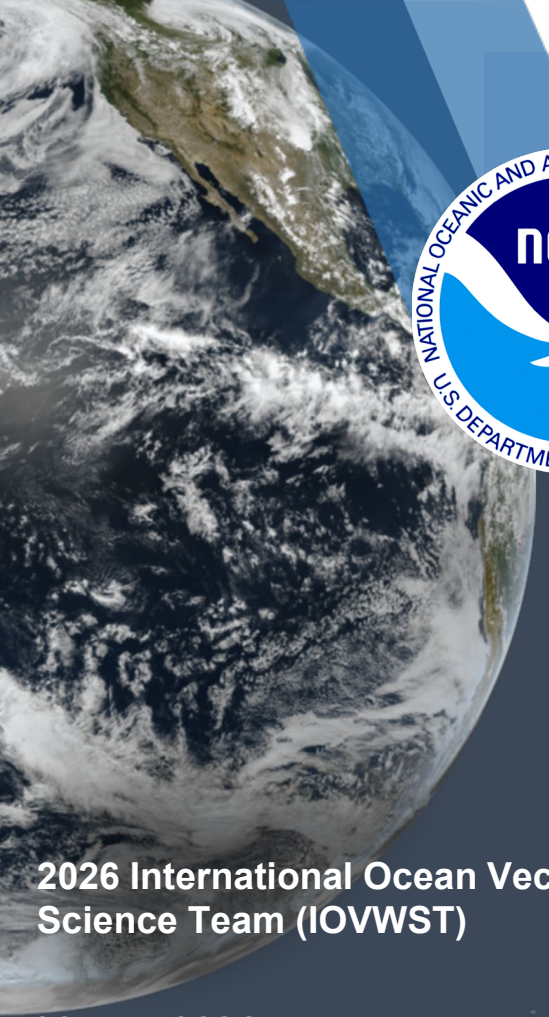


Validation Challenges SAR-Derived Tropical Cyclone Winds

Christopher R. Jackson
Consultant Scientist, GST, LLC., NOAA / NESDIS / STAR

Jessie C. Moore Torres
Junior Scientist, GST, LLC., NOAA / NESDIS / STAR

Tyler W. Ruff
Senior Programmer/Analyst, GST, LLC., NOAA / NESDIS / STAR

Marilyn Yuen Murphy
Science Team Lead, NOAA / NESDIS / STAR

2026 International Ocean Vector Winds Science Team (IOVWST)

20 May 2026

SAR Winds Reference.



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Fostering tropical cyclone research and applications with Synthetic Aperture Radar

Alexis Mouche [a], Arthur Avenas [b], Paul Chang [f], Bertrand Chapron [a], Théo Cévaër [c], Clément Combot [l], Joseph Courtney [q], Quentin Febvre [a], Ralph C. Foster [m], Antoine Grouazel [a], Masahiro Hayashi [h], Takeshi Horinouchi [l r], Yasutaka Ikuta [h], Osamu Isoguchi [p], Christopher R. Jackson [k], Zorana Jelenak [n], John A. Knaff [g], Sébastien Langlade [o], Jean-Renaud Miadana [c], Frédéric Nouguier [a], Masato Ohki [i], Clément Pouplin [s], Tyler W. Ruff [e], Charles R. Sampson [d], Joseph Sapp [e f], Udai Shimada [h r], Takeo Tadono [i], Taiga Tsukada [j], Léo Vinour [l]

We examine how, over its first decade, the Sentinel-1 mission has advanced the estimation of ocean surface winds over tropical cyclones, supported their global monitoring, and fostered related research. C-band S1 Synthetic Aperture Radar have been instrumental in refining wind retrieval algorithms, relying on the co- and cross-polarized normalized radar cross-section sensitivity to the ocean wind–waves, especially for major category (3-5) tropical cyclones observed in wide swath modes. Systematic comparisons with airborne multi-frequency radiometer measurements confirm the ability of Synthetic Aperture Radar to provide estimates of the ocean surface wind field at kilometer resolution during a tropical cyclone (bias of 0.08 m/s, standard deviation of 3.84 m/s, correlation of 0.97) and to extract its main characteristics, including the center of the wind circulation, the maximum possible extent of a given wind speed around the tropical cyclone and the radius of maximum wind. Now available globally and in near-real time at operational tropical cyclone forecasting centers, Synthetic Aperture Radar observations are part of the mix used to diagnose the state of the tropical cyclones and issue warning bulletins. Sentinel-1 decametric-backscatter and kilometric-wind resolutions have also been shown to be a reference for interpreting and calibrating other satellite, in situ measurements, and algorithms. Sentinel-1 synoptic observations benefit from new observing systems. Their synergistic use enables us to provide improved temporal resolution of TCs inner core structural parameters. Research efforts exploiting Synthetic Aperture Radar measurements to document such a dynamical system, infer tropical cyclone boundary layer properties, TC-generated waves, and interactions with the upper ocean are presented. This growing increase in acquisitions from multiple C-band Synthetic Aperture Radar missions (e.g. the Radarsat Constellation Mission) over TCs (a factor of 4 over the last decade), combined with other observational data and numerical models, opens opportunities to revisit robust data-driven approaches. These advances shall support a better representation of tropical cyclones in digital twin frameworks. Both algorithm improvements on existing and future Synthetic Aperture Radar missions are attractive perspectives to provide more accurate predictions and a deeper understanding of these complex weather systems.

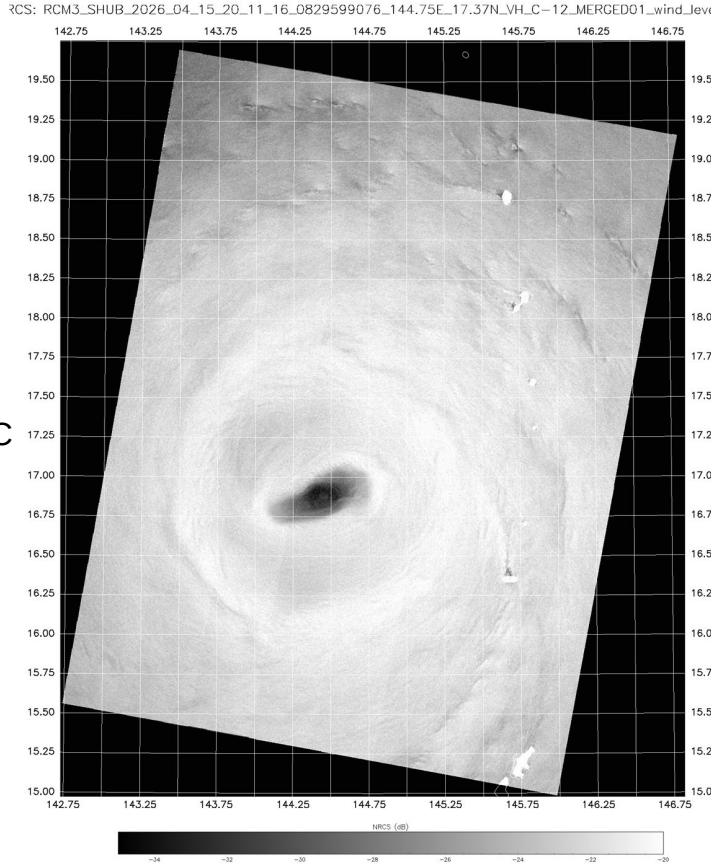
Remote Sensing of Environment, Volume 333, 2026, https://doi.org/10.1016/j.rse.2025.115139 .

