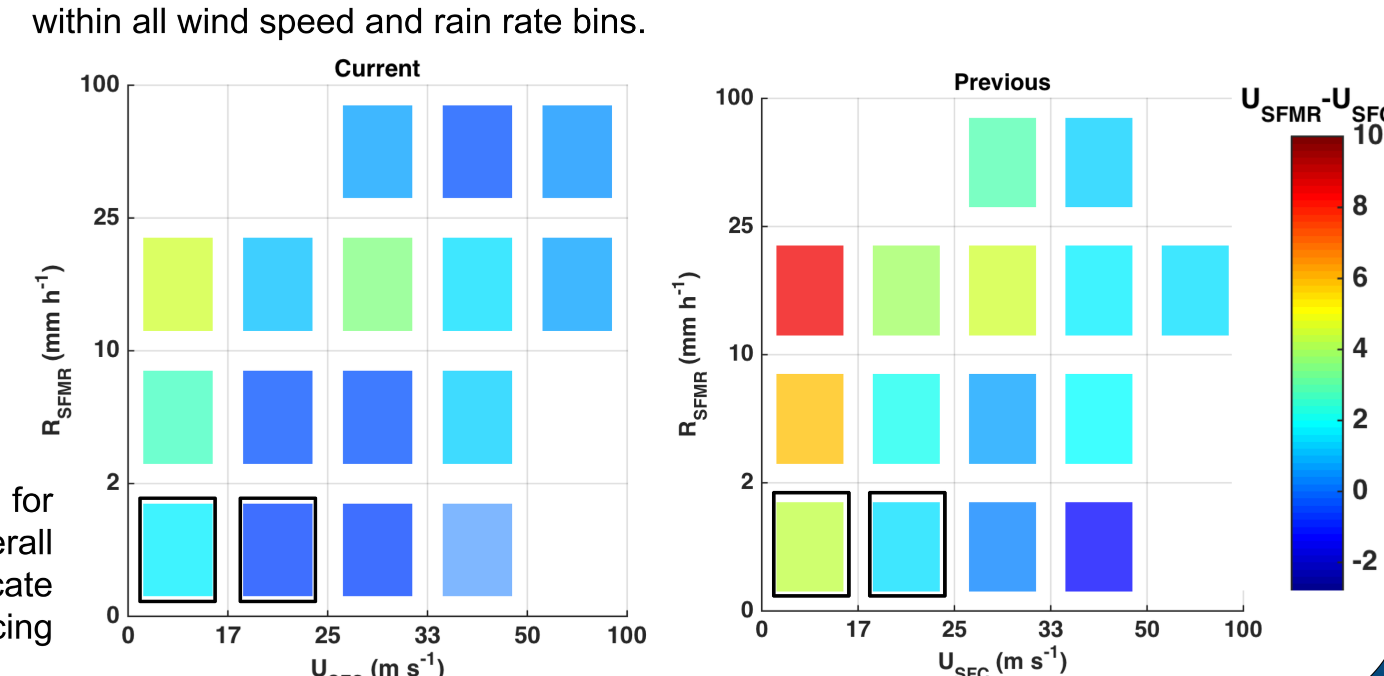



**Above (Figure 4):** Current and previous algorithm calculations are considered for comparison. The fits in **(a)** and **(b)** indicate that the current algorithm overall outperforms the previous when related to dropsondes. Panels **(c)** and **(d)** indicate that the weaker wind speeds are reduced by ~3 m $s^{-1}$ on average while producing little change hurricane force wind speeds.

**Right (Figure 3):** Rain rate comparison between the two algorithms is shown, where a scaling, 3rd order least squares fit function (black line) is used to place the previous algorithm rain rates within the same range as the current version. A more accurate assessment of the impact of rain rate on wind speed difference is then determined. The inset histogram provides the fit error.




**Below (Figure 5):** Bin-averaged wind speed differences ($U_{sfmr}$-$U_{sfc}$) for both algorithms are plotted. While still having a slight high wind speed bias at weak wind speeds within rain, the current algorithm clearly improves the wind speed estimate within all wind speed and rain rate bins.




