

Retrieving/Measuring Extreme Winds Status and Next Steps

IOVWST Virtual Meeting
November 15, 2023

The ocean surface under the eye wall viewed from
just inside the eye of Hurricane Matthew

Objectives

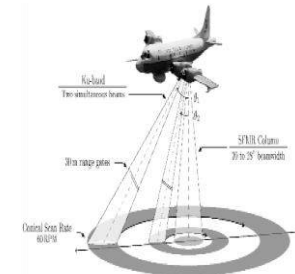
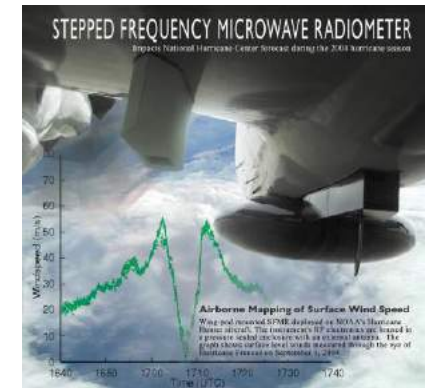
- To identify and discuss where we think our current understanding of measuring extreme winds is
- To identify and discuss the strengths and weaknesses of the various measurement methods (in-situ, satellite and airborne remote sensing)
- To discuss research and development areas where the community should focus attention on to address the weaknesses and unknowns.

Extreme Winds

What do we know and what don't we know?

What do we have?

- Remote sensing
 - Satellite and aircraft-based sensors
- In-situ
 - Buoys, Dropsondes, Saildrones
- Derivative products
 - Wind radii, peak intensity estimates, RMW



In-Situ – some of the issues

- Buoy and dropsondes provide in-situ measurements
 - Buoys and saildrones get impacted by waves
 - To what degree? How can we quantify?
 - High density observations from Saildrone should help understand measurement and geophysical variability
 - Dropsondes don't measure the true vertical profile and are also impacted by waves (turbulence at the air-sea interface)
 - Variability in physical structures in the boundary layer (i.e., fine scale wind structure in the atmosphere) can impact representativeness of what dropsondes/buoys are measuring

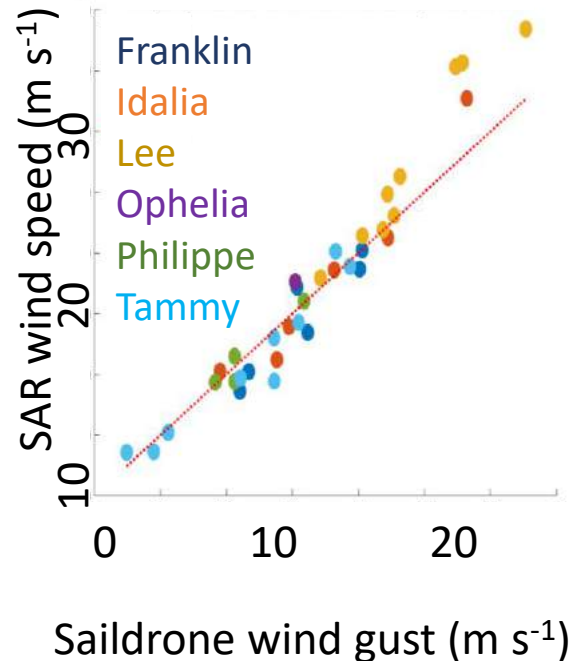
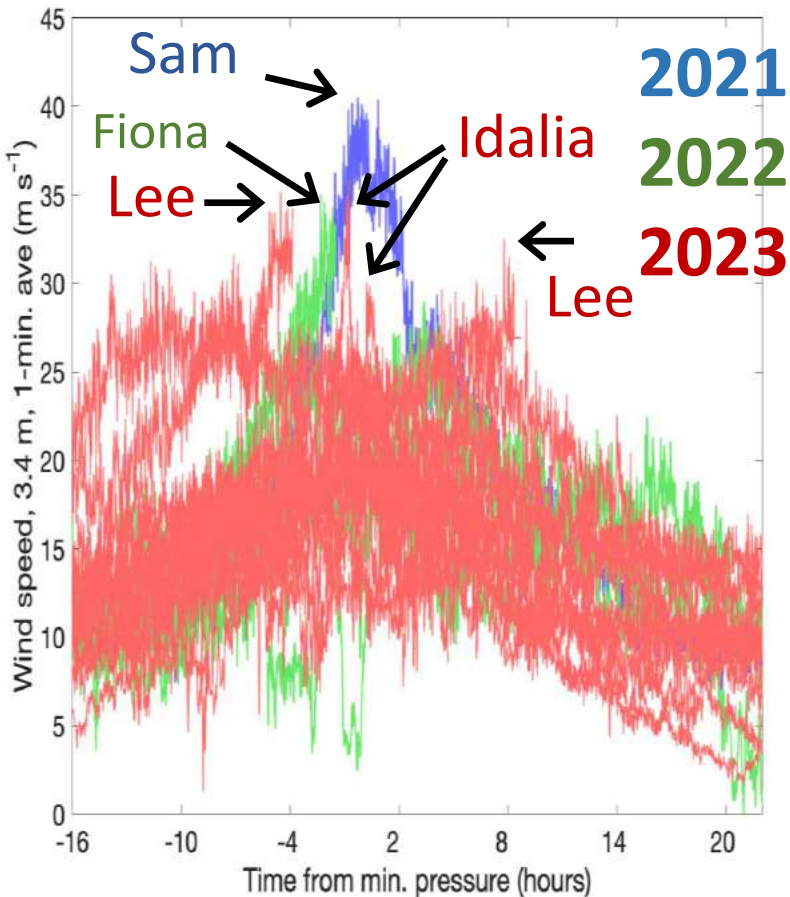


Saildrone wind measurements in hurricanes

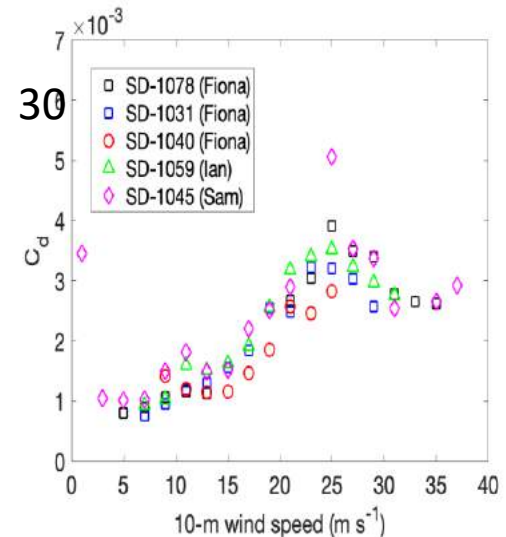


Comparison of saildrone and SAR wind speeds

Wind speed from 26 TC intercepts



Drag coefficient from 20-Hz wind measurements



Remote Sensing

- What are active and passive microwave remote sensing measurements actually responding to in the extremes?
 - Does Bragg scattering break down for scatterometry at some point (I think yes)
 - Does areal foam extent on the surface keep increasing with wind speed
 - Rain impacts cannot be ignored
 - Wave conditions impact passive measurements and perhaps active measurements

