Retrieving Winds in Storms with Radiometers without L- or C-Band

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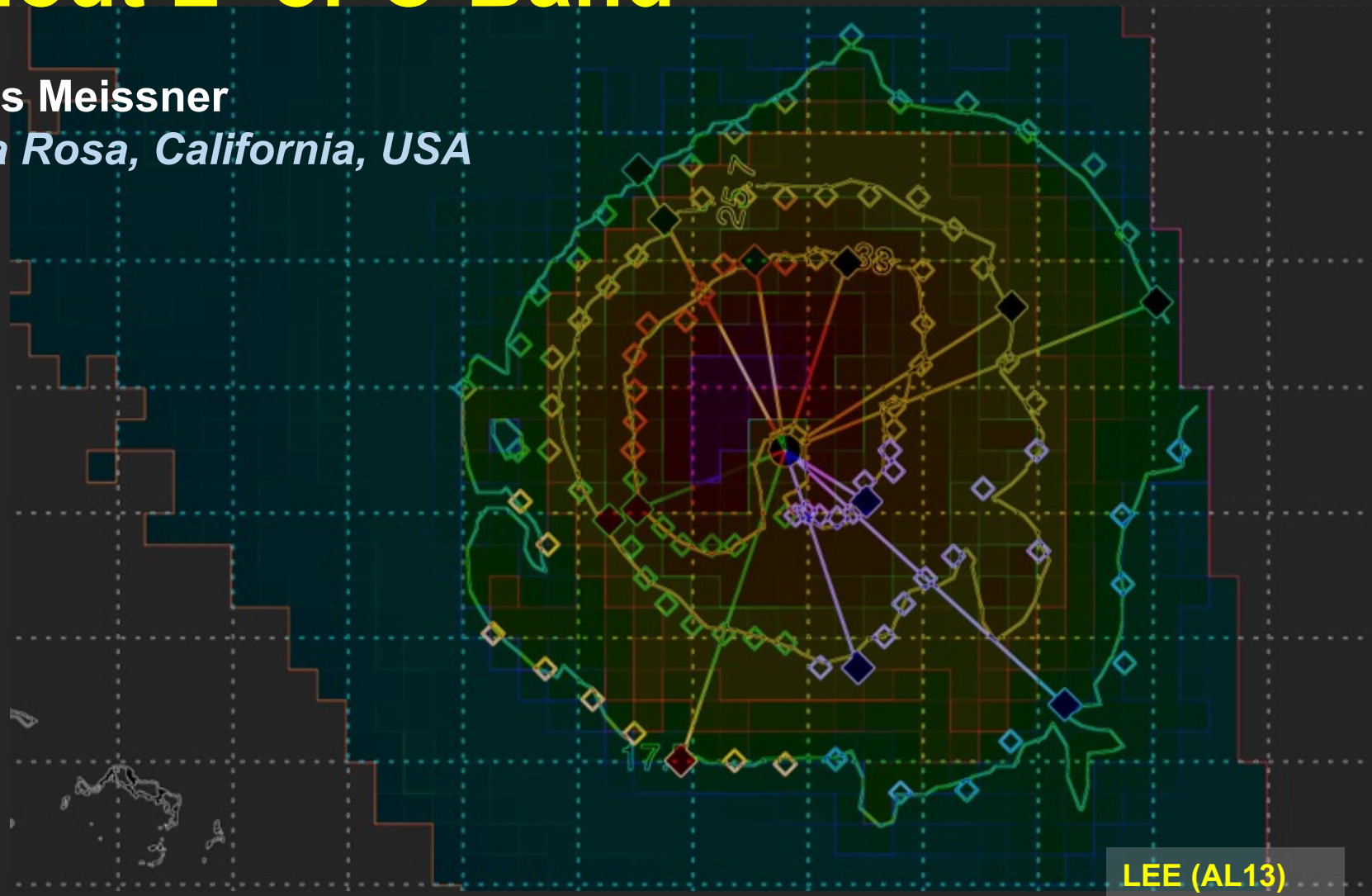
Supported by NASA OVWST program



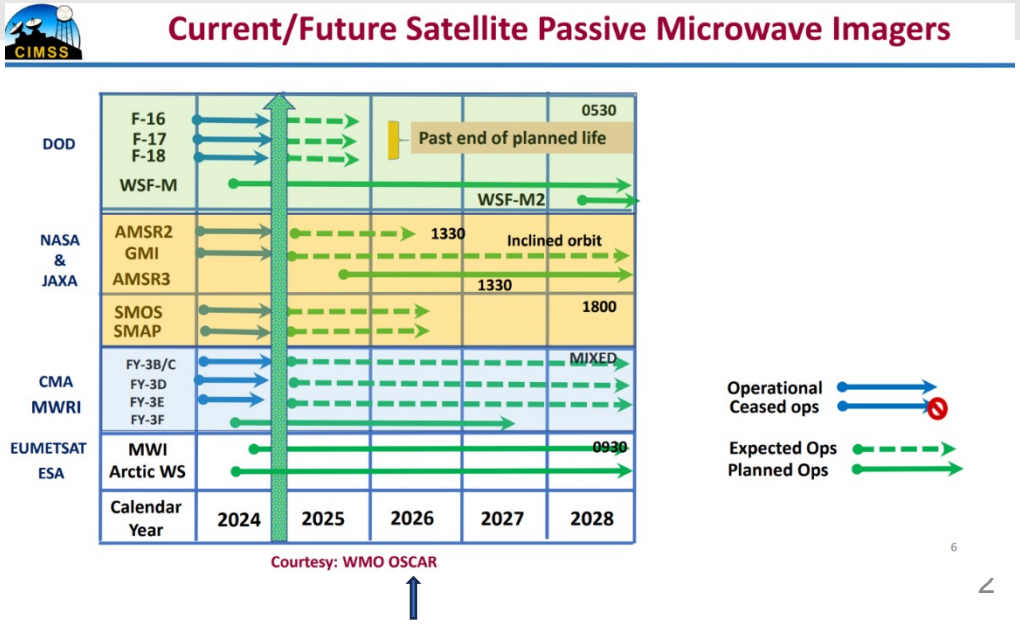
IOVWST meeting, May 18-21, 2026, Miami

Future Challenges of TC Analysis from MW radiometers

- Wide-swath MW radiometers provide useful estimates of TC size and intensity.
- Many MW radiometers are several years past their planned operation time: the DoD SSMI/S series (F16, F17, F18) will end in Sep 2026, SMAP, SMOS, AMSR2, and GMI are operating in their second decade, and they are approaching the end of their lifetime. The launch of the EUMETSAT MWI has been delayed to late 2026. Currently, and in the near future, there is poor to modest global TC coverage with radiometers. TC monitoring with MW radiometers requires large and costly antennas.

WMO IWSATC-4 report (2025) and Jeff Hawkins' presentation at Dec 2024 meeting

New Objective: Make better use of all available resources for TC, including MW sensors without L- or C-band



TC-Winds algorithms from Microwave Radiometers

Challenge

A wind algorithm from MW radiometers, valid for Tropical Cyclone and rain conditions, typically requires low frequency channels: L-band (SMAP, unaffected by rain) or C-band (AMSR2/3) to separate the wind vs rain signal.

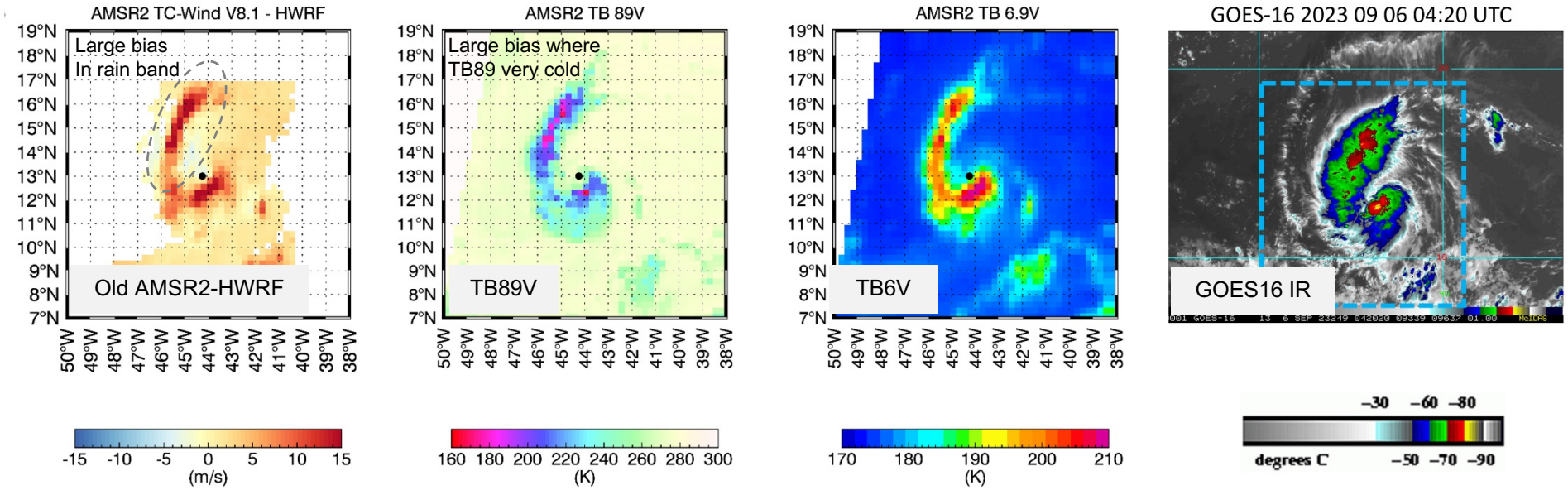
← Surface emission	Source of MW Emission					Atmosphere/clouds emission →
GHz (Band) Sensors	1.4 (L-band) SMAP/SMOS	6-7 (C) AMSR2/3	10 (X) AMSR2/3, GMI, WSF-MWI	18 (K) AMSR2/3, GMI, SSMIS, WSF-MWI	23 (K) AMSR2/3, GMI, SSMIS, WSF-MWI	37 (Ka) AMSR2/3, GMI, SSMIS, WSF-MWI	89 (W) AMSR2/3, GMI, SSMIS, WSF-MWI
Wind	No rain impact/ Sensitivity to high winds						
Rain/Cloud							
Ice/Scatter.							

