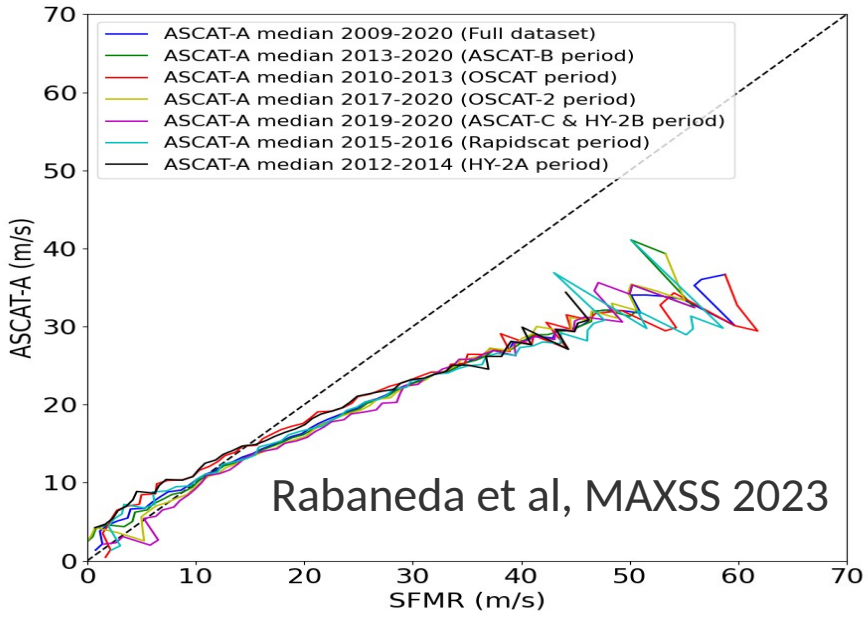
This material is based in part upon work supported by the Office of Weather and Air Quality Research Program within the NOAA/OAR Weather Program Office under Award NO.NA23OAR4590412-01

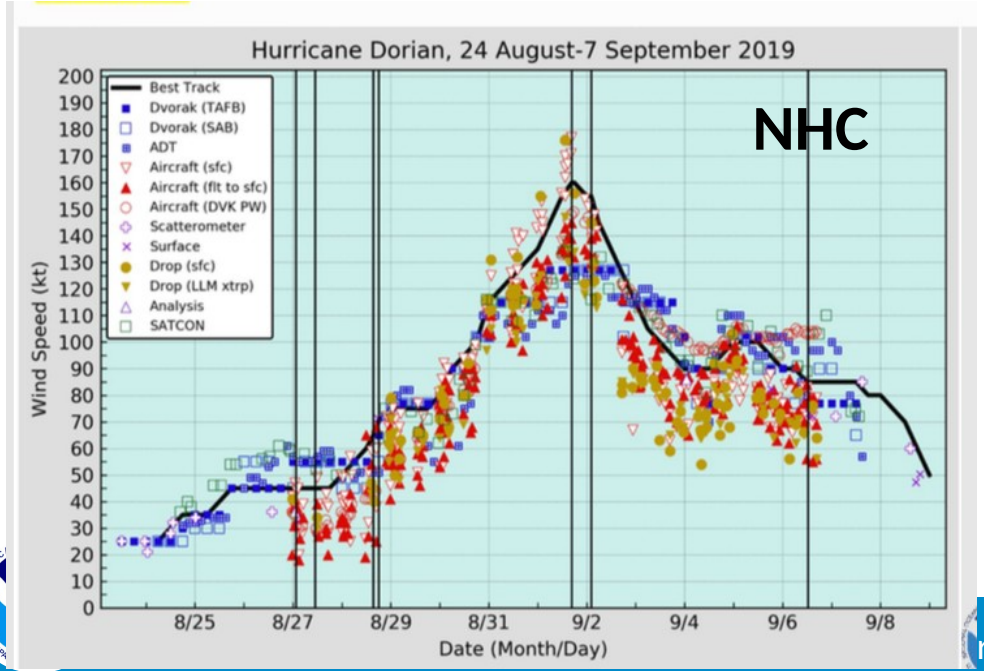
Comprehensive Validation Analysis of the Stepped Frequency Microwave Radiometer Data from 2024 Hurricane Season – Implications for the Entire 20 Years Data Record

[1,3]Zorana Jelenak,[2]Heather Holbach, [3]Paul Chang, [3,4]Joe Sapp,
[3,4]Casey Shoup, [3,4]Suleiman Alsweiss, and [1,3]Seubson Soisuvarn

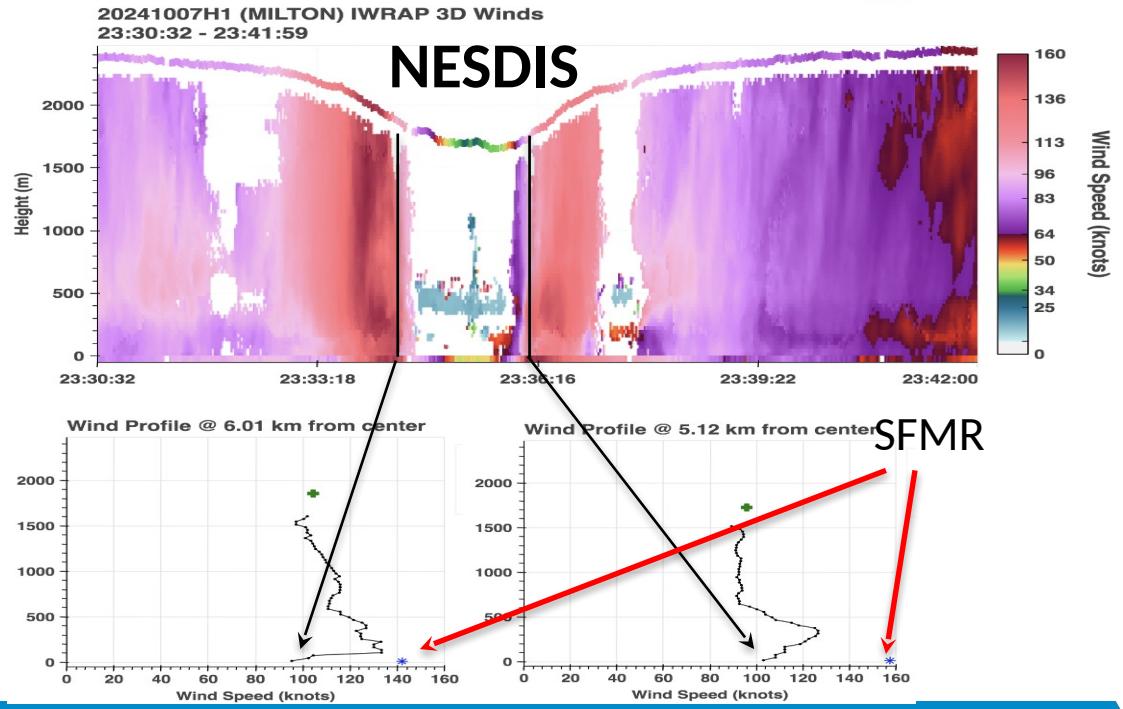
[1]UCAR, [2]FSU, NGI, NOAA/AOML/HRD, [3]NOAA/NESDIS/STAR, [4]Global Science & Technology,Inc.

SFMR Validation Efforts

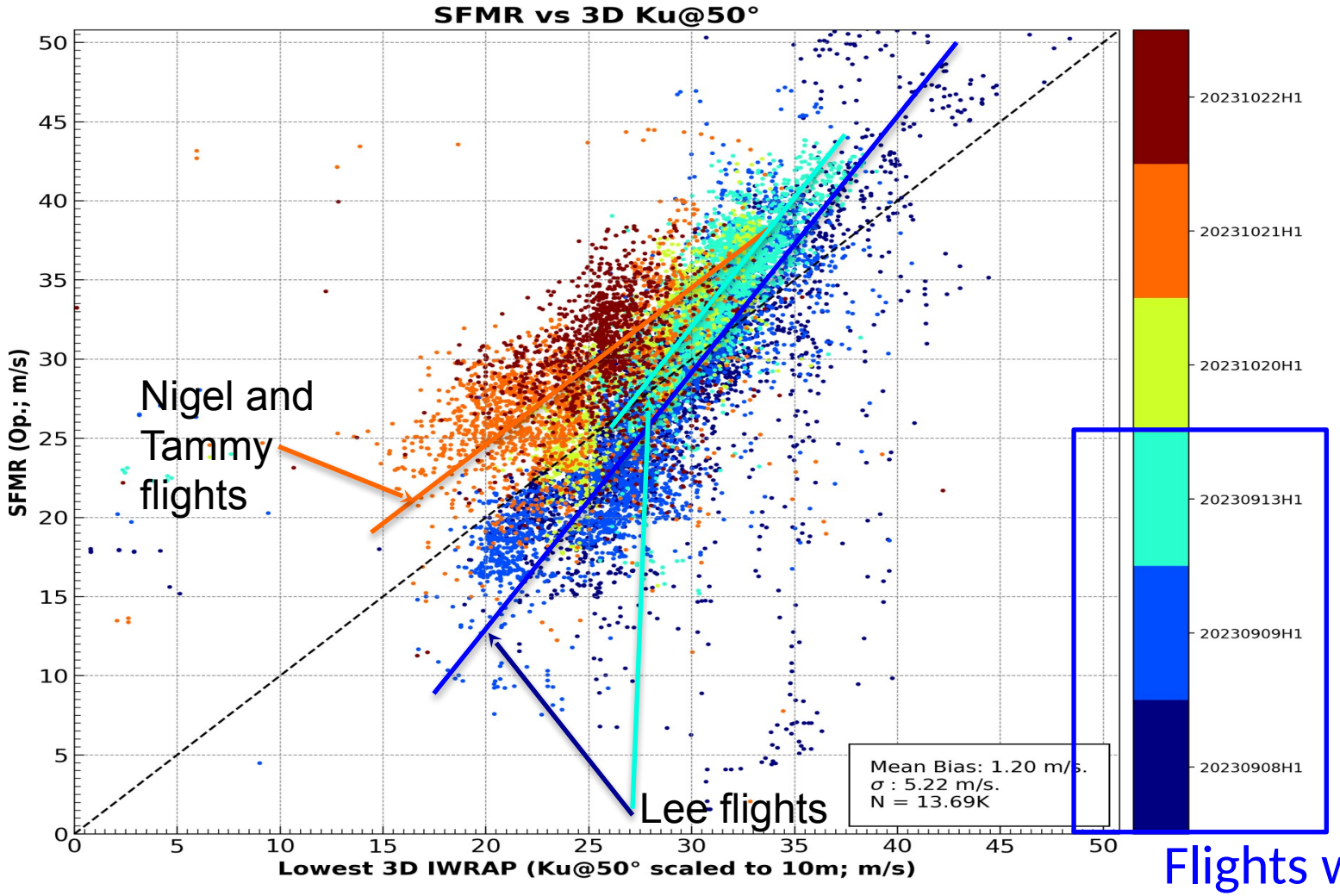




- Over the last 8 years, questions about the validity of extreme SFMR wind measurements were raised by different user communities.
- **The main conclusion from previous validation studies was that the SFMR forward model and retrieval schemes are the leading cause of errors**
- However, attempts to improve upon the forward model still led to both over- and underestimation of winds in the eyewalls



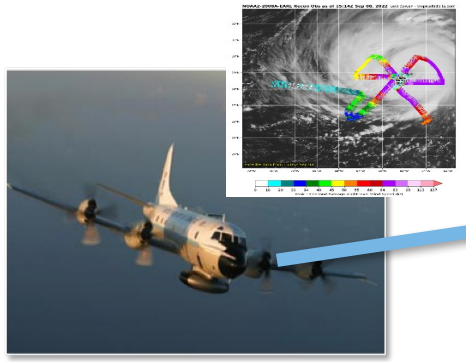
2023 Season Collocated Measurements Provided a Clue