## An Interesting Case: Joaquin

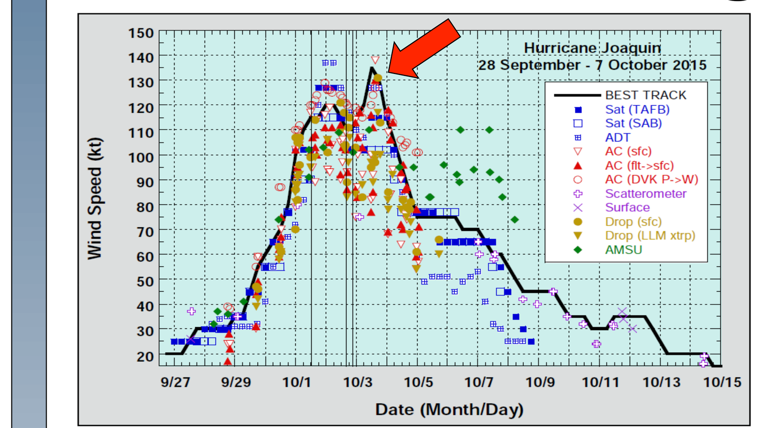
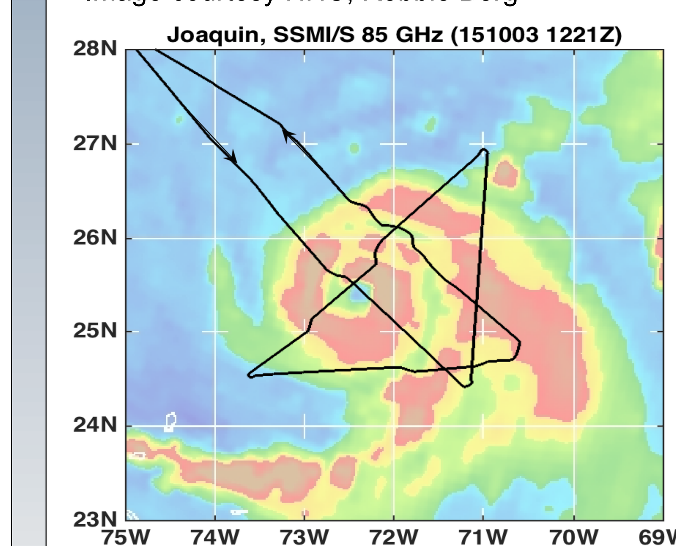