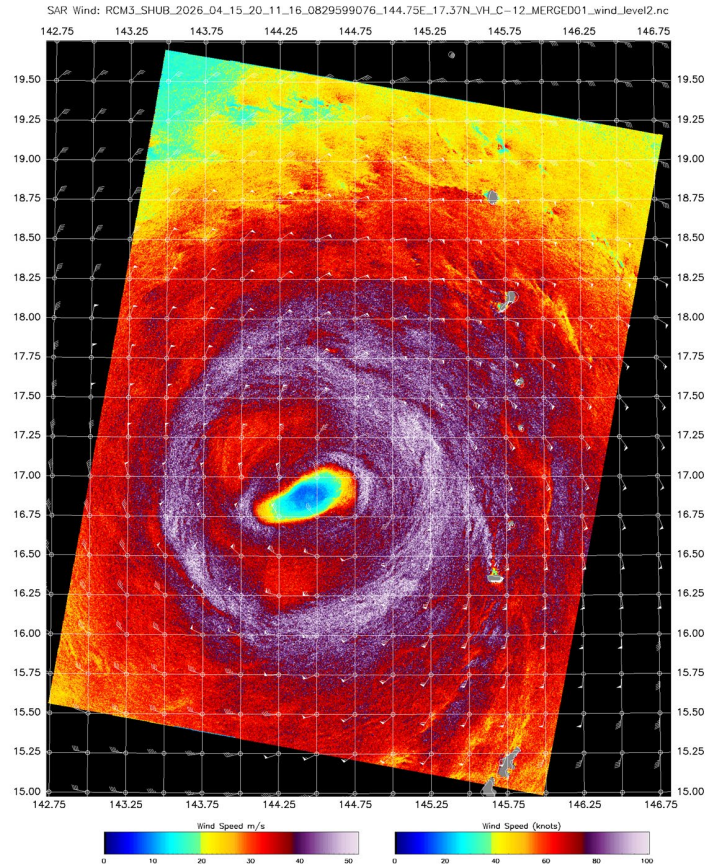
Everything you want to know about SAR cross-pol tropical winds..

SAR for Tropical Cyclones – Sinlaku 15 April 2026 20:11



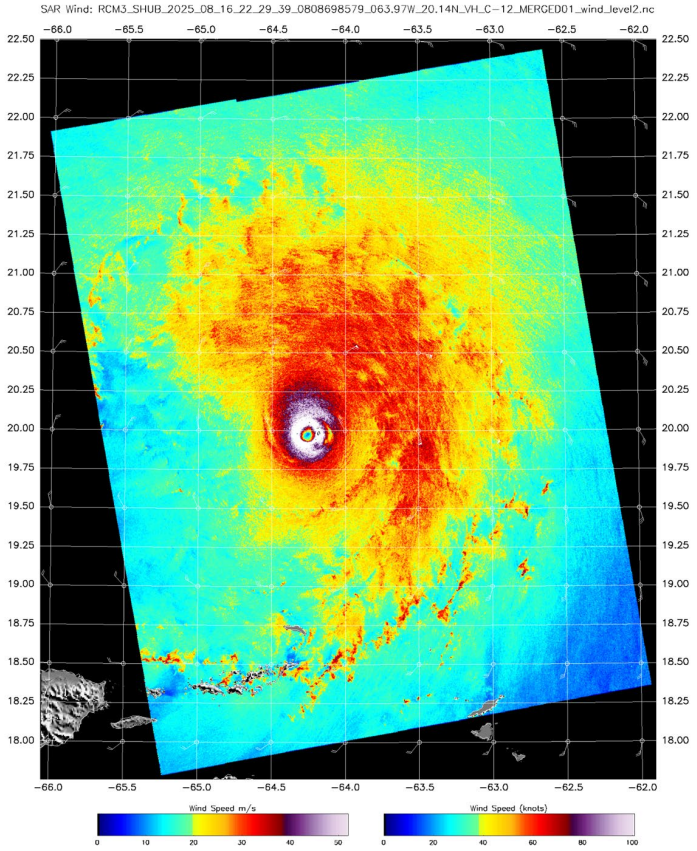
RCM-3
Acquisition Date: 20:11:16 UTC
WP042026 / SINLAKU
Longitude: 144.435
Latitude: 16.870
Incidence Angle (Deg): 46.897
NE VMax (kts): 92.75
SE VMax (kts): 91.93
SW VMax (kts): 91.82
NW VMax (kts): 88.35
RMax (nmi): 47.00 - 57.00