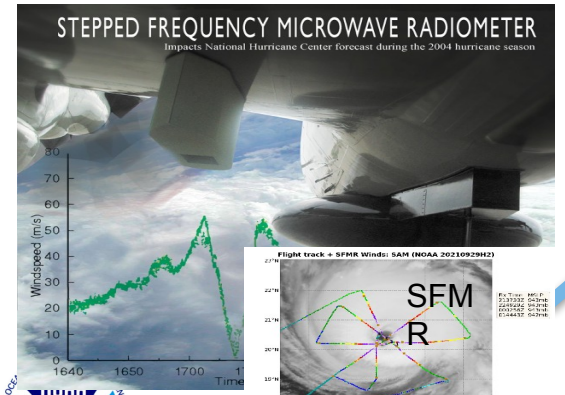


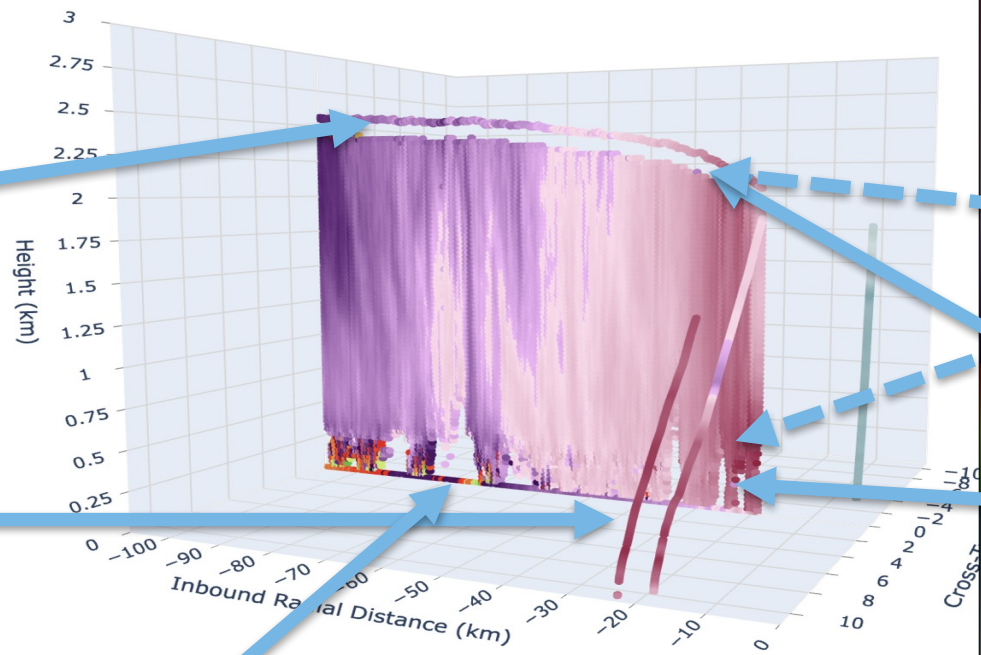
- US001 and US002 were flown coincident with Imaging Wind and Rain Profiler (IWRAP) measurements in 3 flights during 2023 season
- These measurements present first indication that performance is different from unit to unit and flight to flight

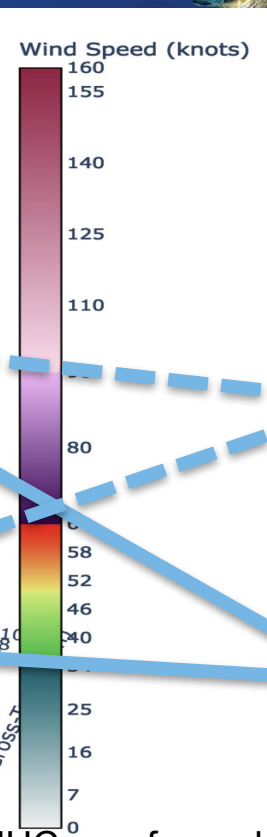
Flights with US002

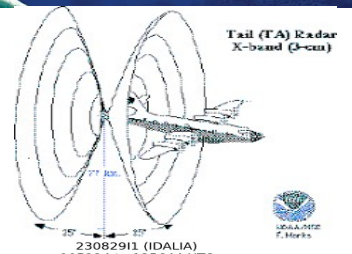
2024 Comprehensive SFMR Validation Campaign

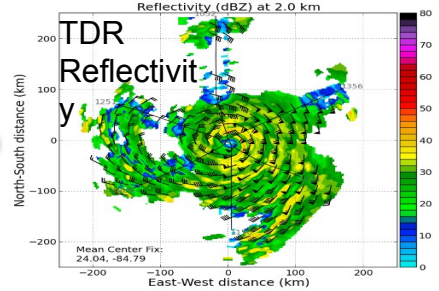


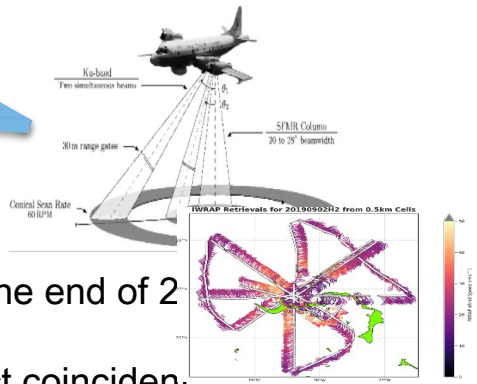








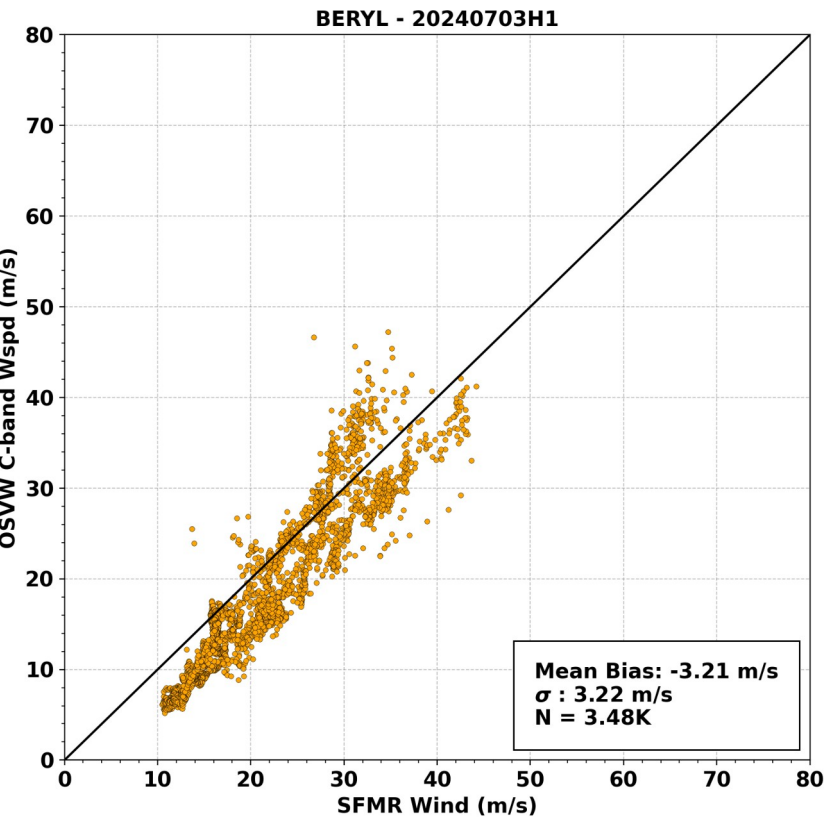




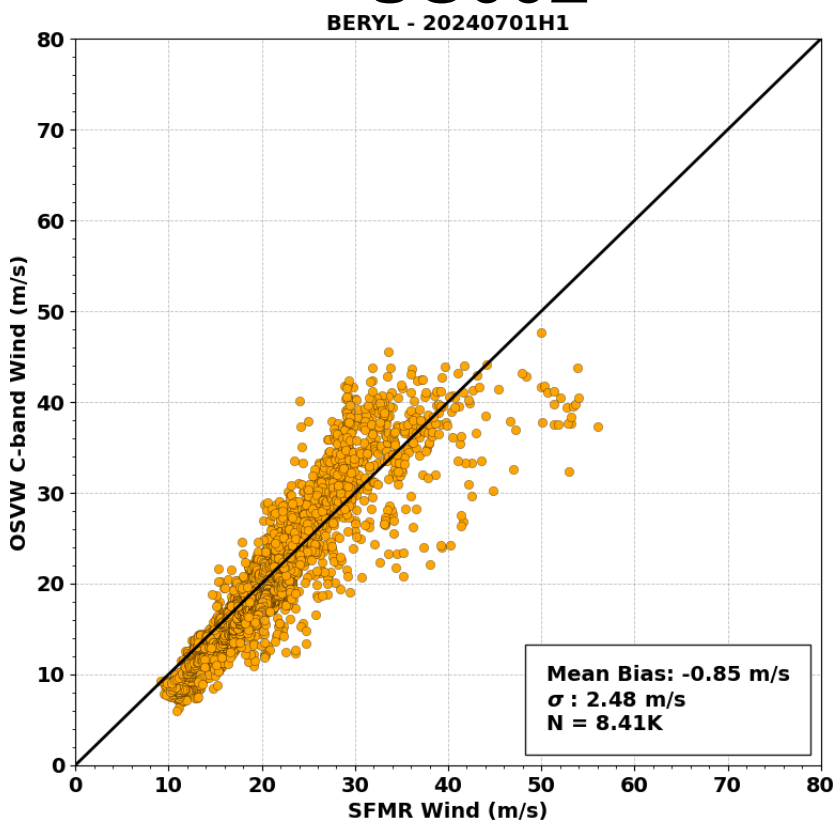
- The Joint Ocean Winds Team from NESDIS, NRD, AOC and NHC was formed at the end of 2 to assess the consistency of the three SFMR units owned by NOAA
  - During the 2024 season, each one was deployed on the N42 aircraft to collect coincident observations with IWRAP
  - Coincident measurements were collected from 4 flights with US001, 3 flights with US002, and 9 flights with US003
  - Dropsonde data, along with coincident SAR and ASCAT satellite overpasses, were used to provide independent validation of both SFMR and IWRAP performance across different wind sources
- Leveraging IWRAP's along-track measurements of ocean surface wind speed, wind direction, and rain rate, this campaign allowed for the first time a systematic characterization of the SFMR measurement stability as a function of time and physical temperature

