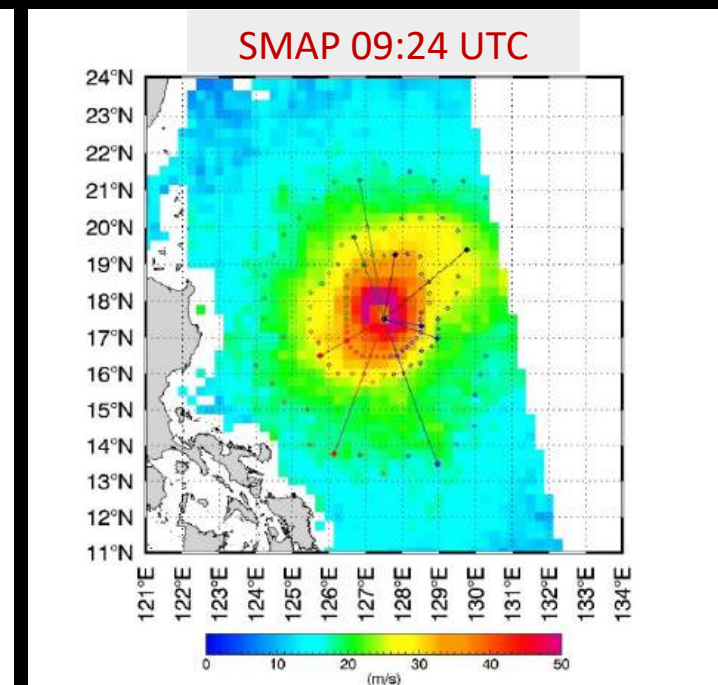
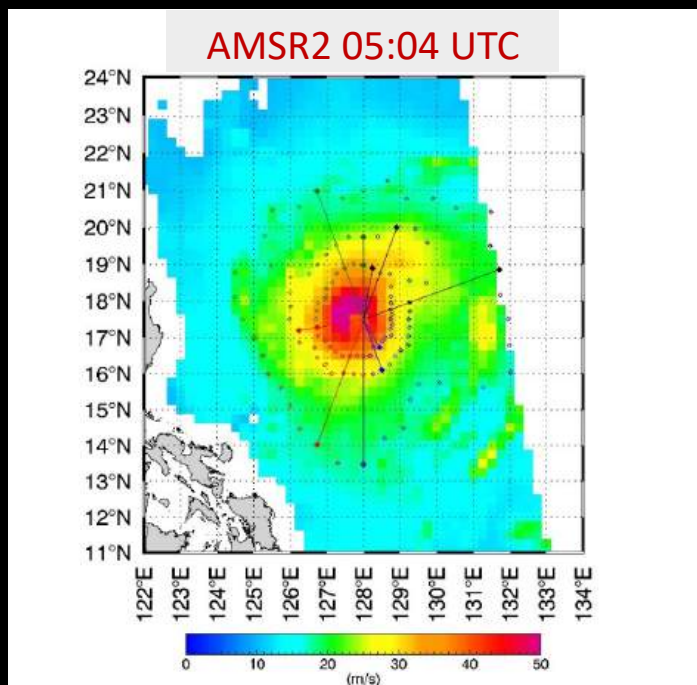
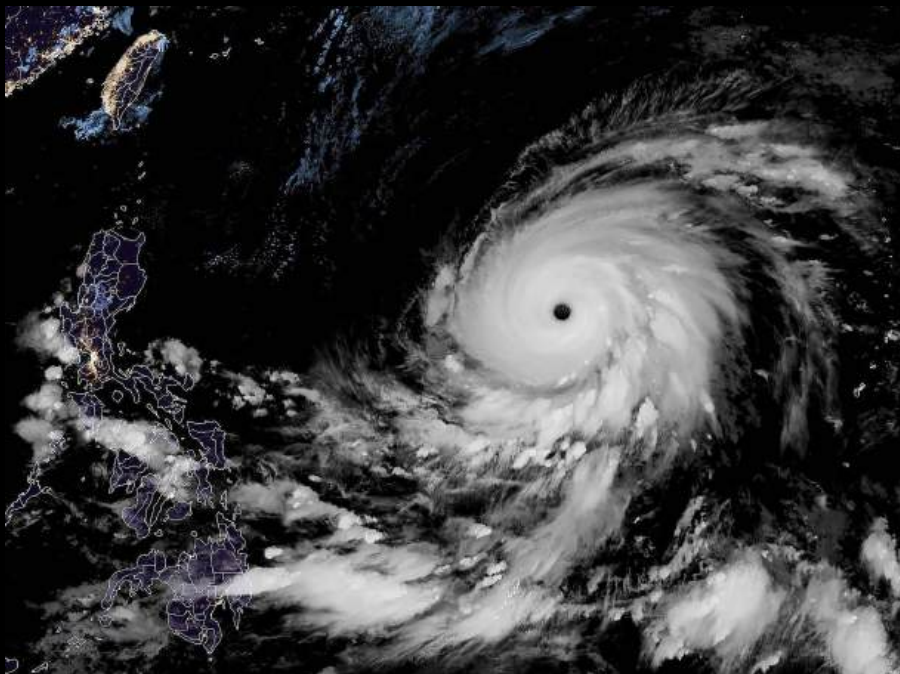




# Updates on extreme wind measurements with satellite microwave radiometers

Lucrezia Ricciardulli, Thomas Meissner, Andrew Manaster  
Remote Sensing Systems, Santa Rosa, CA, USA

MAWAR WP02 2023-05-28



# TC Radiometer Winds: Features and Best Use

## TC-winds: Gridded Asc/Desc maps (0.25°) and fixes (radii, intensity) in NRT

<https://www.remss.com/tropical-cyclones/tc-winds/>

**SMAP (6 pm/am; 2015-present):** L-band (1.4 GHz); sensitive to high winds 10-70 m/s, no rain impact (Meissner et al, *BAMS* 2017)

**AMSR2 (1:30 am/pm; 2012-present):** 6-89 GHz, current TC-trained algorithm uses C/X-band (6/10 GHz; Meissner et al, 2021)

**Archived:** WindSat (2003-2020); AMSR-E (2002-2011)

### Temporal/Spatial scales

- 10-minute sustained winds, 40 km; large swaths, can see full storm

### Best use of radiometer extreme winds

- Remote locations
- Consistency over time: Monitoring storm intensity evolution
- Identify Rapid Intensification (RI)
- Determining the radii, and monitor their evolution

### Disadvantages of radiometer winds

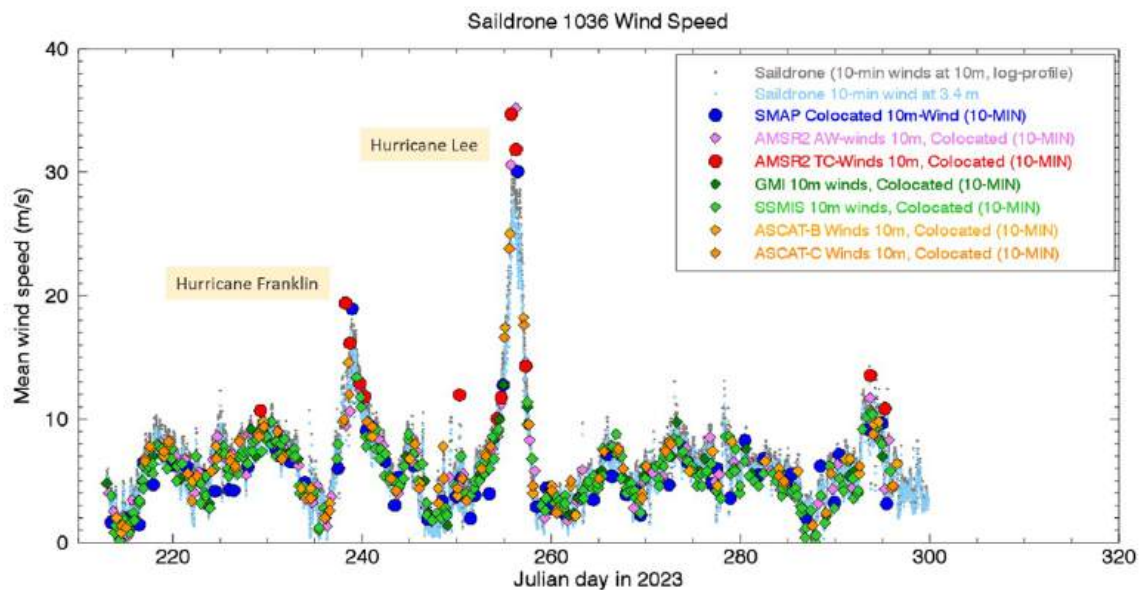
- Low resolution: cannot see real small-scale peak intensity (1-min) or detect Radius of Maximum Wind (RMW)
- Residual rain contamination in AMSR2 TC-winds (addressed in next slides).

# In-situ Validation using Saildrones (SD)

➤ NOAA/SD Hurricane project (2021,2022,2023) deployed several SD in areas with high probabilities of storms to monitor Tropical Atlantic/Caribbean

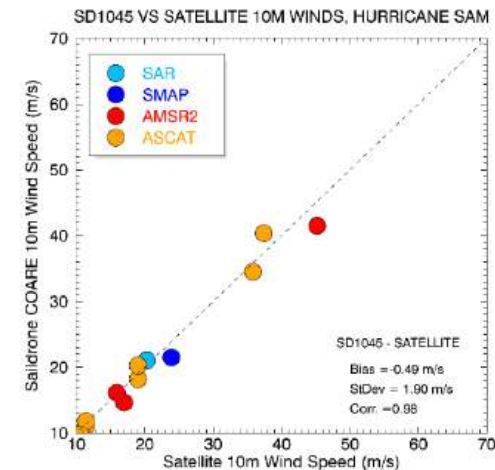
Foltz, et al (*EOS*, 2022); Zhang, Foltz et al (*BAMS*, 2023)

## Saildrone SD-1036 (2023 mission)

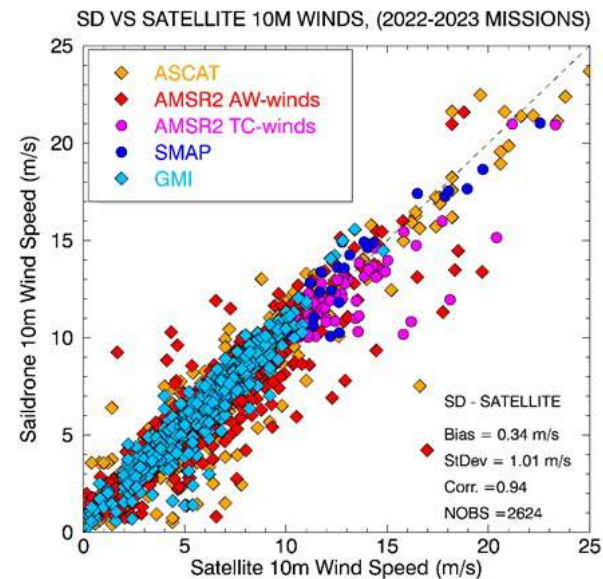


## Validation extreme winds: Hurricane SAM (2021)

Ricciardulli, Foltz et al (2022)



## Validation 0-25 m/s



# MW Channel Utilization in Surface Wind Retrievals

## Primary Channels and Source of Emission

Band (GHz)	1.4 (SMAP)	6-7	10	18	23	37	89
SST							
<u>Wind</u>	No rain impact/ Sensitivity to high winds						
Water Vapor							
Rain/Cloud							
Ice/Scatter.							

Surface } Atmosphere

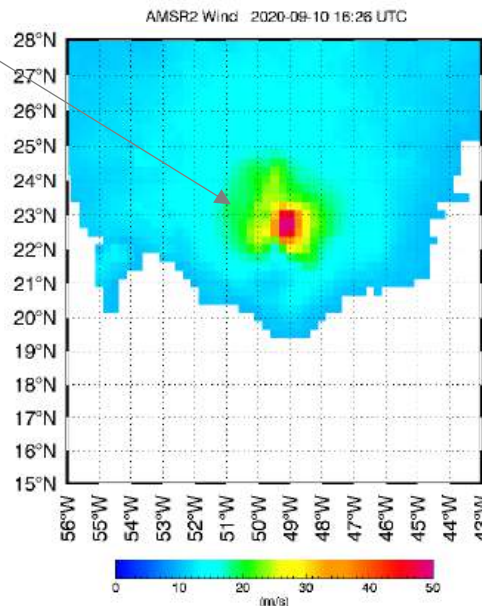
Current AMSR2 TC-winds algorithm for  $w > 20$  m/s,  $SST > 20^\circ\text{C}$   
(and AMSR2 rain retrievals from 37GHz)

# What are the major issues in MW TC winds?

## AMSR2 UNRELIABLE → wrong fix (intensity and/or radii)

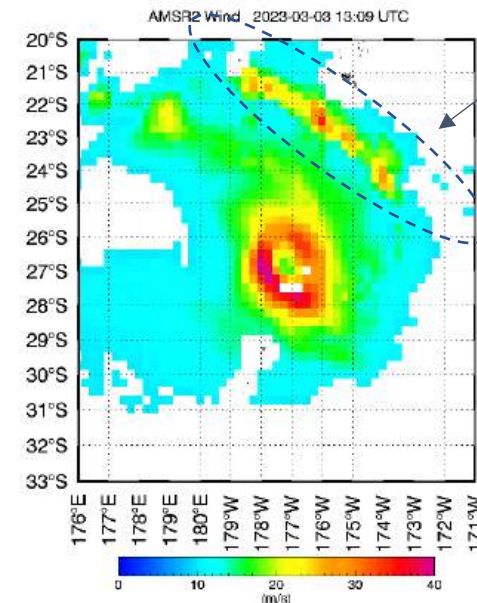
1. Core winds occasional strong bias due to
  - Residual spurious rain signal
  - Areas with unusually cold 89 GHz
  - Ice clouds/overshooting cloud tops?
  - More common in storm's early stage and below 30 m/s
  - *Algorithm not sufficiently trained for these conditions*
2. Rain bands in wind field
  - Residual rain signal contamination.
  - Could affect radii, occasionally the max wind too
  - Easy to visually detect, hard to remove from automated fix
  - Same problems in old WindSat retrievals (similar algorithm)

PAULETTE (AL17, 2020)



AMSR2: 52m/s  
HWRF : 22 m/s  
BT : 23 m/s

JUDY (SH15, 2023)



Rain spurious signal

# Other issues: Radio Frequency Interference (RFI)

## 3. **Recent persistent RFI in SMAP**

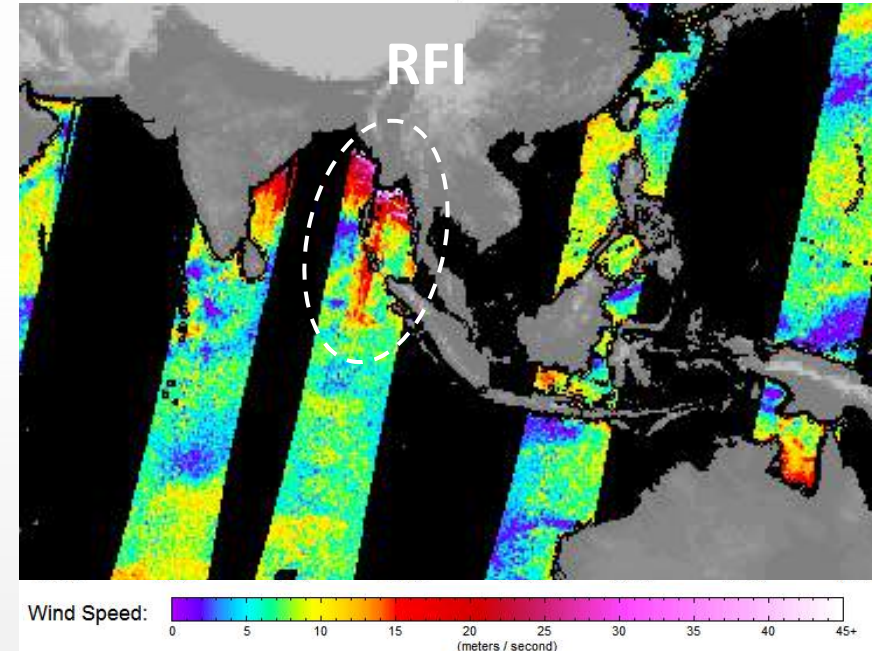
- New L-band (1.4 GHz) RFI in Bay of Bengal
- Since Dec 2023, both asc/desc → land/ship based
- Very large positive bias
- Additional occasional RFI near Taiwan and Mediterranean