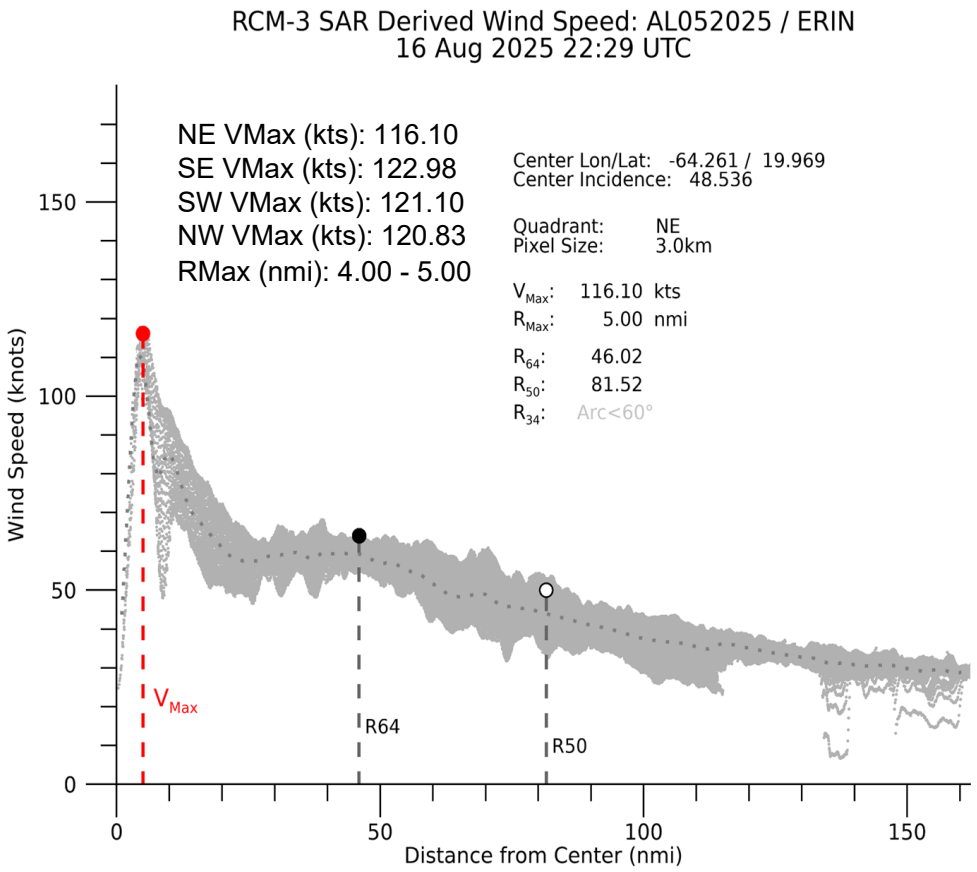




NOAA National Environme
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RADARSAT is an official mark of the Canadian Space Agency
Processed at NOAA/NESDIS/STAR/SOCD 2026 Apr 15 22:57:41 UTC

AL052025 / ERIN RCM-3 2025-08-16 22:30UTC

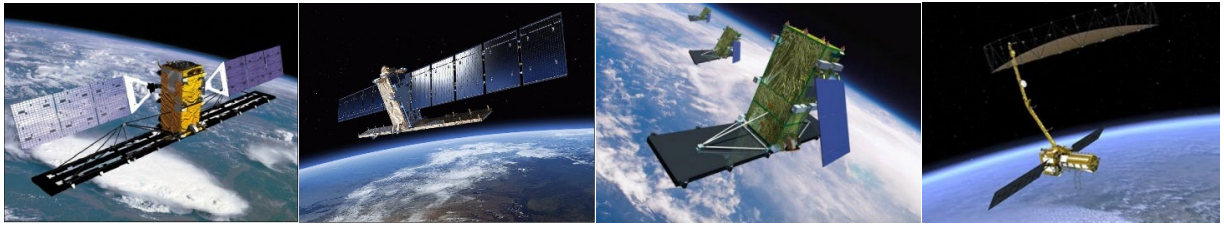




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SAR Satellites Background

- **Sentinel-1D – Launched November 2025**
- **NASA NISAR – Launched July 2025 (L-Band)**



	Radarsat-2	Sentinel-1	RCM	NISAR
Launch	2007	2014 (A) / 2024 (C) / 2025 (D)	2019 (1,2,3)	2025
Altitude	798 km	693 km	593 km	747 km
Repeat	24 Day	12 Day	12 Day	12 Day
LT Ascending Node	18:00	18:00	18:00	06:00
Center Frequency	C-Band 5.405 GHz	C-Band 5.405 GHz	C-Band 5.405 GHz	L-Band 1.25 GHz S-Band 3.2 Ghz
Polarization	HH,VV,HV,VH	VV,VH (HH,HV)	HH,VV,HV,VH, Compact	HH,HV (VV,VH) Quad (US/India)
Swath Width	100,150,300,500	80,240,400	30,125,350,500	240,120 (Quad)
Resolution (Wideswath)	50/100 m	40/80 m	30/50/100 m	25 m (S) / 50 m (L)

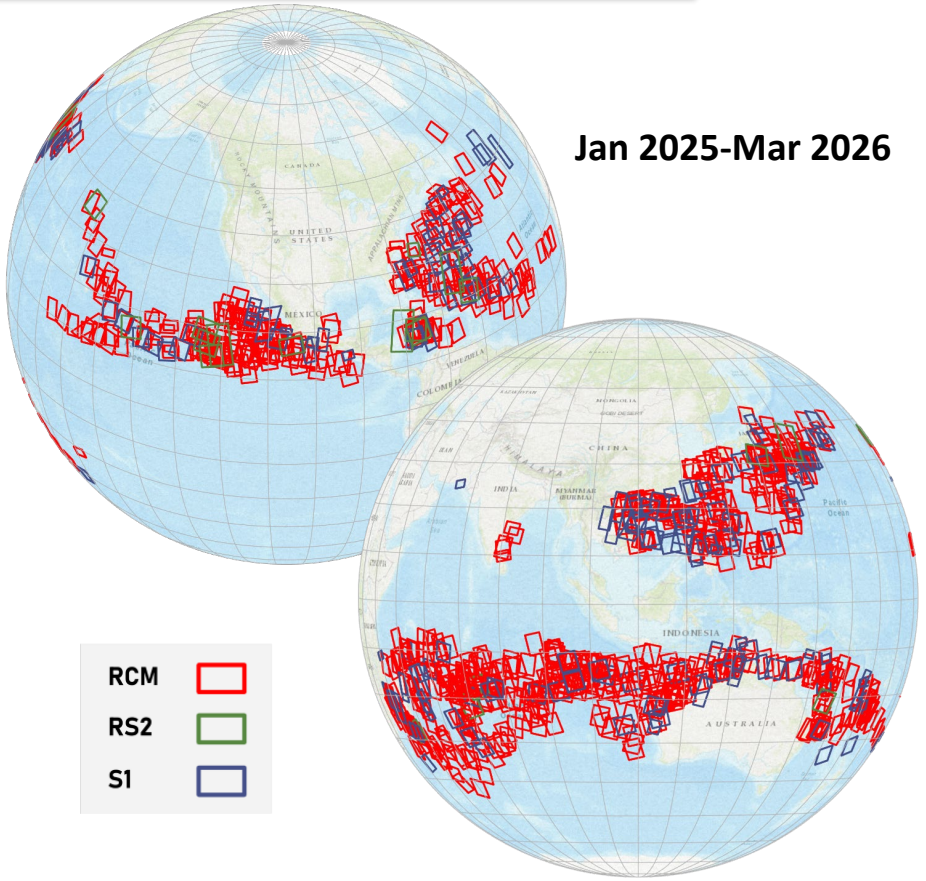
Tropical Cyclone Acquisition Summary (as of March 2026)