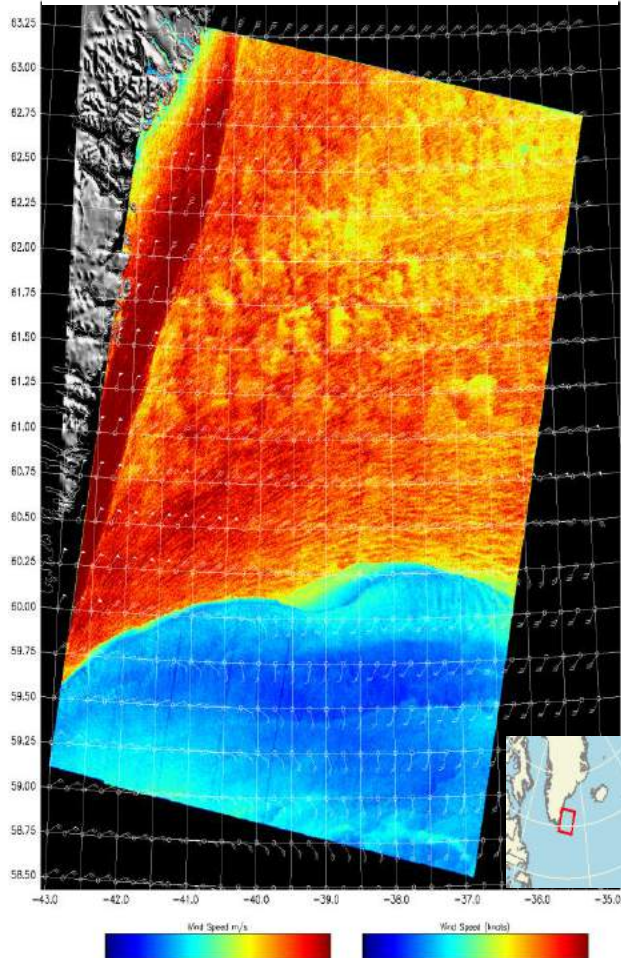
Spatial resolution is important!

- For satellite-based sensors only SAR has the measurement spatial resolution comparable to the areal extent of the highest wind regions in a TC

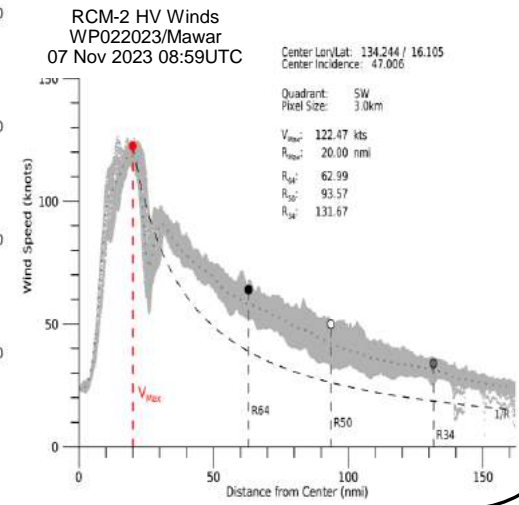
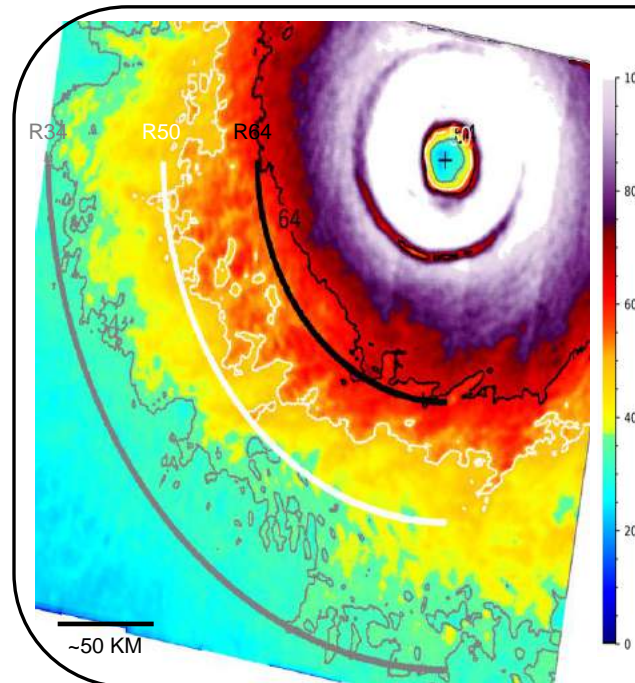
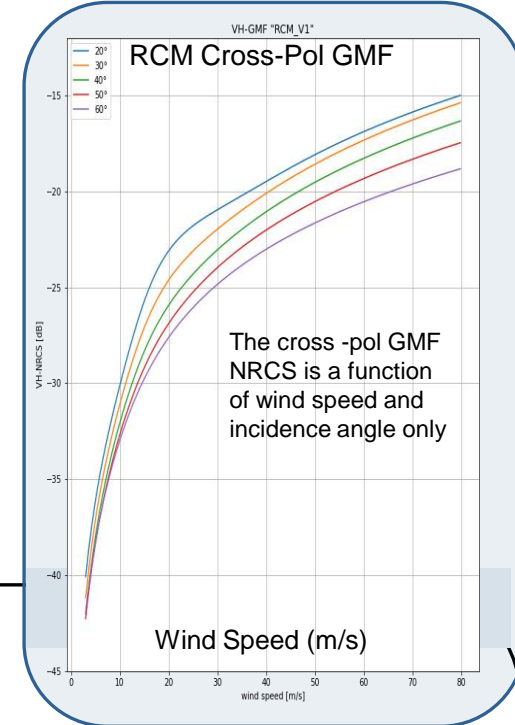
Synthetic Aperture Radar (SAR) for Extreme (> 25 m/s) Winds Determination

The Sentinel-1, Radarsat-2 and Radarsat Constellation Mission (RCM) C-Band SAR systems collect in a cross-polarization (VH or HV) channel that can be used to determine extreme ocean surface wind speeds (up to 80 m/s)

RCM-2 HV Winds 07 Nov 2023 08:59UTC



- Combined with its fine resolution (< 100 m) SAR cross-pol winds provide unprecedented detail into...
 - tropical cyclones (radial wind profiles, Rmax, VMax, eye location, fixes)
 - Near shore extreme winds such as gap flows and near shore jets