→ Develop automated detection (flag) or mask region

## 4. **Occasional RFI in AMSR2**

- New RFI source in C-band (6-7 GHz) and (10 GHz) in Bay of Bengal
- Descending passes (1:30 am)
- Other RFI over global coastal waters at 10 GHz is filtered
- Location changes over time, frequent updates in RFI filter

SMAP NRT-v1.0 Surface Wind Speed: 2024/04/08 - evening passes



# Possible Solutions for AMSR2 TC-winds Algorithm

Three main approaches to address significant occasional bias in the AMSR2 TC winds, due to residual rain, deep clouds

1. Patch: Find a **Flag** that works and just apply it to current winds
- ➔ 2. Develop **New regression algorithm for AMSR2 winds in TC using all channels**
  - PROS: complete view of TC core, no holes; responds to different environmental conditions; Fix intensity/radii more reliable;
  - CONS: Developing multi-year training dataset for wide range of environmental conditions is time consuming; not fail-proof (residual biases might need to be flagged)
3. With the new training dataset, develop a **Machine Learning algorithm**

**Algorithm's success depends on comprehensive and accurate training dataset** 7

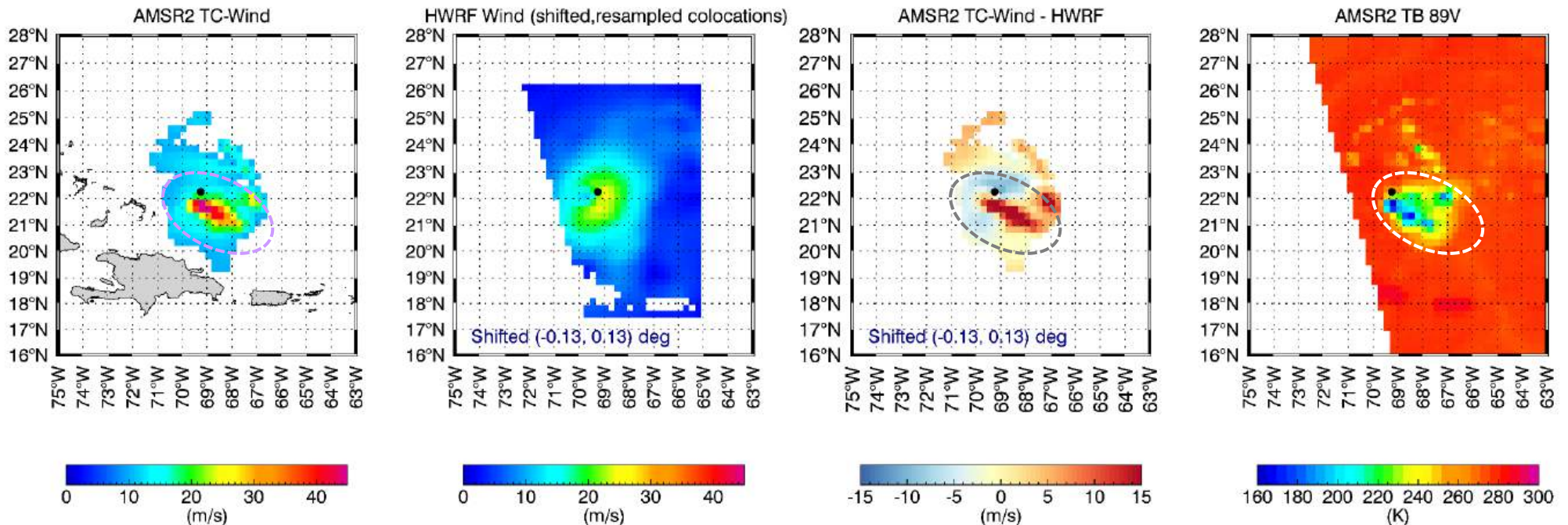
# Building a New Training Dataset Using HWRF

- AMSR2 (1:30 am/pm) doesn't collocate well with SMAP (6 pm/am), so we decided to use HWRF data as ground truth
- Colocate AMSR2 TBs (gridded at 25x25 km) for all channels (6-89 GHz, V/H pol) with HWRF
- HWRF is 6-hourly and high resolution: resampled the 6 hourly at 25 km, using storm-center coordinate and interpolate these at the AMSR2 time and shift it to match the AMSR2 storm center

Training dataset : 18 TCs in 2018-2022 (102 scenes; 70,000+ collocations)

Testing dataset: 20 TCs in 2023

FRANKLIN (AL08) 2023 08 24 17:28 UTC



AMSR2: 48m/s  
HWRF : 24 m/s  
BT : 26 m/s

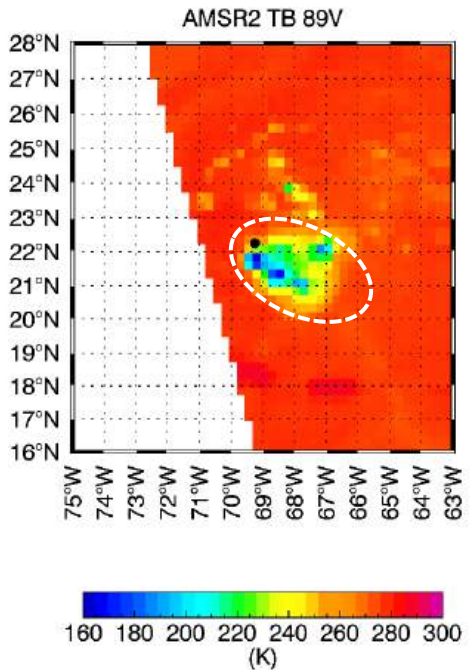
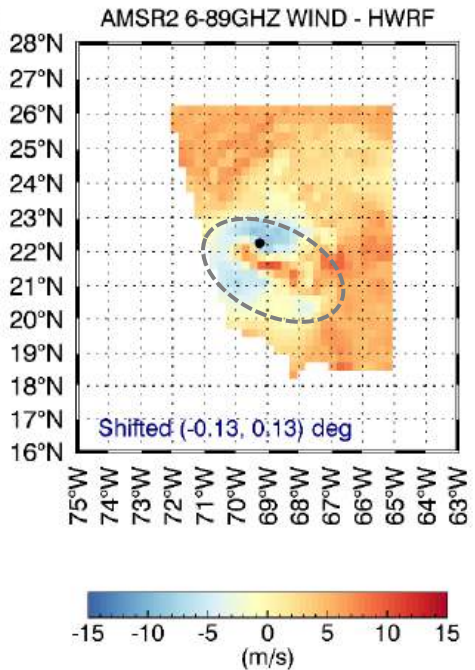
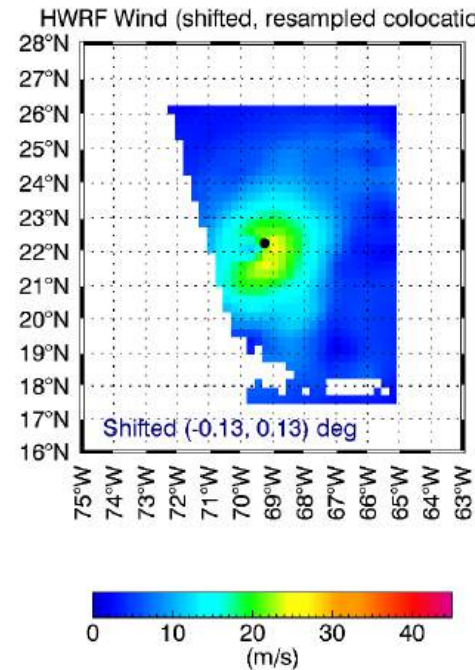
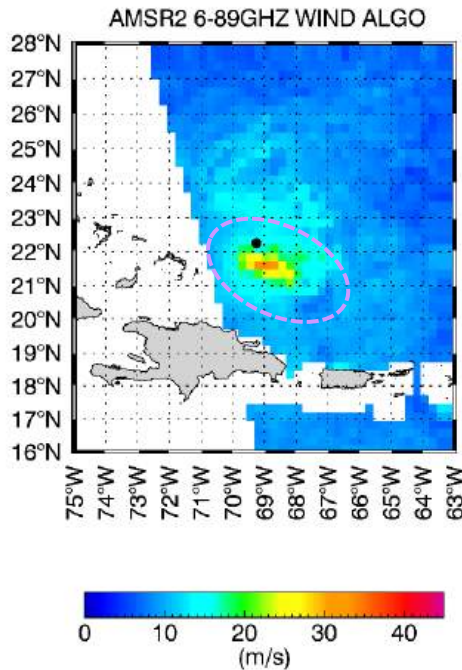
# New Linear Regression Algorithm Using All Channels 6-89 GHz

$$W_{reg} = a_0 + \sum_{iVpol=1,7} b_{iVpol} \times TB_{iVpol} + \sum_{iHpol=1,7} c_{iHpol} \times TB_{iHpol}$$

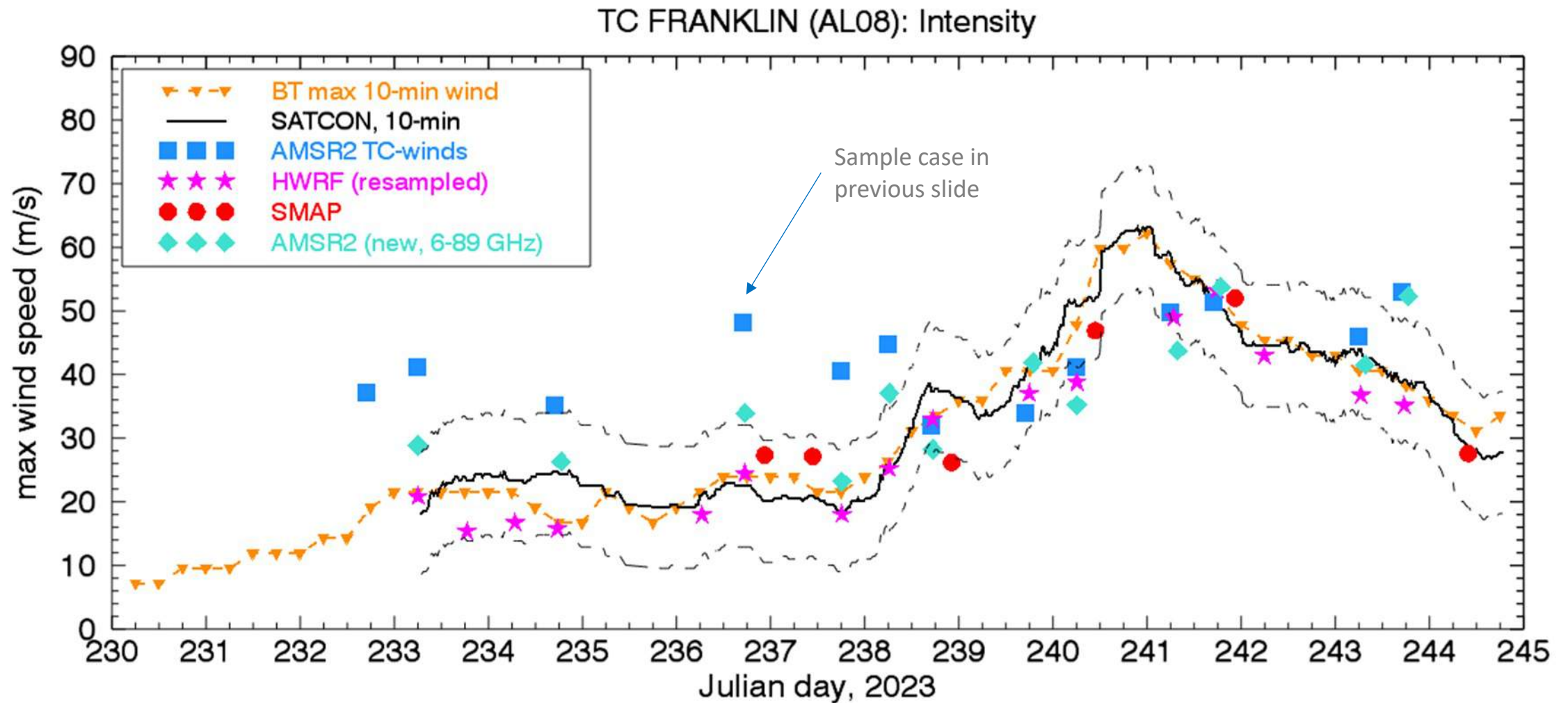
$iVpol = 6.9V, 7.3V, 10.7V, 18.7V, 23.8V, 37.5V, 89V$   
 $iHpol = 6.9H, 7.3H, 10.7H, 18.7H, 23.8H, 37.5H, 89H$

FRANKLIN (AL08) 2023 08 24 17:28 UTC

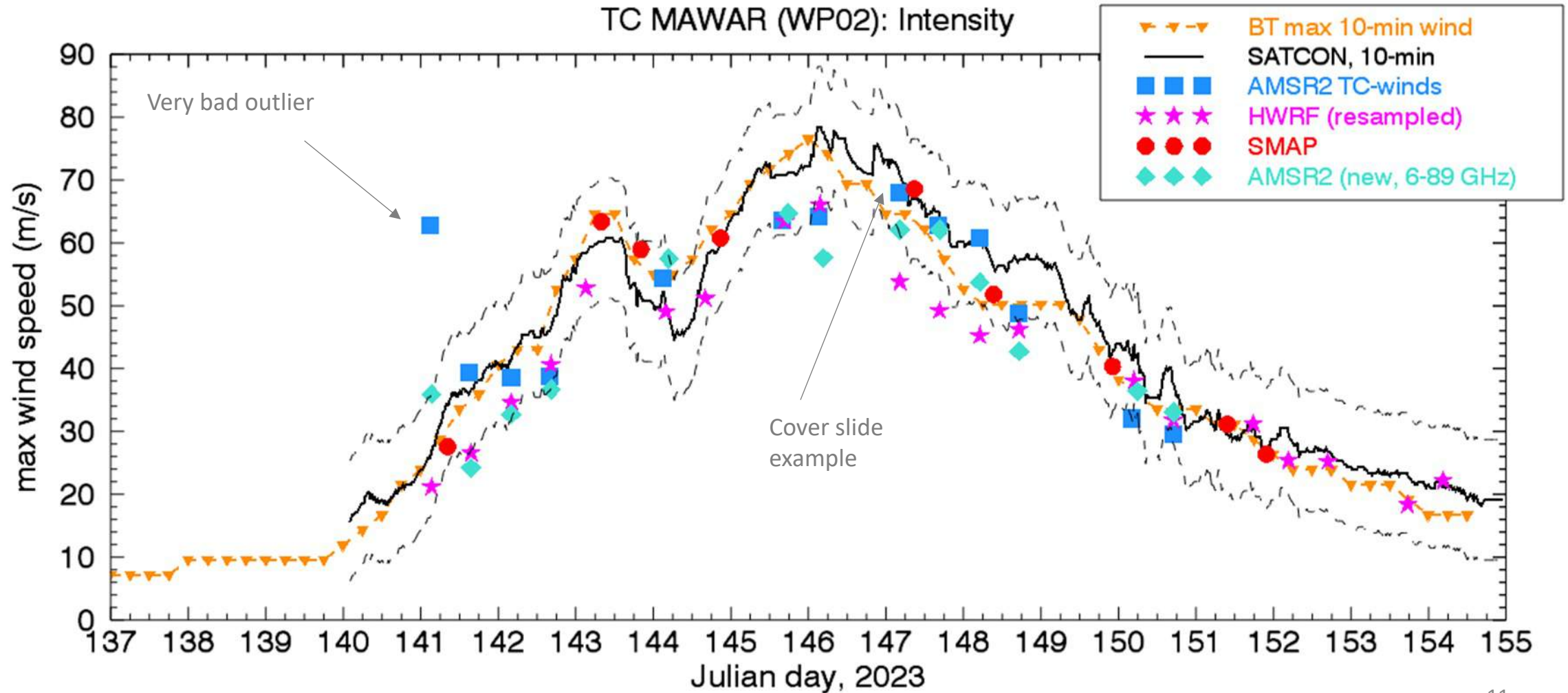
AMSR2: **34 m/s**  
 HWRF : 24 m/s  
 BT : 26 m/s