Overview

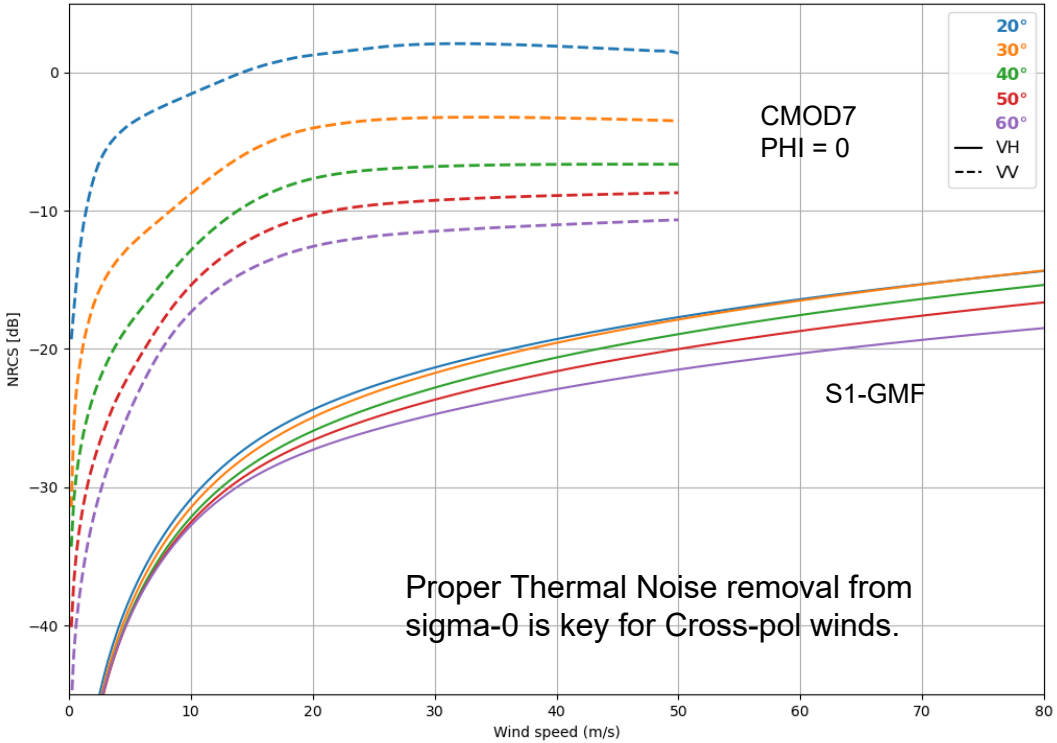
Season	Cyclones	Collections	Eye Hits
2021	50	190	146
2022	40	114	82
2023	61	512	383
2024	80	514	397
2025	**93**	**762**	**576**
2026	27	195	148

In 2022, the Canadian Space Agency updated their Hurricane Watch program to improve RCM TC acquisitions by adding dedicated storm tracking. The result has been an increase in TC collection tasking and an increase to the number of “eye hits” obtained.

Archive goes back to 2014
Tracking earlier and longer…

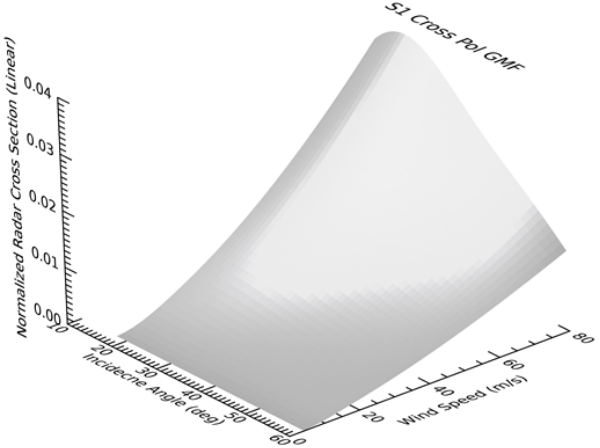


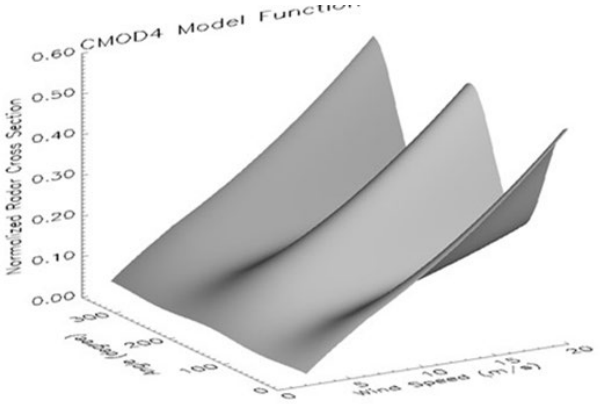
GMF Comparison CMOD7 Copol vs S1A Crosspol



Proper Thermal Noise removal from sigma-0 is key for Cross-pol winds.

Possible starting point for ASCAT-SG B1





Overview

SAR Validation Challenges

- SAR provides fine-resolution imagery that captures details of the eye and surface wind structures and other features not observed by other sensors.
  - A wide swath (500 km) SAR image is captured in ~ 30 seconds
  - SAR is Measuring Cross-Polarization Backscatter (Thermal noise is a factor)
- Hurricane winds are highly variable both spatially and temporally
- There is no known absolute truth to compare against. Every sensor or technique has limitations (either in what, where, when or how it samples the TC)
- Two different sensors can each make “perfect” measurement and still produce different answers due to inherent sensor characteristics
  - conversion of a sensor measurement into wind measurement
- The number of samples of wind speed values available decreases with increasing wind (there are a lot more Cat 1 storms than Cat 5 storms)
  - And it’s the extremes that are of the most interest