Cal/Val of Three SFMR Units Owned by NOAA

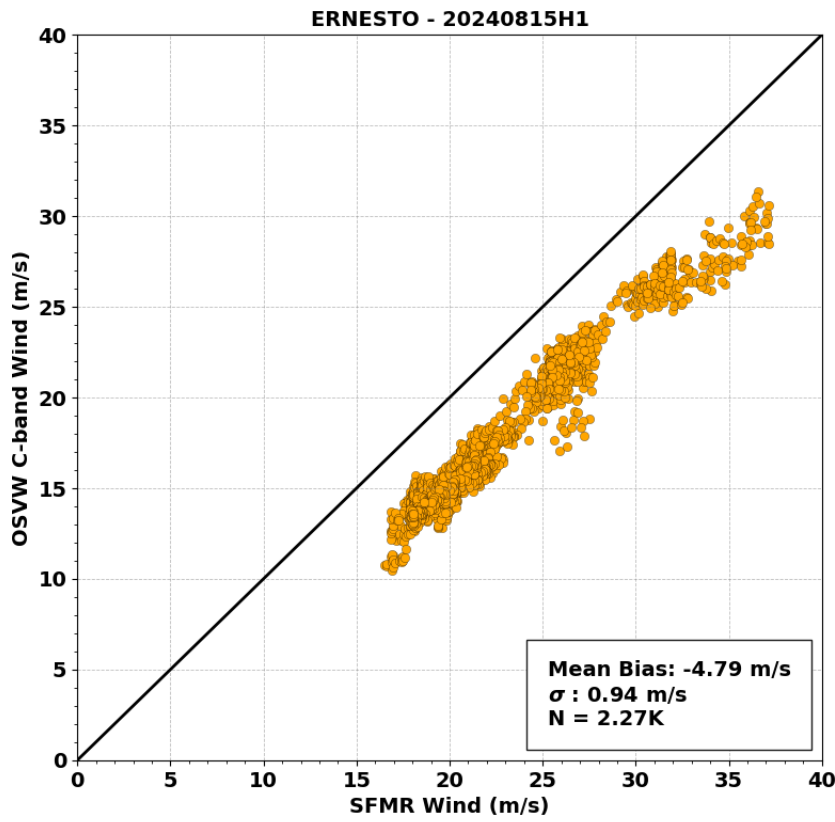
US001



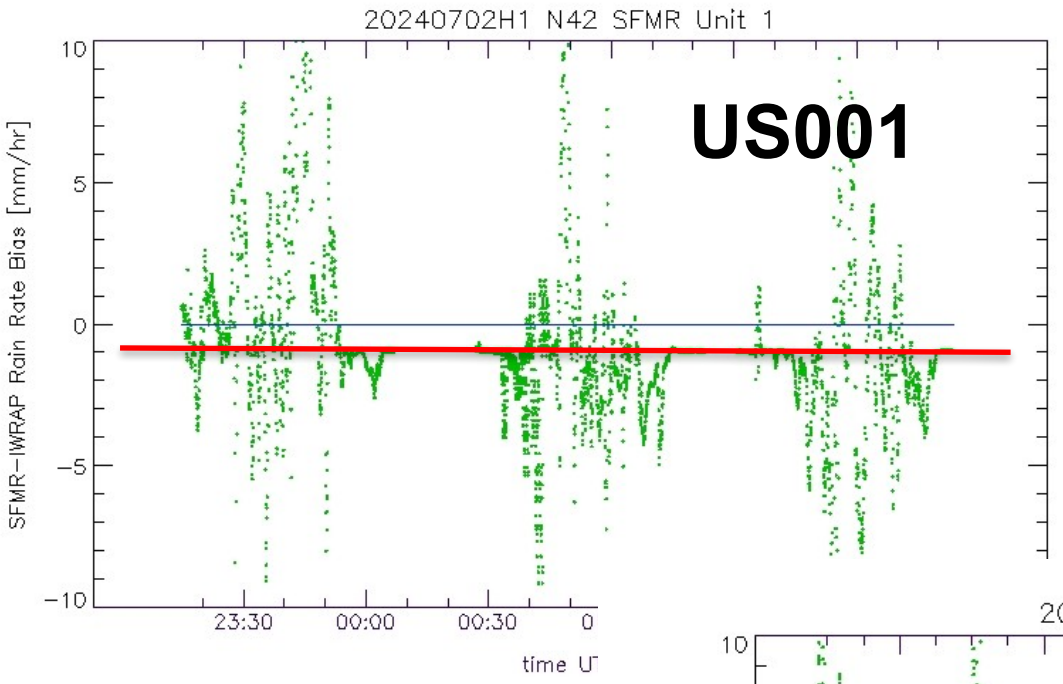
US002

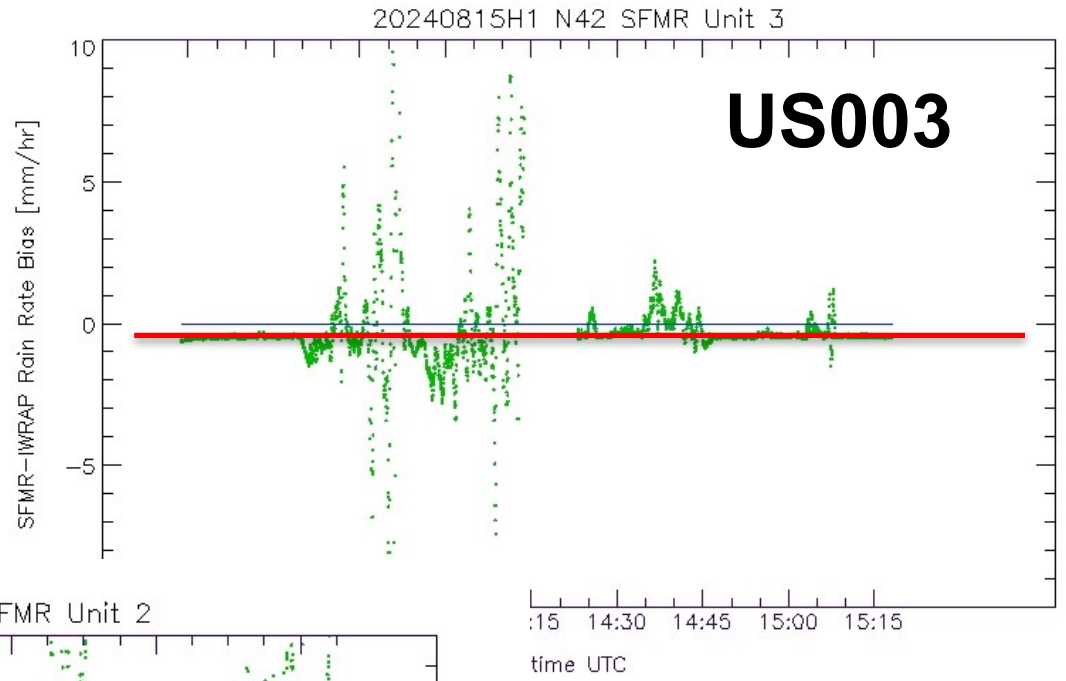


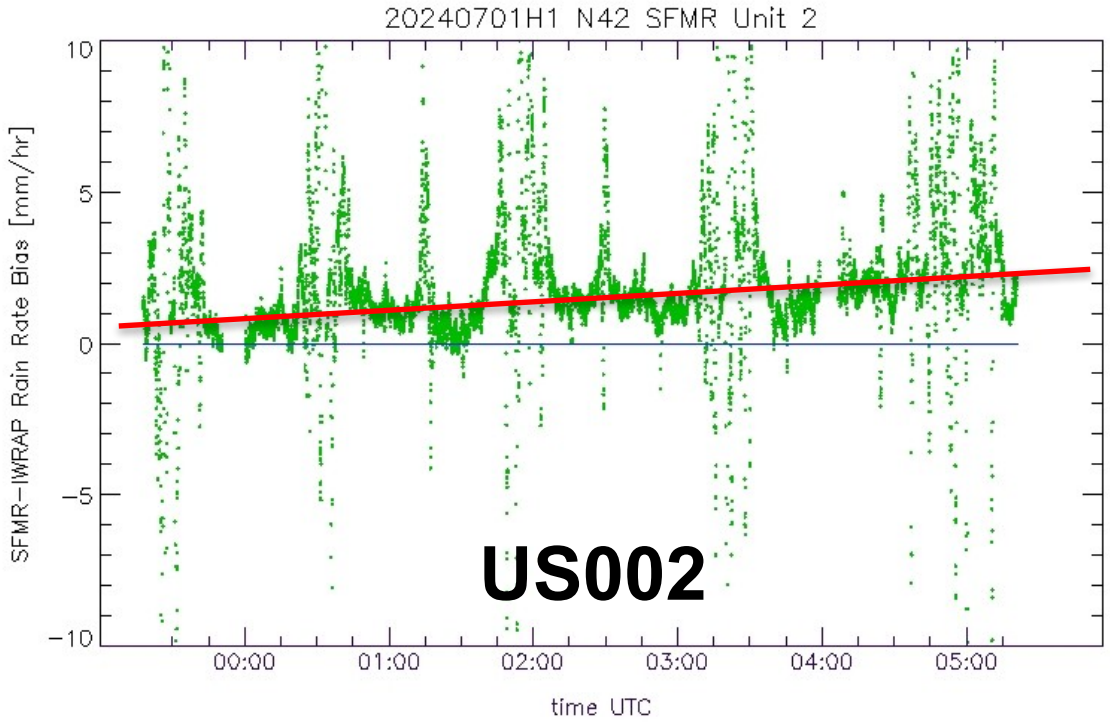
US003



All three units exhibit different biases relative to IWRAP scatterometry winds:
US002 linearly dependent bias with increased wind speed
US001 scatter plot bifurcation later correlated with system temperature changes
US003 constant bias

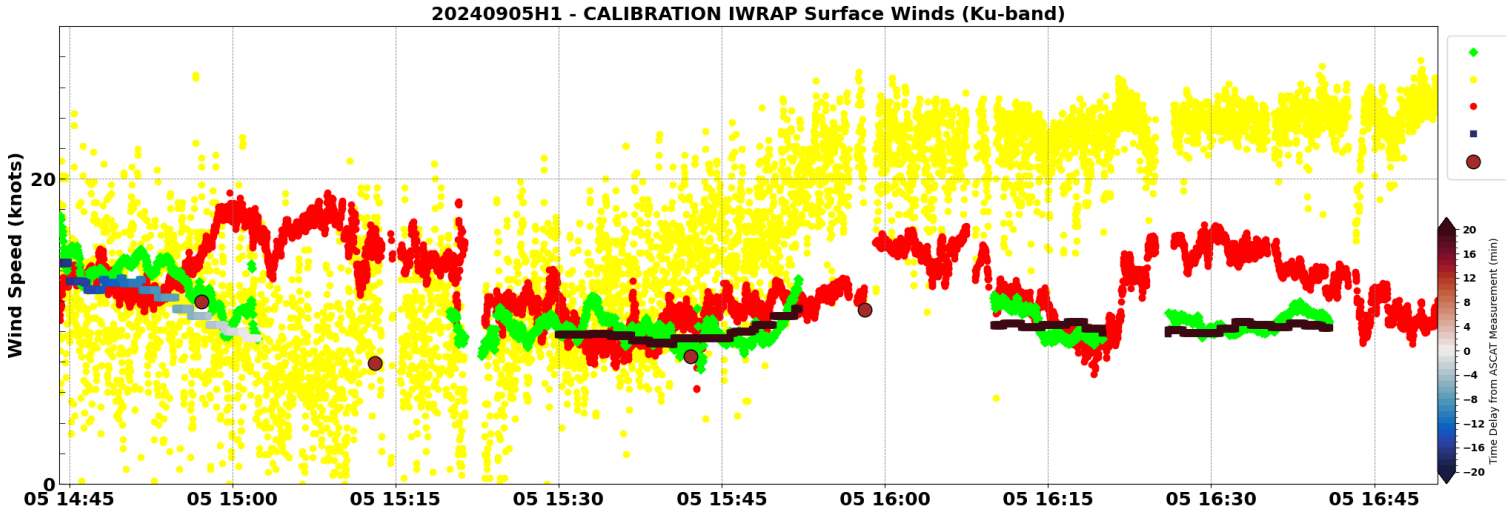


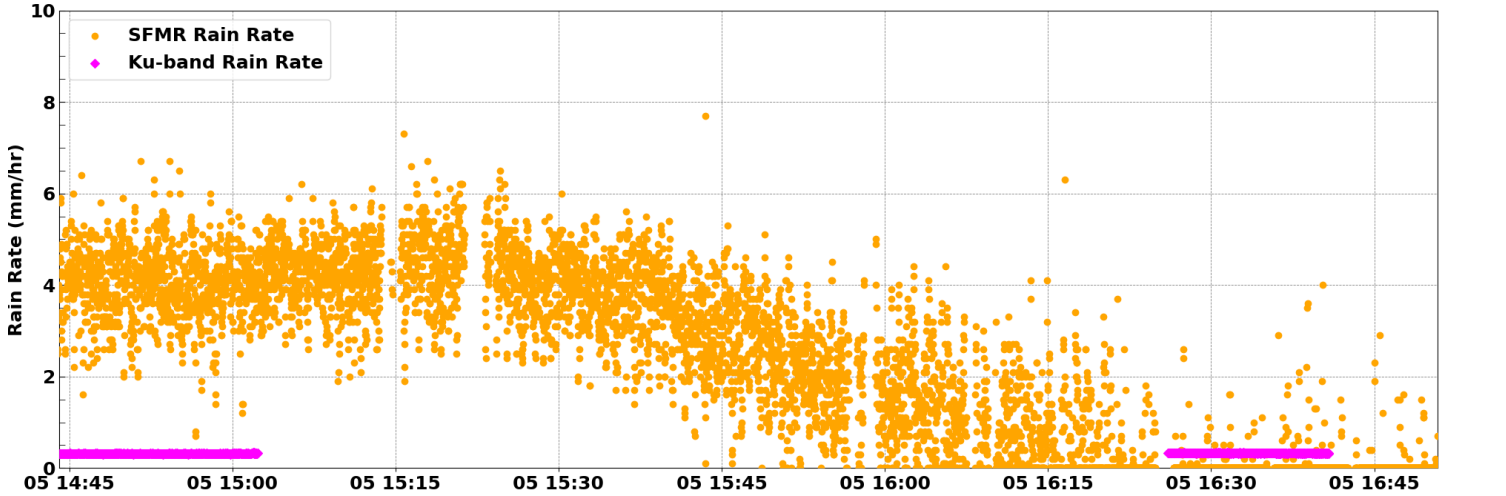


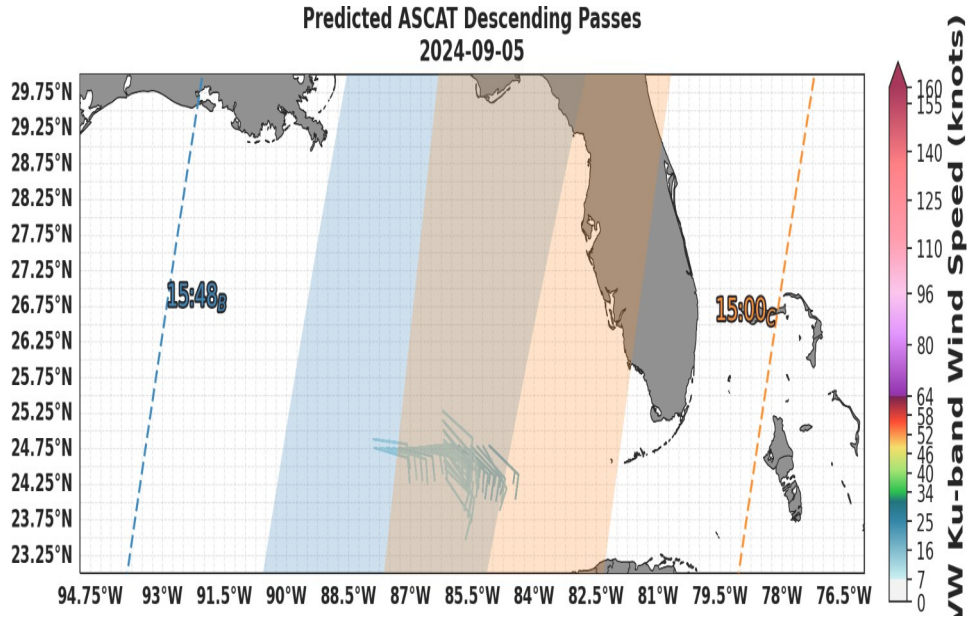


Units 1 and 3 exhibit a constant mean rain rate bias, while Unit 2 exhibits time-dependent linear bias relative to the IWRAP rain rate retrievals.