# New algorithm (6-89GHz) vs Old (6-10GHz): FRANKLIN

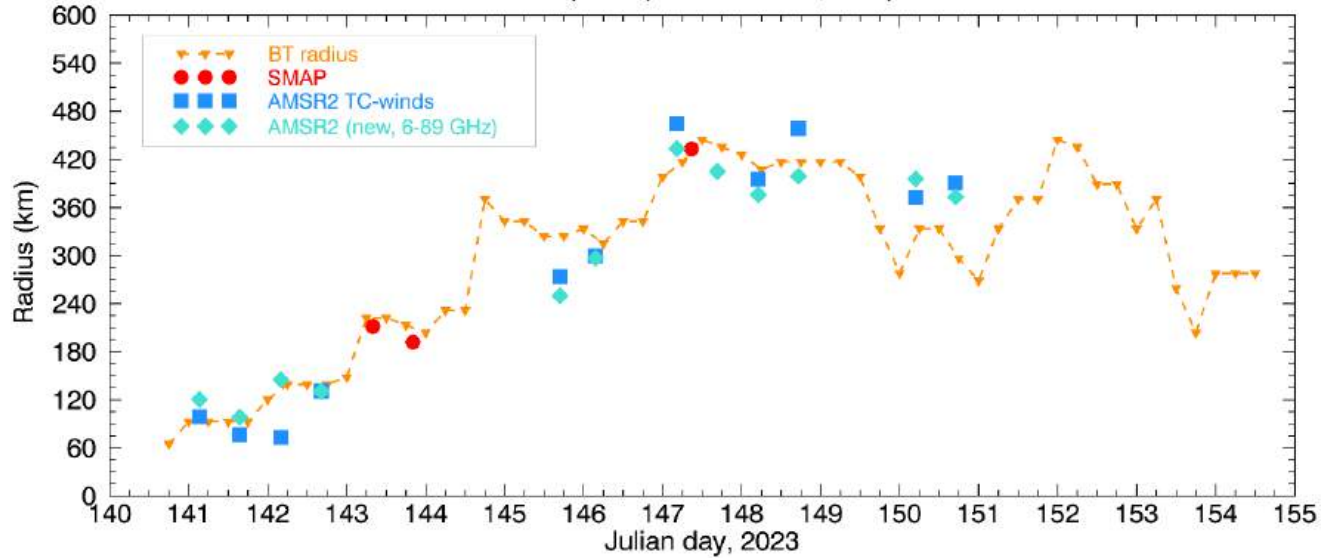


# New algorithm (6-89GHz) vs Old (6-10GHz): MAWAR



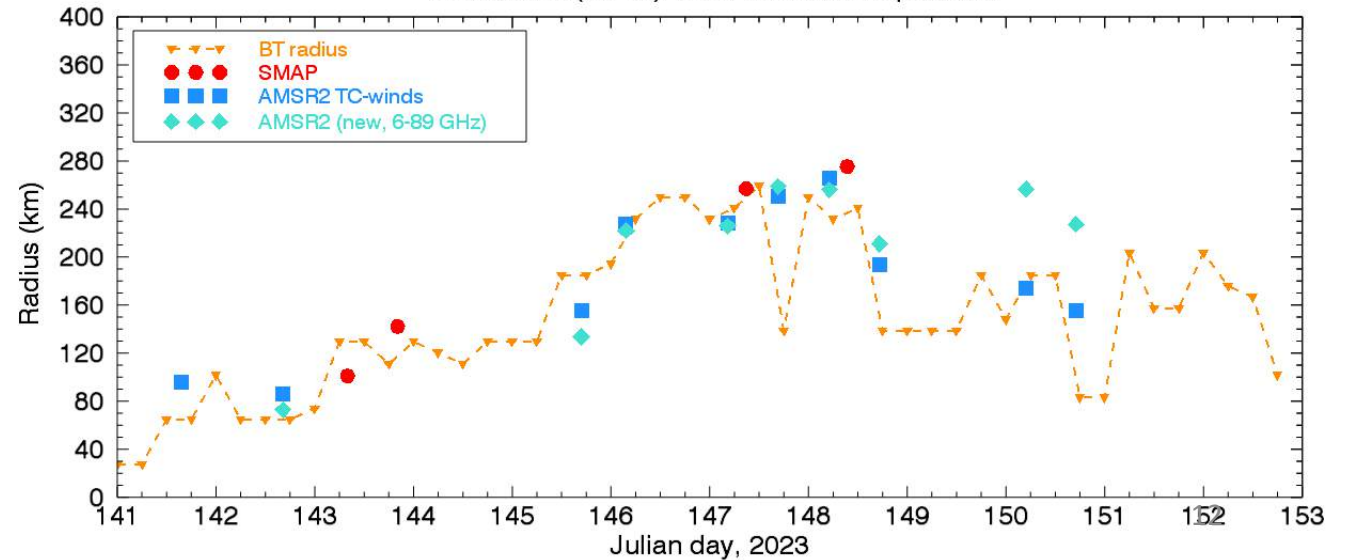
# Radii Timeseries: MAWAR

TC MAWAR (WP02): 34 kt Radius, NE quadrant



34 kt

TC MAWAR (WP02): 50 kt Radius, NE quadrant



50 kt

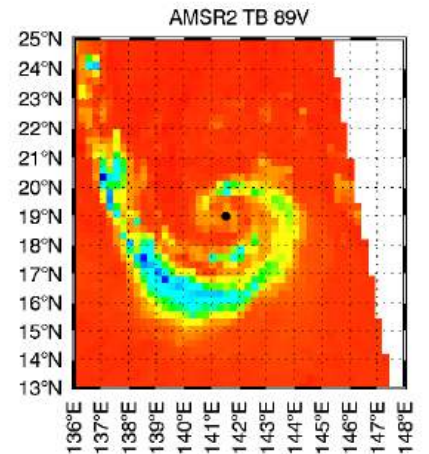
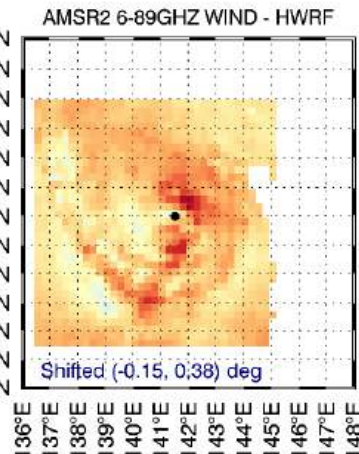
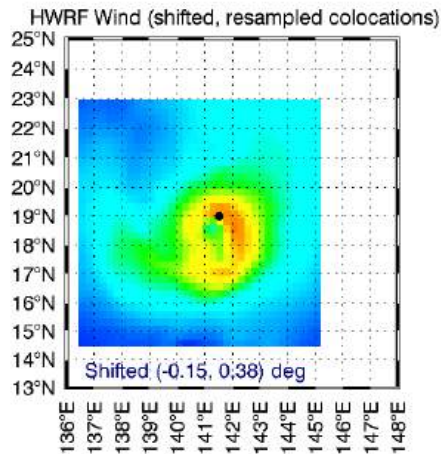
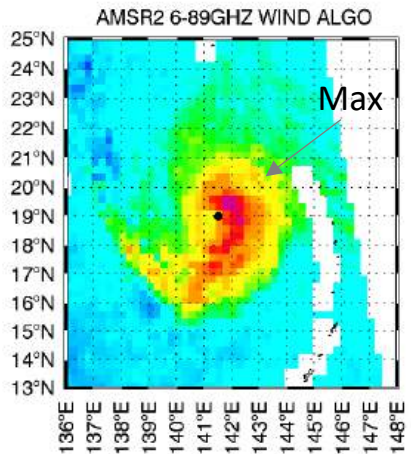
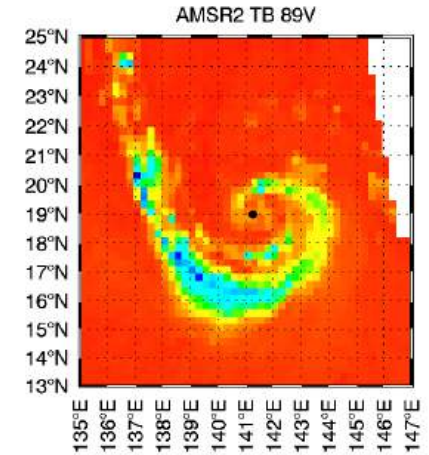
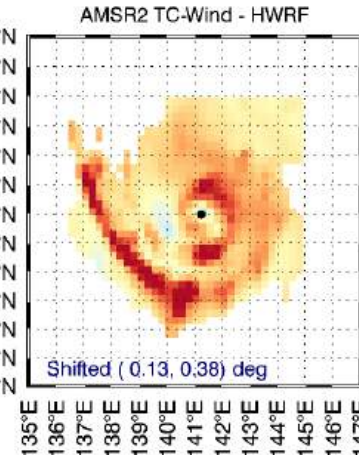
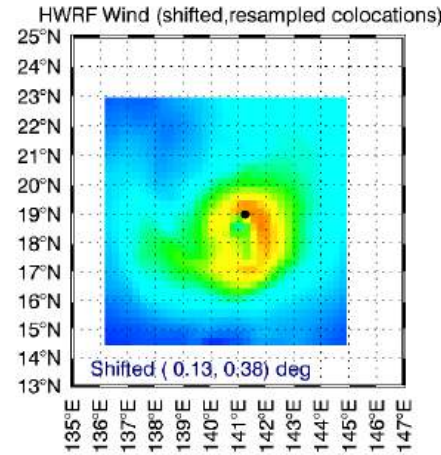
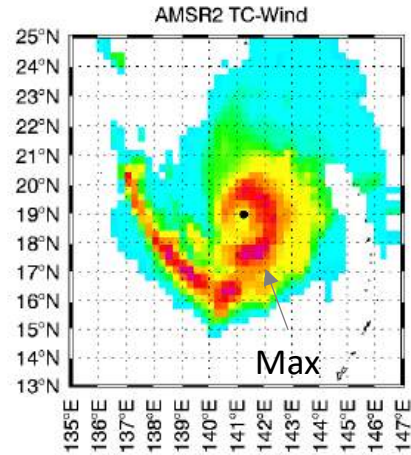
# Algorithm comparison: HAISHEN (WP11)

HAISHEN (WP11) 2020 09 02 04:03 UTC

Current C/X-band  
TC-algorithm

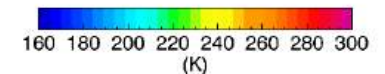
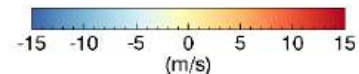
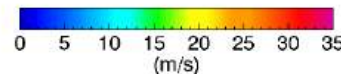
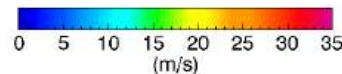
AMSR2: **35 m/s**  
HWRP : **33 m/s**  
BT : **37 m/s**

Large rain band bias  
Max SE



New 6-89 GHz  
Linear regression  
TC-algorithm

AMSR2: **37 m/s**

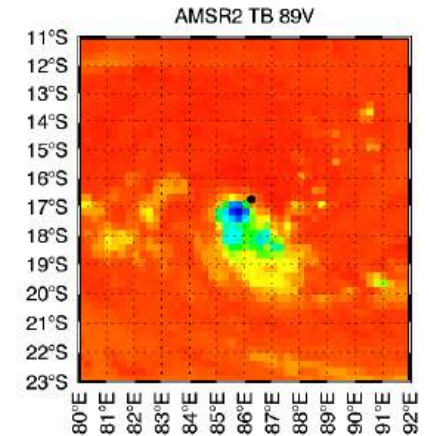
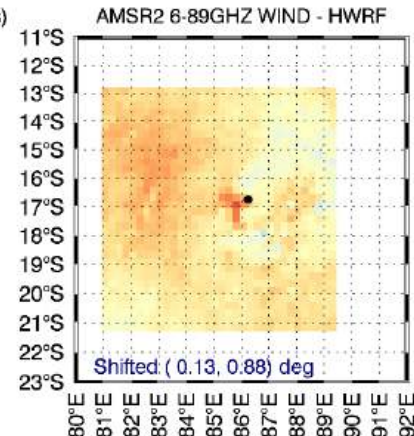
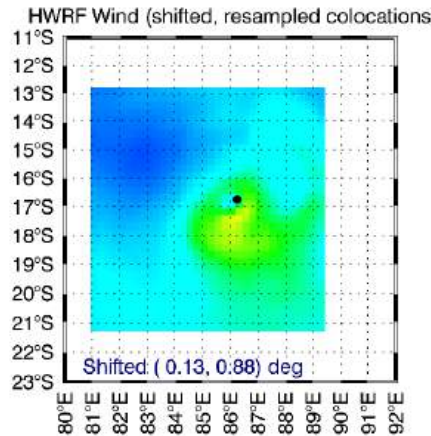
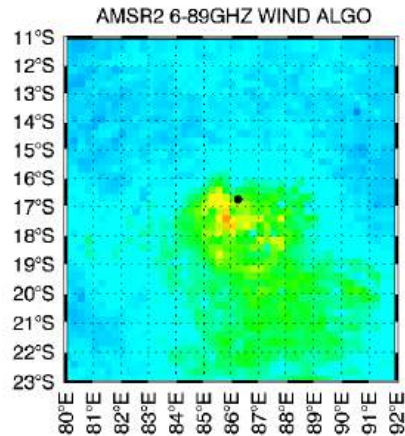
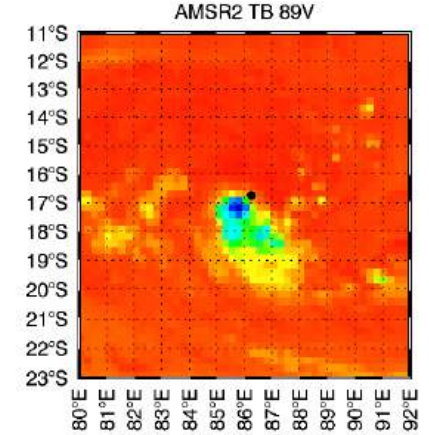
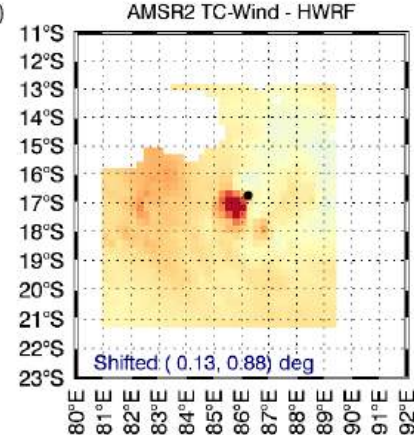
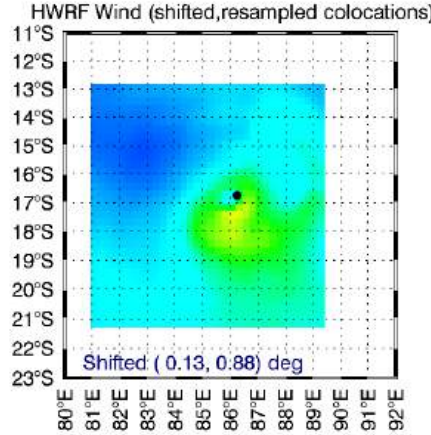
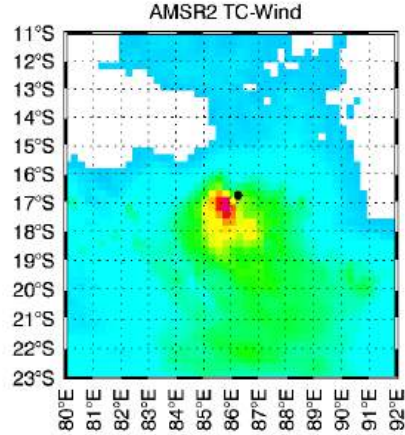