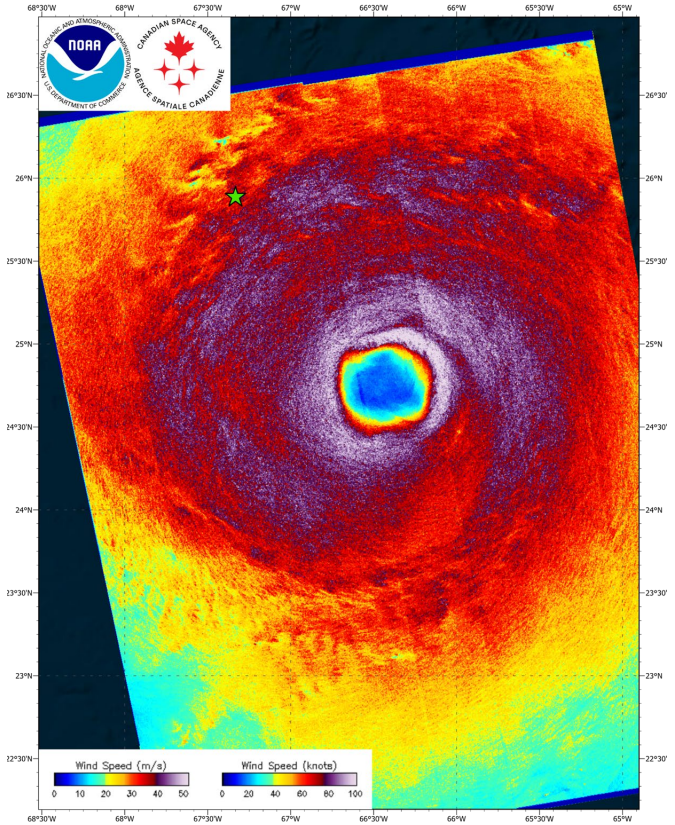
Overview

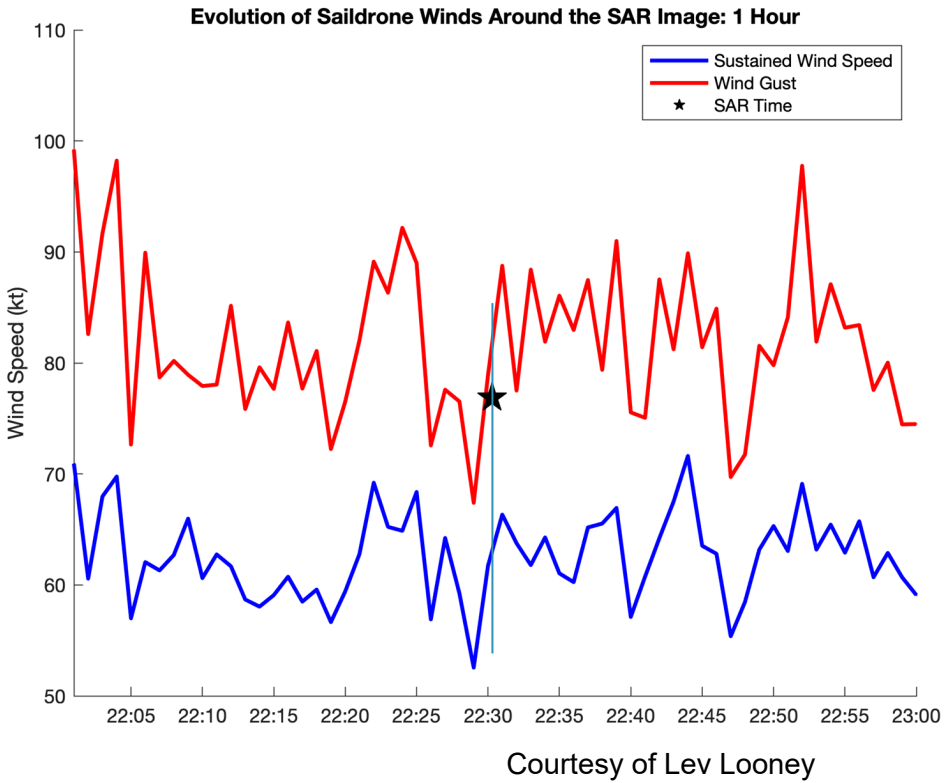
SAR Validation Challenges

- In-situ measurements are only single point in time and space, (temporal averaging)
  - **Buoys, Saildrones, Aircraft** (Flight Level Data, SFMR, Dropsondes)
  - Limited in number
  - In general the aircraft flight times are several hours removed from the SAR overpass times
- Satellite Imagery are mismatched in spatial resolution (1-2 orders of magnitude), there are sensor limitations and lag time with SAR observations
  - Scatterometers (ASCAT), Radiometers (SMAP/SMOS), Altimeters
- Analysis Products (Best-Track, SATCON)
- Validation = Consistency (How much difference is acceptable)

GOAL: Establish trust in the SAR Wind Measurements Tropical Cyclones

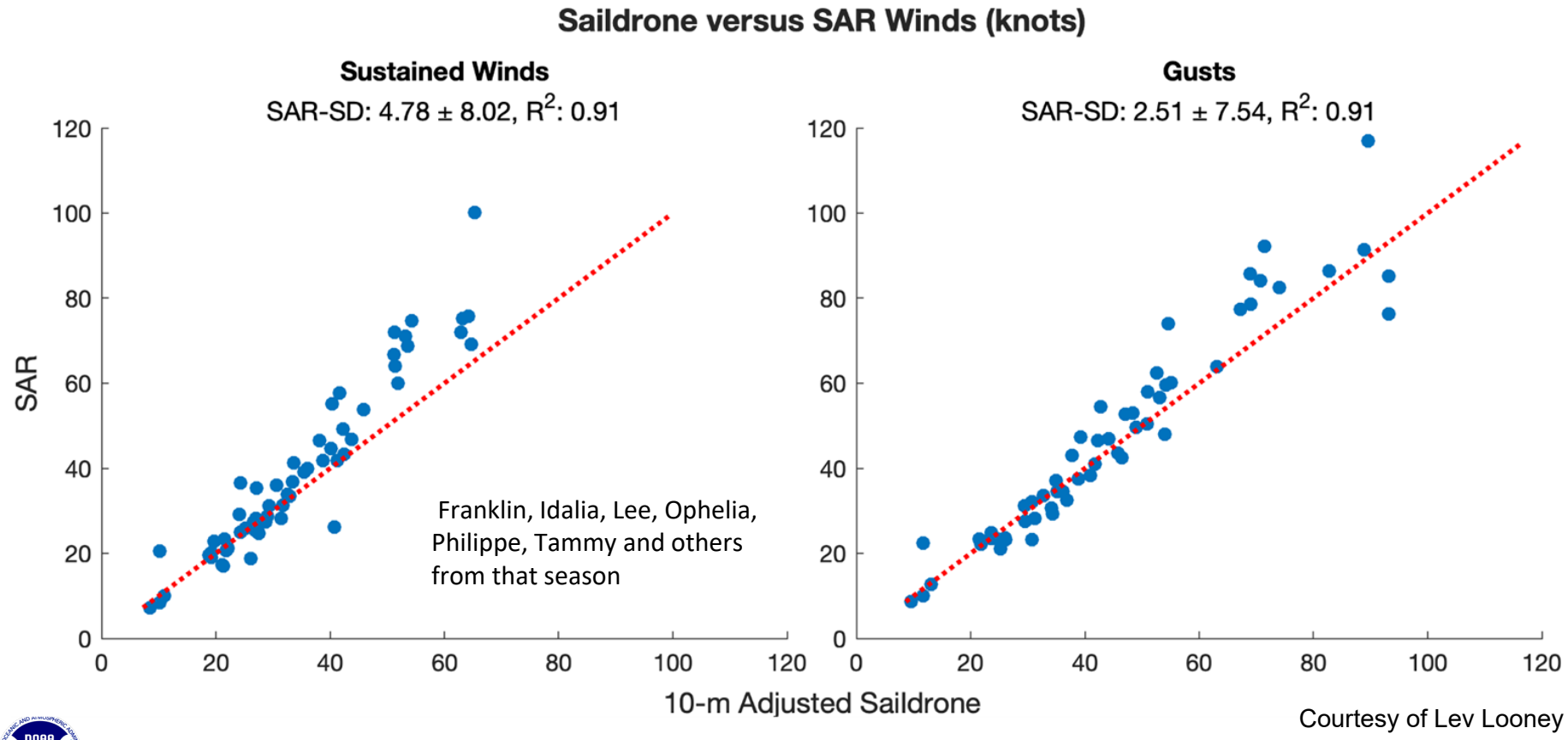
Saildrone Comparisons - TC Lee, 2023 Sept 12 22:30 UTC