Airborne remote sensors

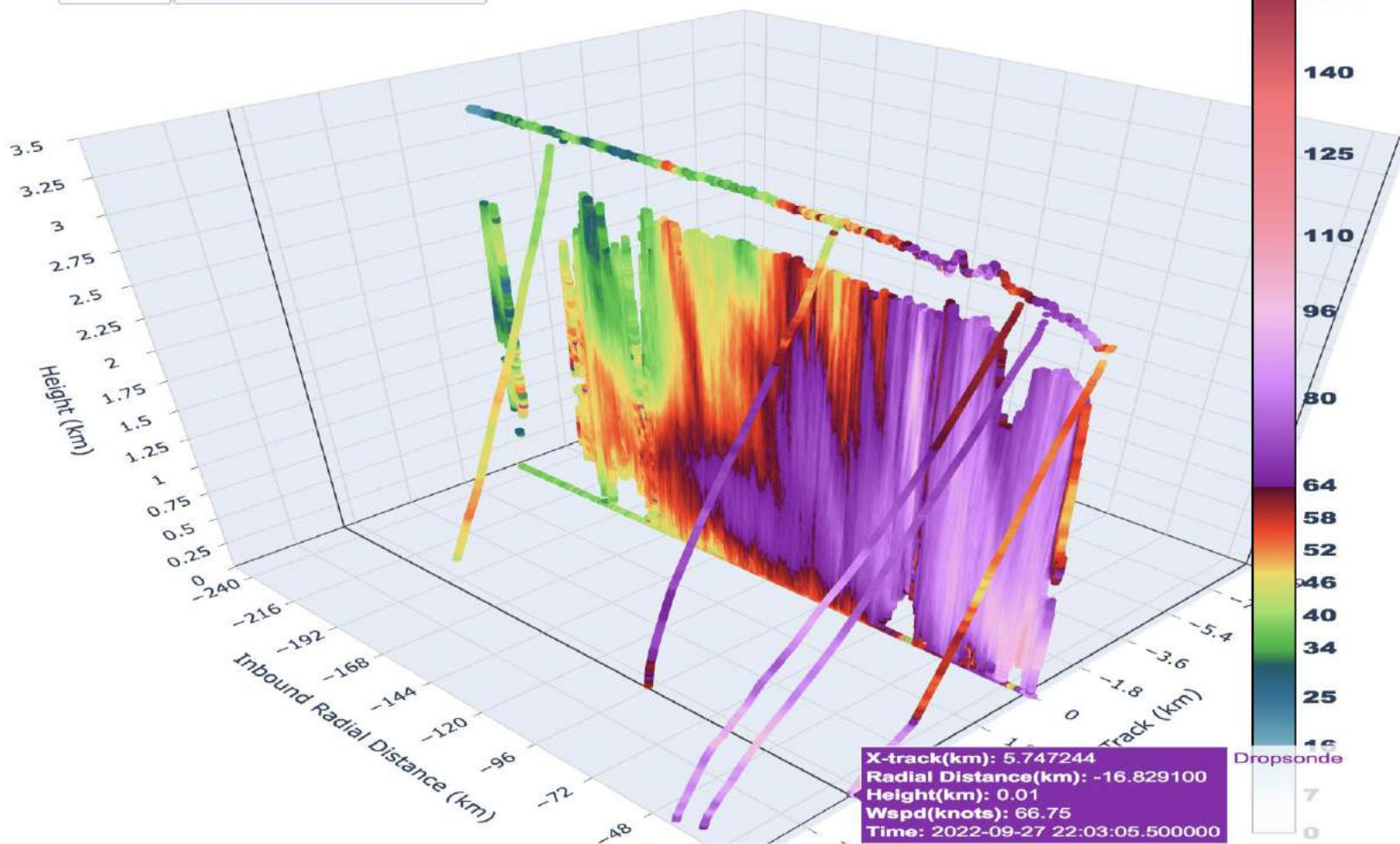
- SFMR
 - Problems in high wind/rain gradient regions (i.e., the eye wall)
 - Residual calibration errors, wind retrieval process, measurement scheme all impact retrievals
 - This needs to be characterized
- IWRAP
 - Can measure the actual vertical wind profile in the presence of rain (Doppler) from below the plane to just above the surface and the surface wind via scatterometry
- KaIA
 - SWH at Ka and Ku-band
- WSRA
 - SWH at Ku-band and directional wave spectra

IWRAP Horizontal Winds and Dropsonde Winds

2022092711 (Ku @ 50°) - IAN: Inbound 1 21:28:22 - 21:59:22
VDM Storm Center: (24.16°N,-83.13°E) @ 20220927 22:01:10
Avg Heading: 146.62 (SSE)



Default Radial Distance/Cross-Track

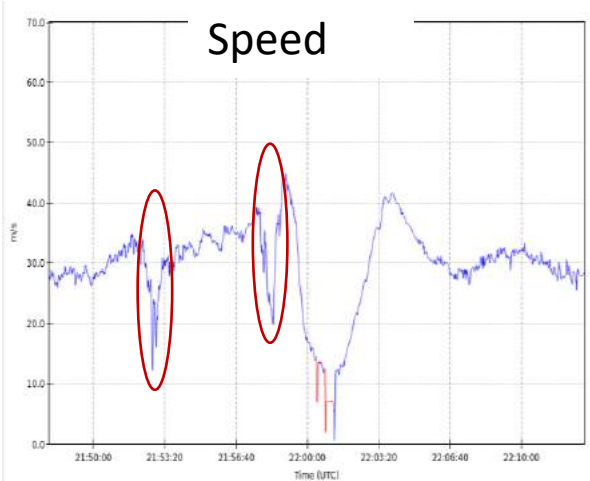


SFMR High Wind/High Rain Errors

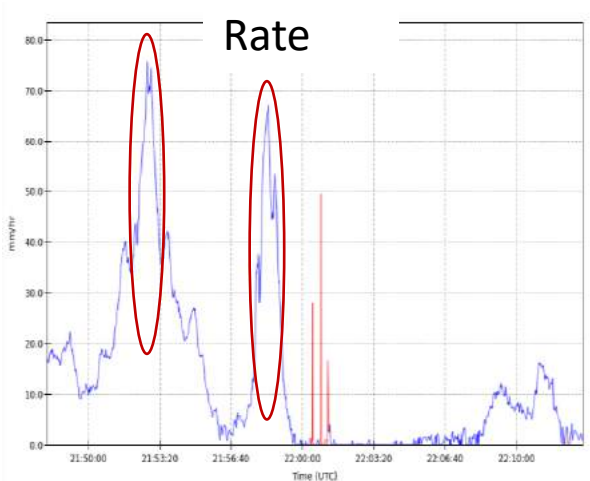
Heather Holbach – FSU, NGI, NOAA/AOML/HRD

Hurricane Ian 20220827I1

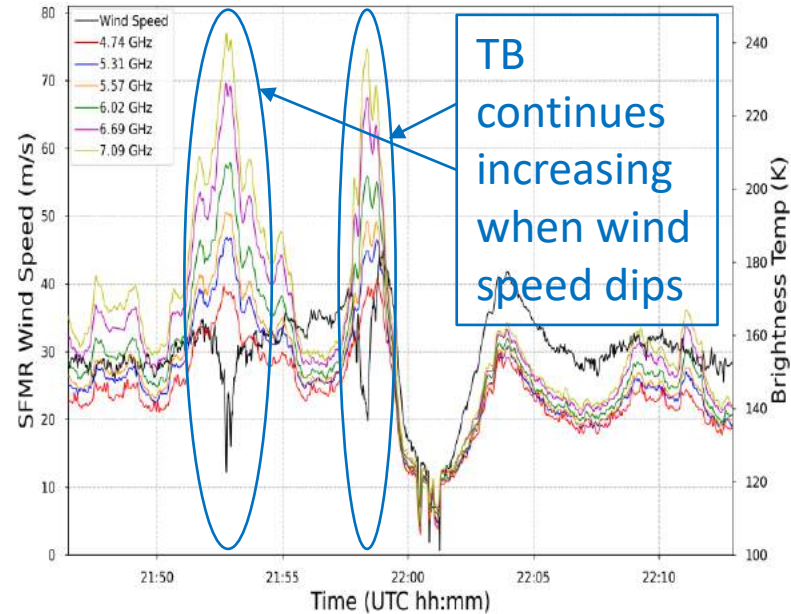
Wind Speed



Rain Rate



NOAA43 202209271922 US003



- Problem with assignment of TB to rain vs wind
 - Likely a deficiency of the iterative inversion algorithm and sensitivity to first guess
 - SFMR radiative transfer equations may not be accounting for rain correctly when larger drops are present
- Comparisons with TDR, PIP, and IWRAP will be used to investigate and correct algorithm (joint effort with NESDIS team)

Satellite Remote Sensors

- Scatterometers
 - ASCAT B/C
 - OceanSat-3/EOS-6 (OSCAT-3)
- Synthetic aperture radar (SAR)
- Passive
 - SMAP (L-band)
 - AMSR-2 (multi-frequency 6-89Ghz)

Derivative Products for Operational Weather Users

- Extracting more information from existing satellite-based sensors
 - Particularly important for regions of the world that do not have aircraft TC reconnaissance
 - Satellite-based sensors also are the only way to systematically measure TCs globally and routinely
- All existing satellite data has shortcomings
- Satellite estimates in the extremes can still provide valuable information for forecasters
- However, critical to provide guidance on use!