# VERNON (SH14)

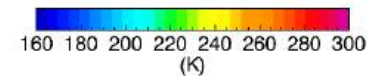
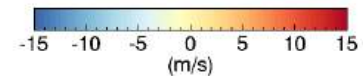
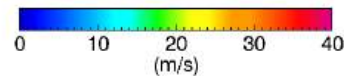
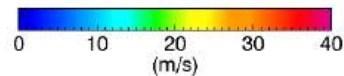
VERNON (SH14) 2022 03 01 07:54 UTC

Large bias in the core  
(cold 89GHz)

AMSR2: **45 m/s**  
HWRP : **21 m/s**  
BT : **23 m/s**



AMSR2: **29 m/s**



# New MW sensors, coming soon

## **MWI (DoD, successfully launched 11 April 2024):**

- MW Imager (MWI) by US Department of Defense, Weather System Follow-on (WSF), similar to WindSat, 6 pm/am orbit
- Includes 10-89 GHz channels, but will not have the lower frequency (C-band 6 GHz) channel.
- It will provide wind speed and direction but wind retrievals in TC without the 6 GHz channel might be challenging
- There is some potential for winds in light rain using other channels 10-89 GHz.

## **NISAR (NASA/ISRO, ~October 2024):**

- L-band SAR in 6pm/am orbit (mainly for land/ice mission)
- NASA added planned acquisitions 650 km offshore US coastal waters (include Hawaii, Caribbean) for wind retrievals in hurricane regions
- Potential L-band high resolution SAR winds in TC, no rain effect, high sensitivity at high winds, NRT.

## **AMSR-3 (JAXA, early 2025):**

- Similar to AMSR-2. It will include 11 frequencies between 6.9 and 183 GHz (new channel); In 1:30 am/pm orbit.
- RSS will provide TC-winds using algorithm similar to the new one developed now for AMSR-2.
- Additional observations: Rain, Water Vapor, SST.

# SUMMARY

- SMAP and AMSR2 continue to operate well and provide estimates of TC intensity and radii in NRT
- AMSR2 displayed significant biases in rain/icy clouds
- RSS is developing new algorithm to mitigate these biases
- A preliminary version of this algorithm is very promising. The new algorithm will be finalized in the coming weeks/months after retraining it with more extensive training dataset
- Additional flag could be applied when new algorithm displays residual spurious biases
- New RFI in Bay of Bengal, both L-band (SMAP) and C-X band (AMSR2)

Thank you!

## Recent Publications

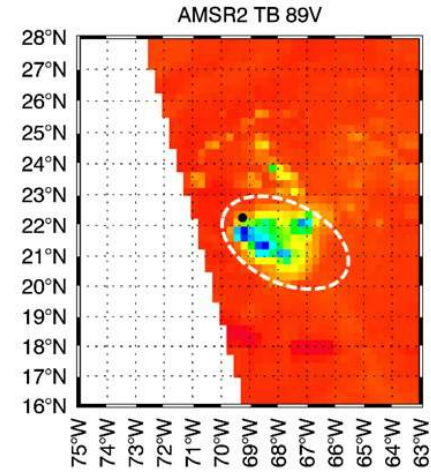
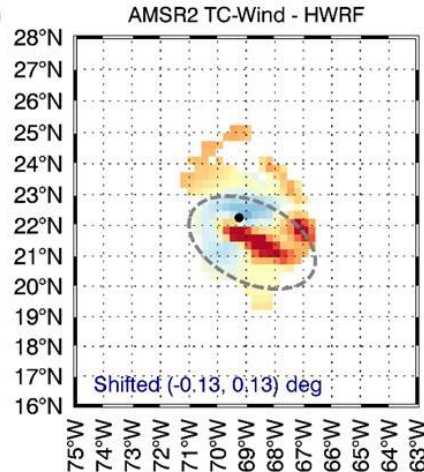
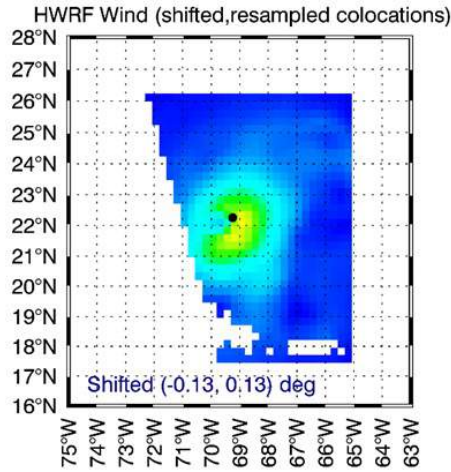
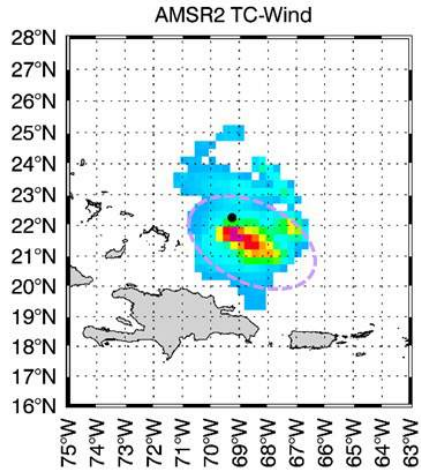
Ricciardulli, L., Howell, B., Jackson, et al, (2023): Remote Sensing and Analysis of Tropical Cyclones: Current and Emerging Satellite Sensors. *TCRR*, Vol 12(4).



# Extra slides

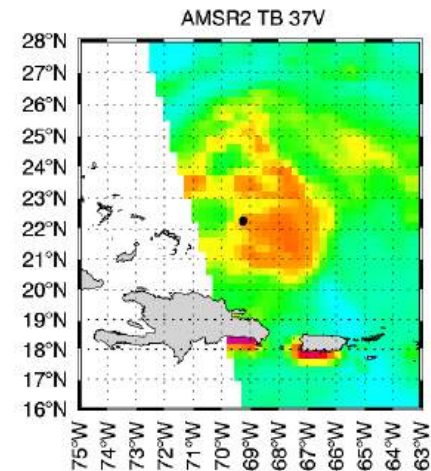
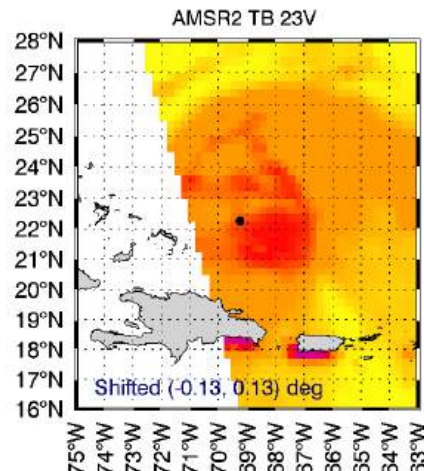
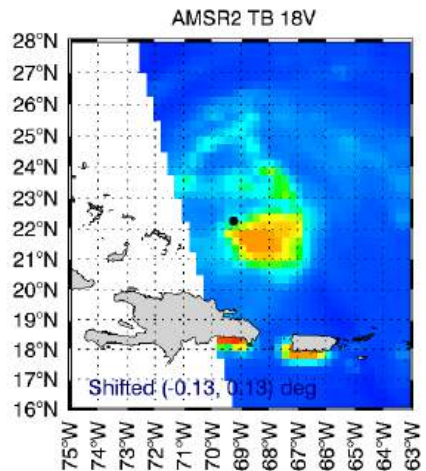
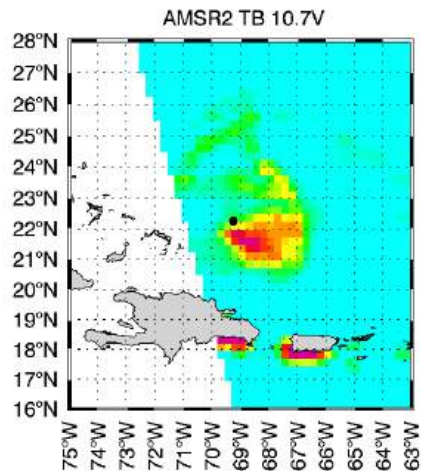
FRANKLIN (AL08) 2023 08 24 17:28 UTC