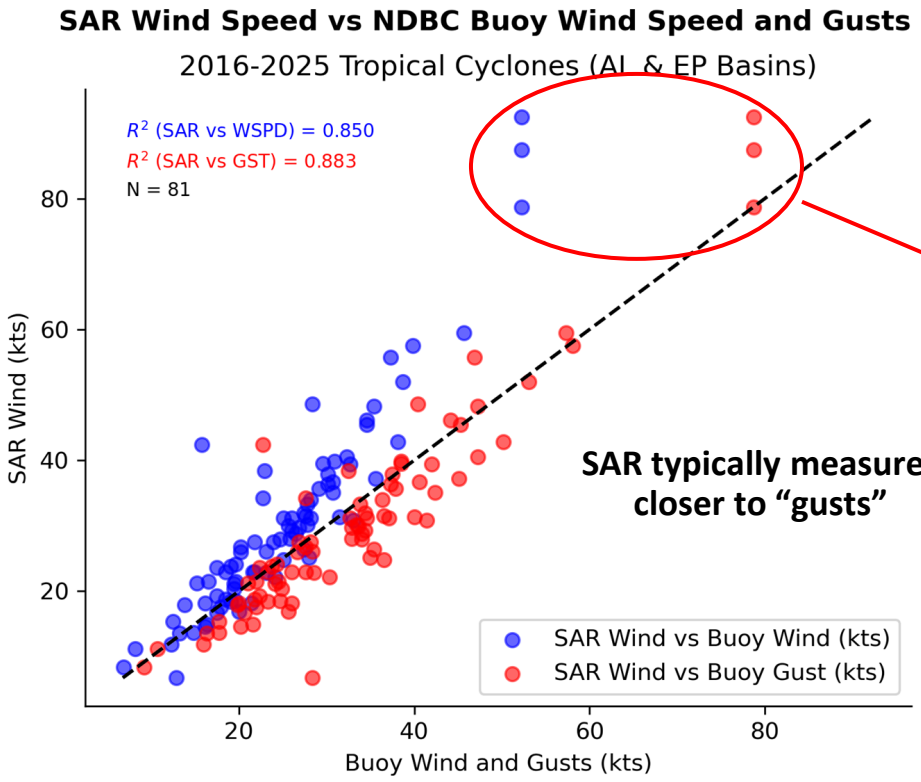
Courtesy of Lev Looney

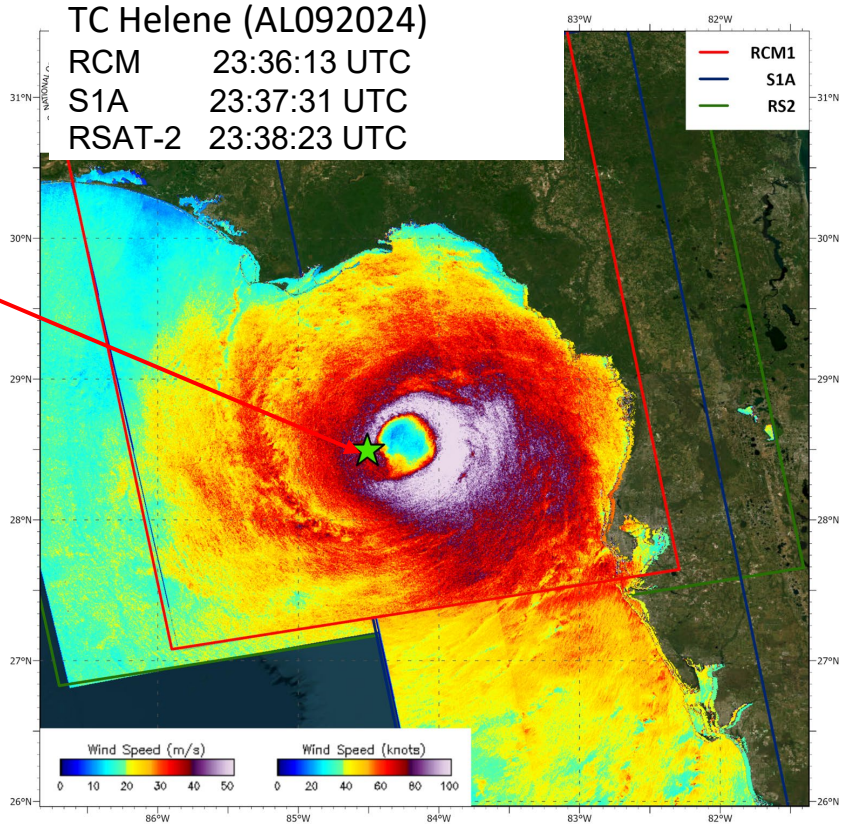
Saildrone Comparisons



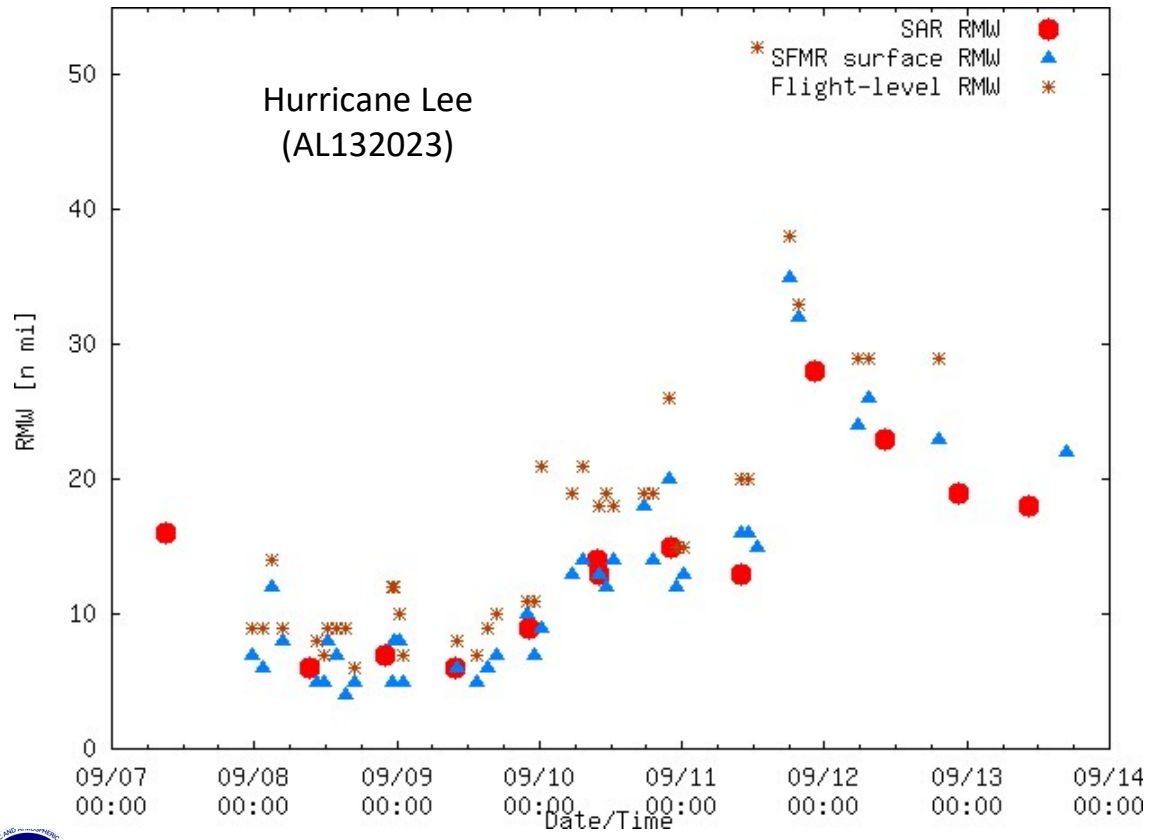