JTWC: Wind Product Priorities for Tropical Cyclone Analysis



- Tropical cyclone (TC) analysis requires *all-weather/all-wind* capable sensing:
 - › Wind direction provides critical center positioning
 - Particularly challenging prior to eye formation
 - › Wind estimates should include the full range of TC intensities, including super typhoon (130+ kts)
 - › Coverage: Storm center to capture maximum associated core wind speeds, extending out 1 to 2 degrees of center to analyze wind radii (34-, 50-, 64-kts)
 - › Revisit: Six-hourly or more frequent (TC warning cycles every six hours)
- Satellite winds have significant impact on numerical models that initialize with TC vitals parameters
 - › Heavily influence forecaster analysis of key vitals parameters
 - TC intensity forecast model (e.g., HAFS, COAMPS-TC) vortex initialization highly dependent on 2D wind structure provided in TC vitals data
 - › Informing the forecaster with accurate wind data directly improves accuracy of operational model forecasts used by U.S. and international forecast agencies!

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Space-based Surface Wind Data: Trusted Sources



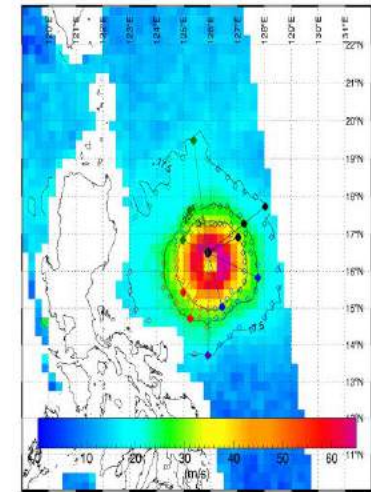
- Active scatterometry is a critical tool for identifying TC circulations since it can provide both wind speed and direction in heavy moisture
 - › Current mean ASCAT TC center revisit time ~28.5 hours (= a lot > 6 hours ☹)
 - › Next generation ASCAT capable of overcoming current ~50 knot sensing limitation
- Extreme wind speeds derived from Synthetic Aperture Radar (SAR; S1A, RS2, RCM), SMAP, SMOS, and AMSR2 sensors integral to TC intensity and wind radii analysis - all currently provide wind speeds only
 - › SAR particularly useful – resolves small-scale features including TC eye
 - › Wind vectors derived from SAR data a top item on the TC analysis “wish list”
- Note: U.S. Indo-Pacific Command and Joint Typhoon Warning Center Tropical Cyclone Conference, mid-April 2024
 - › Annual invitation only gathering of DoD, R&D, academia, and industry partners to synergize TC forecasting, disaster preparedness, and risk communication
 - › POC: Matthew Kucas (matthew.e.kucas.civ@us.navy.mil)

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L-BAND RADIOMETERS WINDS: SMAP

- Global surface winds, 10-min sustained, 10-70 m/s
- L-band very sensitive to high winds but insensitive to rain
- At extreme winds, emissivity signal comes mostly from sea foam; linear emissivity at high winds
- Footprint: 40 km (over 25 km grid); Uncertainty ~ 10%
- Files with TC size and 10-min sustained winds in NRT
- Available also as archive (2015-present)

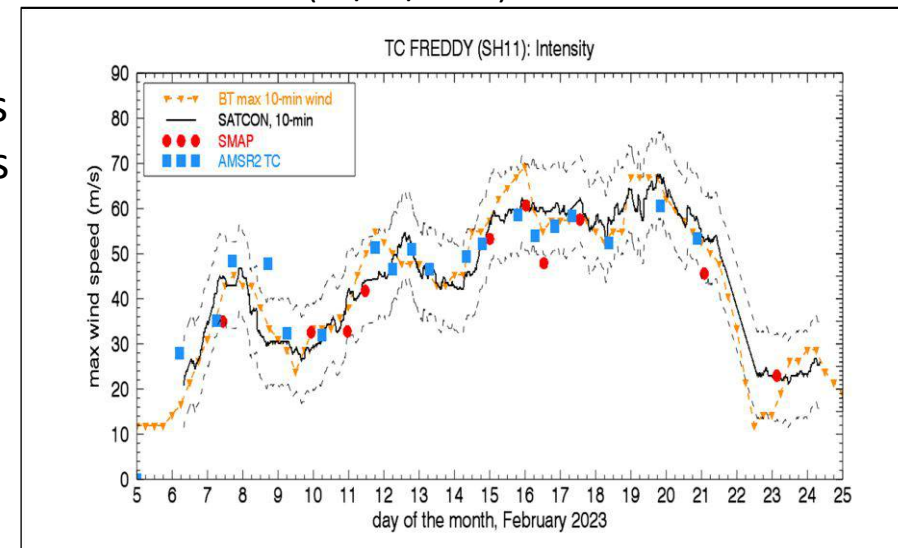
SMAP Wind WP02 2021 04 20 09 34



SMAP wind field for SURIGAE (2021), with radii R35, R50, R64 (35/50/64 kt) determined in NRT

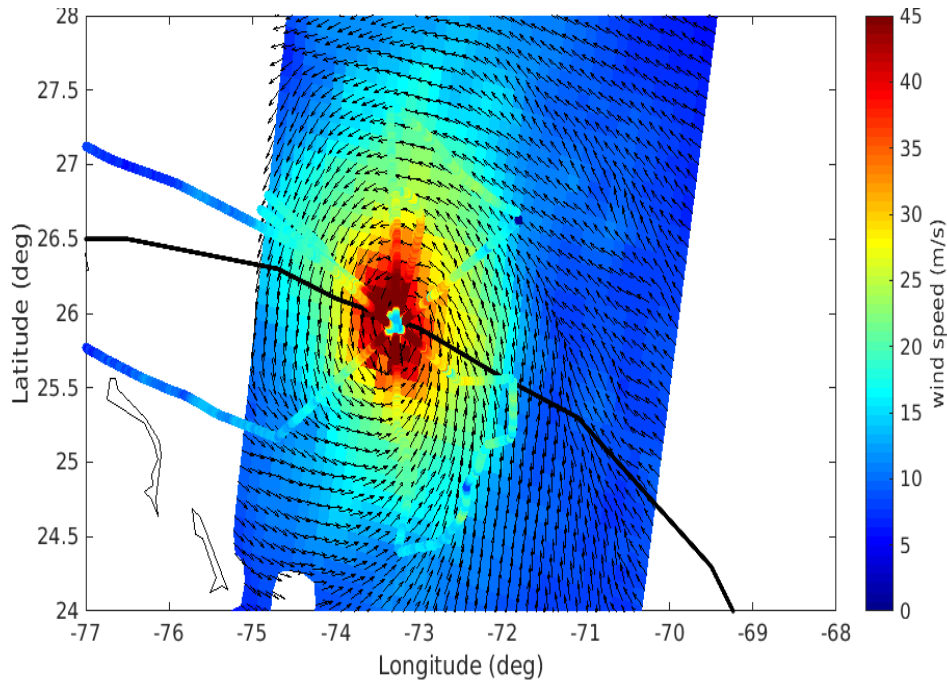
C/X BAND: AMSR2 TC-WINDS

- TC-specific algorithm trained using SMAP winds
- Uses a linear combination of C-X band channels to mitigate rain effect
- Provides TC surface wind fields, (10-min sustained winds, 40 km resolution on 25 km grid)
- Files with storm size/10-min intensity in NRT
- Archive since 2002 (AMSR-E), 2003 (WindSat) and 2012 (AMSR2)
- <https://www.remss.com/tropical-cyclones/tc-winds/>



Consistency AMSR2 TC-WINDS, SMAP Best Track (BT) and SATCON (CIMSS) max winds for TC Freddy (2023). From WMO report, IWTC-10, 2023