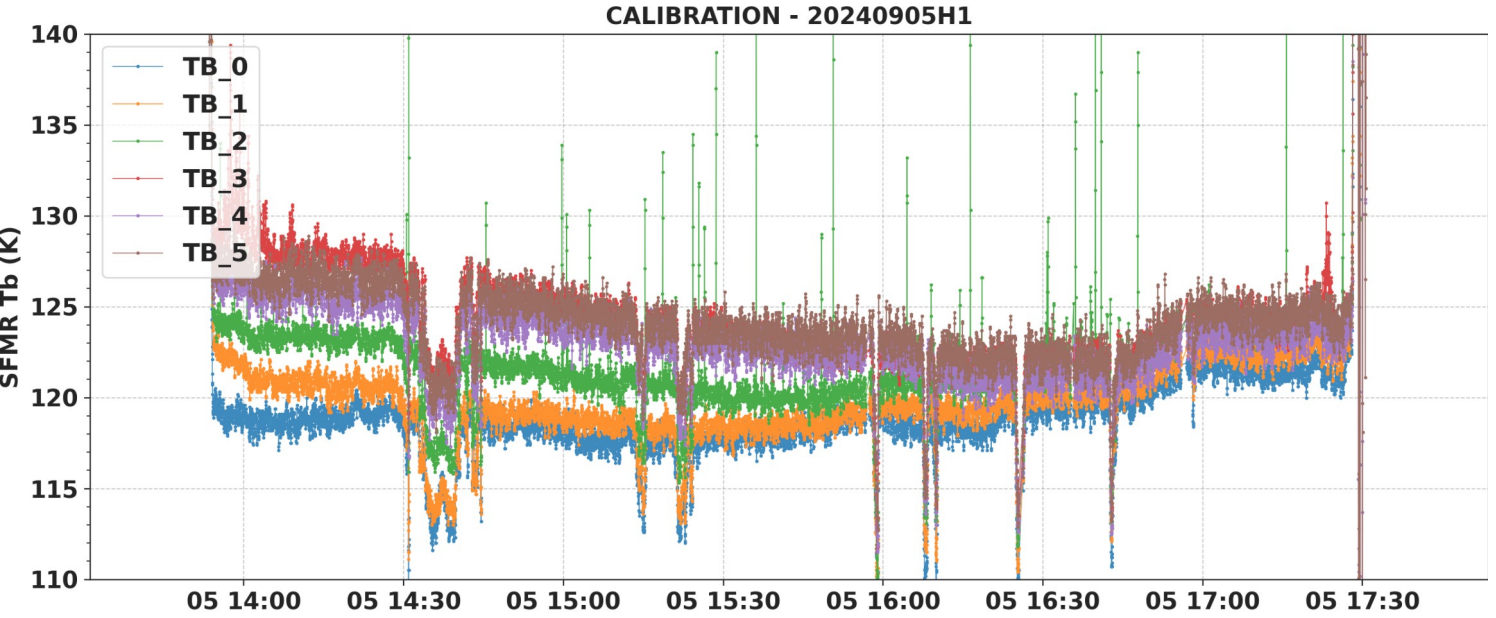
US002 Test flight Coincident with ASCAT Pass On September 5th, 2024

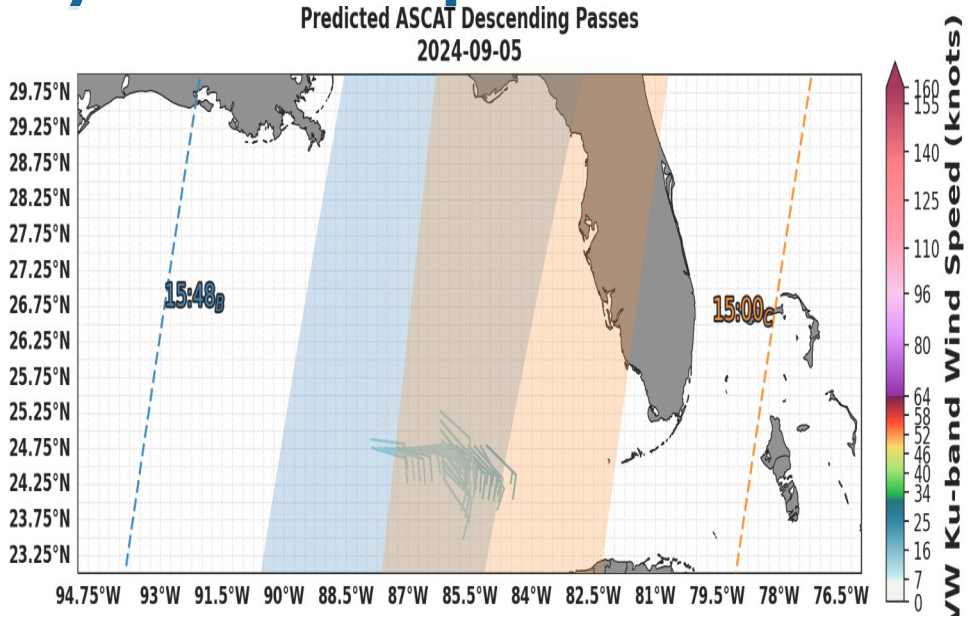


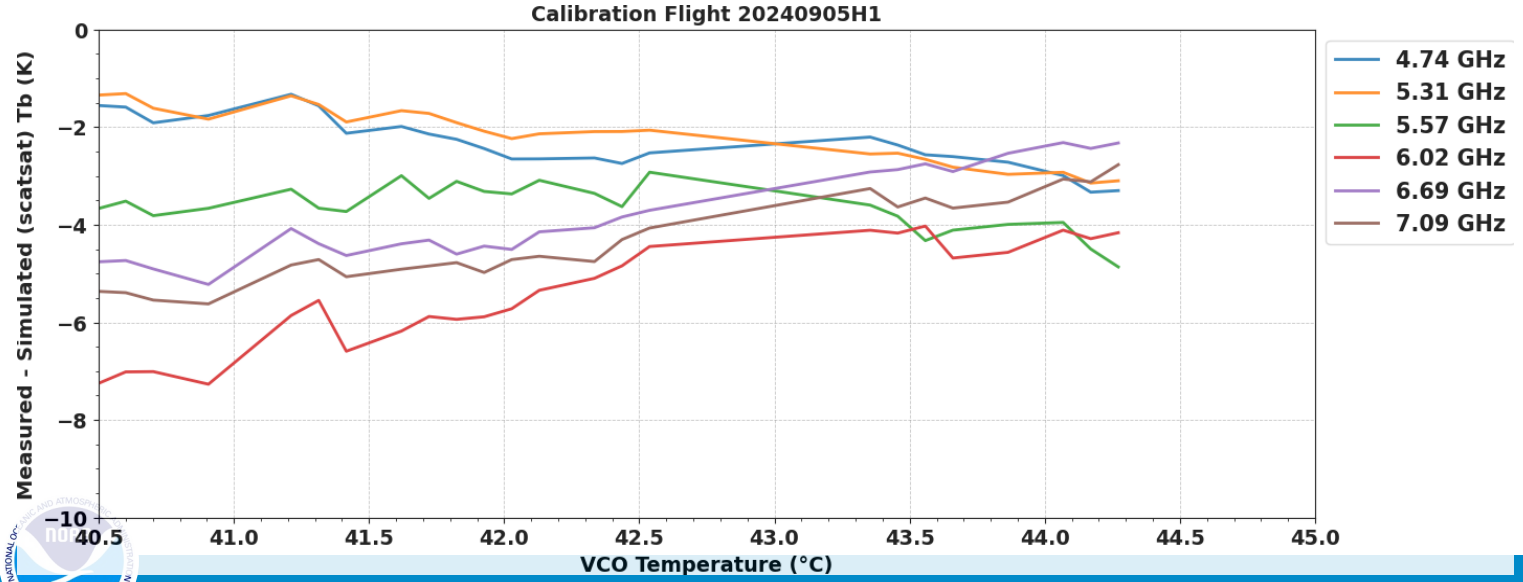




Source of Error – Frequency Drift with System Temperature



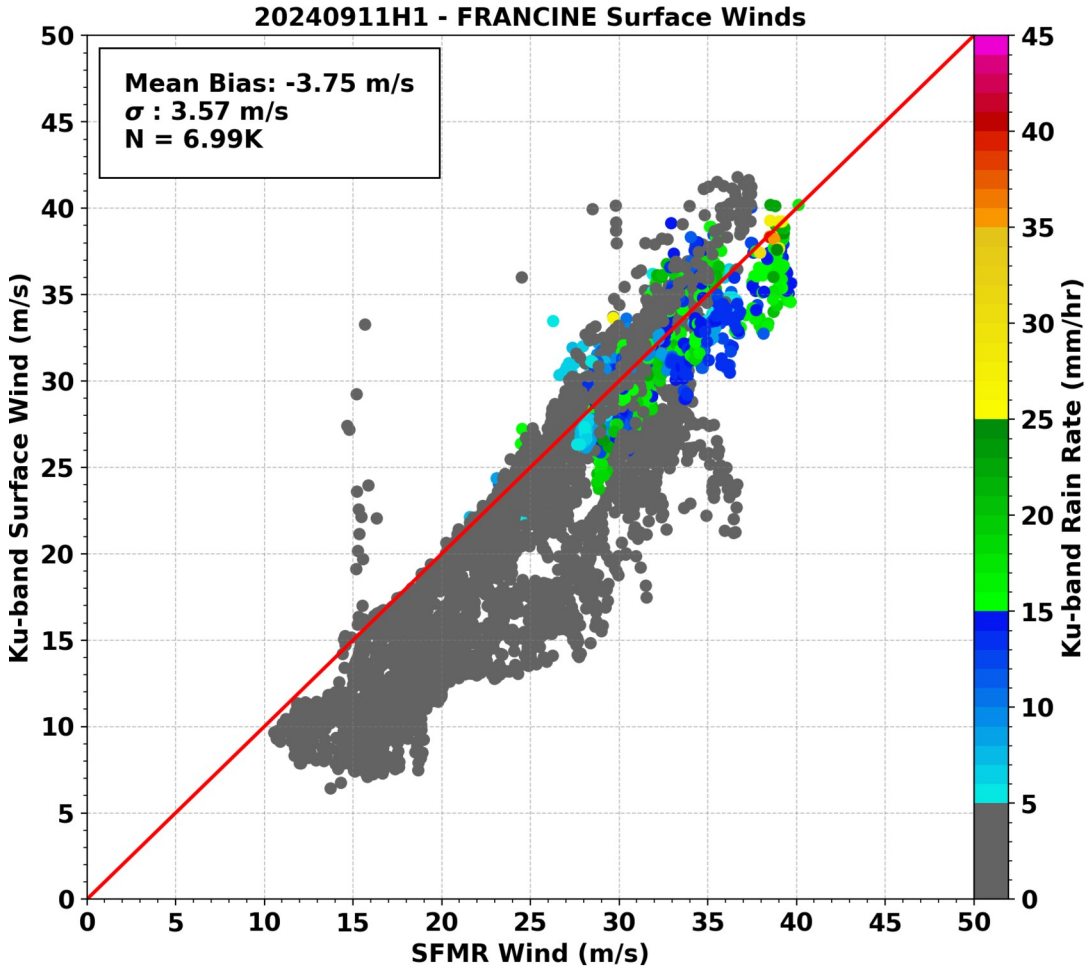


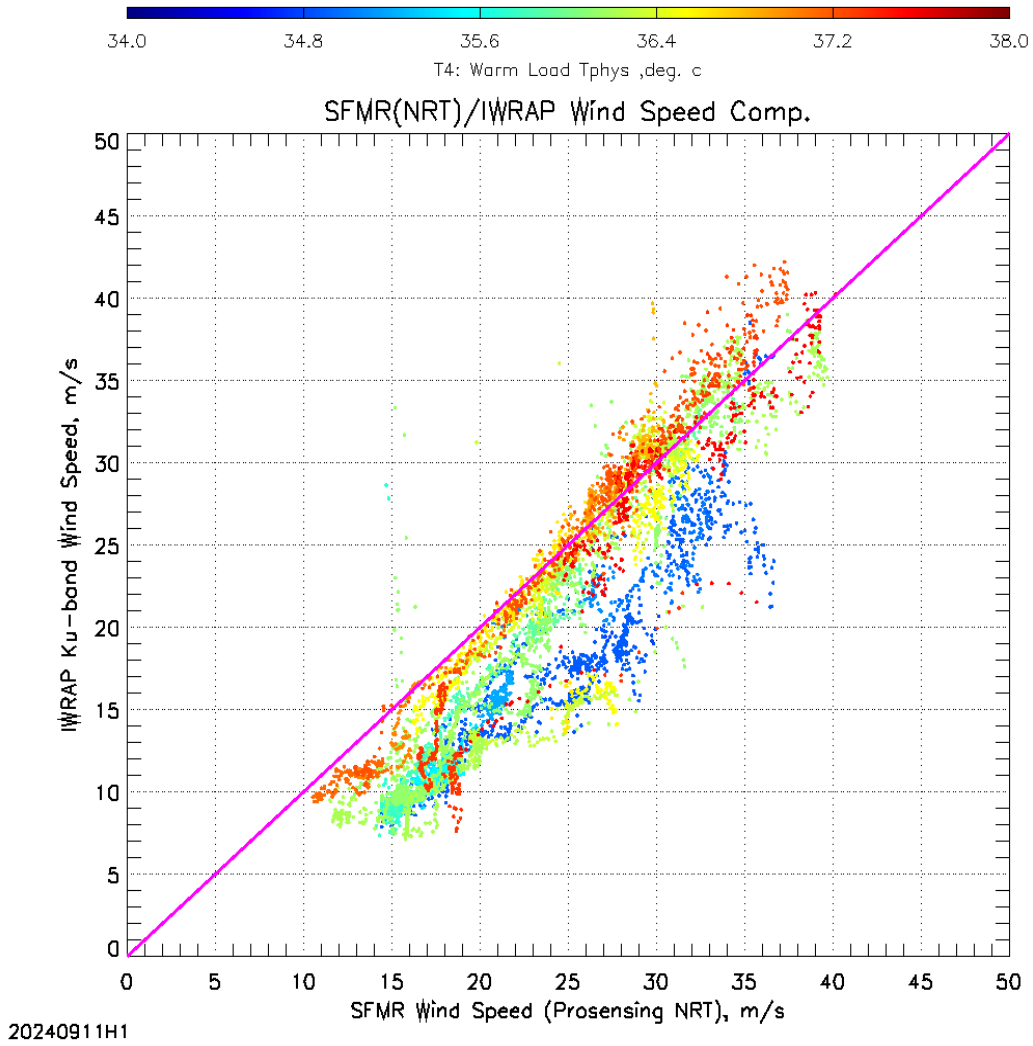


Once recognized, we identified this type of error in most of SFMR Units for which system temperature was rising above 40C usually during low level flights, <1000ft