AMSR2  
Wind



AMSR2  
89 GHz

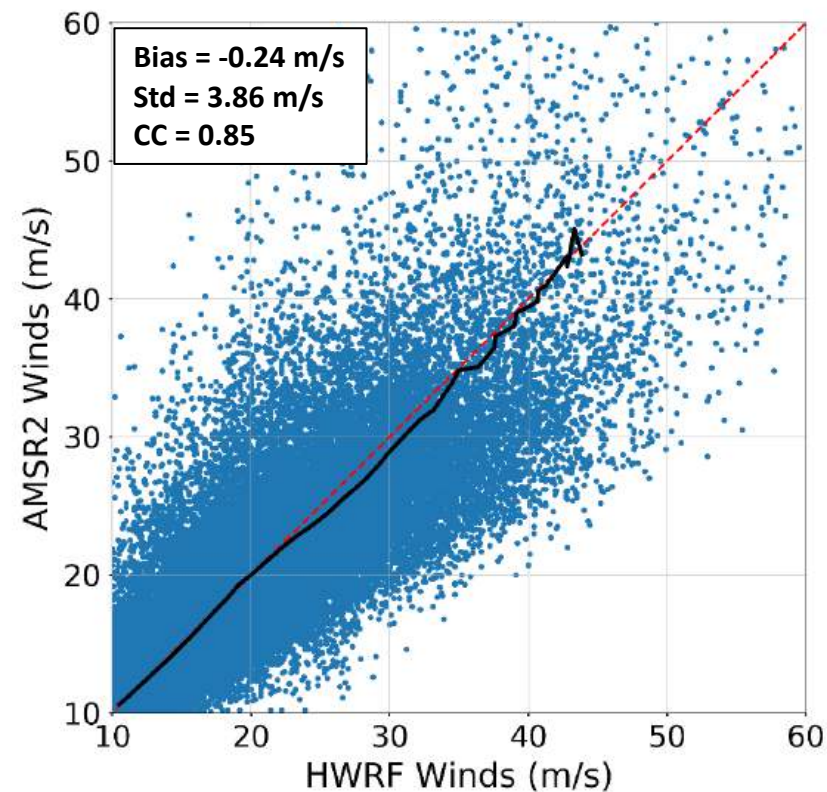
FRANKLIN (AL08) 2023 08 24 17:28 UTC



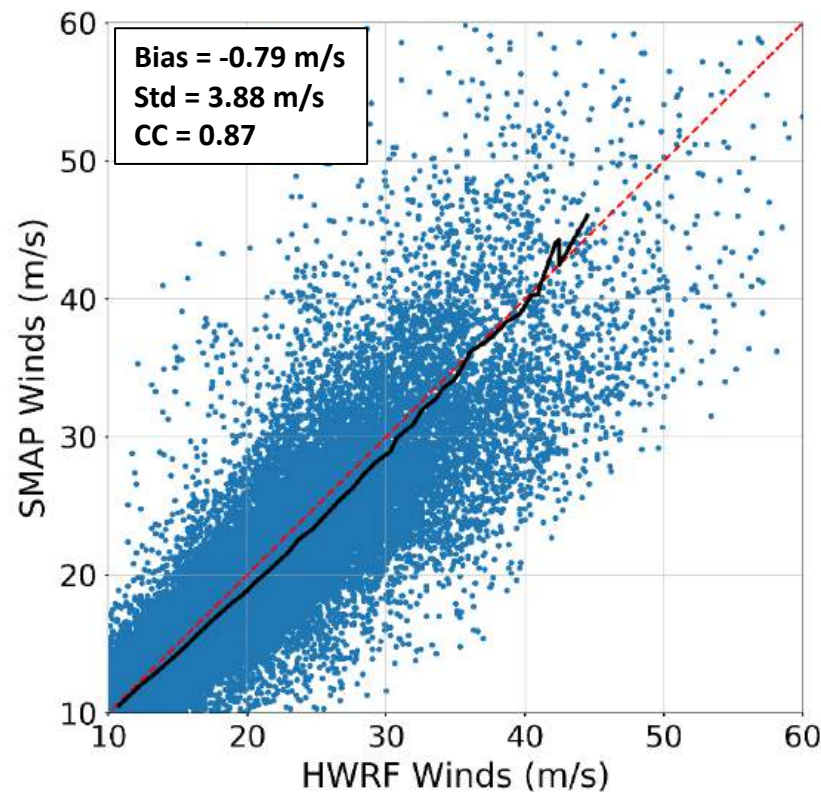
AMSR2  
37 GHz



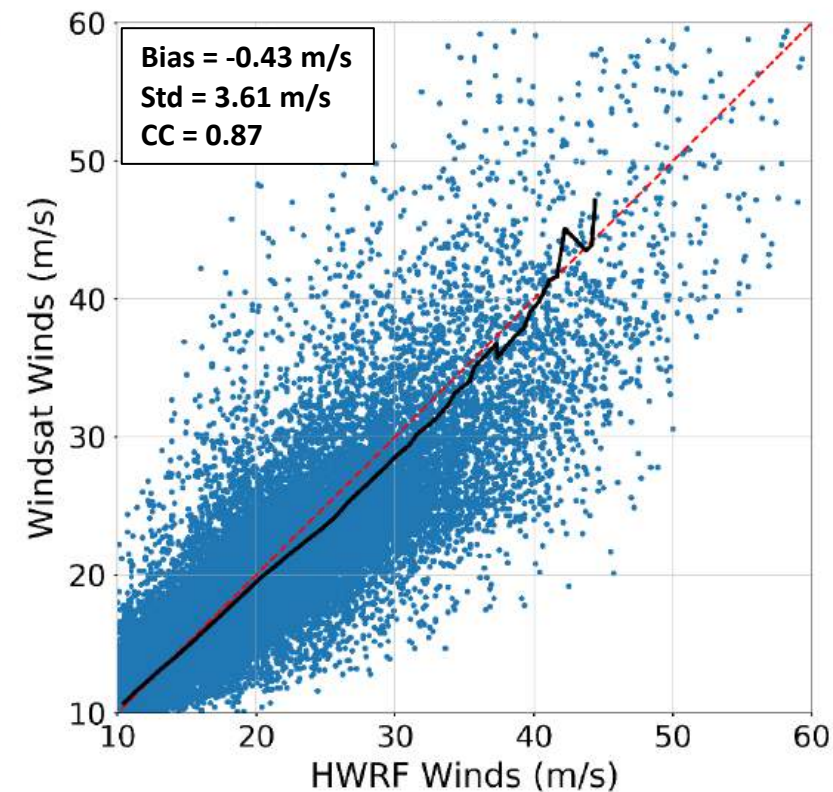
## AMSR2



## SMAP

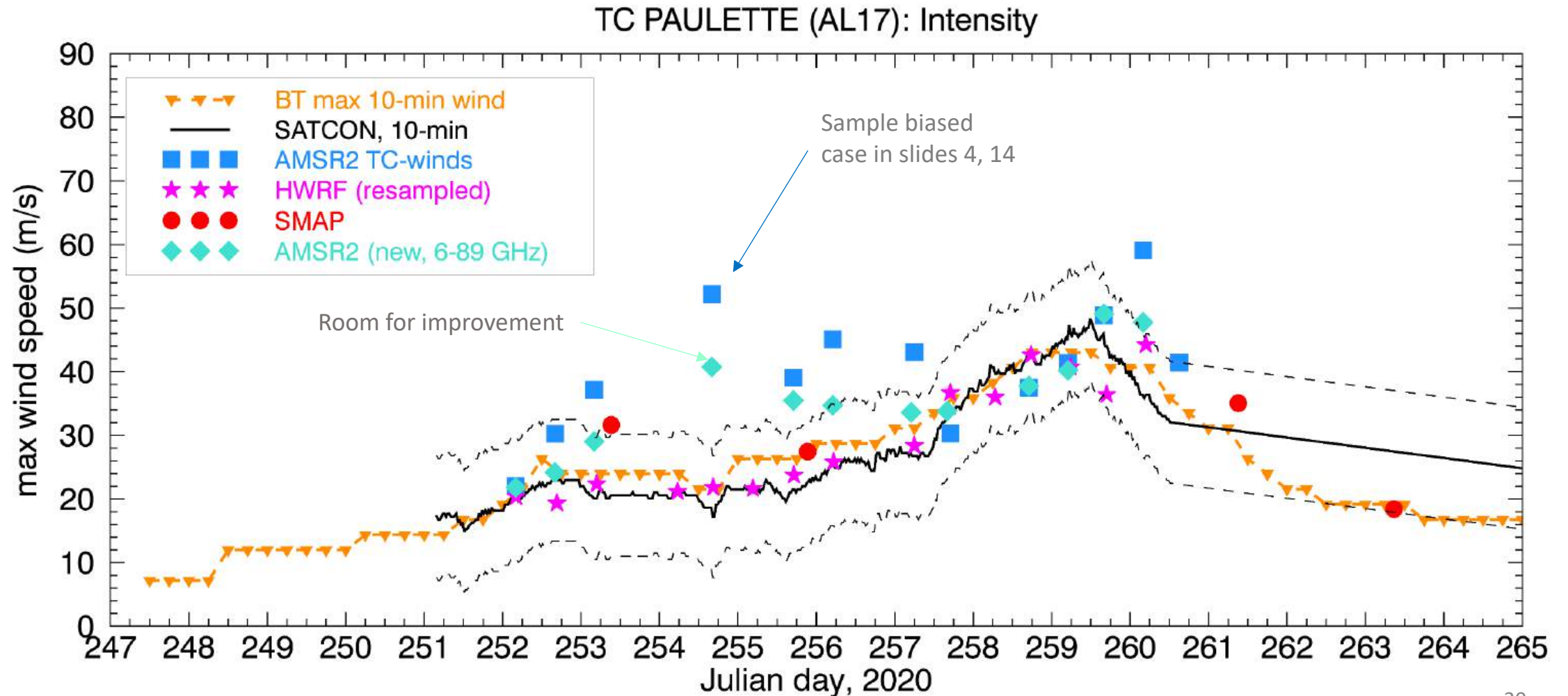


## WindSat



Good agreement between HWRP and the satellites in terms of bias, standard deviation, and correlation coefficient for winds between 10-60 m/s for 19 storms analyzed between 2017-2020.

# New algorithm (6-89GHz) vs Old (6-10GHz): PAULETTE

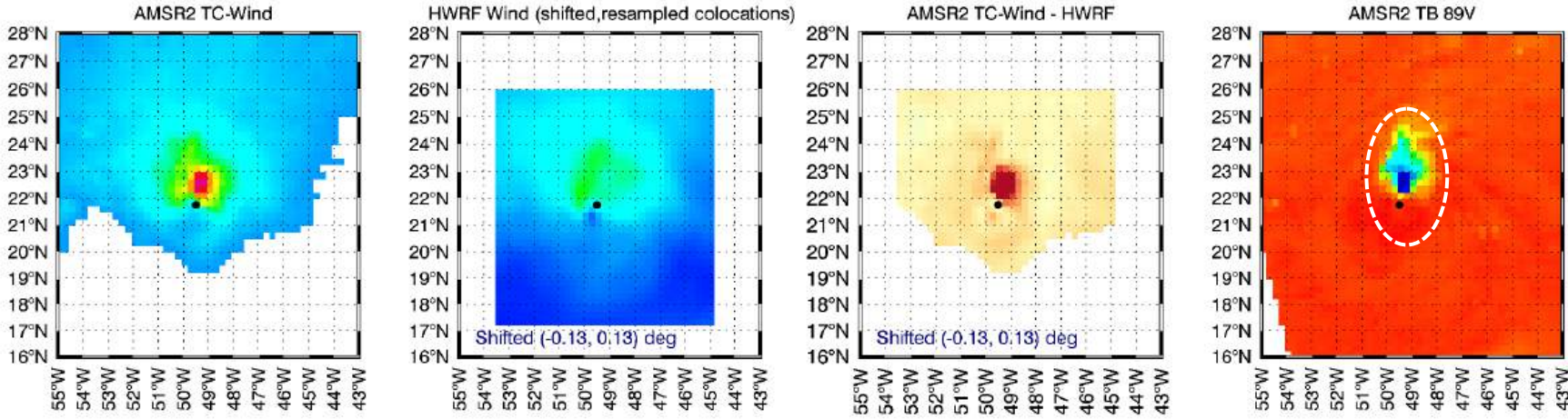


# PAULETTE (AL17, 2020)

PAULETTE (AL17) 2020 09 10 16:25 UTC

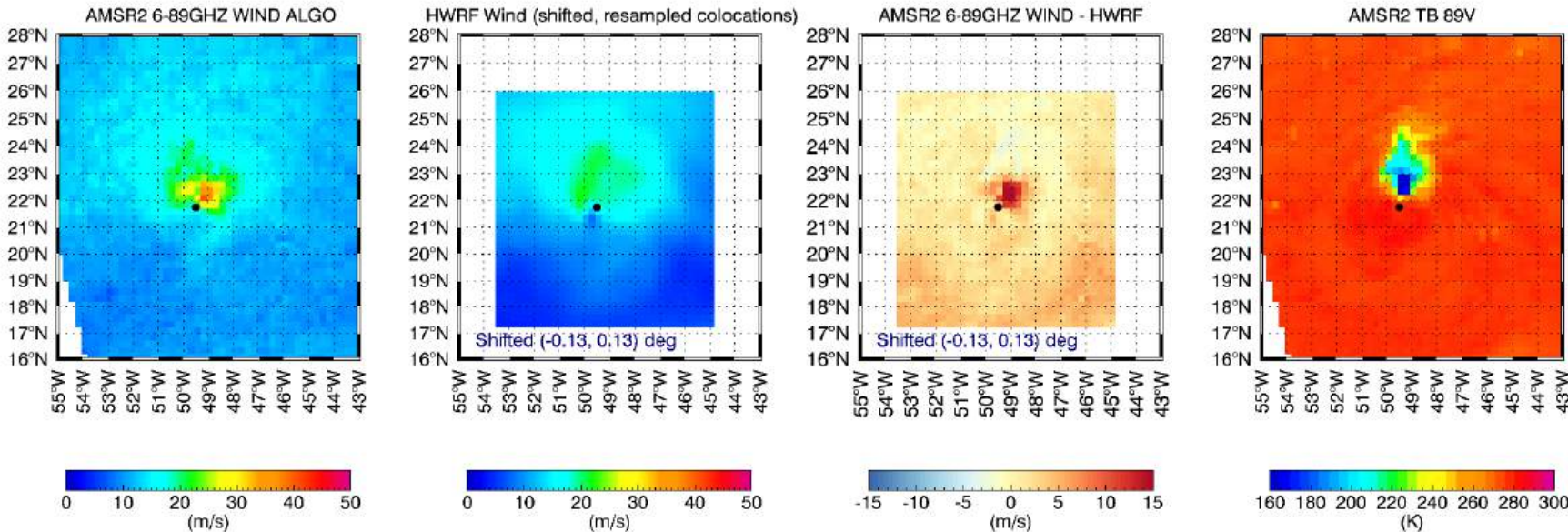
This was one of the worst case of bias with very cold 89GHz