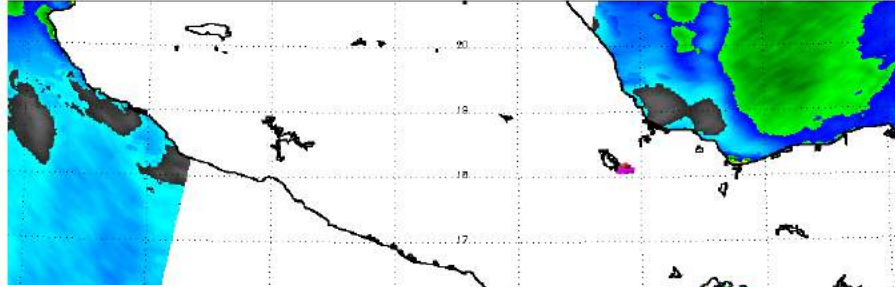
Adjusted ASCAT Winds (KNMI)



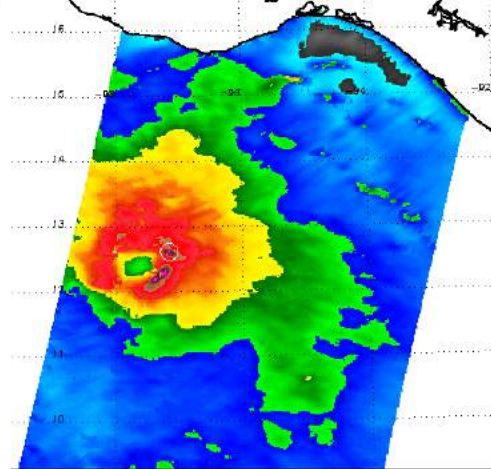
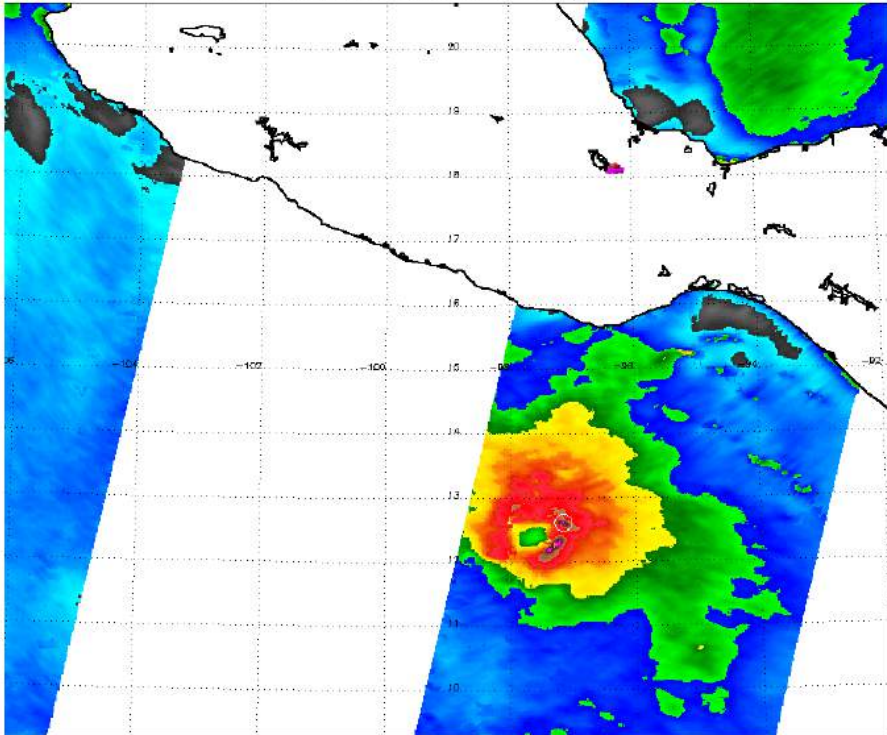
ASCAT adjusted wind field over Hurricane Dorian
using SFMR winds as calibration reference

ASCAT UHR (Resolution Enhancement) and TC GMF (NOAA)

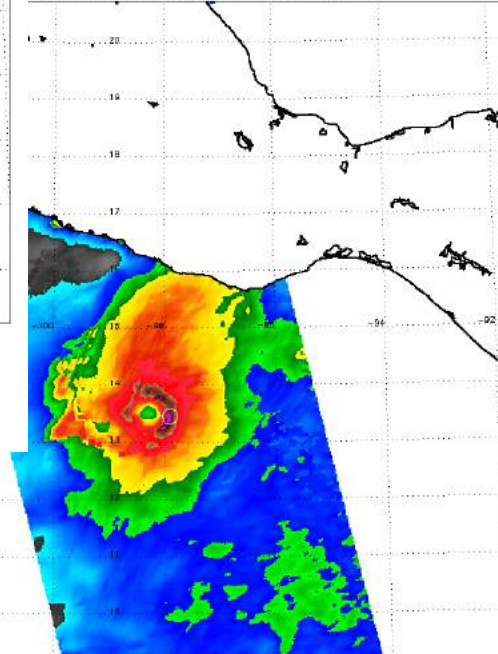
OTIS, 2023-298T16:22:24.000, Max Wind Speed: 21.3 m/s



OTIS, 2023-298T16:22:24.000, Max Wind Speed: 21.3 m/s

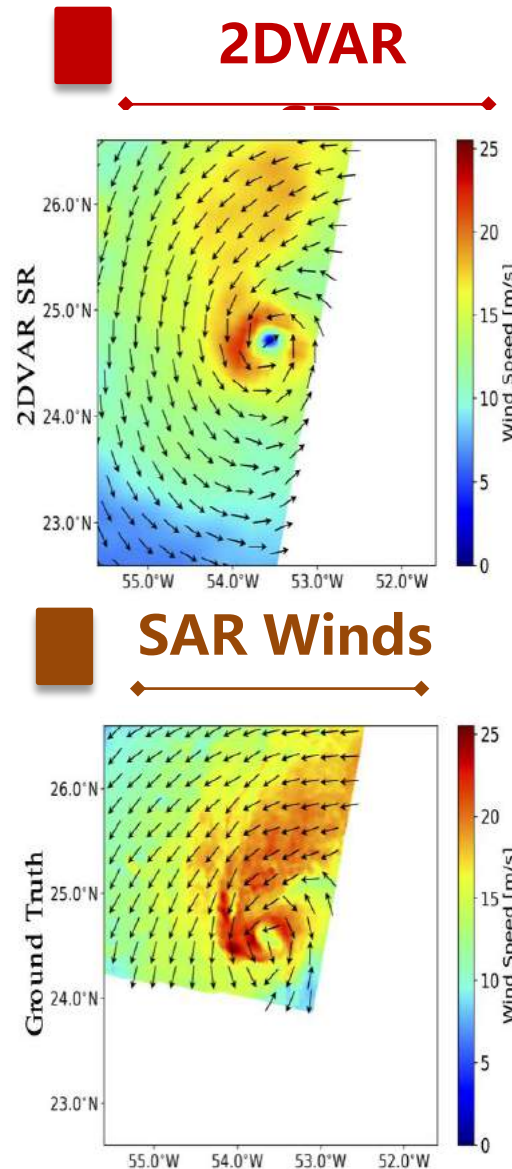
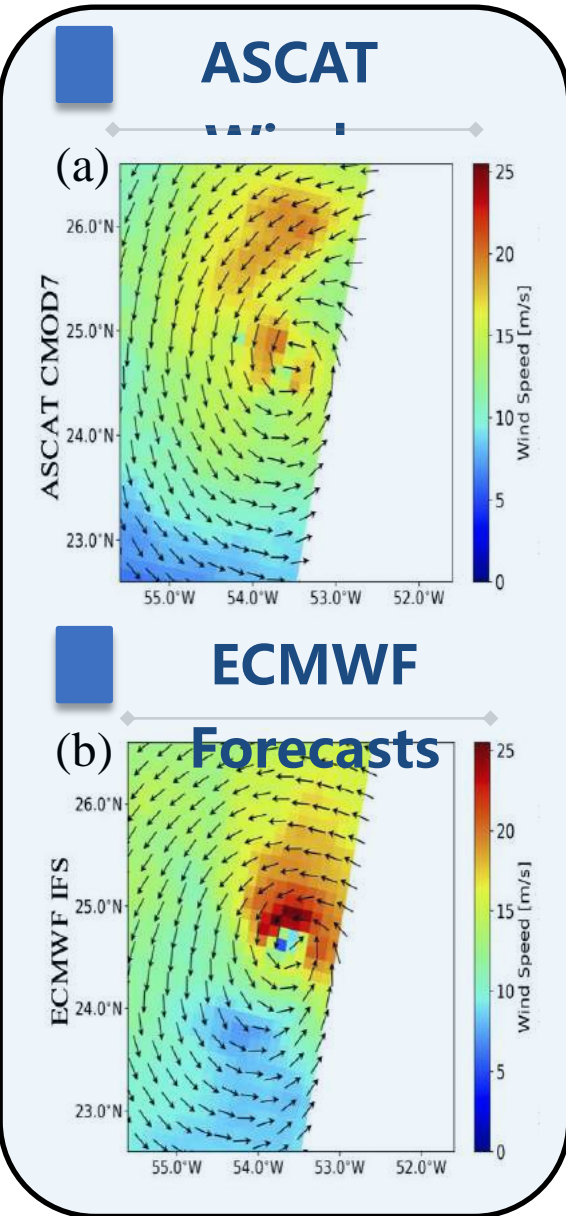