US001 Investigating Scatter plot Bifurcation

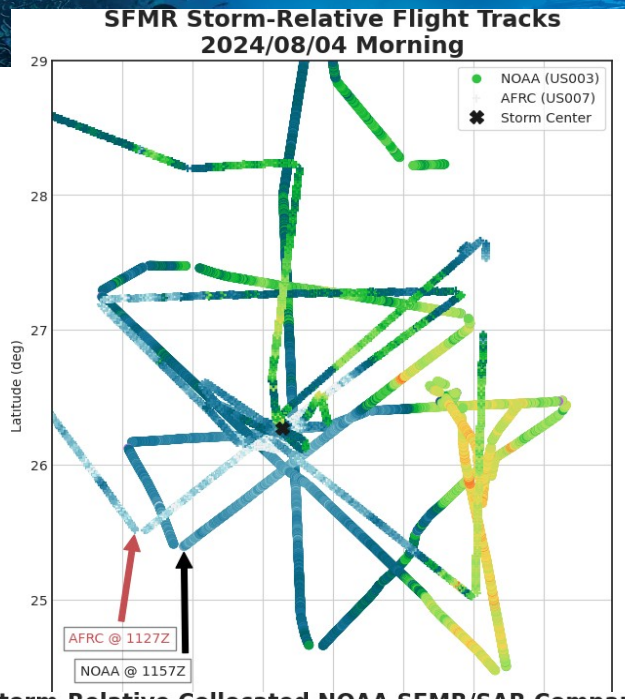
Source of Error: Tb variations with Warm load temperature resulting in temperature depende

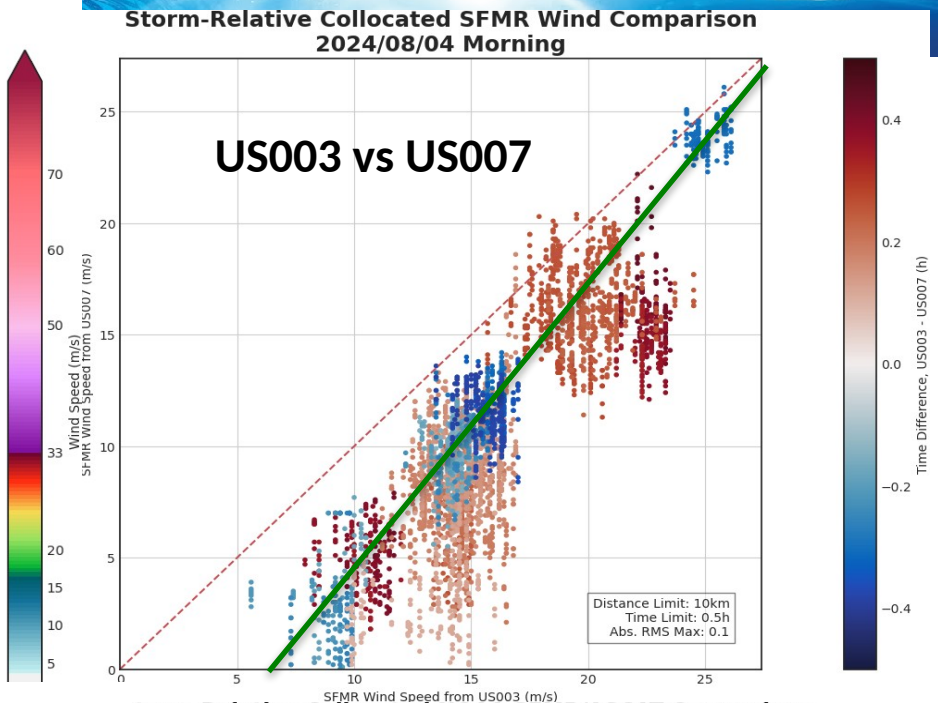


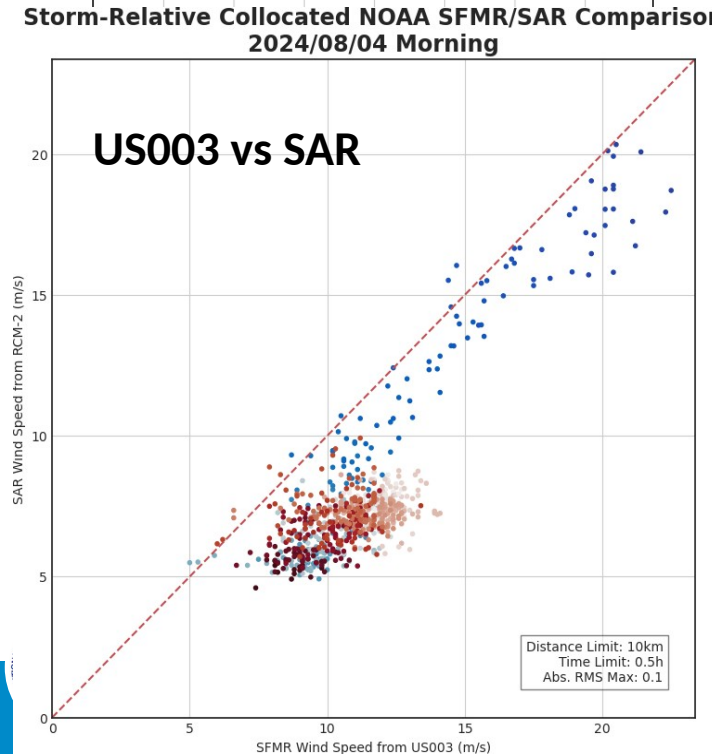


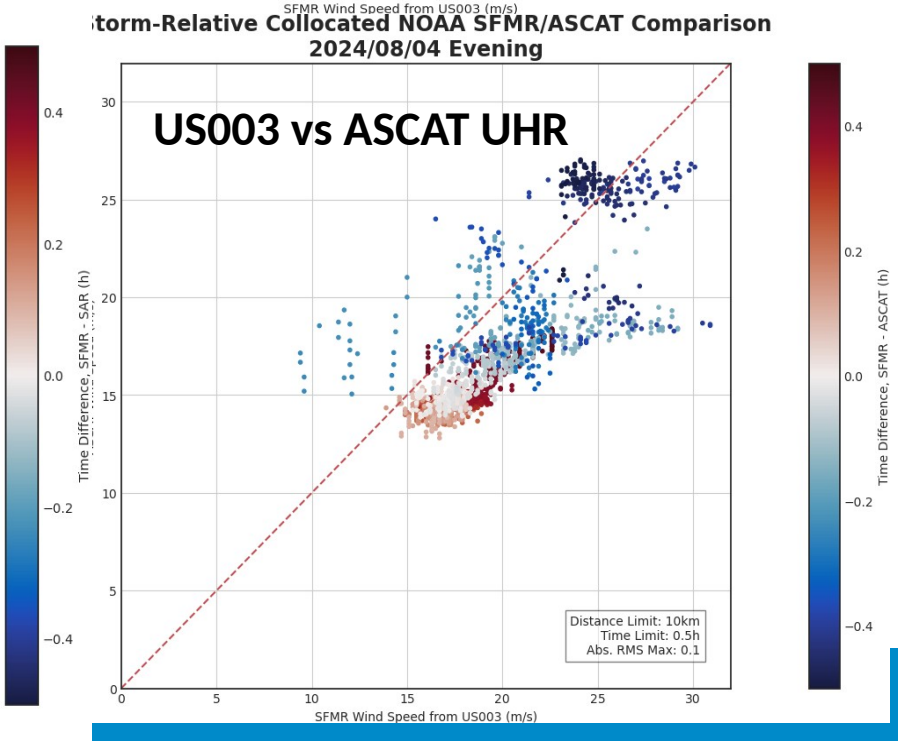
US003 Unit Validation

- First opportunity for validation in TC Debby August, 4th 2024
- Coincident measurements with AFC US007 together with ASCAT and SAR overflights
- US003 consistently ~5 m/s higher than US007
- US007 rain rate higher than US003
- Similar bias observed with coincident ASCAT and SAR passes