AMSR2: **52 m/s**  
HWRP : **23 m/s**  
BT : **22 m/s**

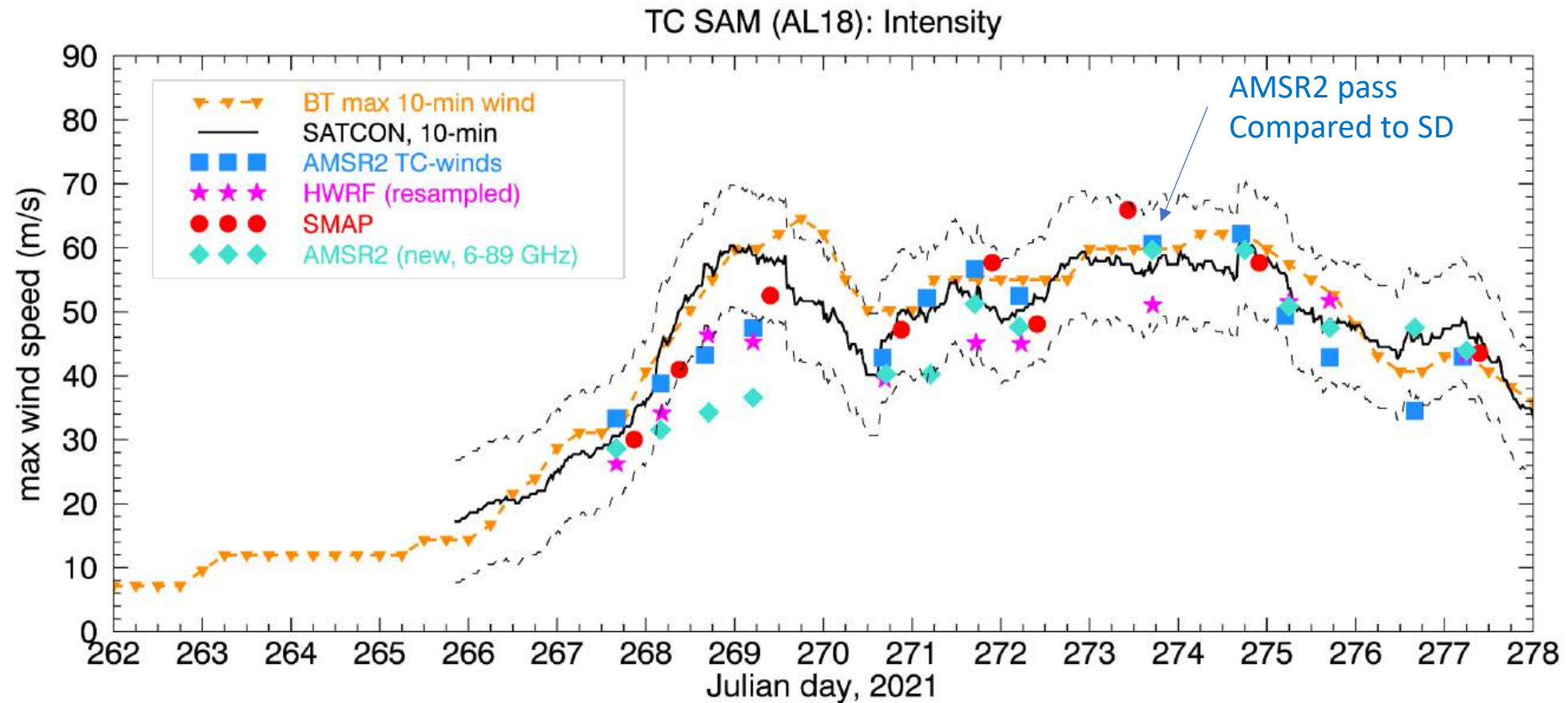


Improved but still strongly biased

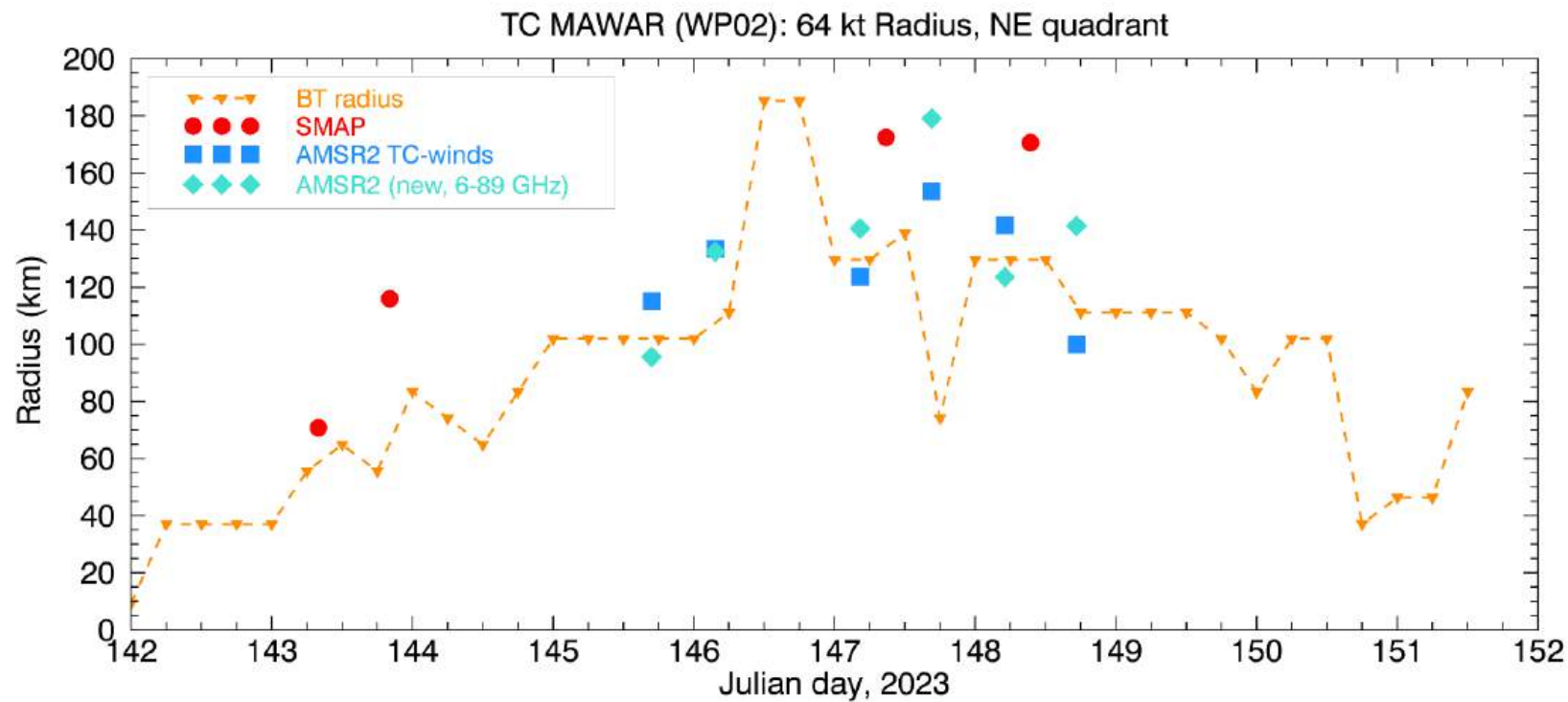
AMSR2: **41 m/s**



# New algorithm (6-89GHz) vs Old (6-10GHz): SAM

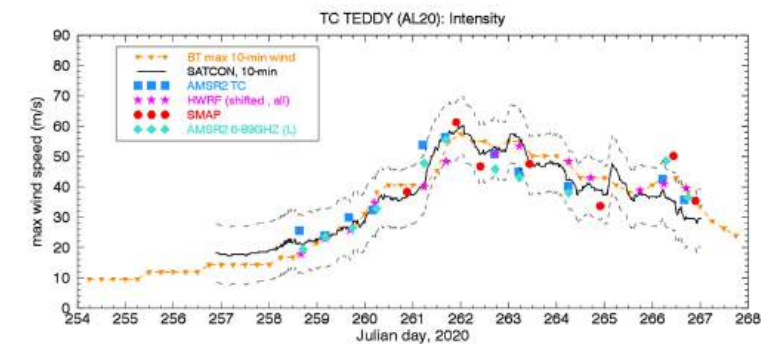
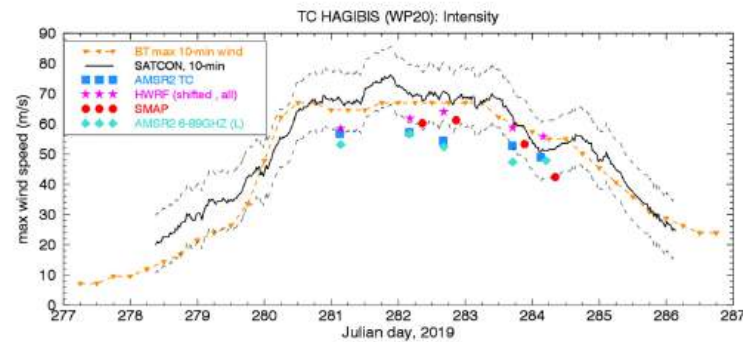
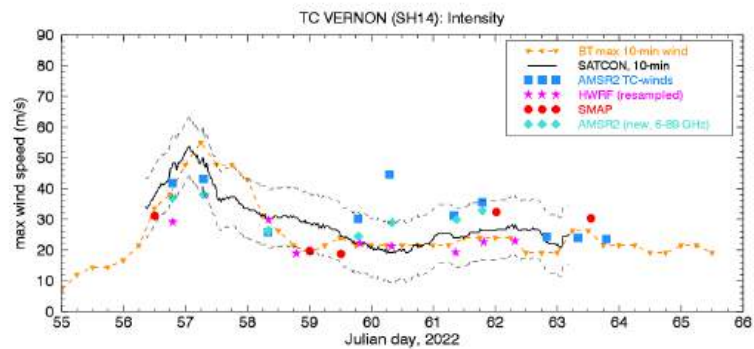
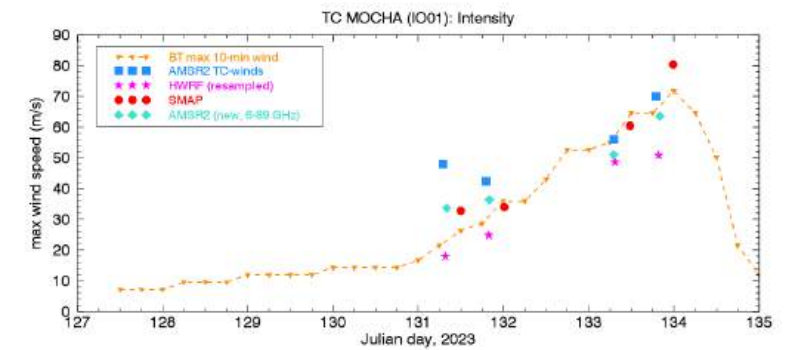
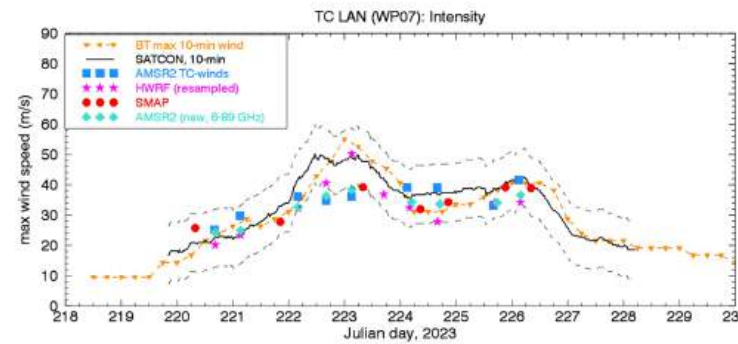
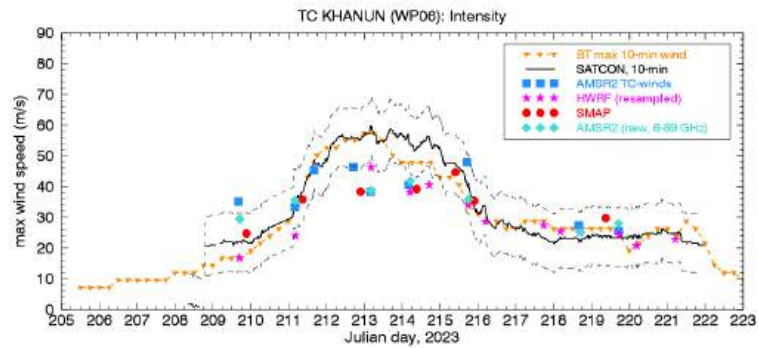
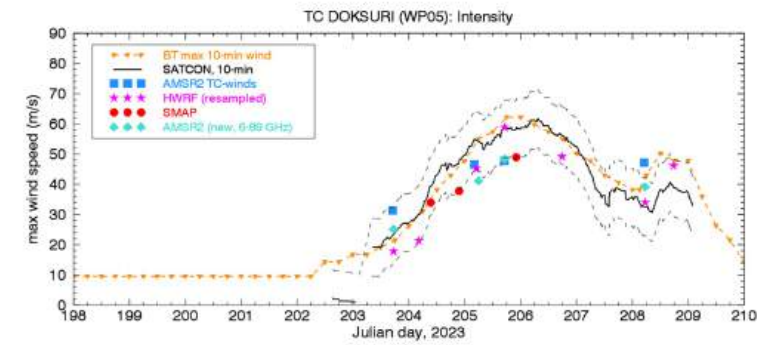
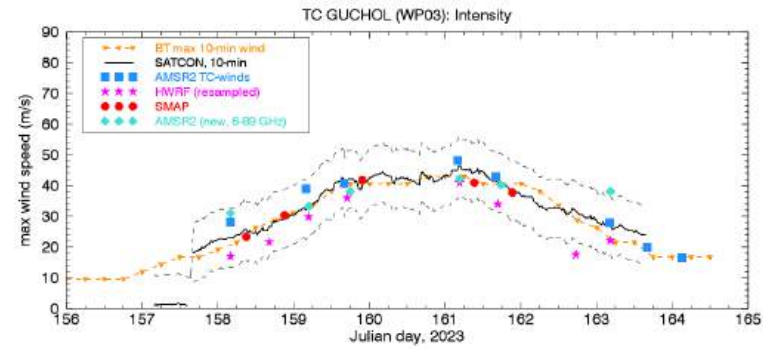
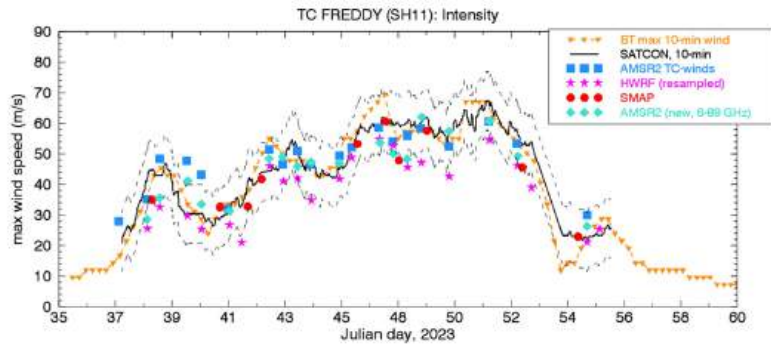


# 64 kt Radii Timeseries: MAWAR



64 kt

# TC archive for post-storm analyses: How often does it happen?

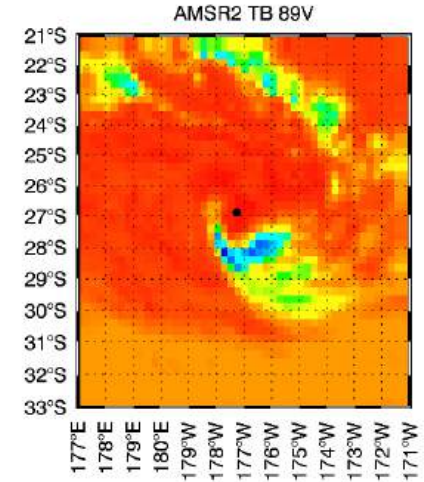
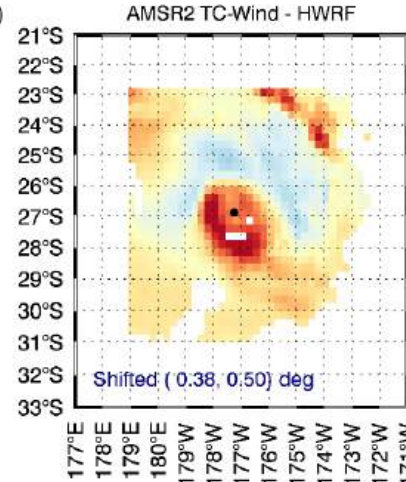
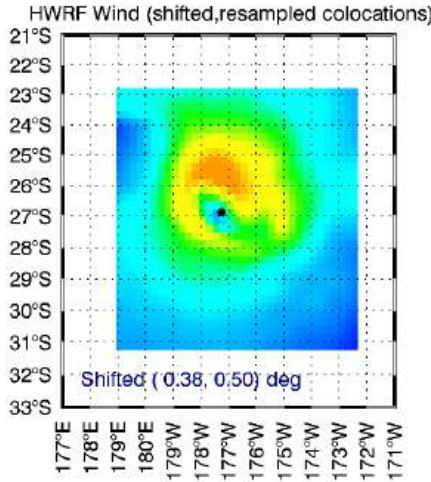
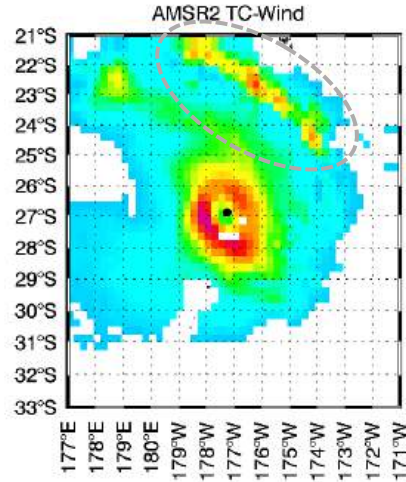


# JUDY (SH15)

JUDY (SH15) 2023 03 03 13:09 UTC

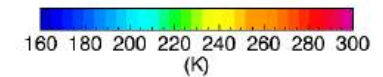
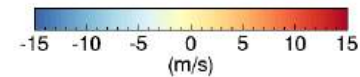
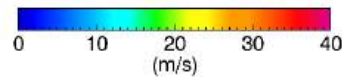
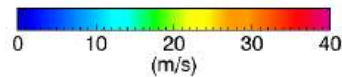
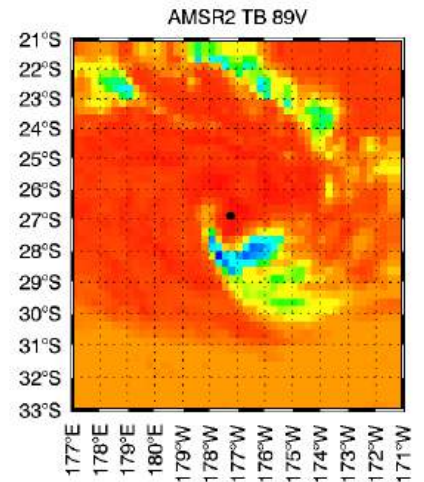
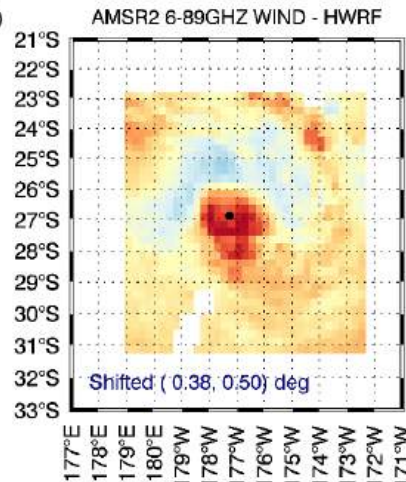
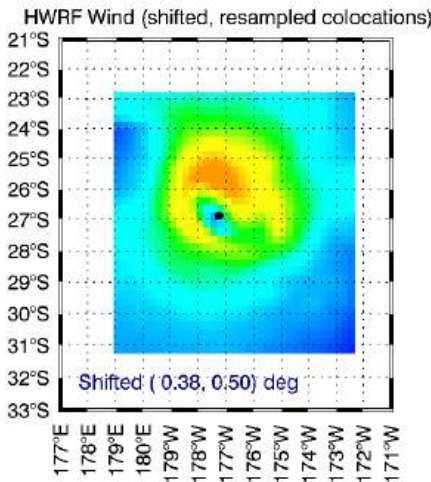
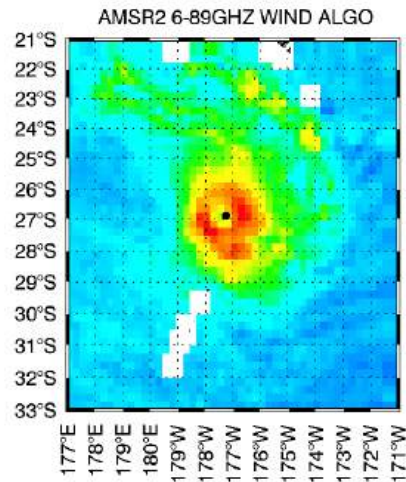
Large bias in the core and rain band