OTIS, 2023-298T16:29:03.000, Max Wind Speed: 21.5 m/s



Tropical Cyclone Resolution Enhancement for ASCAT Winds

Weicheng Ni, Ad Stoffelen, Kaijun Ren, Jur Vogelgang, Yanlai Zhao, Wuxin Wang
National University of Defense Technology, KNMI



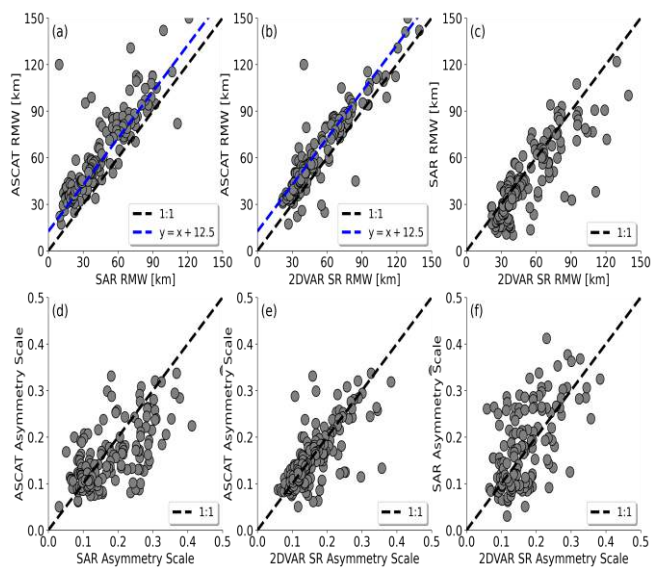
A novel method for generating **Super-Resolution (SR) winds** from low-resolution wind scatterometers is proposed by “learning” the specific TC spatial details from **SAR** winds at high spatial resolution for different classes of TCs.

The resulting empirical spatial structure functions are used for the assimilation of **ASCAT winds** and **ECMWF forecasts**.

Poster: Tropical Cyclone Resolution Enhancement for ASCAT Winds
Weicheng Ni, Ad Stoffelen, Kaijun Ren, Jur Vogelgang, Yanlai Zhao and Wuxin Wang

Tropical Cyclone Resolution Enhancement for ASCAT Winds

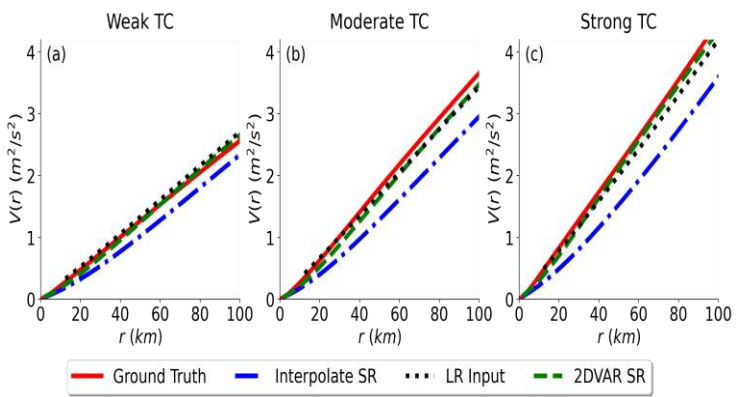
Morphological Analysis



1. The proposed SR method is capable of preserving consistency at large scales with original ASCAT winds while compensating for the ASCAT footprint blurring effect of the small-scale information and enhancing TC vortex structures in a physically meaningful manner, regardless of TC strength category.
2. The obtained SR products possess the correct small-scale properties of TC inner-core structures, such as **Radius of Maximum Wind, TC asymmetry and wind variability**.

Quality Evaluation by Triple Collocation Analysis

Spatial Variance Estimates



TC Category	SR Method	SAR (m/s)	ASCAT (m/s)	ECMWF (m/s)	(m ² /s ²)	Number of Points
Weak	2DVAR SR	1.51	0.57	1.51	0.31	5,034,681
	Interpolate SR	1.53	0.82	1.53	0.06	
Moderate	2DVAR SR	1.42	0.60	1.43	0.35	2,891,969
	Interpolate SR	1.43	0.95	1.43	0.12	
Strong	2DVAR SR	1.31	0.52	1.31	0.43	1,418,252
	Interpolate SR	1.31	0.77	1.30	0.24	

Derivative Products

- A GMF can be developed to use coarse spatial resolution measurements to infer peak winds in TCs (by adjusting the slope of the GMF).
- These products do provide value for TC forecasters
 - However these products do not resolve the actual wind speeds which are still important to measure (climate monitoring, advancing knowledge of the air-sea interaction process, wind coupling into other parameters, TC forecasting/warning, etc.)