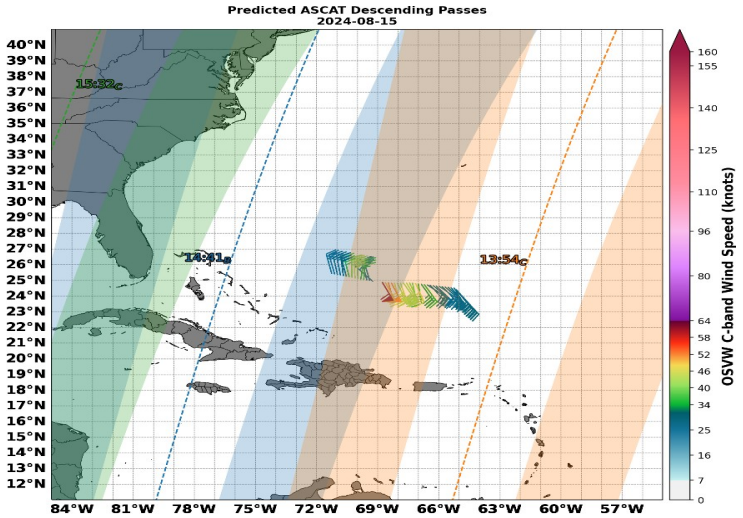


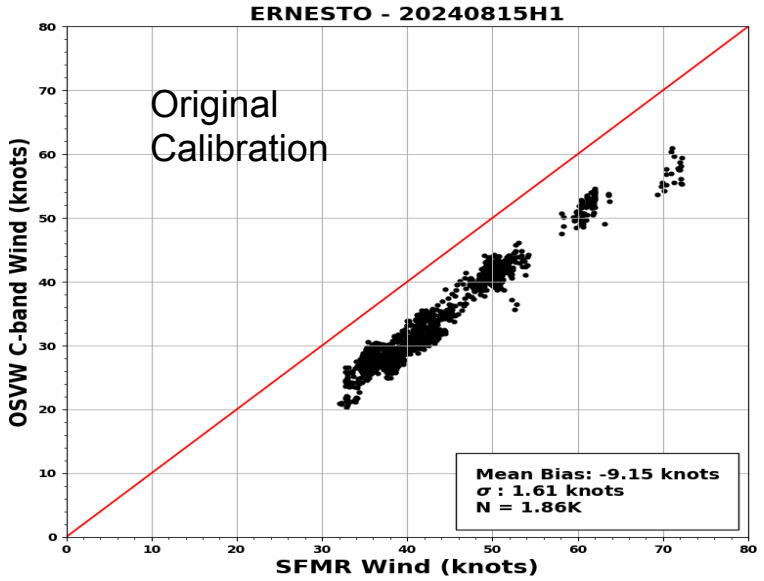






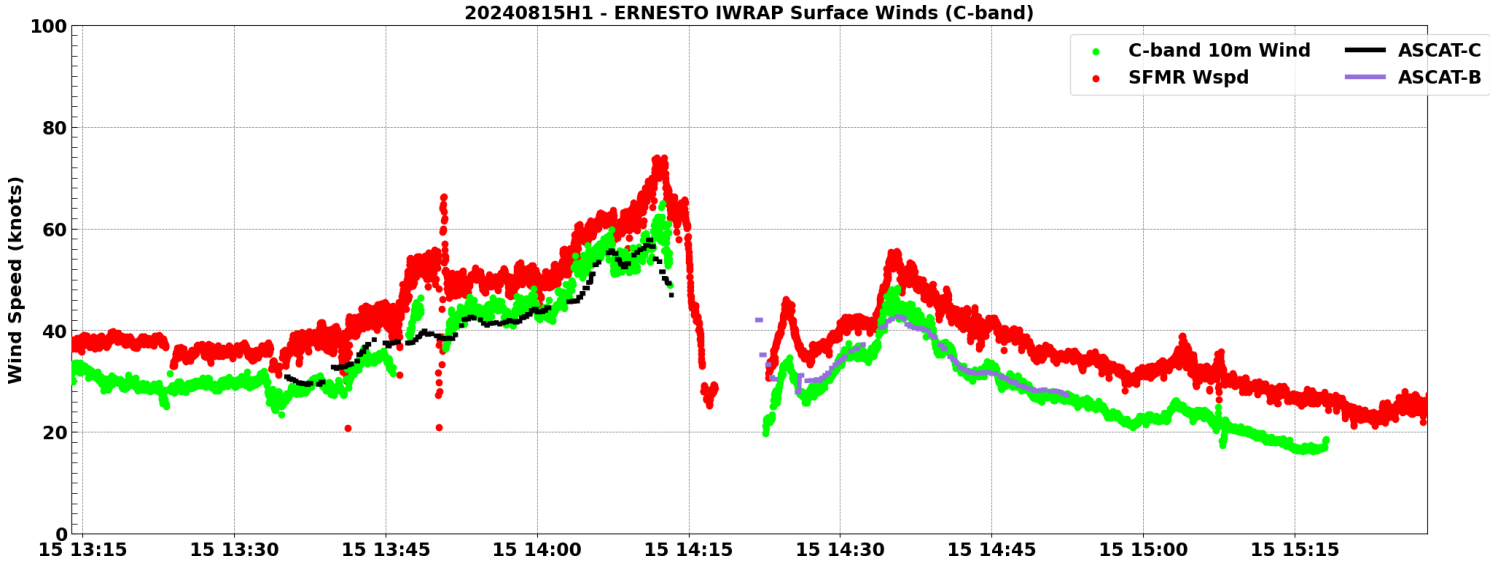
Unit 3 Flight in Ernesto, Aug 15th, 2024 coincident with ASCAT



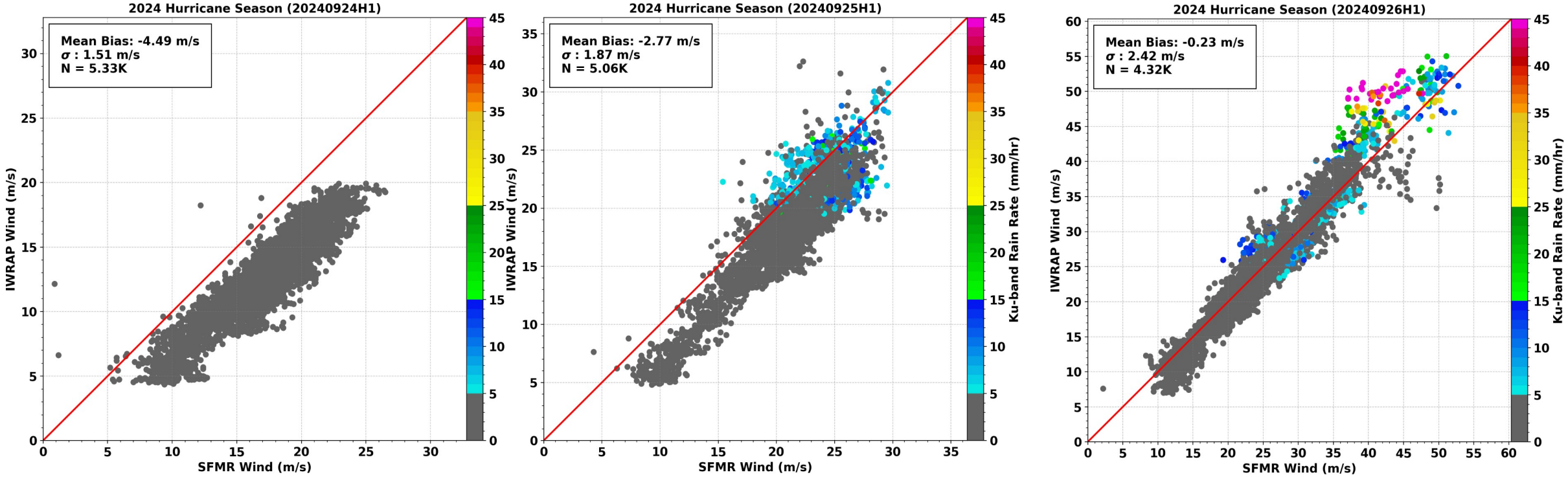


On August 15th, SFMR Unit 3 calibration flight was conducted in Hurricane Ernesto.

Two ASCAT passes were targeted for additional IWRAP and SFMR verification.

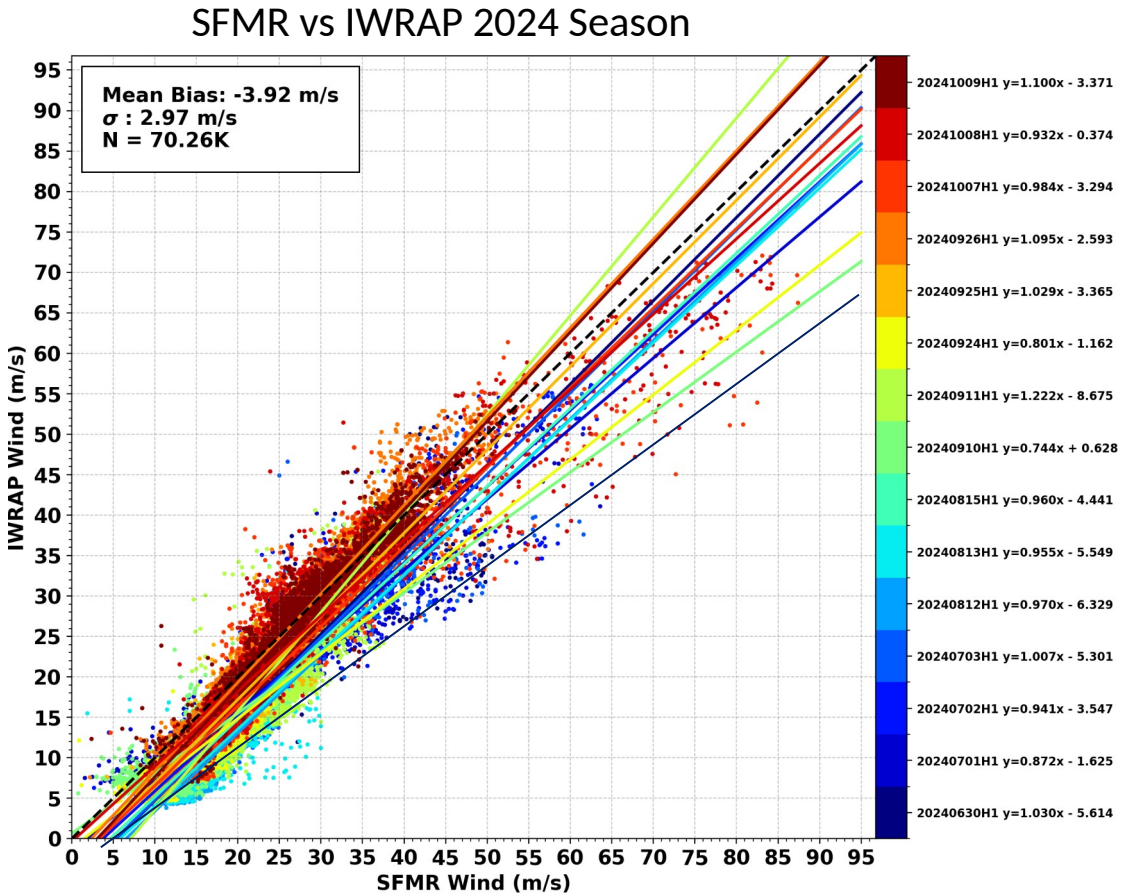


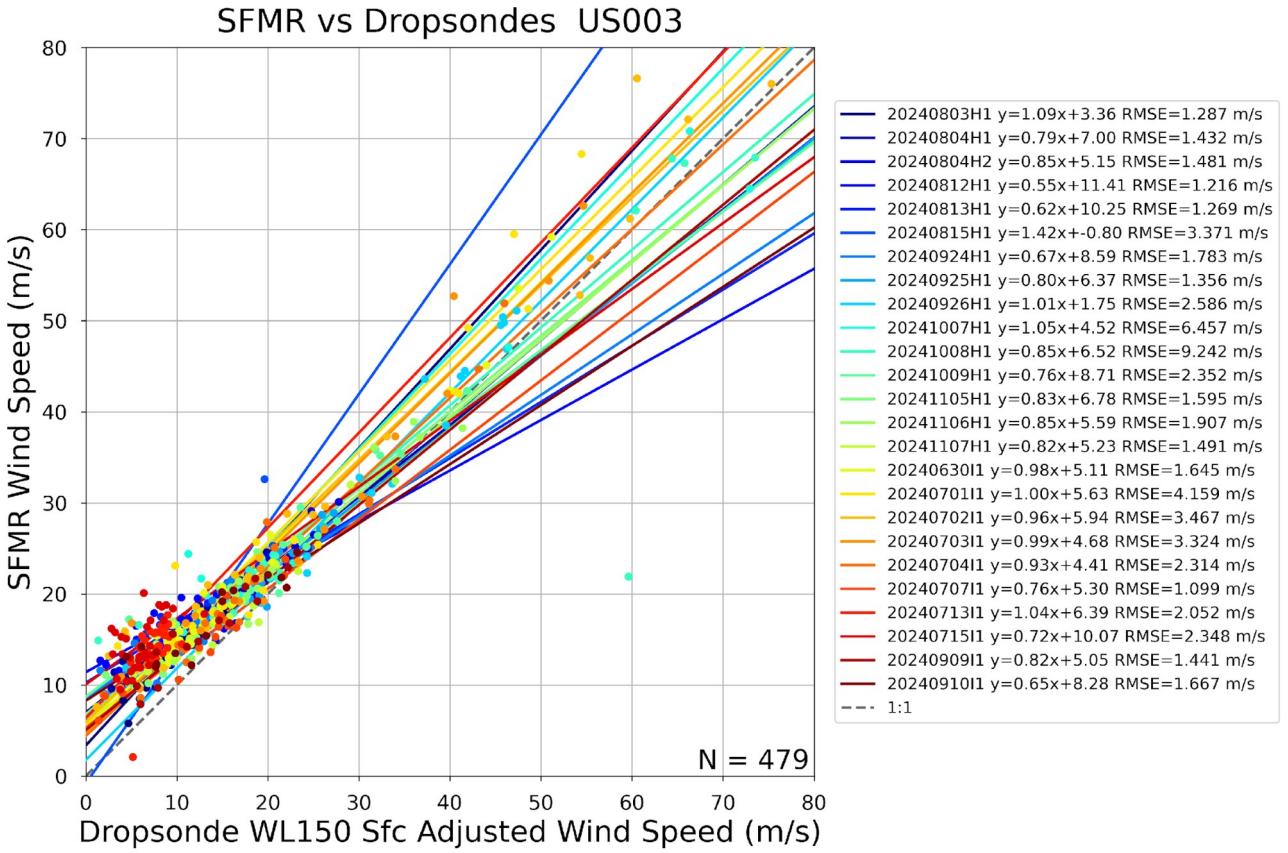
3 Flights Into Helene with US003



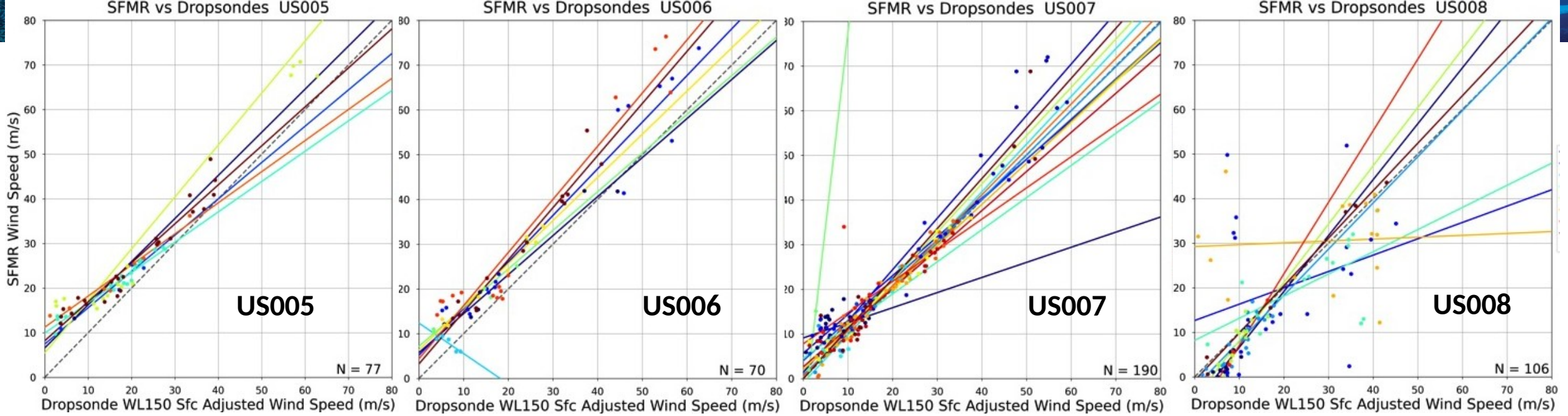
- Comparisons with IWRAP revealed performance changes from flight to flight
- **The change in performance from flight to flight or within one flight is the most concerning issue for the operational applications**