V8.1 (Meissner et al, 2021) — Old AMSR2 TC-wind algorithm

V8.2 (Ricciardulli et al, 2026) — New AMSR2 TC-wind algorithm

Motivation for new AMSR2 wind algorithm in TC

Spurious large wind bias ← Very cold TB_{89} (< 200K) ← Very warm $TB_{6\text{-}10}$ ← Very deep cloud (cold T_{IR})



- Occasional large positive biases in old TC-winds were found in regions where TB89 was very cold (< 200K, ~3% cases)
- Using AMSR2 TBs, we found that the 89 GHz channel is very valuable for mitigating rain/cloud impact in TCs
- It provides a proxy of the cloud depth, cold troposphere emission, and amount of cloud water in the column, which all impact the wind retrievals.
- A new algorithm using 6-89 GHz was developed for AMSR2 and performs very well in TCs

New AMSR2 wind algorithm: TC-winds V8.2

- New algorithm (V8.2): statistical linear regression using all channels 6-89 GHz (C to W-band); TBs are the only input.

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

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

- Training dataset: HWRF wind fields in TCs (~200 passes, 2018-2023) colocated with AMSR2 TB, after resampling
- Testing/validating dataset: HWRF (~150 passes, 2023-2024)
- Large biases significantly mitigated, especially for TB89 < 200K.

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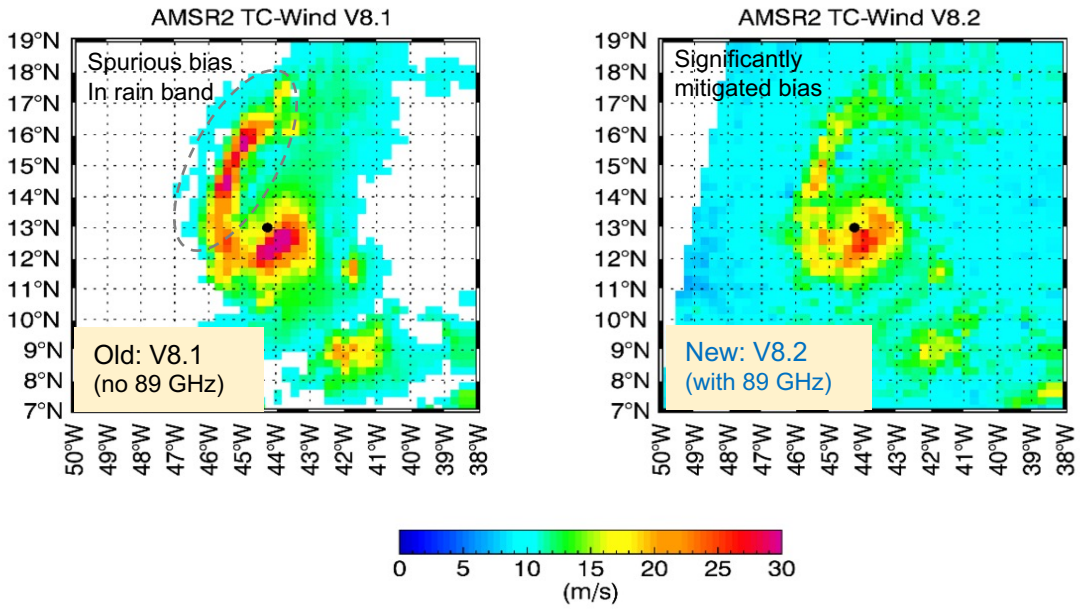
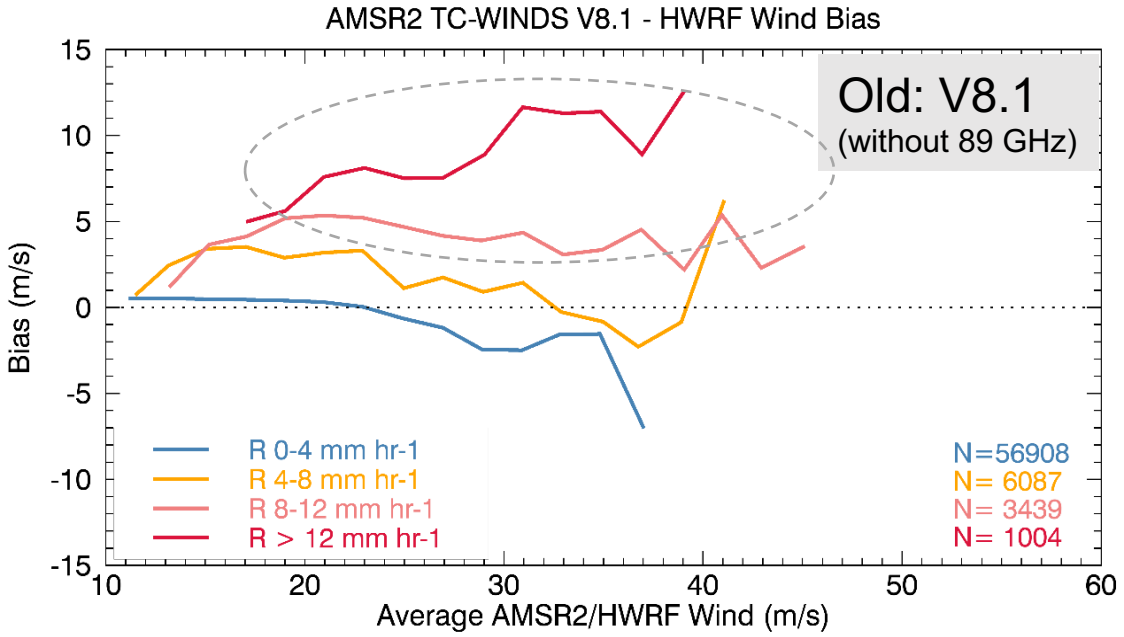


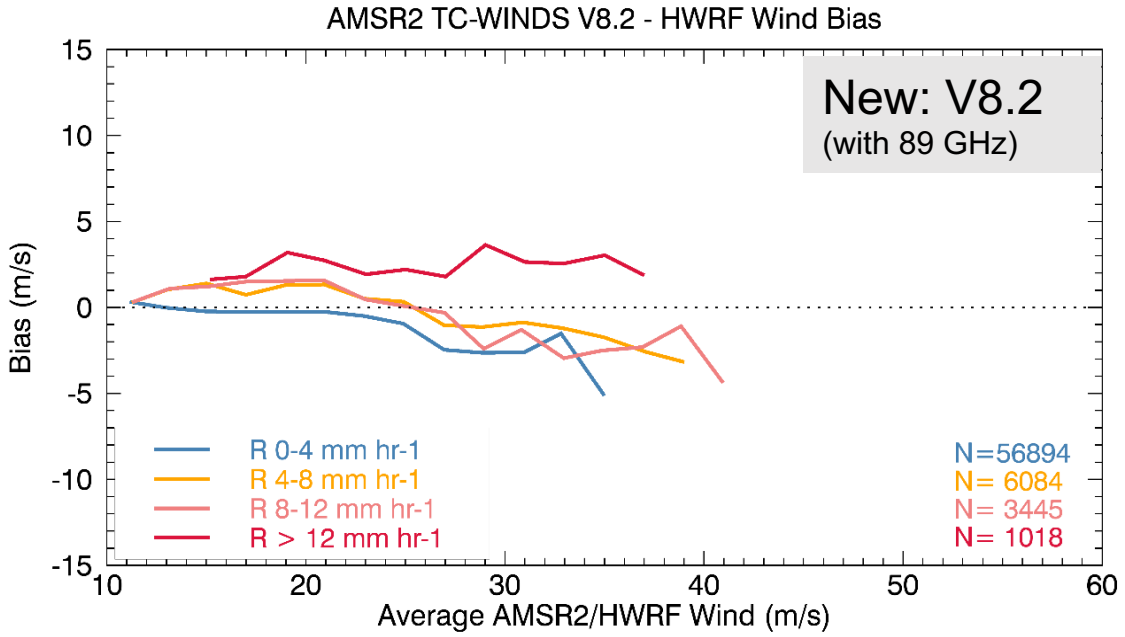
- AMSR2 TC-winds V8.2 implemented in Nov 2024 in NRT at RSS
- Data, fixes, images in NRT at https://www.remss.com/tropical-cyclones/tc-winds/

Ricciardulli, Meissner, Manaster: *Advanced AMSR2 Radiometer TC-Wind Algorithm for Mitigation of Rain Impact*, IEEE TGRS, 2026, accepted, under final revision

Rain impact in AMSR2 winds (V8.1 and V8.2)

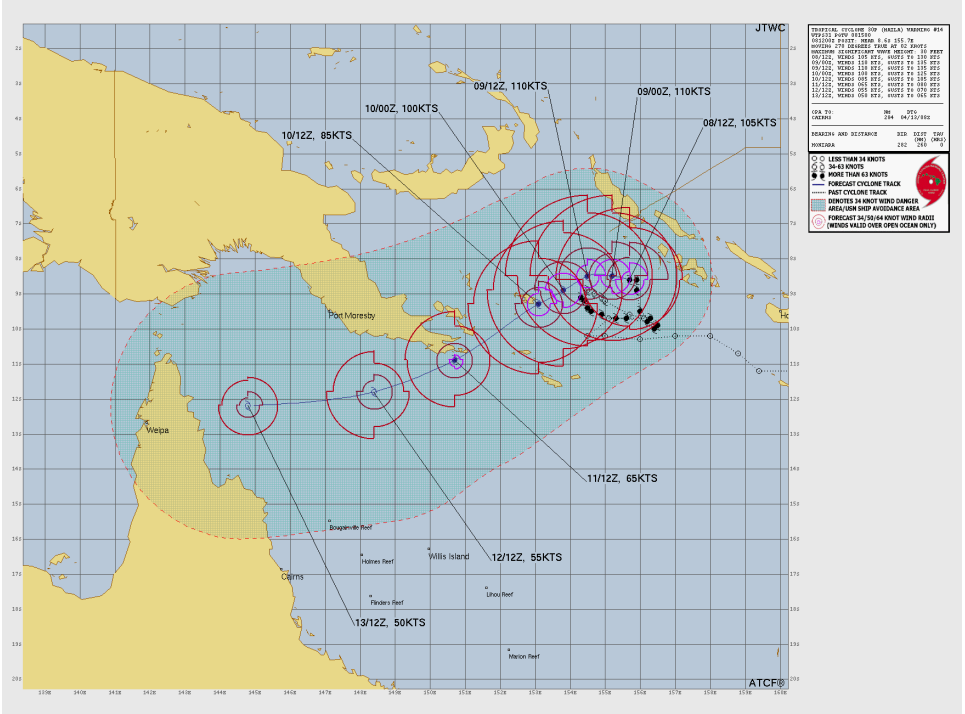
BIAS: AMSR2 vs HWRF as a function of RAIN RATE