AMSR2: **43 m/s**  
 HWRF : 29 m/s  
 BT : 36 m/s



Rainband bias reduced

AMSR2: **37 m/s**

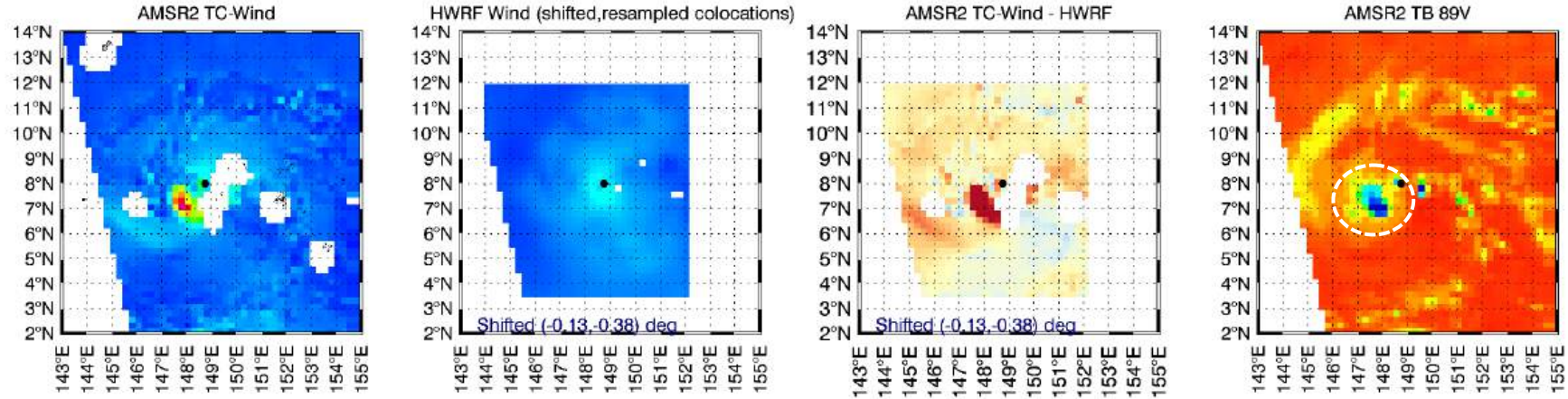


# MAWAR (WP02)

MAWAR (WP02) 2023 05 21 03:17 UTC

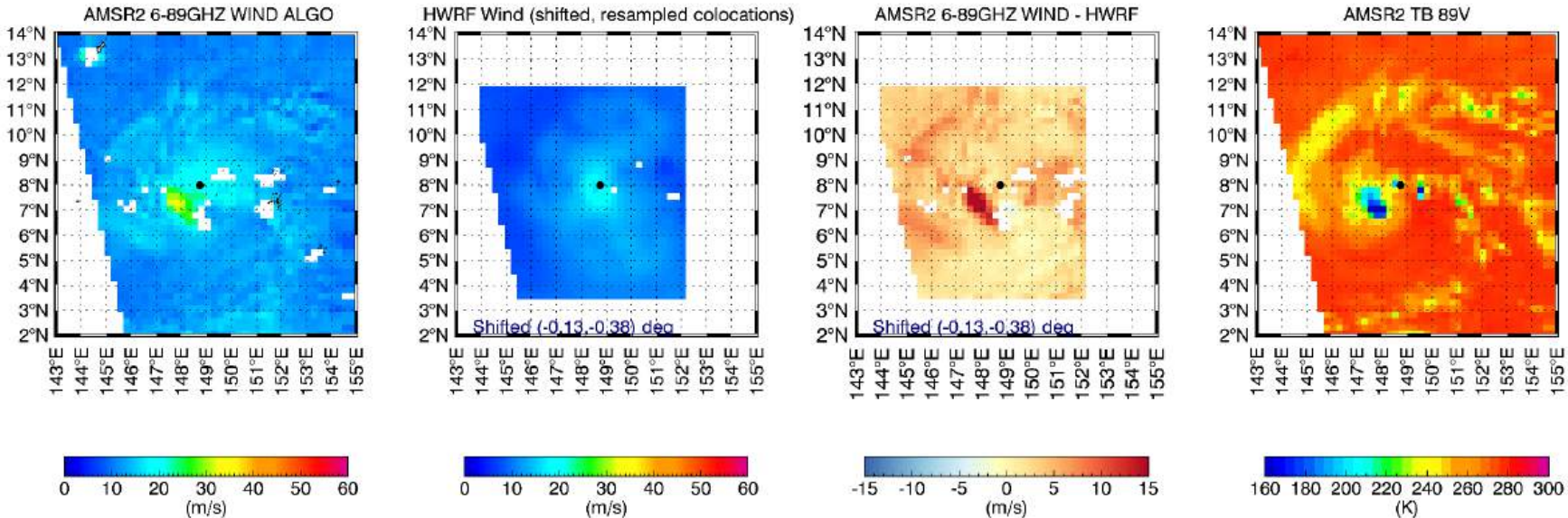
Very large bias in cold 89GHZ core (early stage)

AMSR2: 62 m/s  
HWRP : 21 m/s  
BT : 28 m/s



Improved but still some bias

AMSR2: 36 m/s



# MAWAR (WP02)

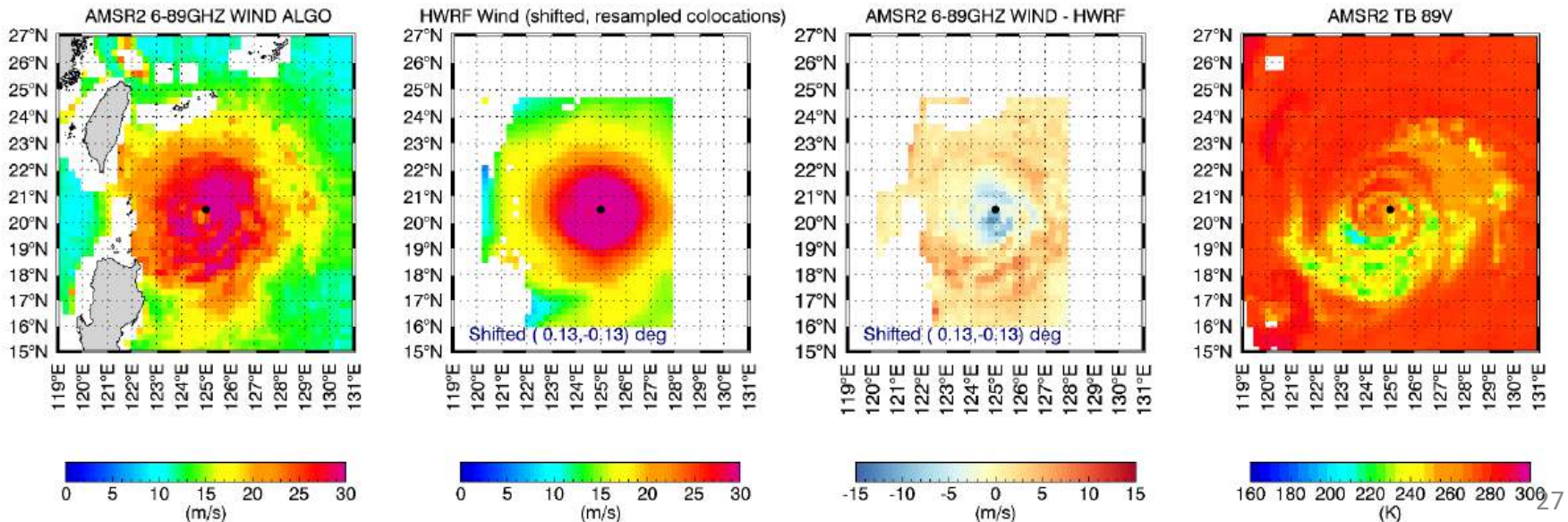
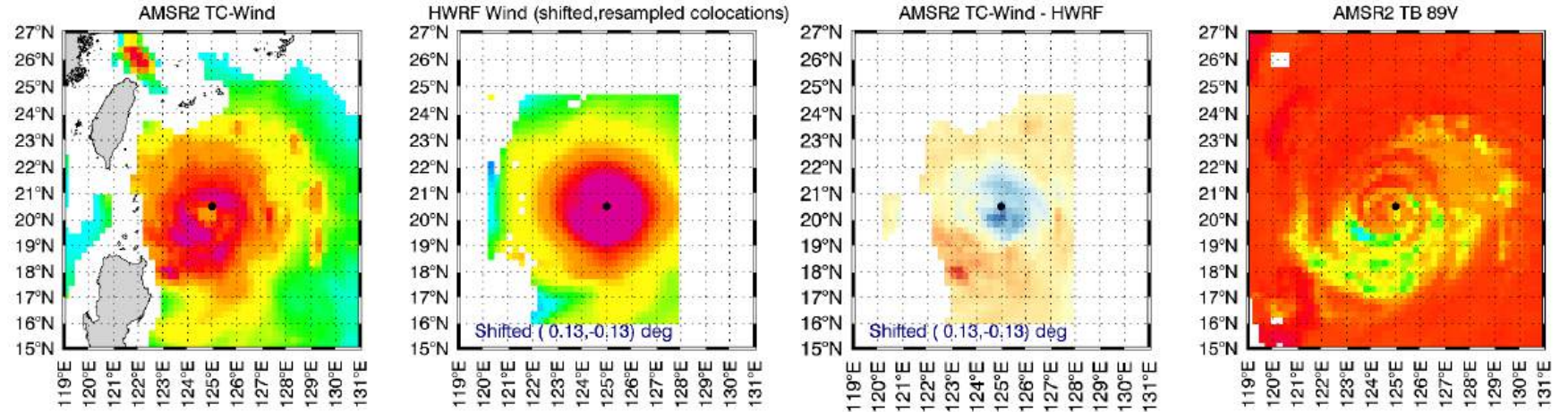
This MAWAR case is interesting because is one of the few cases where the new algorithm increases the winds

**AMSR2: 32 m/s**  
**HWRF : 38 m/s**  
**BT : 38 m/s**

The new wind field looks more similar to HWRF. Note that this storm was NOT used for training the new algorithm

**AMSR2: 36 m/s**

MAWAR (WP02) 2023 05 30 04:52 UTC

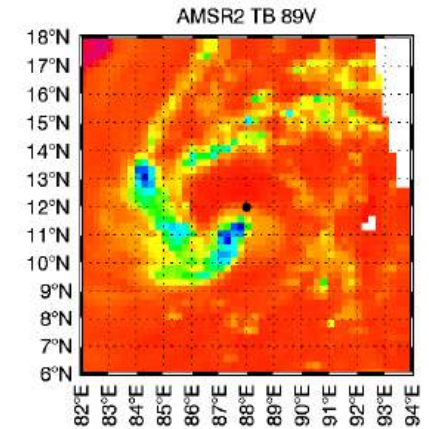
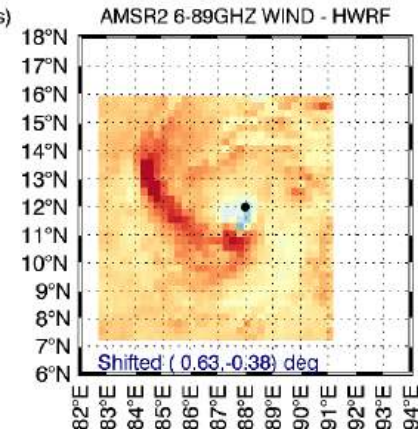
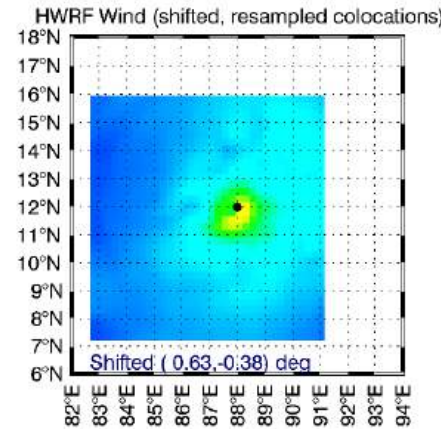
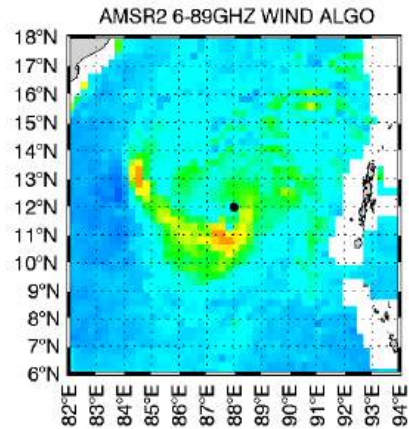
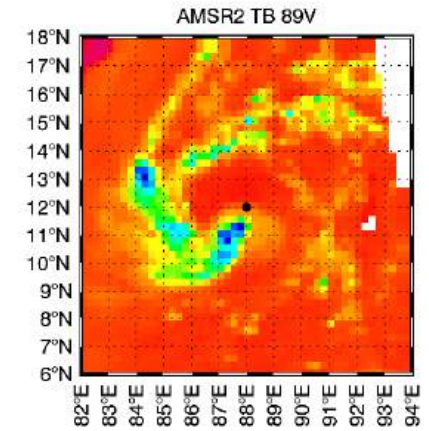
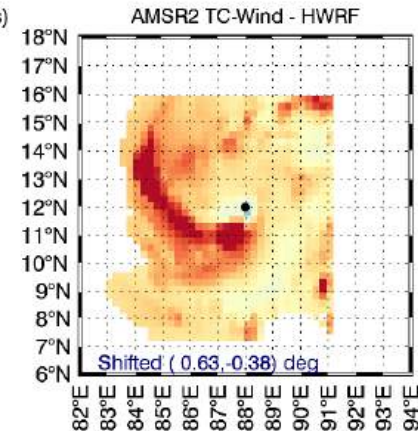
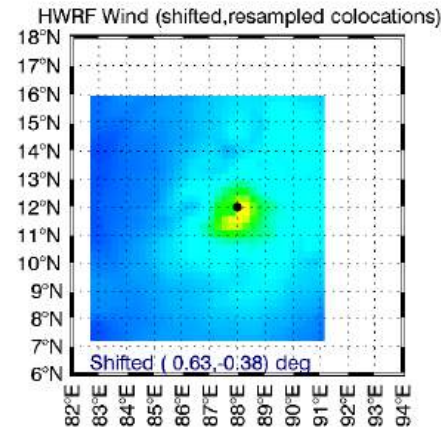
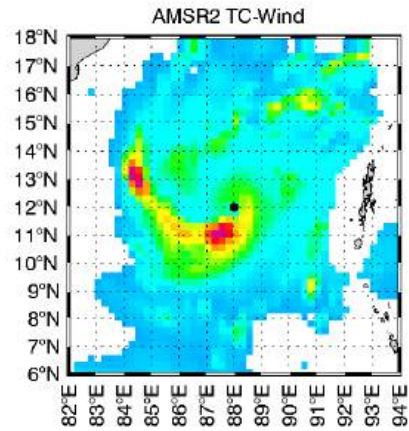


# ASANI (IO02, 2022)

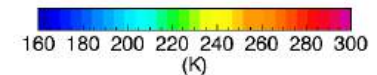
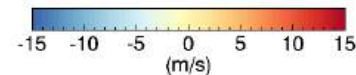
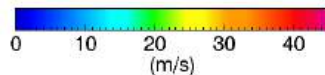
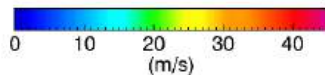
ASANI (IO02) 2022 05 08 07:37 UTC