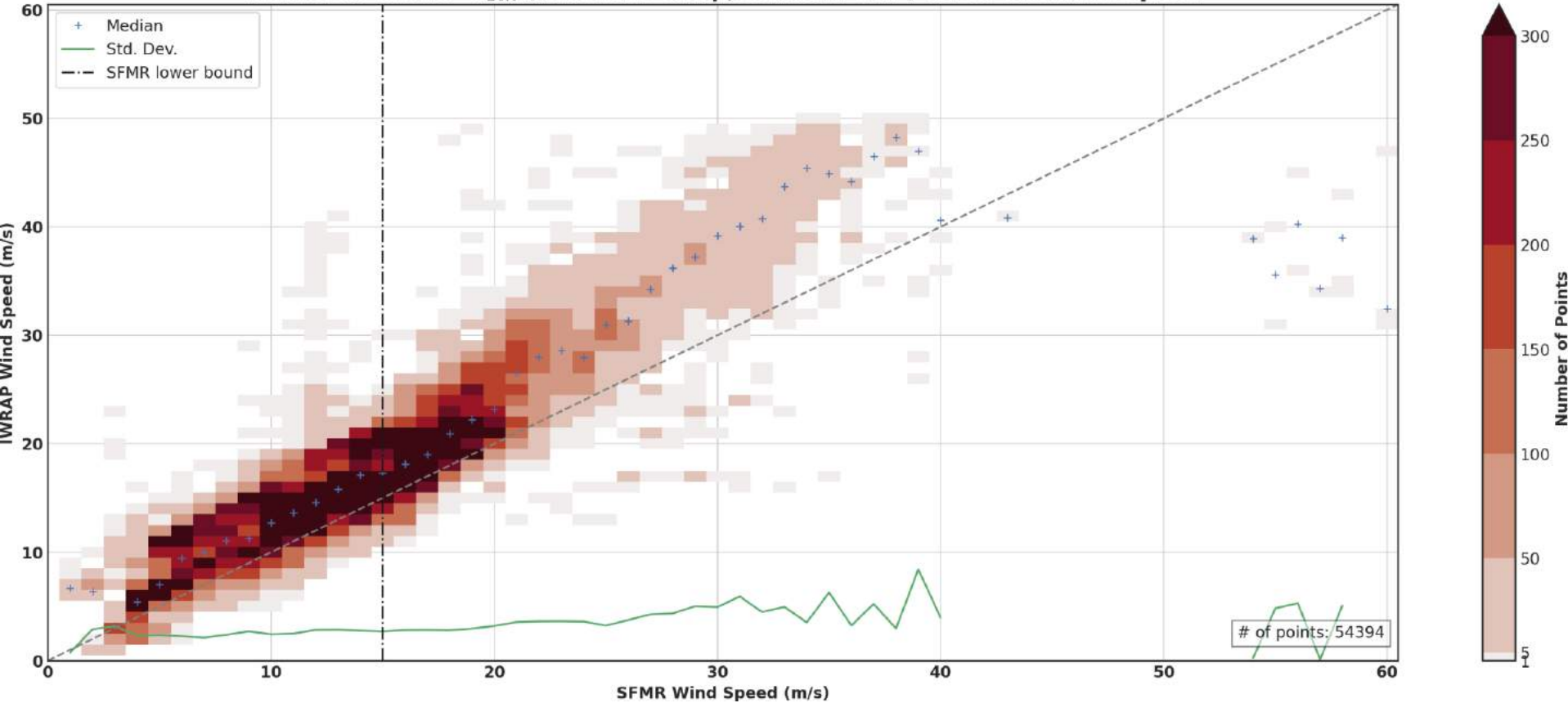
If the spatial resolution of the observing system is larger than the areal extent of the wind speeds being retrieved then the product is indirectly inferring the wind intensity

Next 3 slides illustrate differences one can get using different GMFs for the same measurements.

ScatSat GMF

Operational SFMR

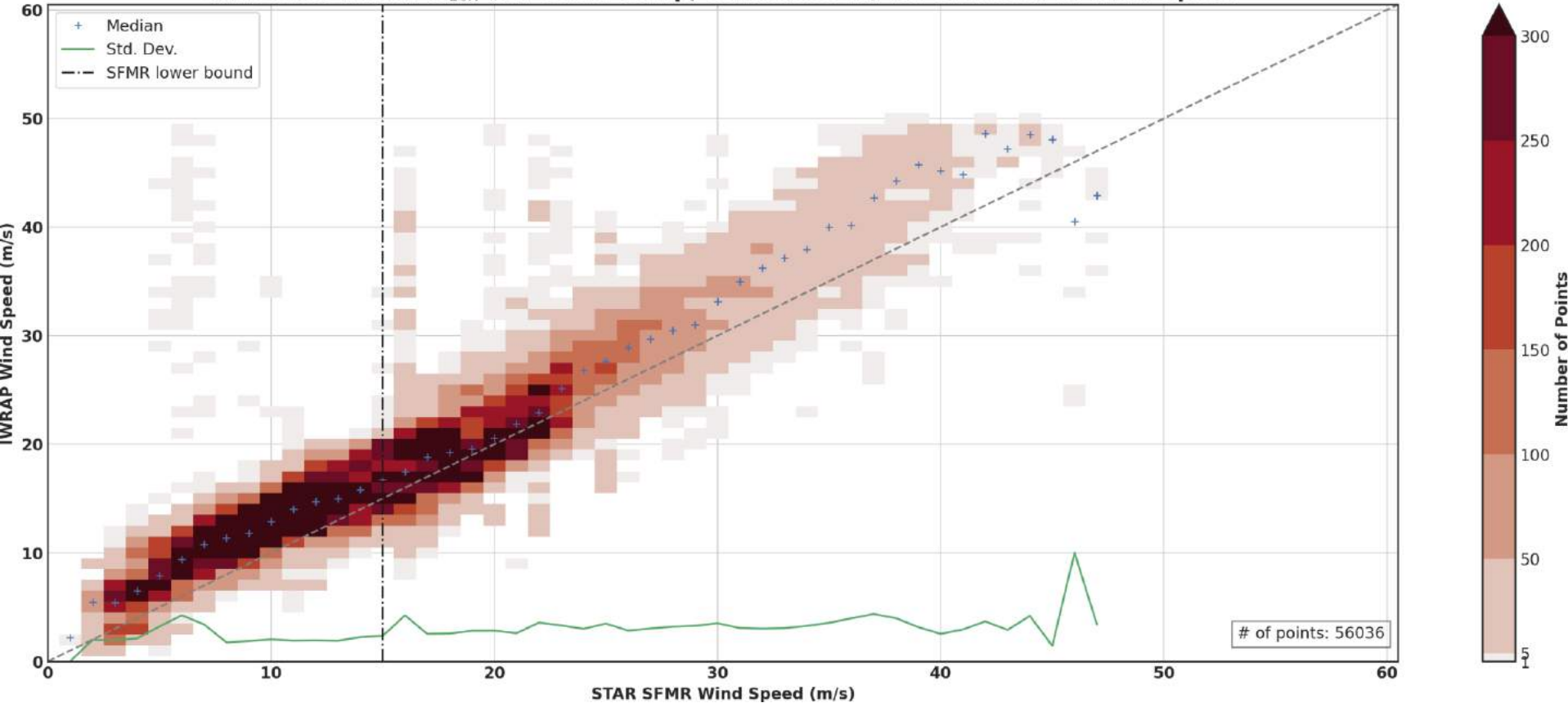
Rain-Free IWRAP U_{10N} (Ku Outer Chirp, ScatSat GMF) vs. SFMR Wind Speed