Overall Performance vs Individual Flights

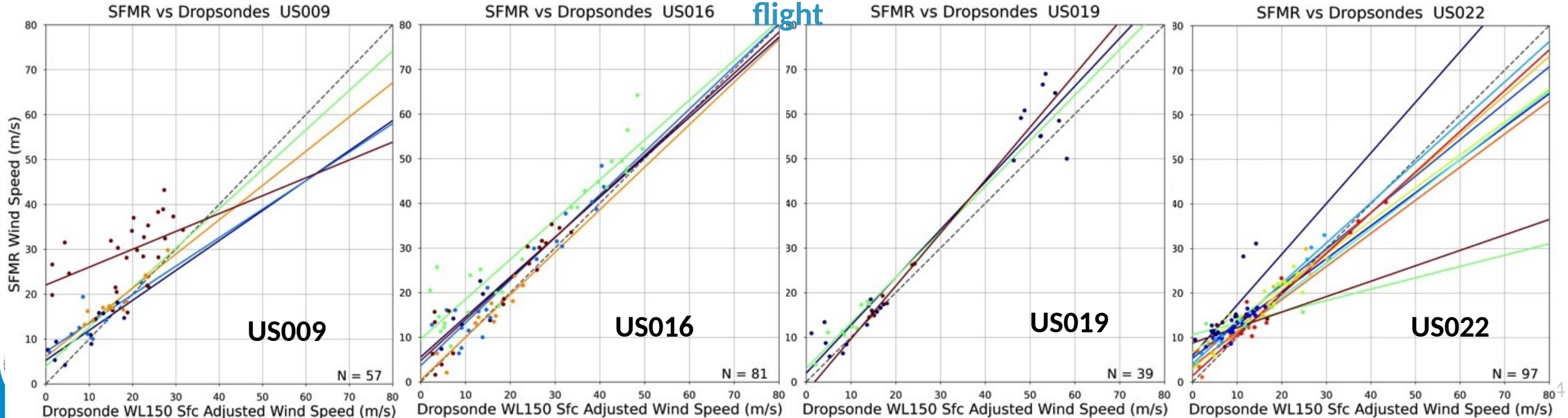




- Individual flight validation reveals more linear wind speed dependent error variation that changes from flight to flight and from unit to unit
- Results consistent with IWRAP and Dropsondes
- This is the main reason why changing the SFMR forward model led to mixed results



The 53rd C-130 SFMR Unit Performances vs Dropsondes – Lines represent fit to the data for each individual flight



Tb Calculation

$$T_B = a_0 + a_1 \cdot \frac{t_4}{35} + a_2 \cdot \gamma + a_3 \cdot \gamma \cdot \frac{t_4}{35} + a_4 \cdot \frac{t_5}{35} + a_5 \cdot \frac{t_2}{35} + \cancel{a_6 \cdot \gamma \cdot \frac{t_3}{35}}^{0} + \cancel{a_7 \cdot \frac{t_3}{35}}^{0} + a_8 \cdot \frac{t_6}{35} \qquad (1)$$

$$\gamma = \frac{C_W - C_A}{C_W - C_C}$$

Where environmental information is contained

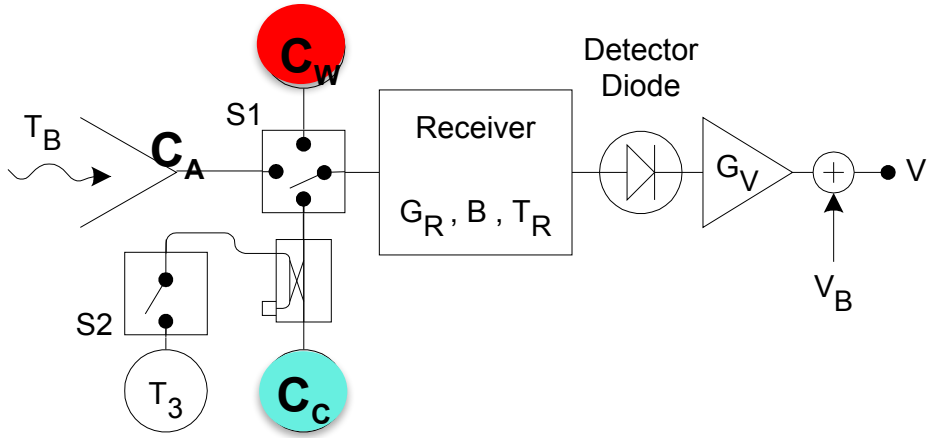
t_2 – cylinder base plate thermistor temperature

t_3 – cold load thermistor temperature

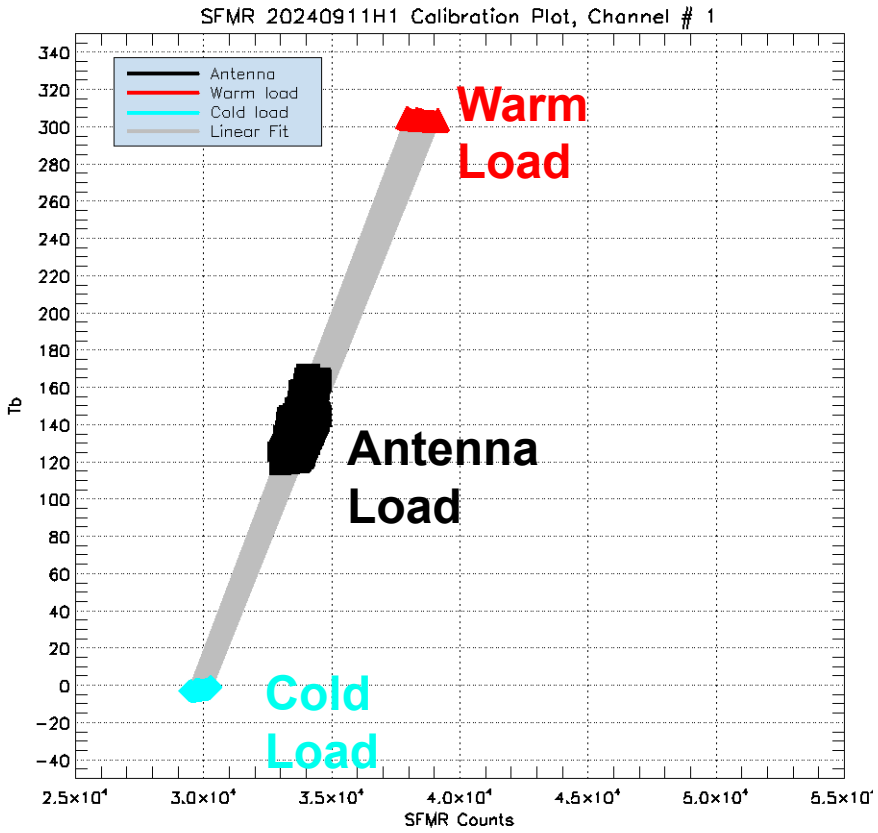
t_4 – warm load thermistor temperature

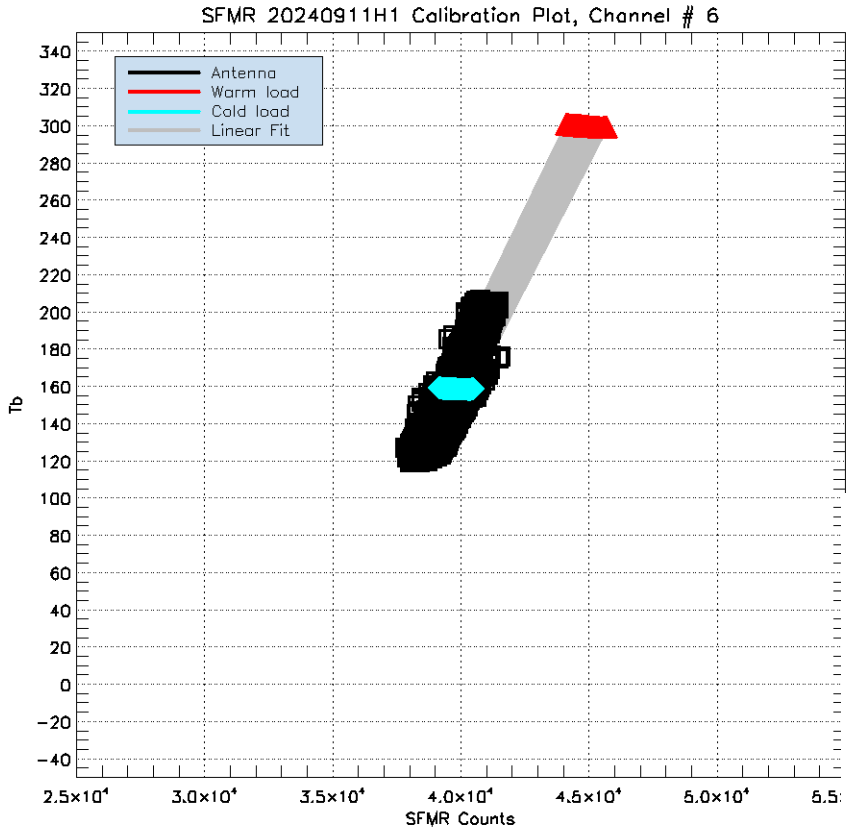
t_5 – antenna radome thermistor temperature

t_6 – antenna waveguide thermistor temperature

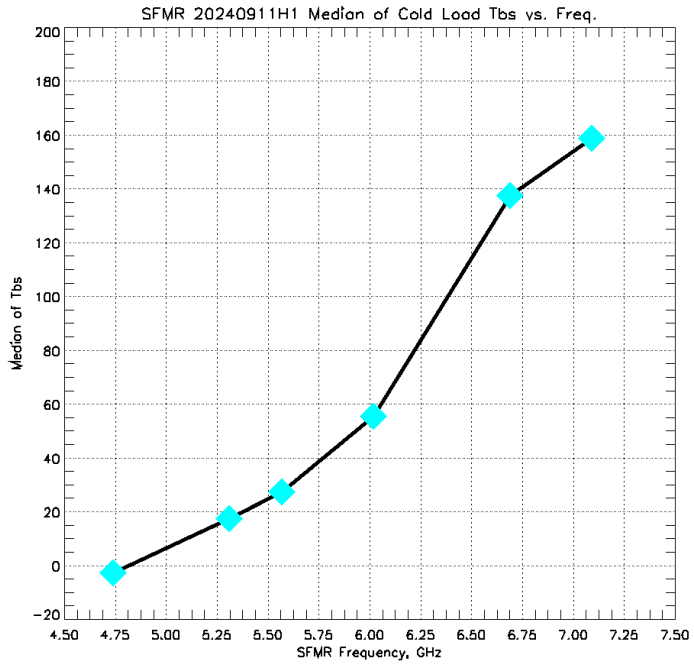


Checking for System Linearity: Instrument Cold Load





$$\gamma = \frac{C_W - C_A}{C_W - C_C}$$



We have noticed that for all units cold load counts for certain regimes are higher then antenna counts for channels 4,5 and 6. This does not affect system linearity