Storm parameters for Operational Users: Satellite-based Intensity and Radii

1) Estimates of intensities (max wind at 25 km res, ~ 10-min sustained)
2) Estimates of radii:
   - Gale-force: R34 radius of 34 kt (17 m/s) → solid contour
   - Storm-force: R50 radius of 50 kt (25 m/s) → dotted contour
   - Hurricane-force: R64 radius of 64 kt (33 m/s) → dashed contour



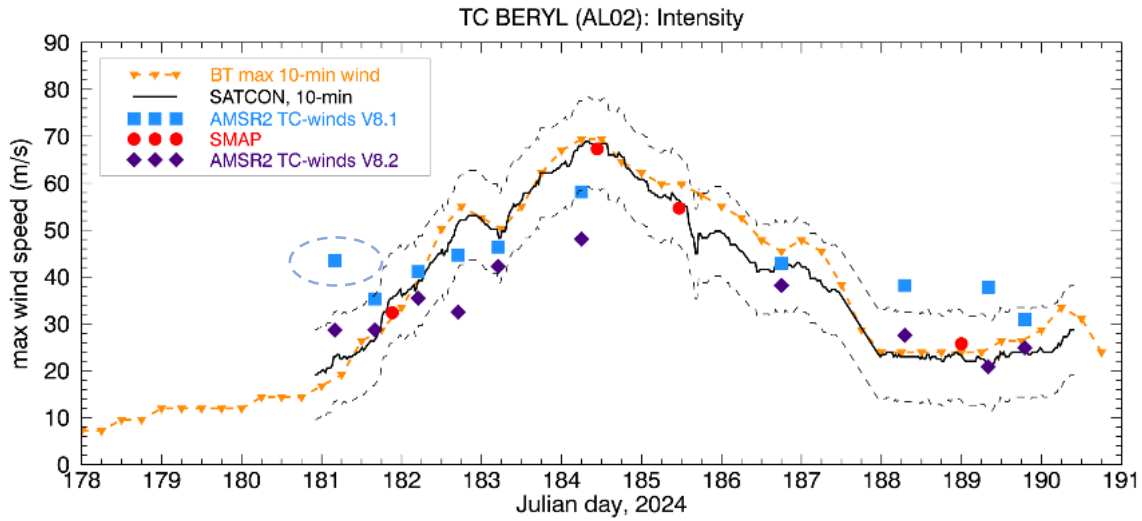
Joint Typhoon Warning Center (JTWC)
Tropical Warning page for Active TC

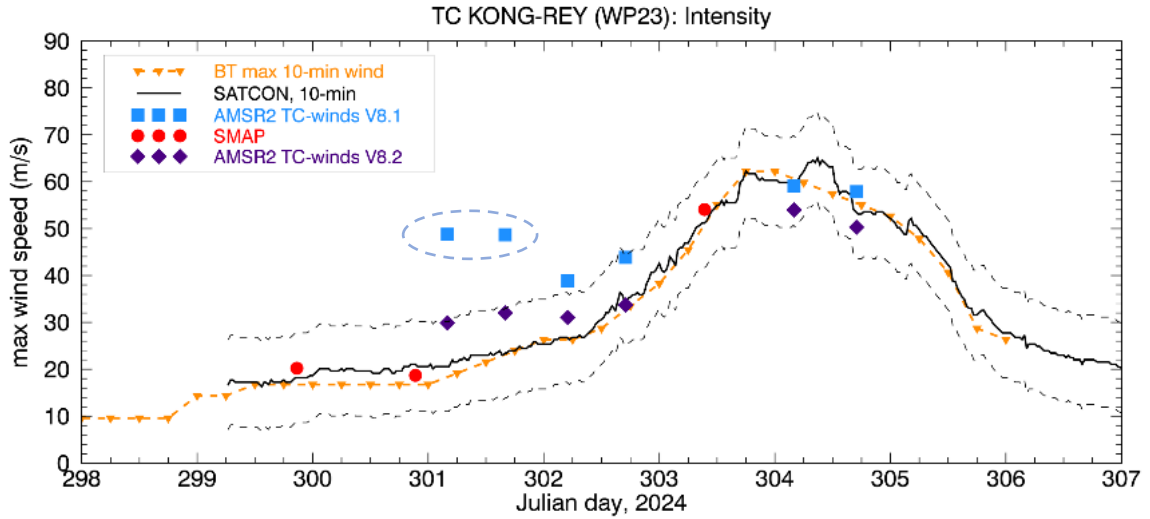
https://www.metoc.navy.mil/jtwc/jtwc.html?tropical

Example: TC MAILA (SH30) Apr 4-11, 2026

Satellite Estimates of TC Intensity Timeseries

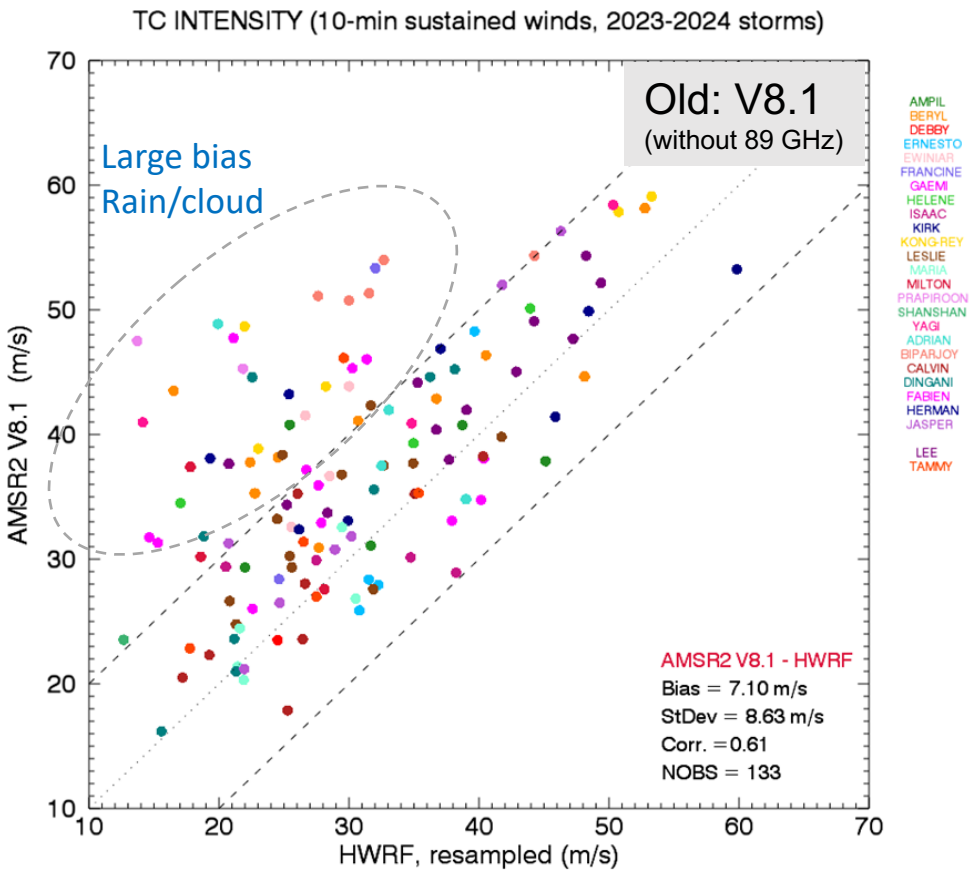
- Satellite-derived intensity should be considered a maximum for 10-min sustained wind
- We used operation products for validation: SatCon (Satellite Consensus by U. Wisconsin CIMSS) and the Best Track from NHC/JTWC
- Here for comparison with satellite intensity estimates, we converted SatCon and BT 1-min sustained to 10-min (scaling factor 0.93, a ~ 7% reduction)
- Old algorithm (V8.1) had some spuriously high estimates occurring at the early stages of the storms, more conducive to rain-contamination and TB89 < 200K
- The new algorithm (V8.2) successfully mitigates the rain/deep-cloud induced bias