Large bias in the core and rain band

AMSR2: 48 m/s  
 HWRF : 26 m/s  
 BT : 33 m/s



AMSR2: 32 m/s

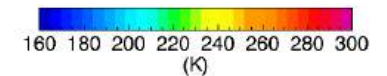
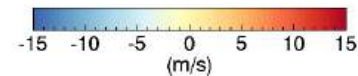
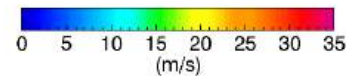
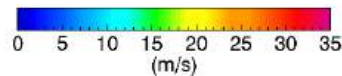
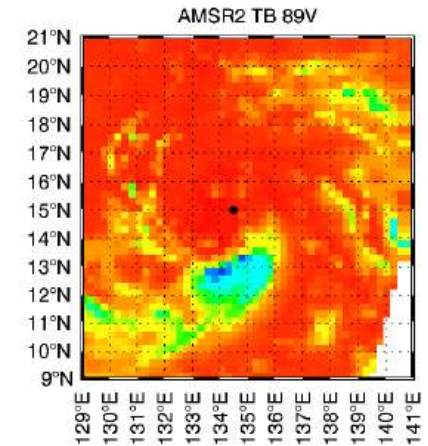
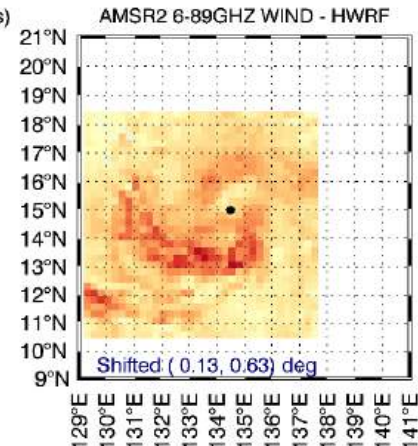
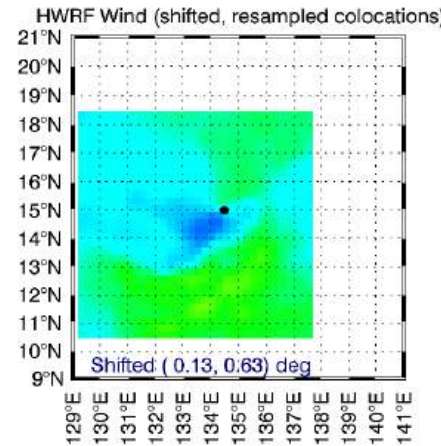
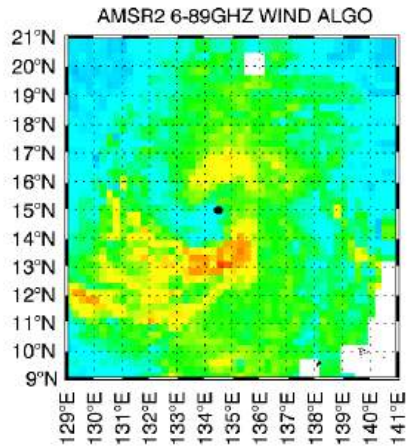
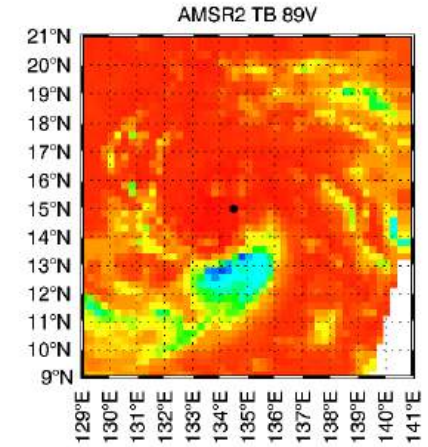
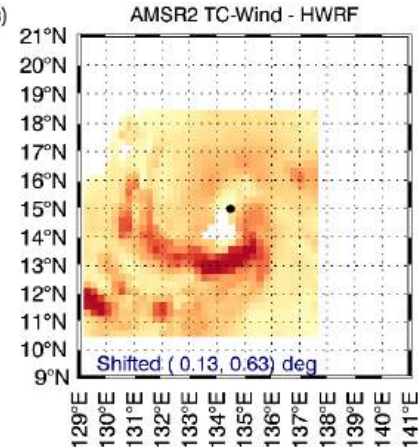
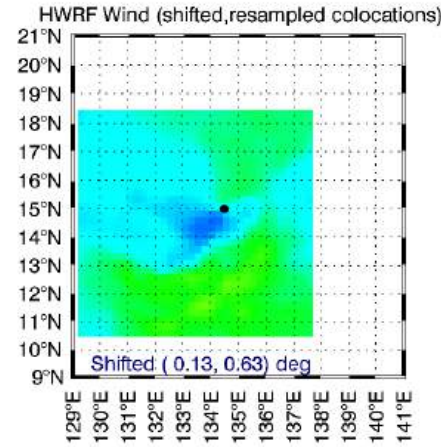
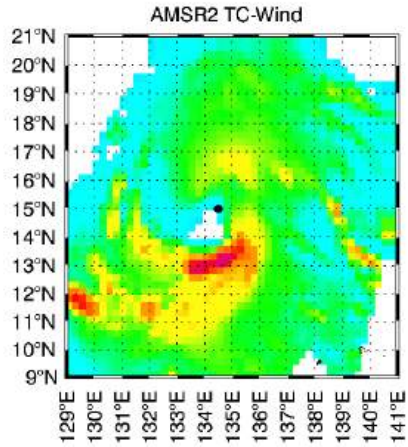


# KHANUN (WP06)

KHANUN (WP06) 2023 07 28 16:46 UTC

Large bias in the core and rain band

AMSR2: 35 m/s  
 HWRF : 17 m/s  
 BT : 18 m/s



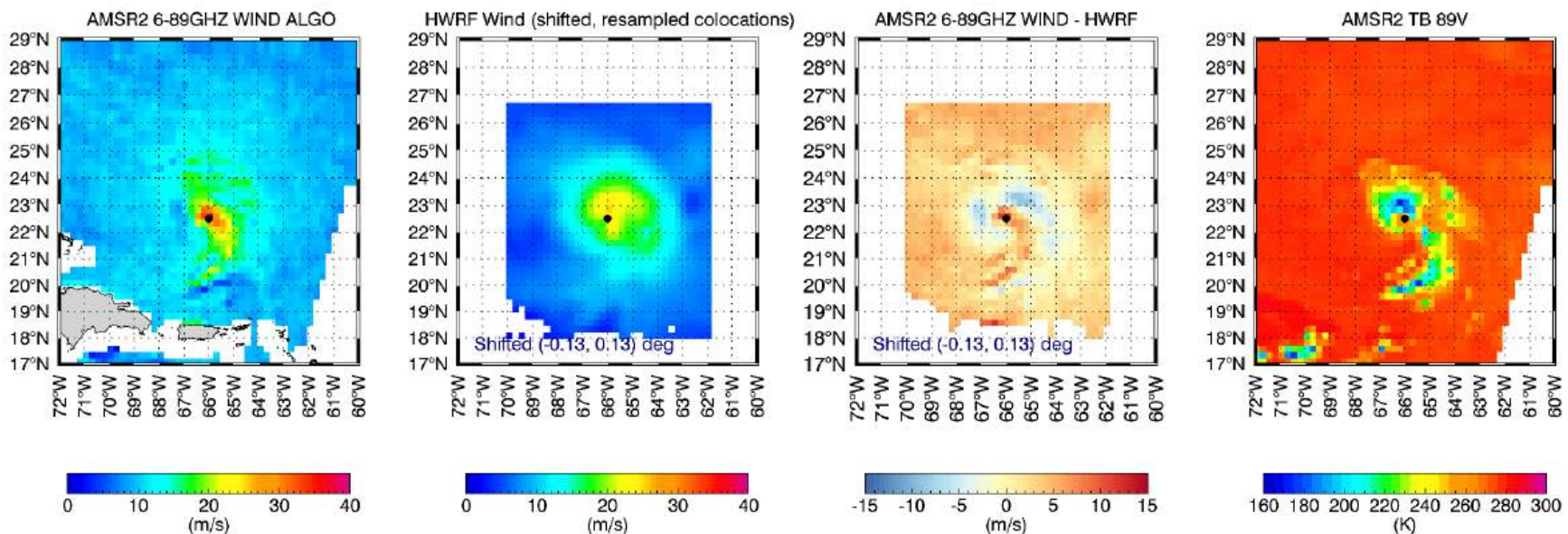
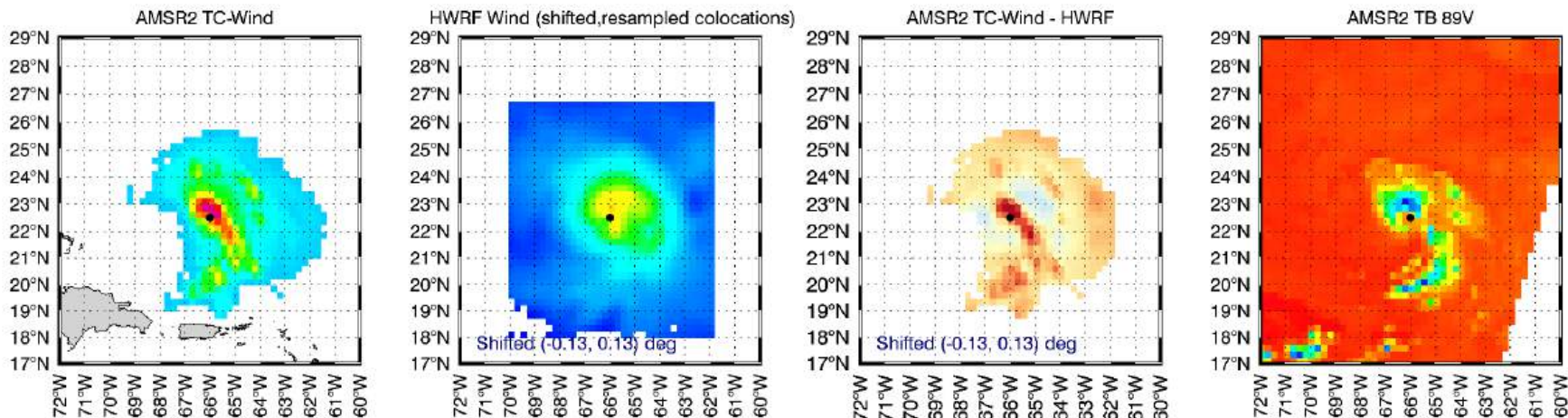
AMSR2: 29 m/s

# FRANKLIN (AL08)

Franklin had many bad cases:  
Environmental conditions with many cases of 89GHz < 200K

AMSR2: 45 m/s  
HWRP : 25 m/s  
BT : 28 m/s

FRANKLIN (AL08) 2023 08 26 06:19 UTC



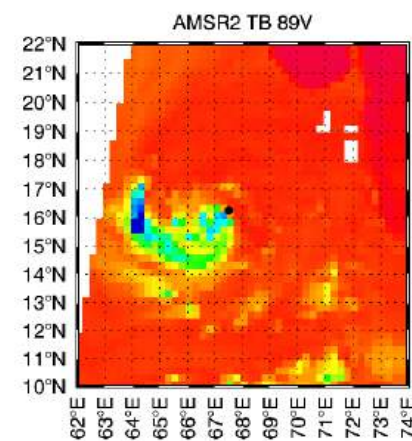
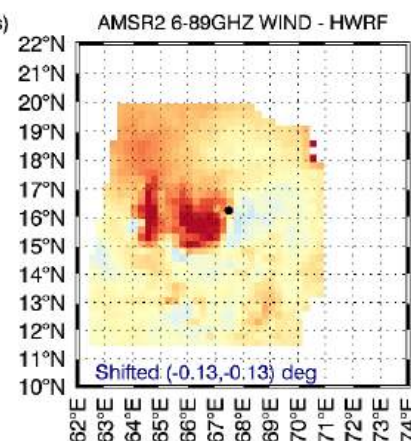
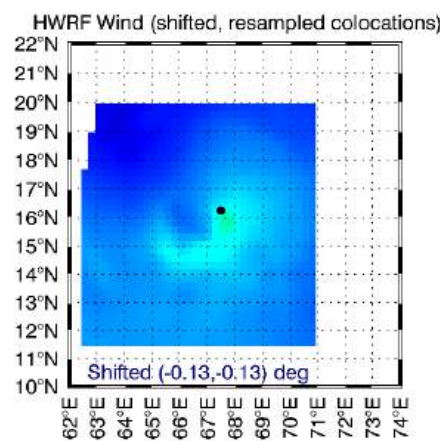
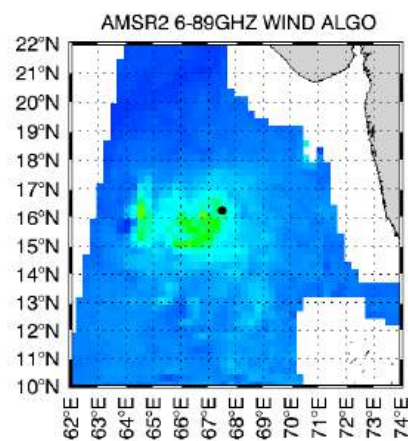
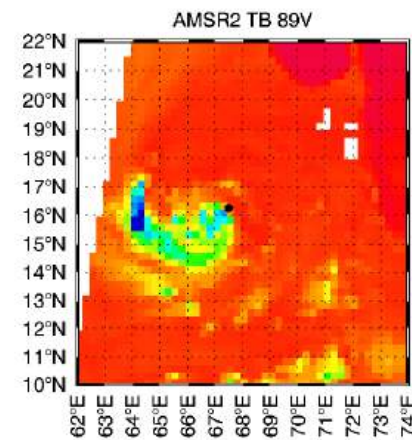
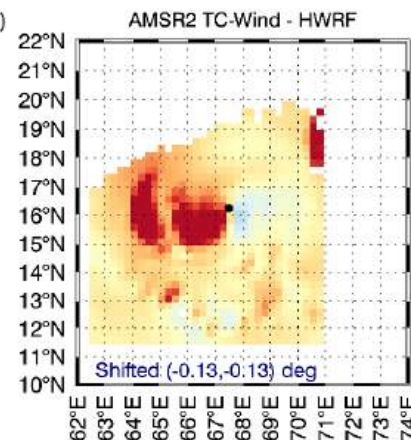
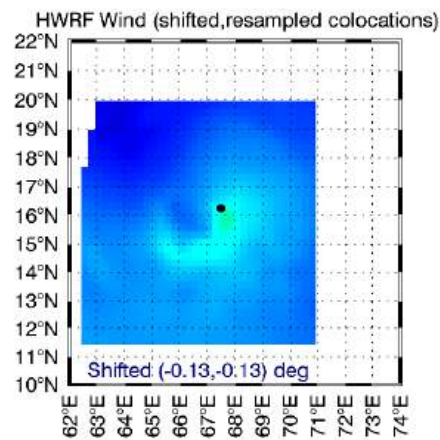
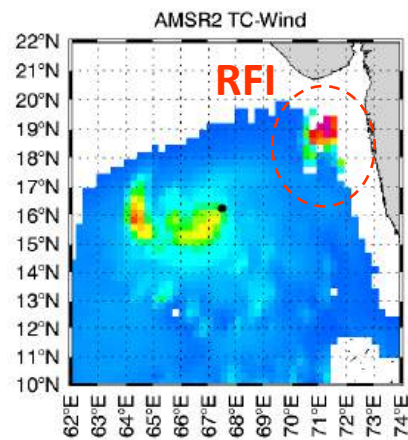
AMSR2: 37 m/s

# BIPARJOY

BIPARJOY (IO02) 2023 06 09 20:59 UTC

Large bias in the core and RFI

AMSR2: 70 m/s  
 HWRF : 27 m/s  
 BT : 36 m/s



AMSR2: 33 m/s