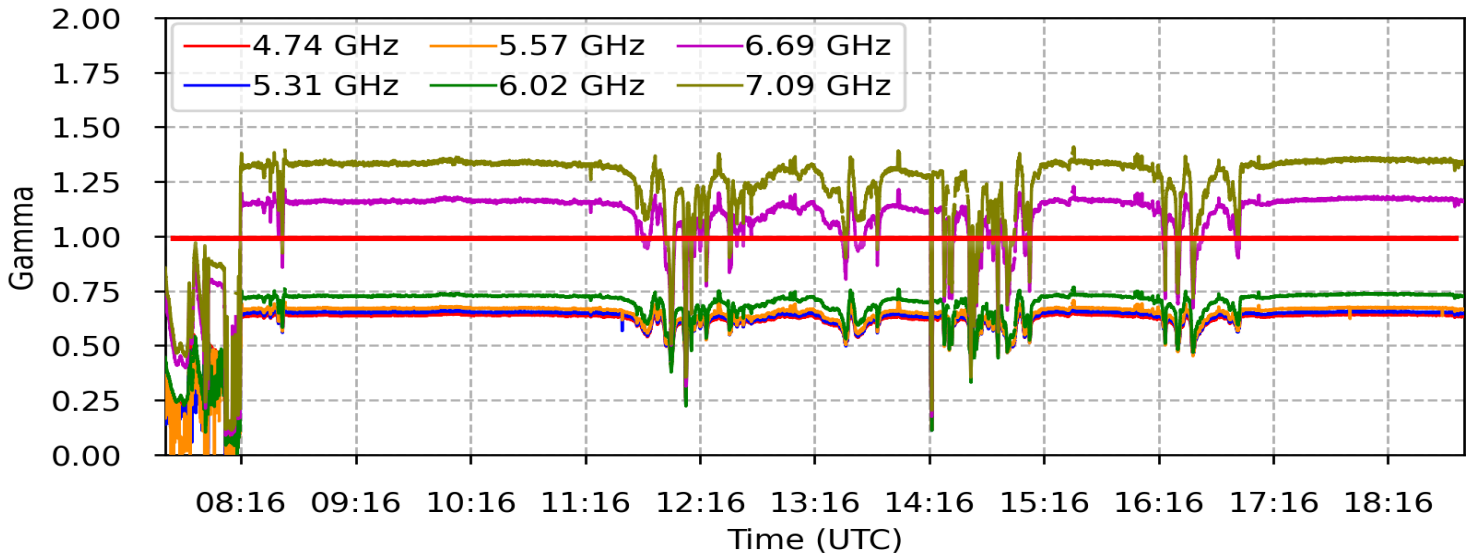
SFMR Error Source: Instrument Cold Load + Tb equation

$$T_b = a_0 + a_1 \cdot \frac{t_4}{35} + a_2 \cdot \gamma + a_3 \cdot \gamma \cdot \frac{t_4}{35} + a_4 \cdot \frac{t_5}{35} + a_5 \cdot \frac{t_2}{35} + a_6 \cdot \gamma \cdot \frac{t_3}{35} + a_7 \cdot \frac{t_3}{35} + a_8 \cdot \frac{t_6}{35}$$

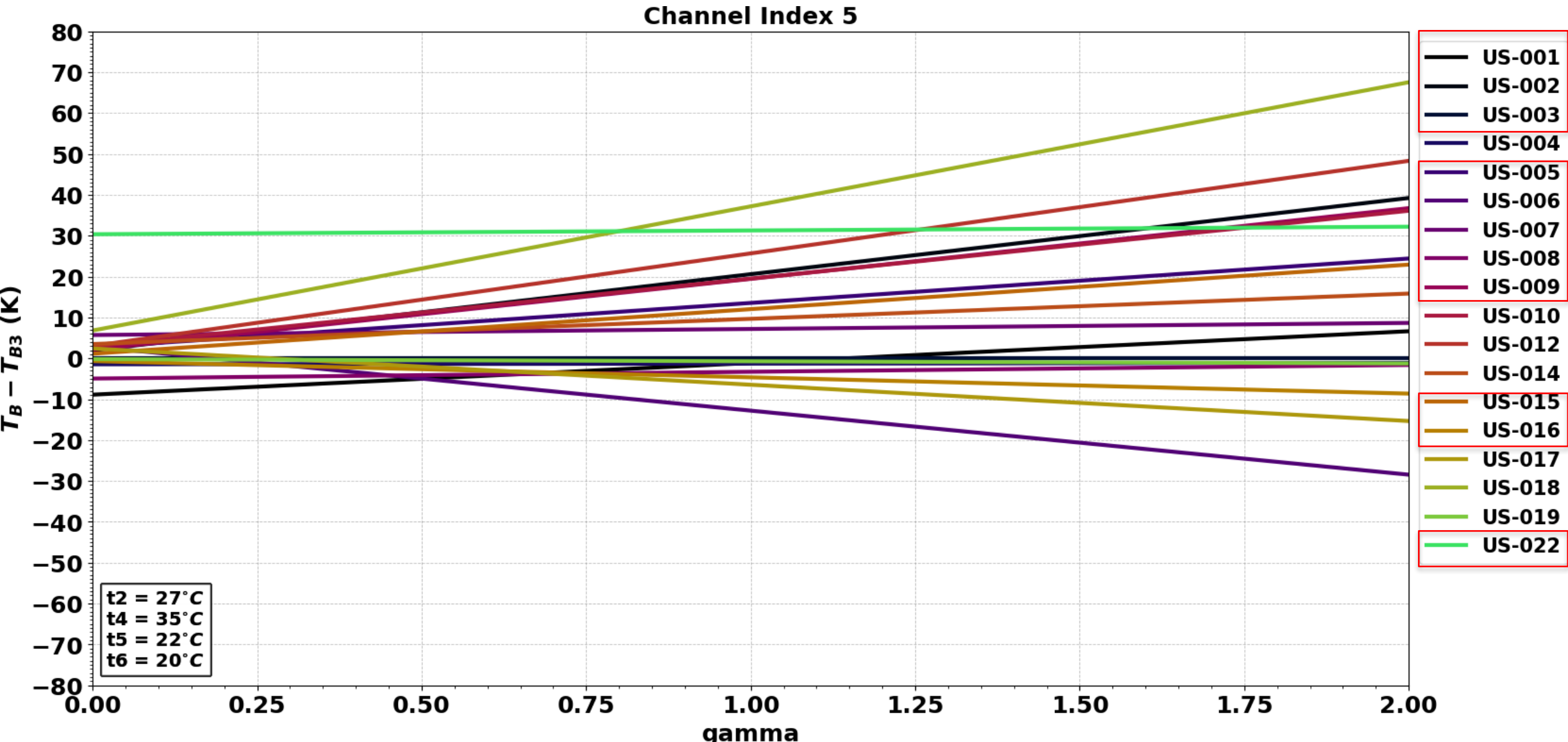
1 1 0 0

$$\gamma = \frac{C_W - C_A}{C_W - C_C}$$ If $C_c \sim C_A$ $\gamma \sim 1$

When antenna counts are close to the cold load counts are $\gamma \sim 1$, hence the dominant contributions to the measured Tb's are from terms calculated from physical temperatures of the radiometric components, not environmental conditions. This occurs in high wind and rain rate regimes

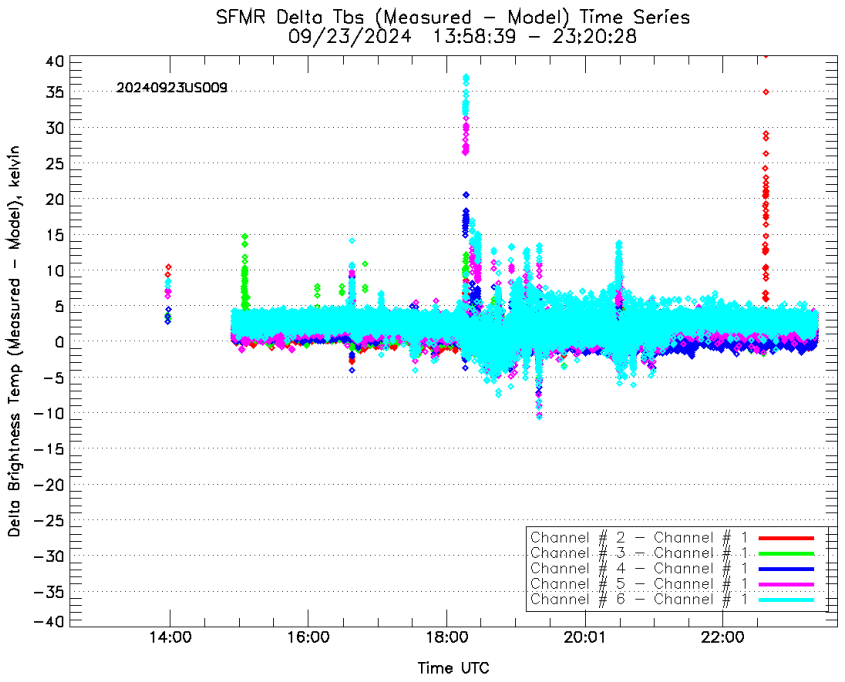


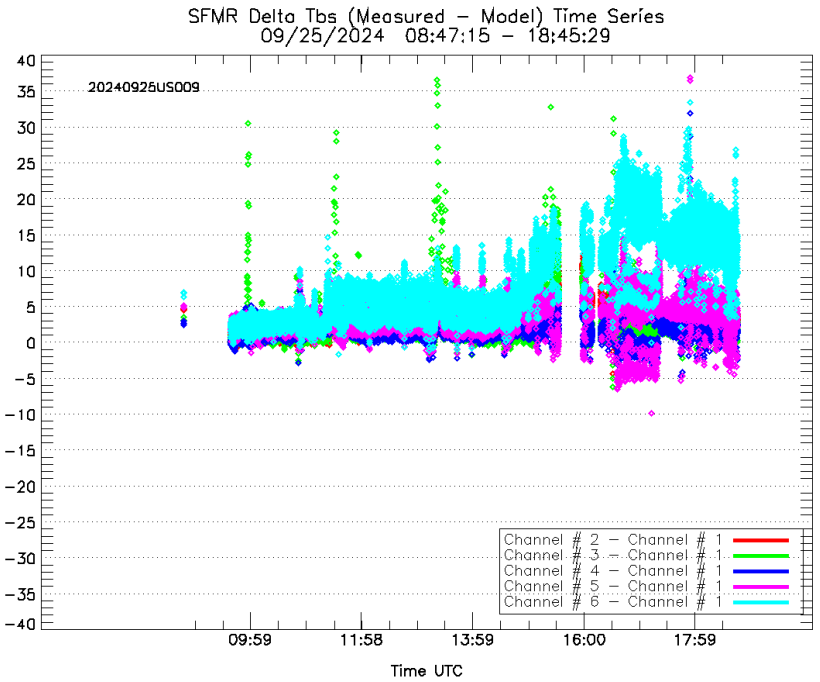
Chanel 5 Calibration Differences between US003 and rest of SFMR Units

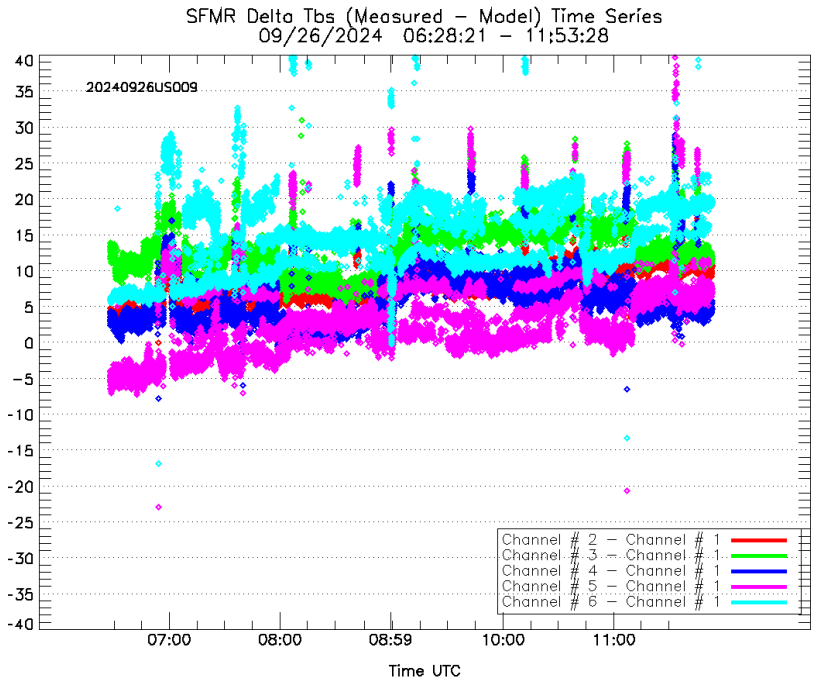


Error Source: Lack of NRT System Monitoring Tool

3 AirForce Flights with US009 into Hurricane Helene September 23-26th, 2024







On October 30th, we have received an email from Amanda Nelson USAF AFRC 53 WRS
"I wanted to let you know that there was a hardware failure with ARU US009 during mission 1109A into Helene on September 25th at approximately 1445Z. This was after the third fix and unfortunately wasn't identified so the same ARU was flown on mission 1409AHELENE (September 26th). After that flight it was removed and sent back to ProSensing for repairs." The subsequent system monitoring tool developed by Joint validation team identified issues with this unit starting with flights in Beryl on July 7th, 2024

Conclusions

- During 2024 season the NRT NOAA SFMR measurements exhibited variable performance characteristics with respect to IWRAP, sondes, ASCAT and SAR
  - Validation performed on all 3 NOAA SFMR units
  - Performance varied during flight time as well as from flight to flight for the same unit
- **Sources of error:**
  1. **Tb Forward model wind speed and rain rate dependencies**
  2. **Algorithm inversion scheme**
  3. **Calibration**
  4. **Frequency drift with system temperature**
  5. **Time and temperature dependent measurement drift**
  6. **Tb calculation**
  7. **Instrument design**
  8. **Ancillary data inputs**
  9. **System health monitoring**
- NOAA decided to terminate SFMR dissemination from NOAA P3's in September 2024
- EMC has performed **SFMR** data denial **DA study** for HAFS model and **found degradation in surface Vmax and pressure bias and rms error when SFMR data was assimilated**
  - Study included all storms between 2022-2024; DA of the SFMR was terminated mid 2024 season
- Impact of SFMR data utilization in satellite wind calibration or AI products is unknown at this point
- 20 years database of SFMR measurements in most extreme surface wind conditions in jeopardy