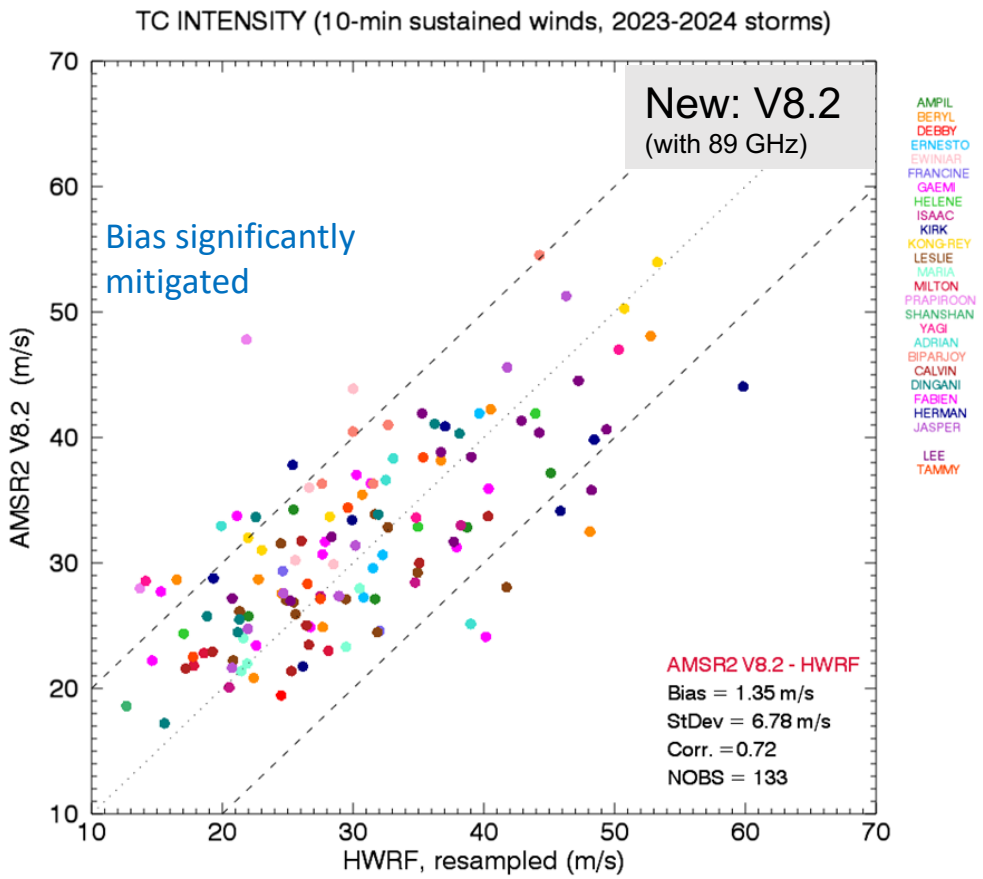


Statistics of Satellite Estimates of TC intensity

Old: V8.1 vs HWRF

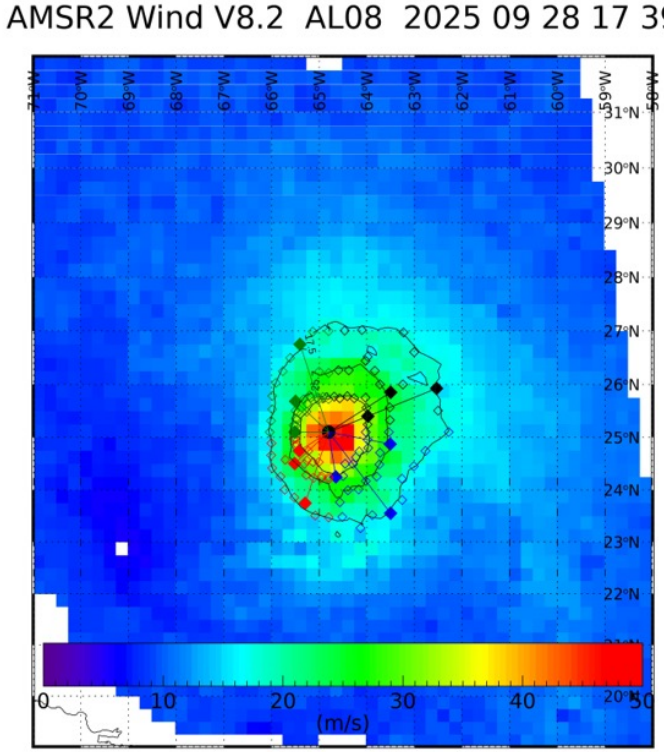


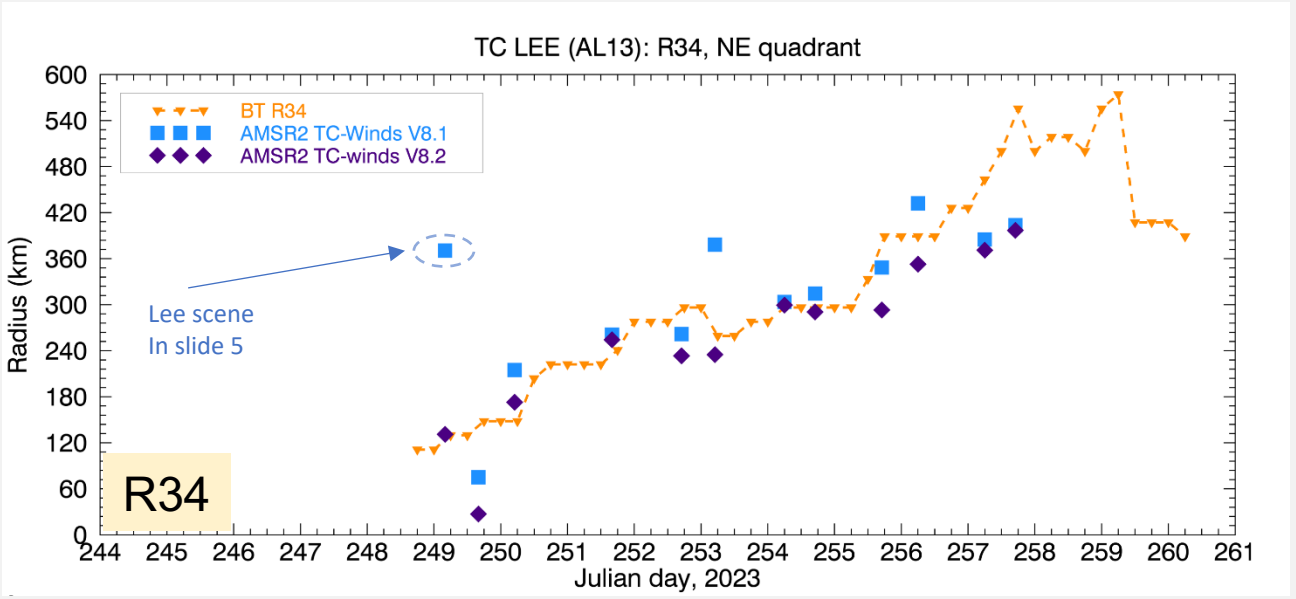
New: V8.2 vs HWRF



Examples of AMSR2 Estimates of Radii

HUMBERTO (AL08)





Radii from Automated fixes from AMSR2:

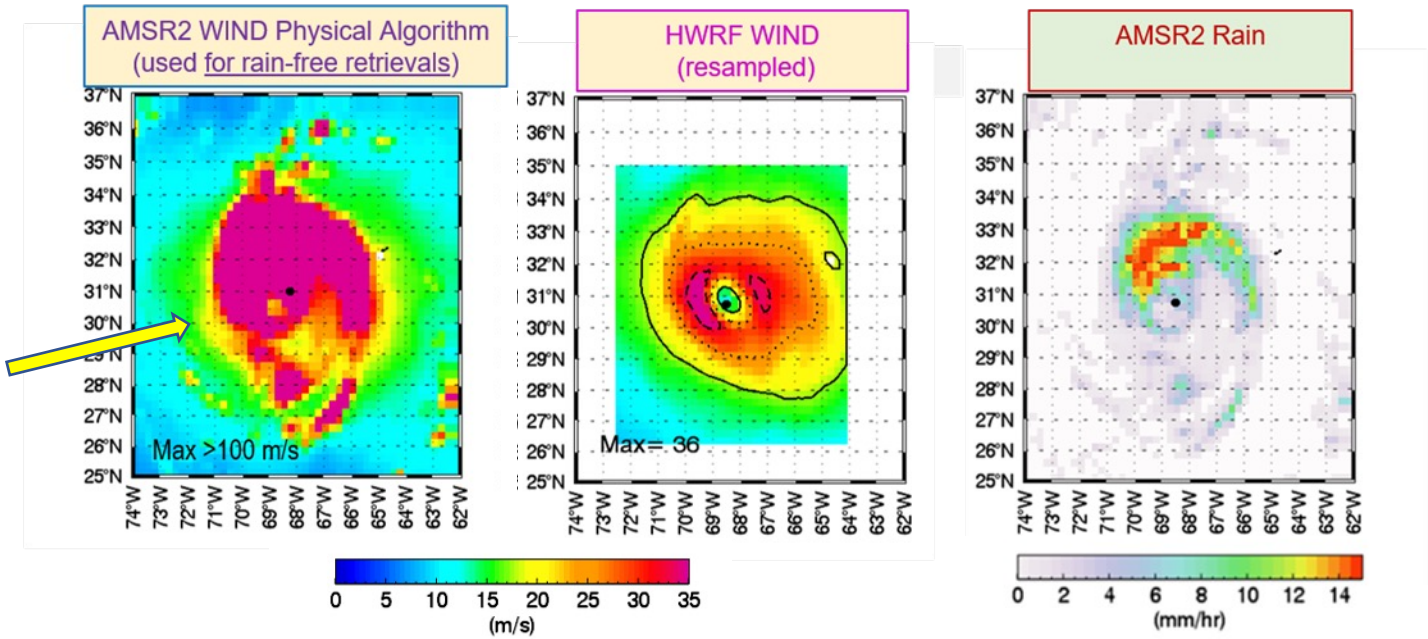
1. Determine contours of 34, 50, 64 kt, using BT center
2. R34, R50, R64 → 80-th percentile defines radii in each quadrant.

What if we don't have L- or C-band?

- For sensors without L- or C-band (GMI, WSF-M), we use traditional physical algorithms based on radiative transfer models, but rain is hard to model.
- These prevent to do wind retrievals in rain, because rain contamination results in very large positive biases in TCs (50+ m/s!)

All data in rain gets flagged

Hurricane Lee 2023-09-14 17:48 UTC



New challenge:

Can we use a similar methodology of new AMSR2 TC-winds to develop a wind algorithm using only 10-89 GHz TB channels for radiometers that do not have L- or C-band?

TC-WIND Algorithm without C-band

Following the methodology used for the AMSR2 V8.2, we designed a statistical linear regression algorithm for radiometers with channels within 10-89 GHz (X to W-band), by using AMSR2 channels but without C-band, and comparing the performance to the algorithm with C-band.