ScatSat GMF

STAR SFMR

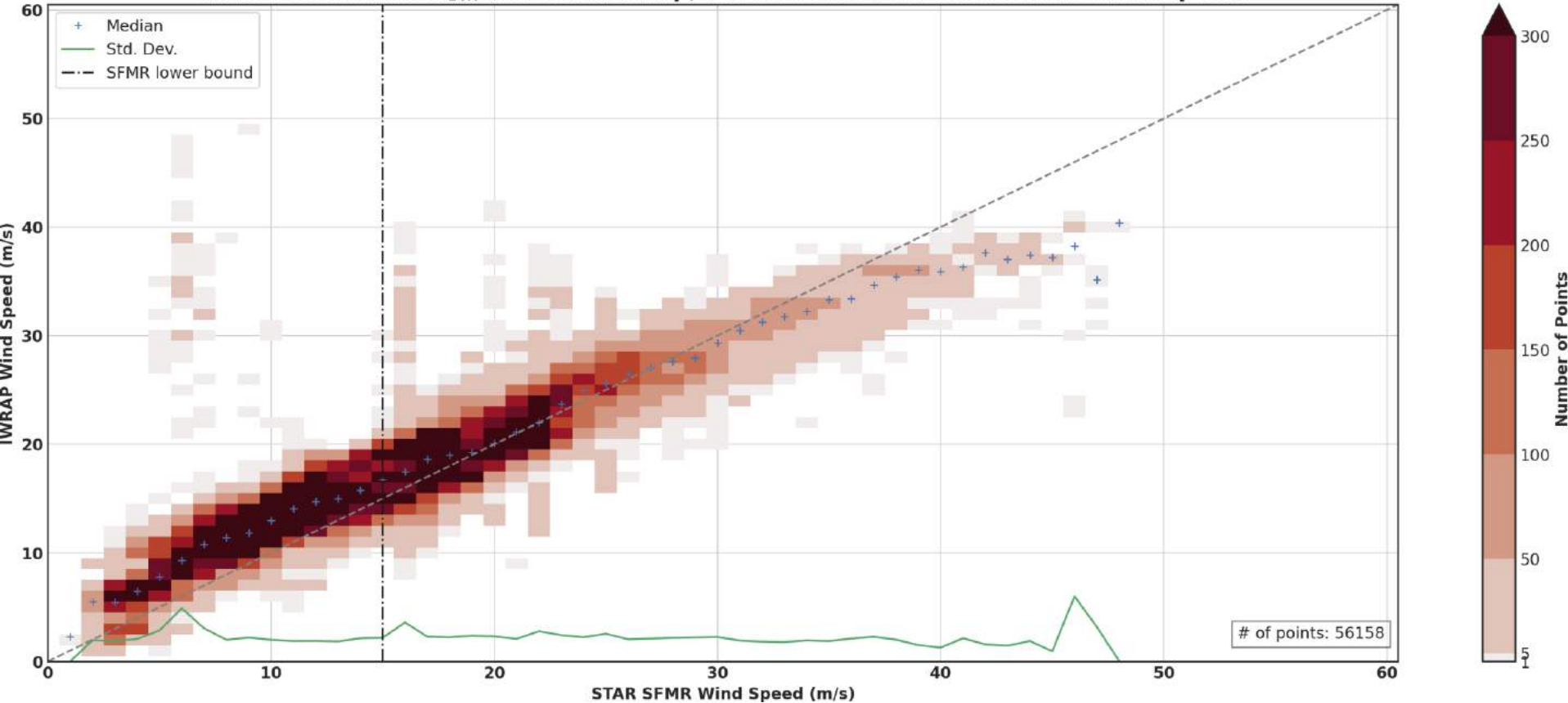
Rain-Free IWRAP U_{10N} (Ku Outer Chirp, ScatSat GMF) vs. STAR SFMR Wind Speed



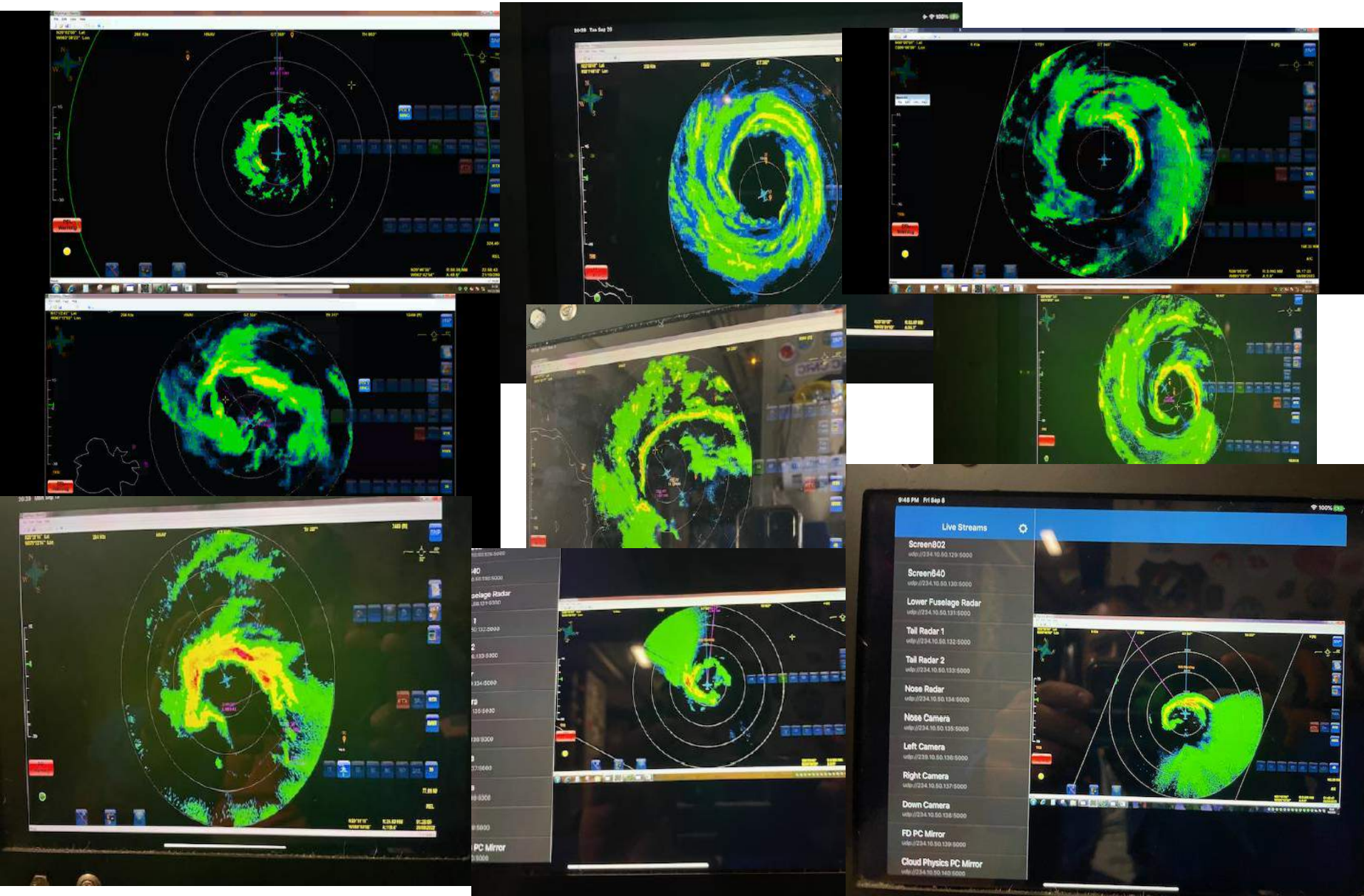
NSCAT4 GMF

STAR SFMR

Rain-Free IWRAP U_{10N} (Ku Outer Chirp, NSCAT4 GMF) vs. STAR SFMR Wind Speed



TC eyes vary in shape and size which can't be resolved properly with coarse measurements



How do we reconcile/What are the next steps?

- We need to fully understand and characterize in-situ and airborne remote sensing measurements in the extremes, which will help understand what capabilities are needed for satellite-based sensors
 - Does enough data already exist?
 - We can continue leveraging hurricane flights but should we also consider a dedicated field experiment?
- 3 possible avenues of attack
 - Characterization of in-situ measurements
 - Characterization of what remote sensors are actually responding to in the extremes
 - Continue development and refinement of derivative approaches/product to more fully exploit existing remote sensing measurements

How do we reconcile/What are the next steps?

- What should the high wind speed calibration reference be?
 - SFMR? It does have issues that need to be fully characterized and resolved
 - Dropsondes?
 - Perhaps a combination of airborne remote sensing instruments to measure a variety of parameters in the TC environment
- What is really happening on the ocean surface in the extremes?
 - Does the sea spray layer need to be accounted for?
 - Bragg scattering enhancement (scatterometers) appears to break down at some point
 - Should the microwave brightness temperature also level off?...there would seem to have to be some maximum foam coverage from wave breaking at some point? Or does the spray layer keep increasing the T_b ?

Gap wind event
Kennedy Entrance, AK



Hurricane Patricia



Hurricane Patricia