Courtesy of Lev Looney

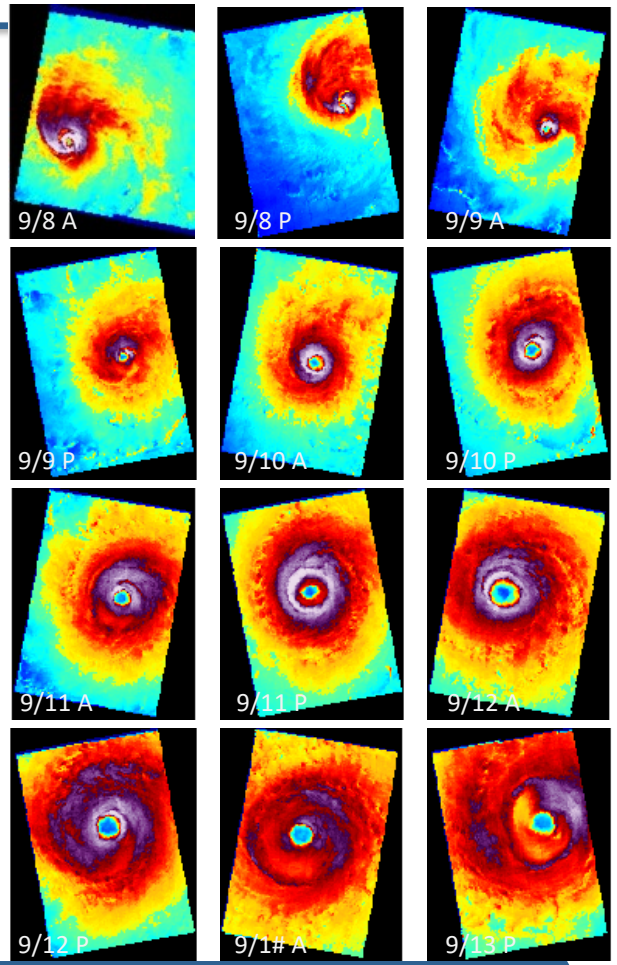
NDBC Numbered Buoys and SAR





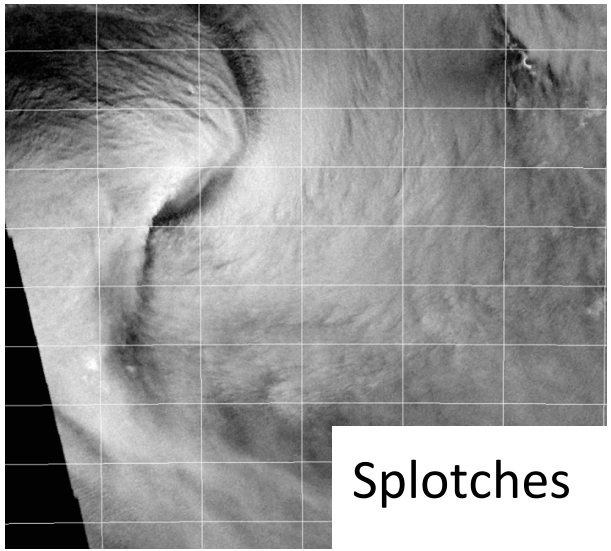
Hurricane Lee RMax – Validation (What is Truth?)