The linear regression equation is similar to the C-band one, but has additional terms weighted by the rain rate

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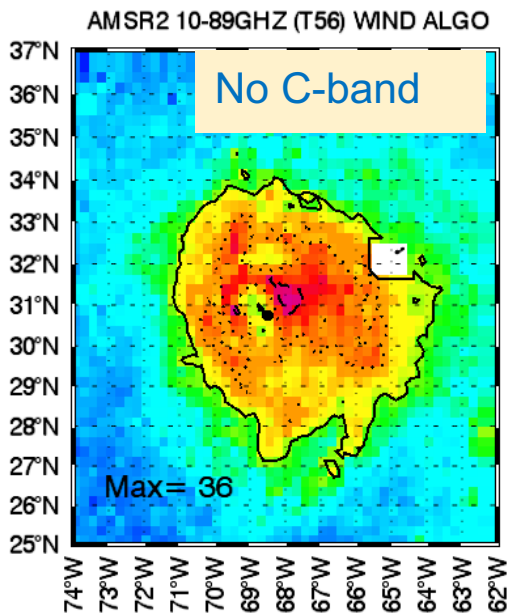
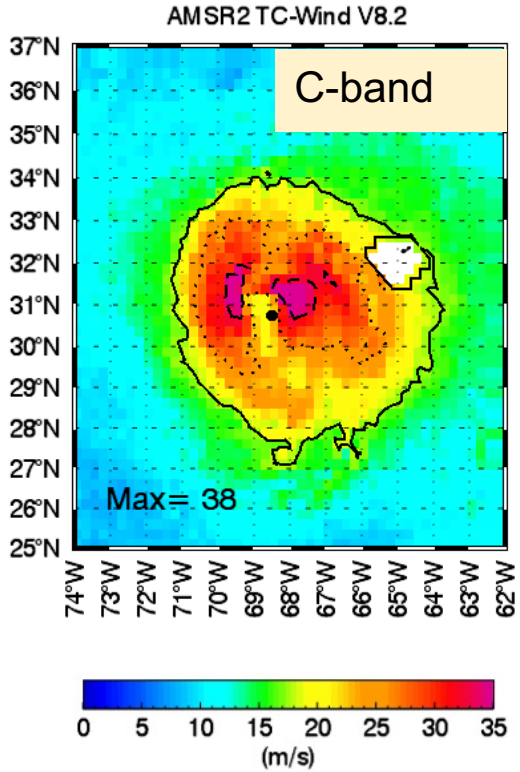
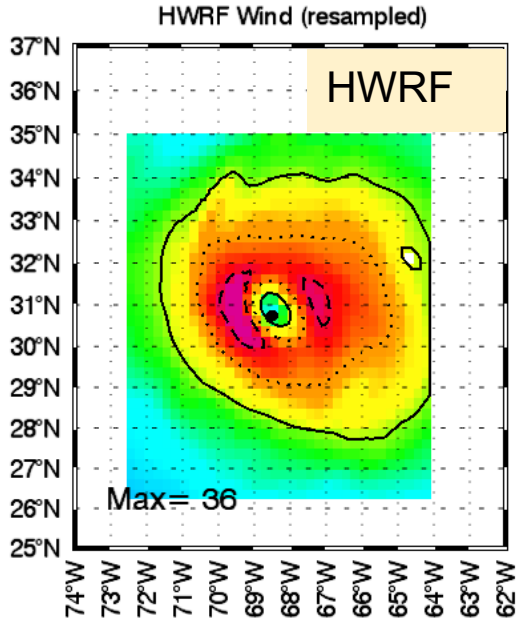
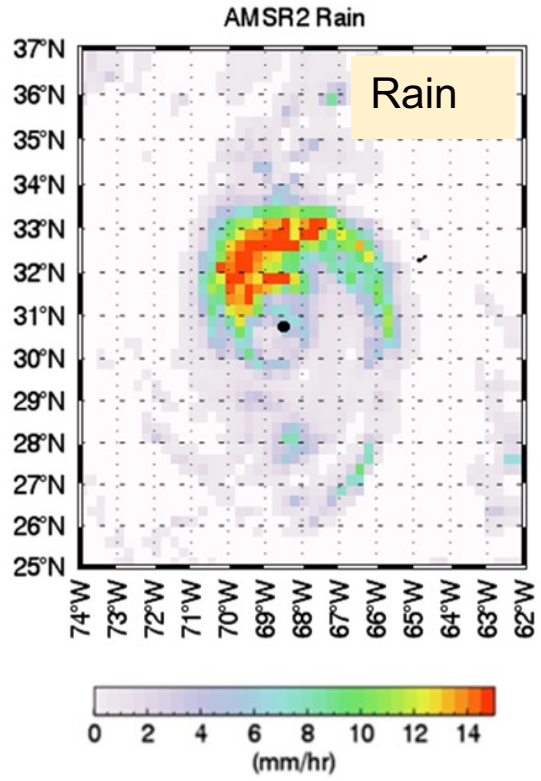
Cat. 1 Heavy Rain

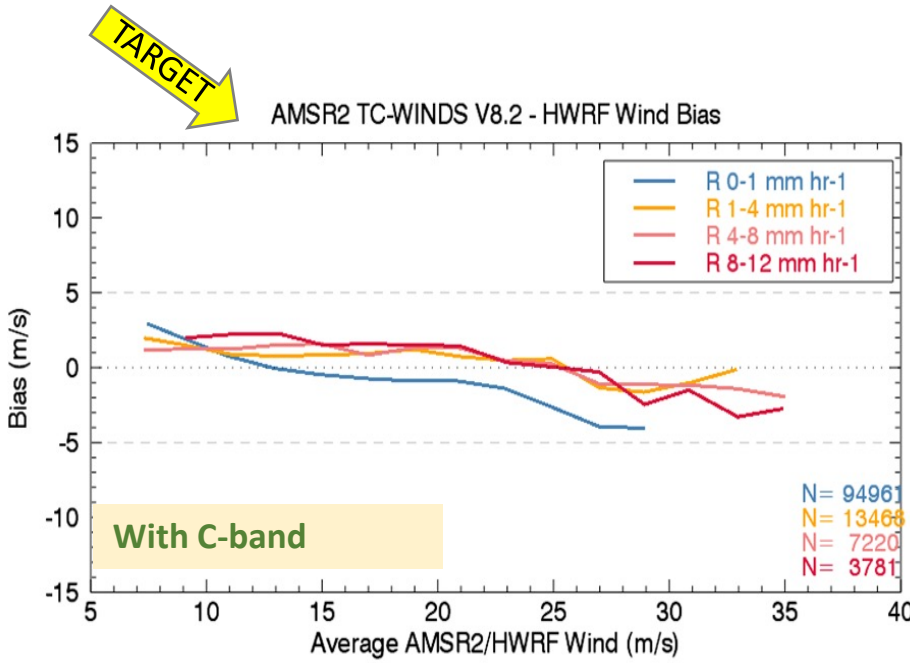


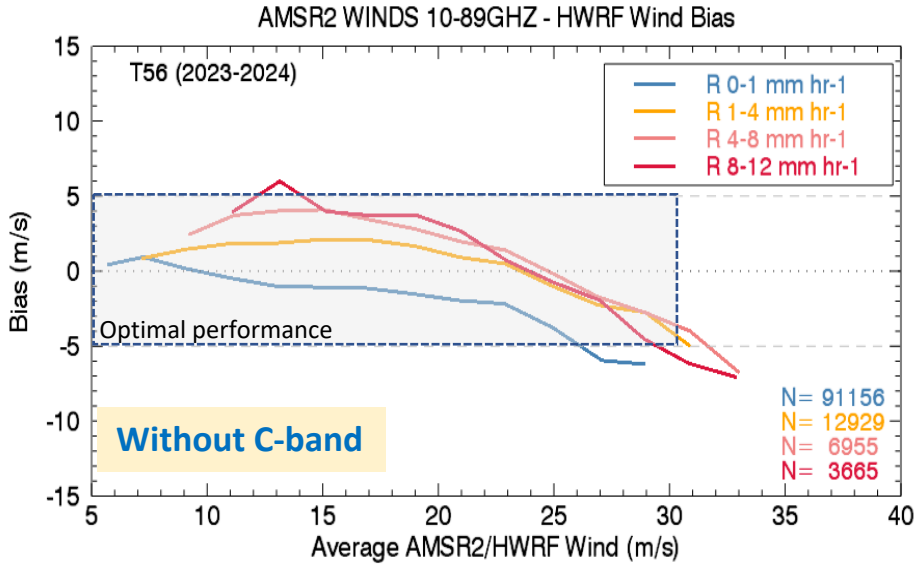






Bias: Algorithm comparison stratified by Rain, 2023-2024





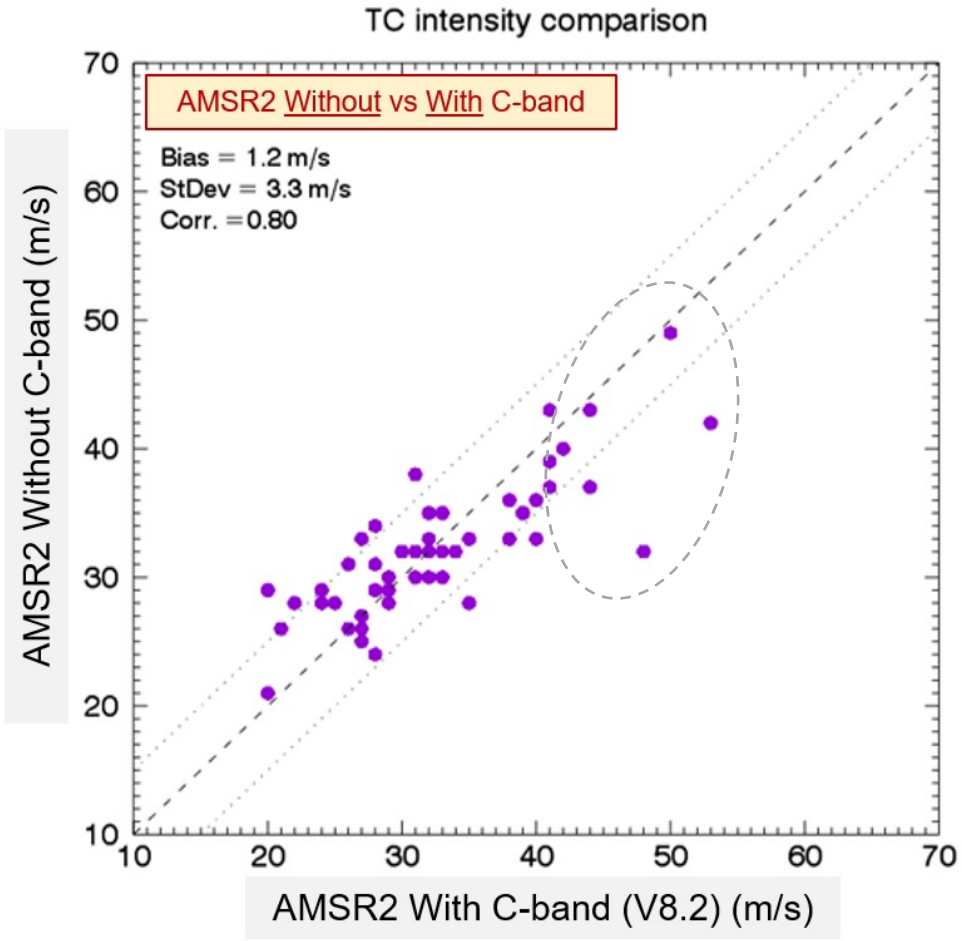
0-12 mm/hr

Statistics on full testing dataset, 2023-2024, 150 TC passes

- Our target performance is the TC algorithm with C-band, which displays *no significant bias at all rain rates< 12 mm/hr*
- The new TC regression algorithm without C-band displays much smaller biases than the standard physical algorithm
- Standard physical (RTM) algo: Bias ~20-40 m/s at moderate rain
- New TC algorithm without C-band: *optimal performance is for 0<w<30 m/s and rain rates <8 mm/hr*:
  - *Average bias < 5 m/s*, weak dependence of bias from rain rate
  - Even for heavy rain 8-12 m/s (red line) the bias might be acceptable.