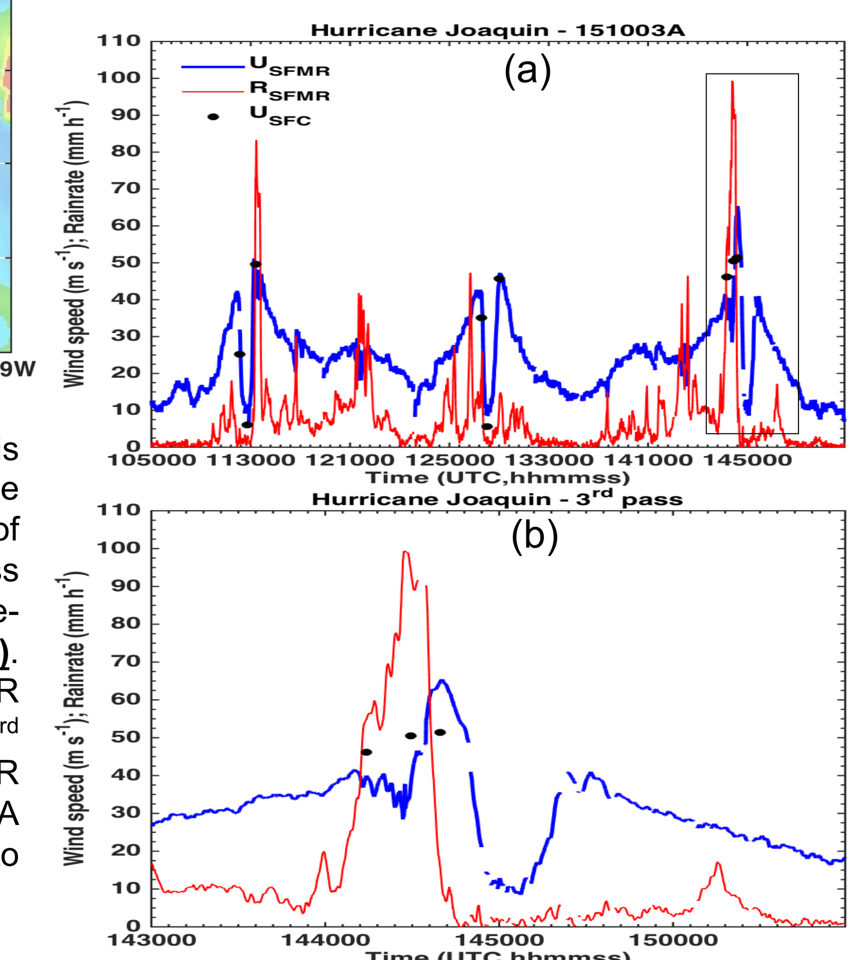

Image courtesy NHC, Robbie Berg

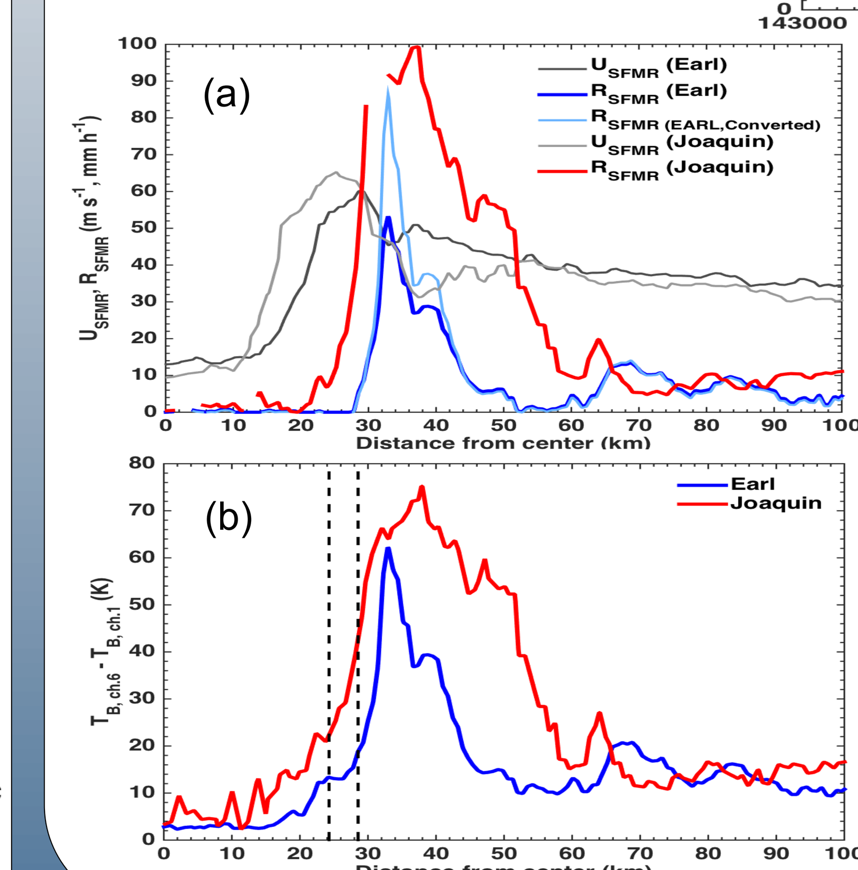
Hurricane Joaquin was a problem case for forecasters due to the very uncertain model forecast tracks and to varying reports from observing systems. **Left (Figure 6):** displays the official best track for Joaquin. From an SFMR perspective, the portion of interest occurred on 3 October (red arrow). The AFRC SFMR was consistently reporting maximum wind speeds from SFMR of between ~50-55 m $s^{-1}$. On the 3rd pass (inbound, SE to NW), the maximum jumped to ~67 m $s^{-1}$. Forecasters at NHC were surprised by this jump in wind speed and seemed to be somewhat hesitant to trust the report. The remaining figures provide evidence to support this wind speed.




SSMI/S Image courtesy NRL

**Above (Figure 7):** The flight track is overlaid on an SSMI/S 85 GHz image from 1221Z on the 3rd. The timing of this image fits nicely with the first pass (NW to SE), shown in the full time-series figure to the **right (Figure 8a)**. The dropsondes match well with SFMR throughout the flight, but in the 3rd pass, the increasing winds from SFMR are not captured by the dropsondes. A first thought might be that this has to be wrong. But is it?




Hurricane Earl (2010) was similar in terms of intensity ($U_{sfmr,max}$ = 60 m $s^{-1}$) and environment (location, SST, and slightly weaker shear), making it a valid comparison case. **Left (Figure 9a):** The wind speed and rain rate profiles from the outbound portion of the 2nd pass in the AFRC flight from 02 September, 2010 are shown. Brightness temperature differences ($T_{B,ch.6}$-$T_{B,ch.1}$) are provided to indicate whether the maximum wind speed from Joaquin is reasonable (**Figure 9b**). With a difference of 3.5 K between the two maxima, and considering the expected increase of ~1 K (m $s^{-1}$)$^{-1}$ at high wind speeds, noise estimate of ~0.8 K (Uhlhorn et al. 2007), the maximum wind speed in Joaquin is reliable.

## *References*

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