Performance of TC algorithm without C-band

- The algorithm without C-band has been tested on 27 TCs in the 2023-2024 season. Our tests show very promising skills in estimating storm intensity and radii, and sample scenes of wind retrievals in storm, for rain rates below 8-10 mm/hour, with some degradation at extreme winds > 40 m/s.
- This new algorithm for sensors without C-band (i.e., GMI, WSF-MWI) allows the recovery of a large portion of data lost in TCs with traditional rain-free wind algorithms.

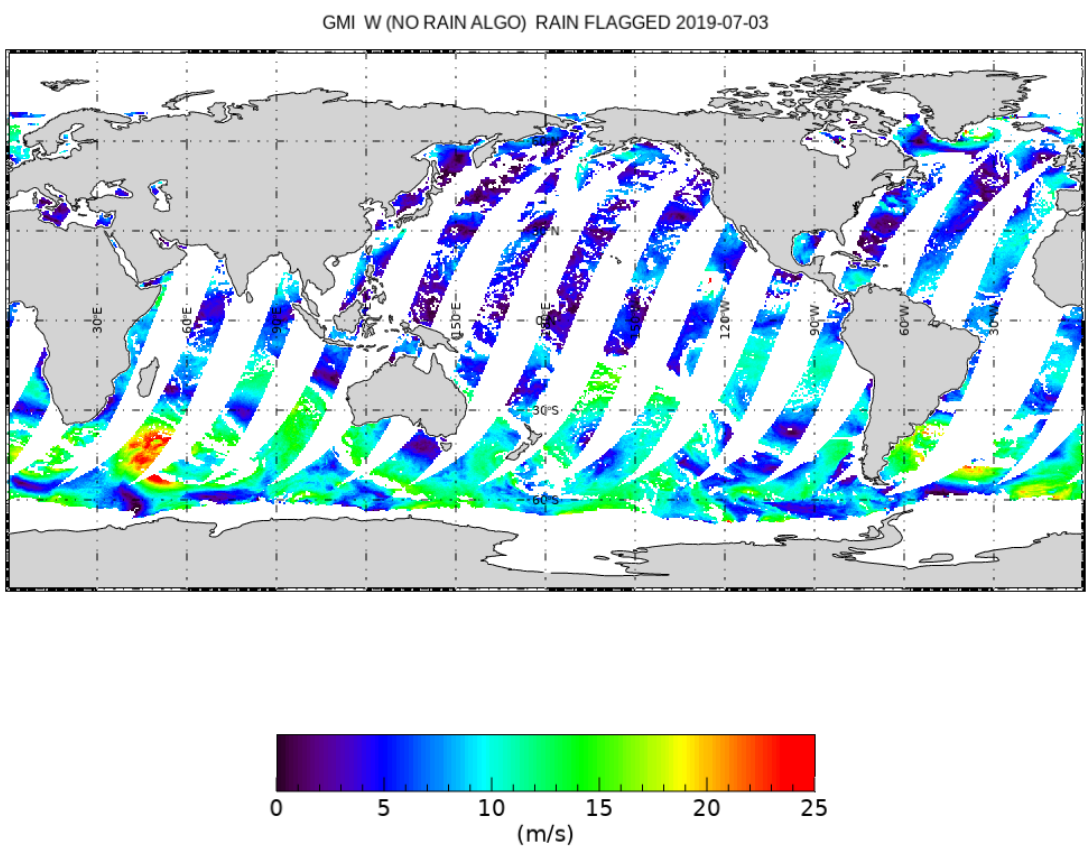


Global Winds-in-Rain Algorithm (without C-band)

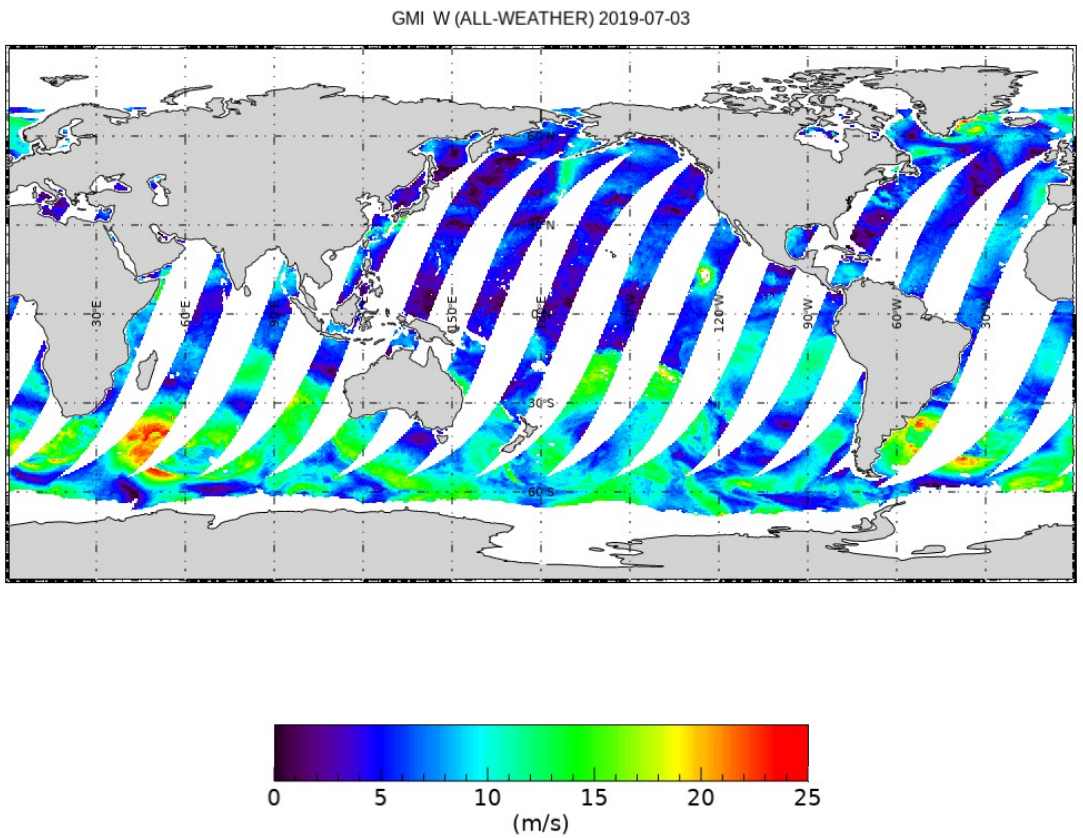
- Empirical Linear Regression in TB measured by microwave imager (GMI, WSF-M, …).
- Regression coefficients depend on:
  - Sea-surface temperature: T_S (Reynolds, ERA5, …).
  - Cloud liquid water path: L (measured by microwave imager GMI, WSF-M, …).
- Trained with match-up wind speed W from external reliable source:
  - CCMP, ERA5
  - valid in rain
- Valid globally for:
  - wind speeds < 20 m/s (no TC core, because not trained in TC)
  - L < 1.0 mm (corresponds to rain rate of about 6 mm/hr).

Global all-weather wind algorithm (no C-band) fills data gaps in rain

GMI
Rain-free wind algorithm
(with extended rain flag)



GMI
Global all-weather algorithm



SUMMARY

Major advancements

- RSS developed a new TC-wind algorithm (V8.2) to mitigate rain biases in AMSR2 winds that uses all channels (6-89GHz), for TC intensity and radii; To be implemented at RSS in AMSR3 as soon as data becomes public (by 2027)
- Data, fixes, images in NRT at https://www.remss.com/tropical-cyclones/tc-winds/
- The 89 GHz channel is very valuable as a proxy of cloud depth and helps mitigating the rain impact
- With the same methodology but different frequency channels (10-89 GHz), a new algorithm for TC-winds from radiometers without C-band (WSF-MWI, GMI) is under development.
- A global all-weather winds algorithm valid in low to moderate rain, and for w< 20 m/s is also under development.

Benefit to forecasters

- TC-winds (10-89 GHz) displays promising skills for intensity and radii, for rain rates < 8-10 mm/hr and winds <40 m/s; fixes can be provided in ATCF format (expected in 2027)
- This helps filling satellite wind data gaps in rain and provides additional fixes in TCs, addressing concerns about diminishing radiometer coverage in the near future

Concerns

- Increasing RFI at L-band (SMAP), and C-X band (6-10 GHz) is a major source of concern
- Data loss in large regions; Advocate for future sensors with RFI-mitigation strategies, protect bands

Thanks to the community for the valuable feedback!

Extra slides, sample cases

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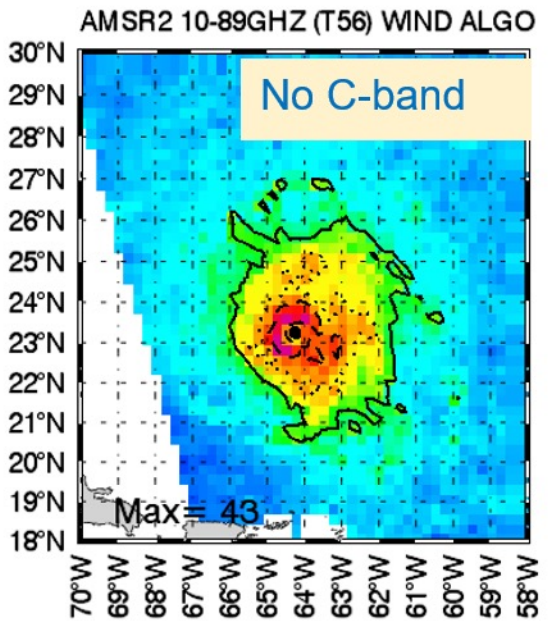
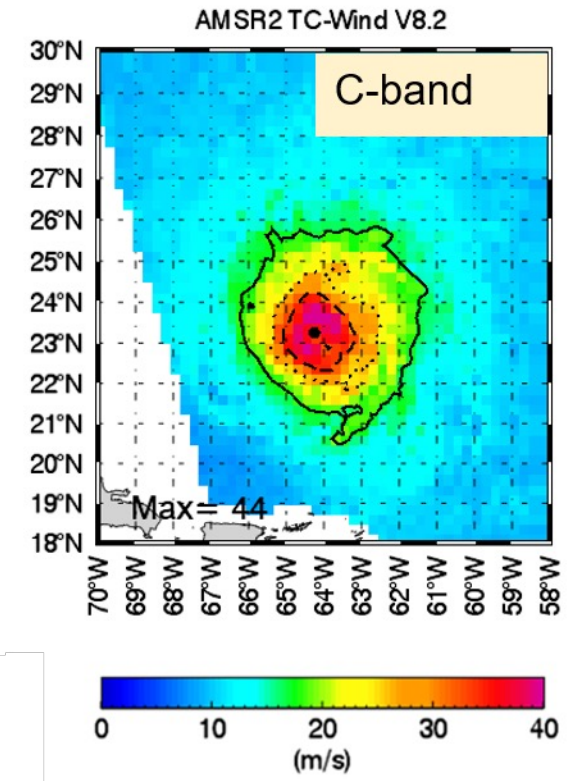
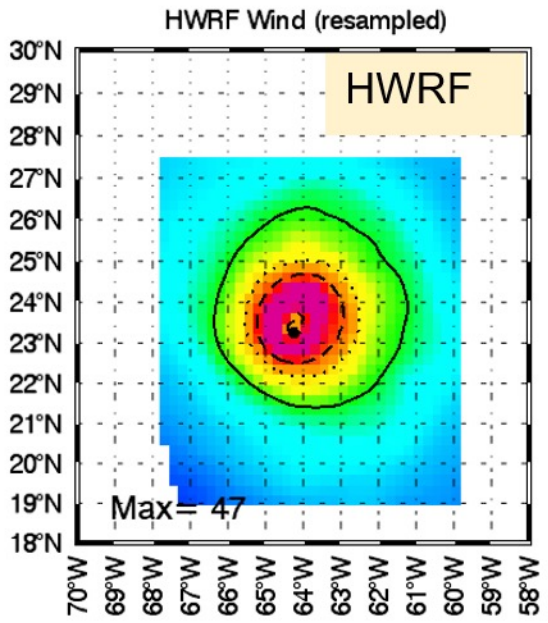
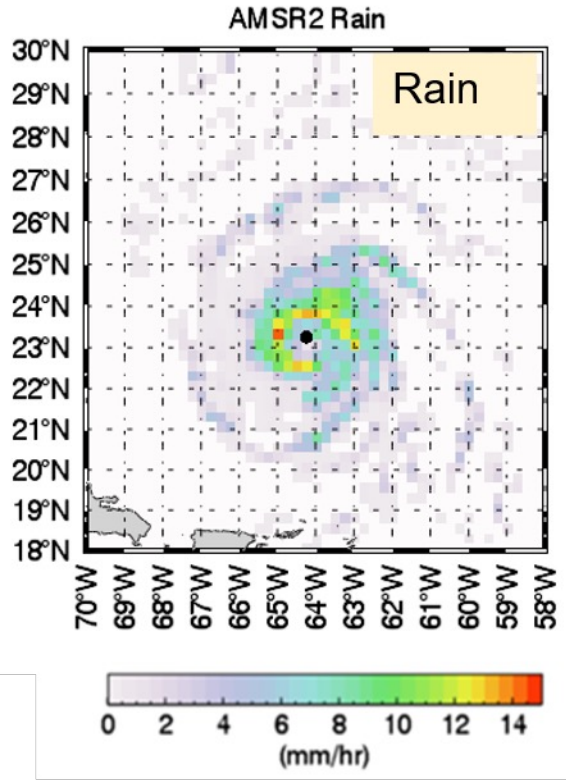
Cat. 2 Heavy Rain









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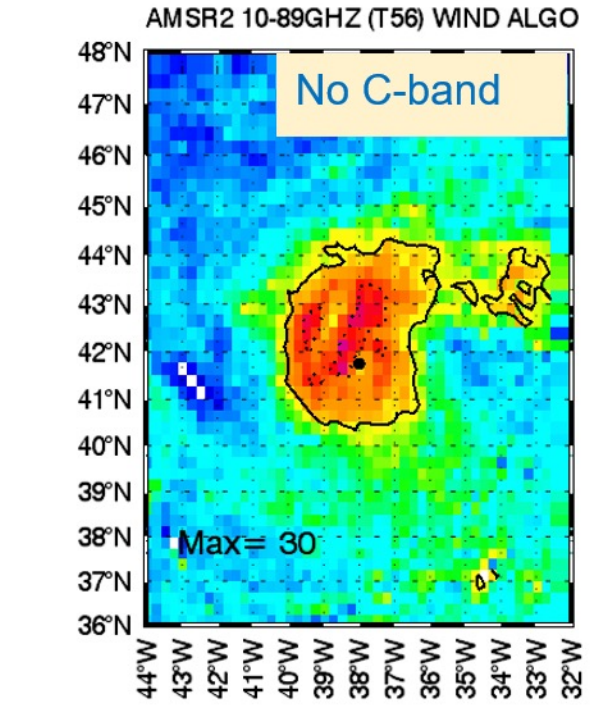
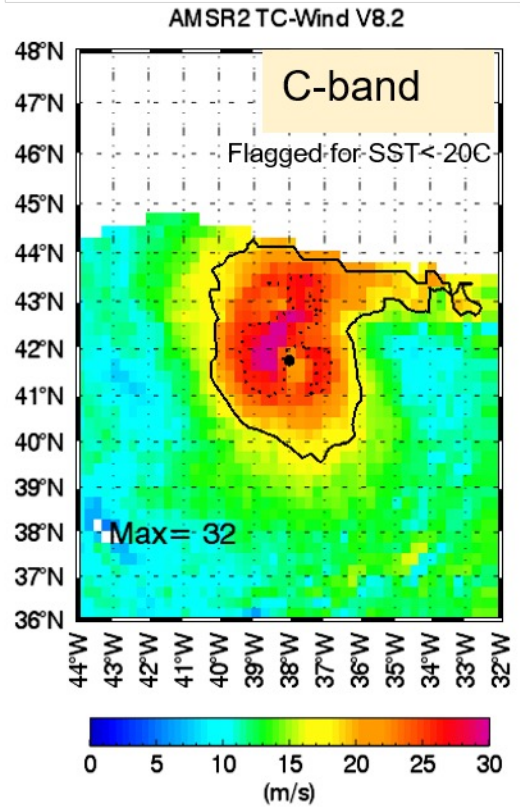
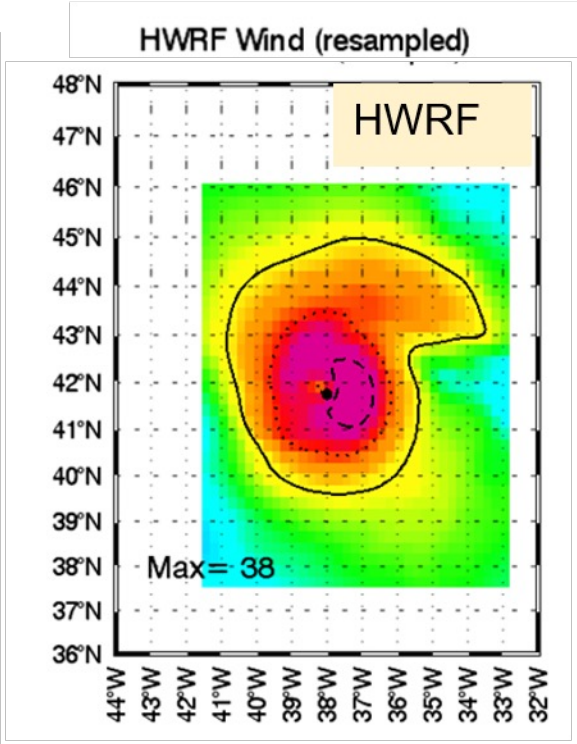
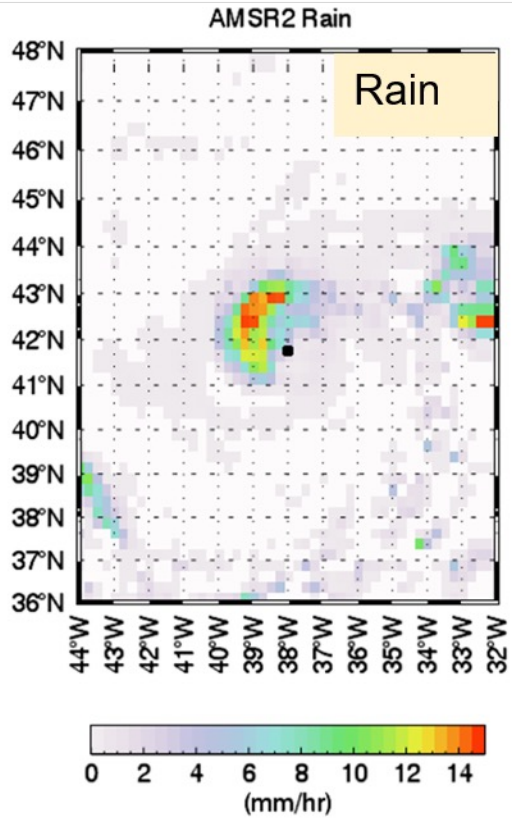
EXTRA-TROPICAL transition









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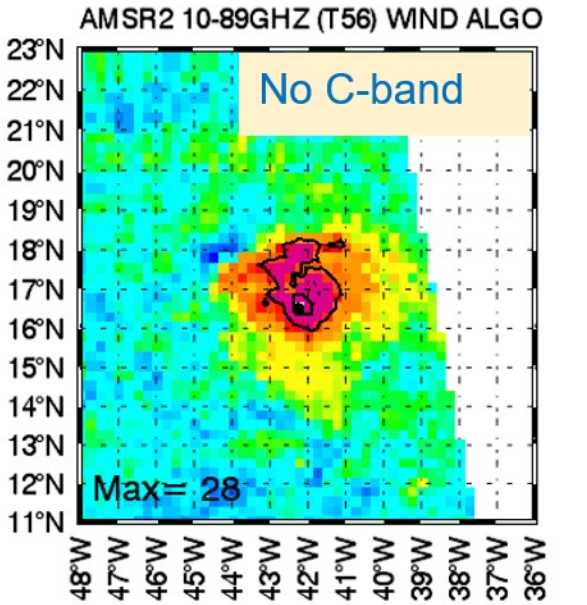
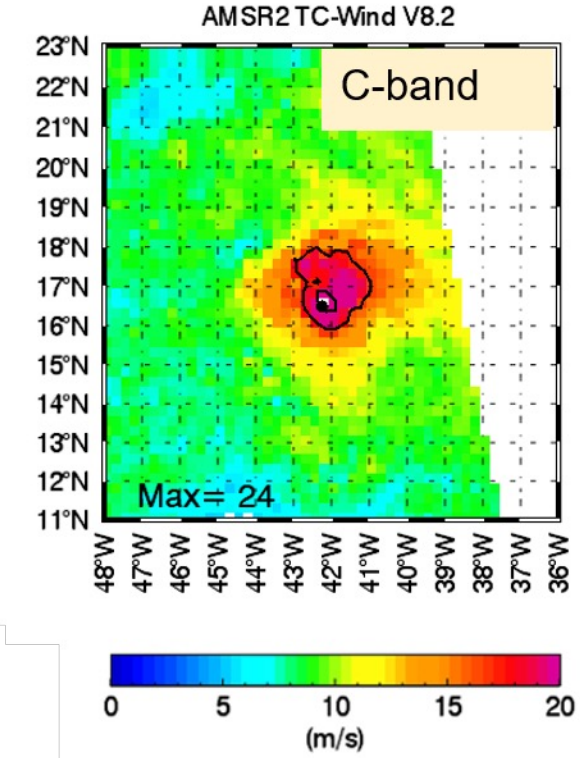
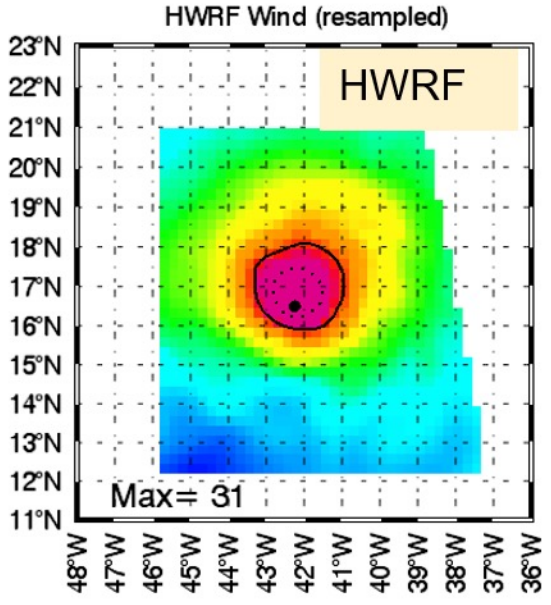
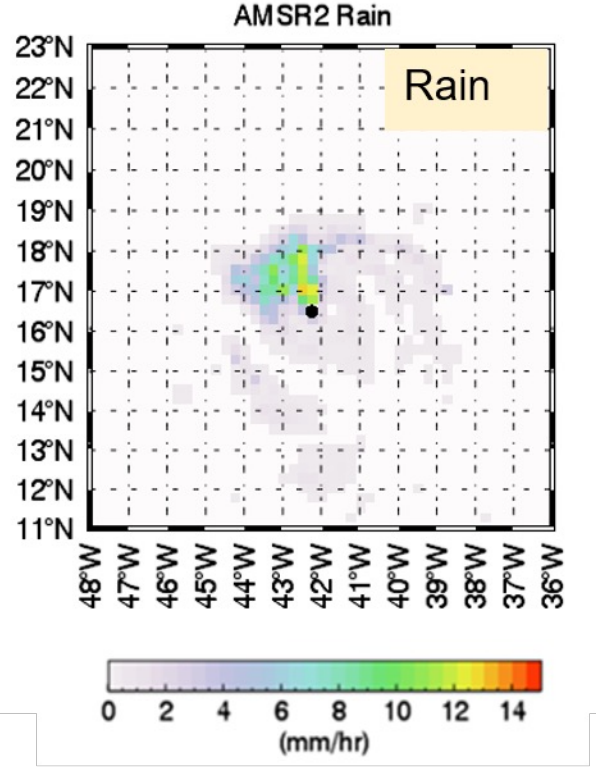
TS Light Rain









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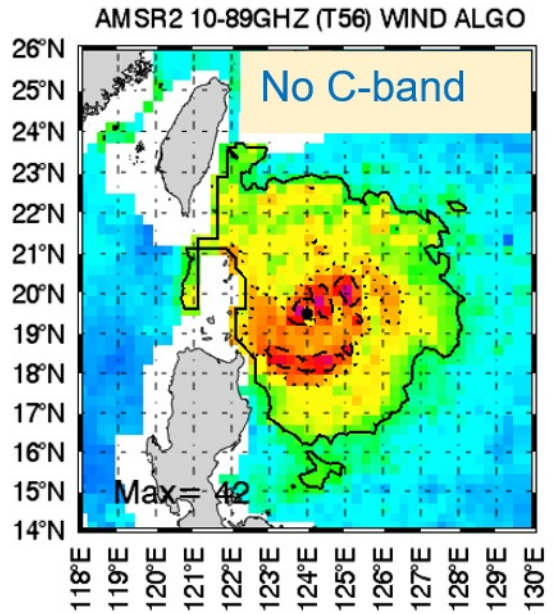
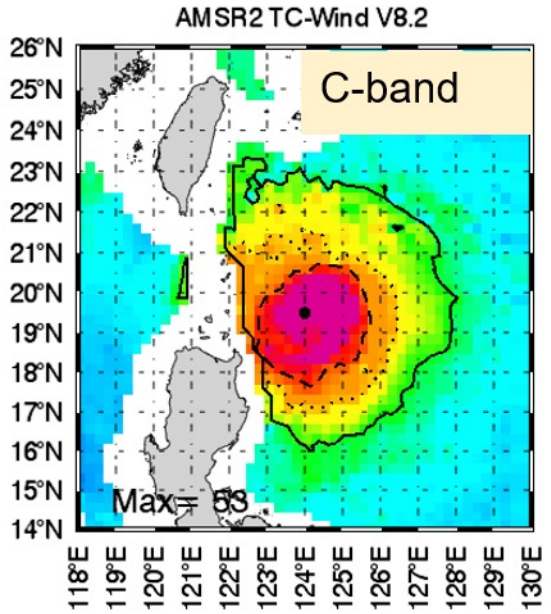
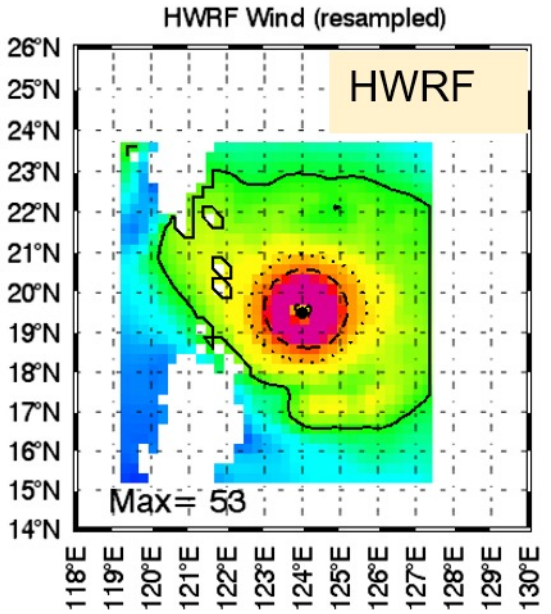
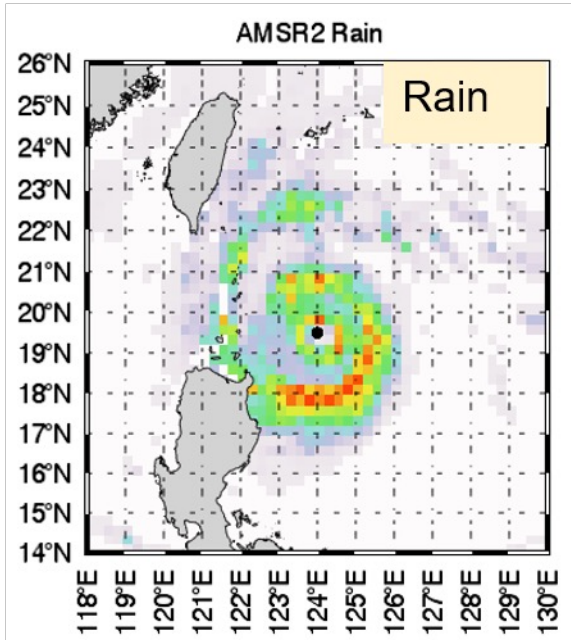
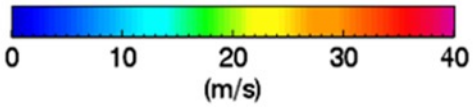
Cat. 3 Heavy Rain

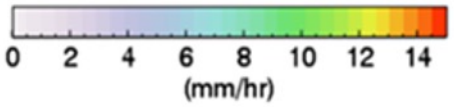












KONG-REY (WP23) 2024 10 30 17:09 UTC

Cat. 2 Heavy Rain