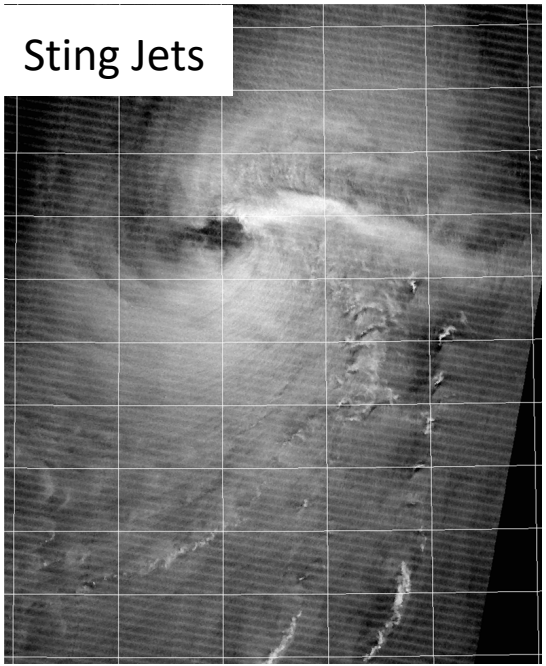
Unknown High Cross-Polarization Feature

SH292026 / INDUSA | RCM2 - VH | 2026-04-05 13:41:09



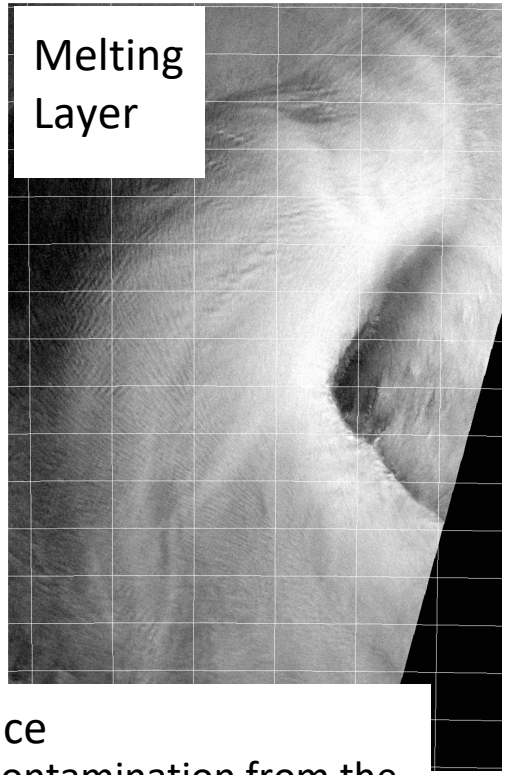
Splotches

WP132024 / LEEPI | RCM3 - HV | 2024-09-05 20:14:23



Sting Jets

SH192025 / RAE | RCM3 - VH | 2025-02-26 16:30:41

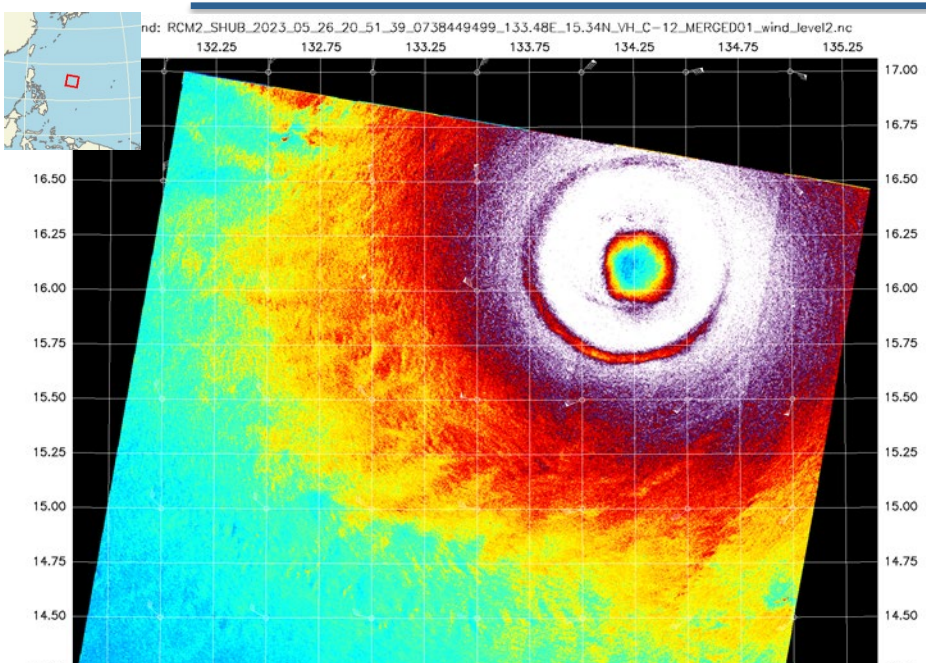


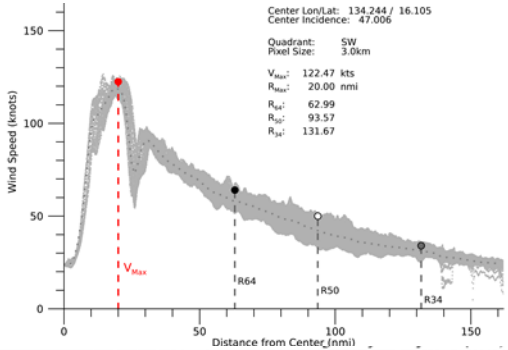
Melting Layer

The SAR can “see” features which don’t represent the ocean surface

- Only radar returns from the ocean surface are valid wind retrievals – contamination from the atmosphere, including ice and strong rain bands/convection can affect results

Typhoon Mawar (WP022023)– 26 May 2023





An example providing evidence of the eyewall's structure with rainfall maximizing just outside the radius of maximum wind as the eyewall's maximum wind slopes outward with height (Jorgensen 1984 - Figure 19).

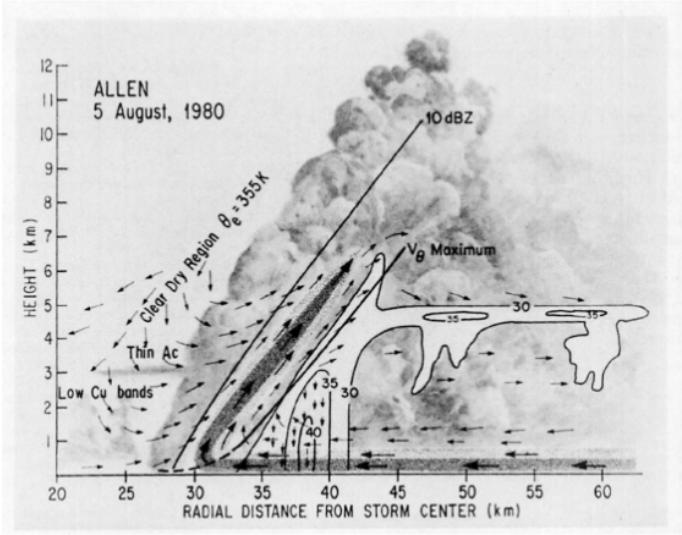
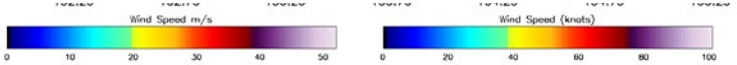
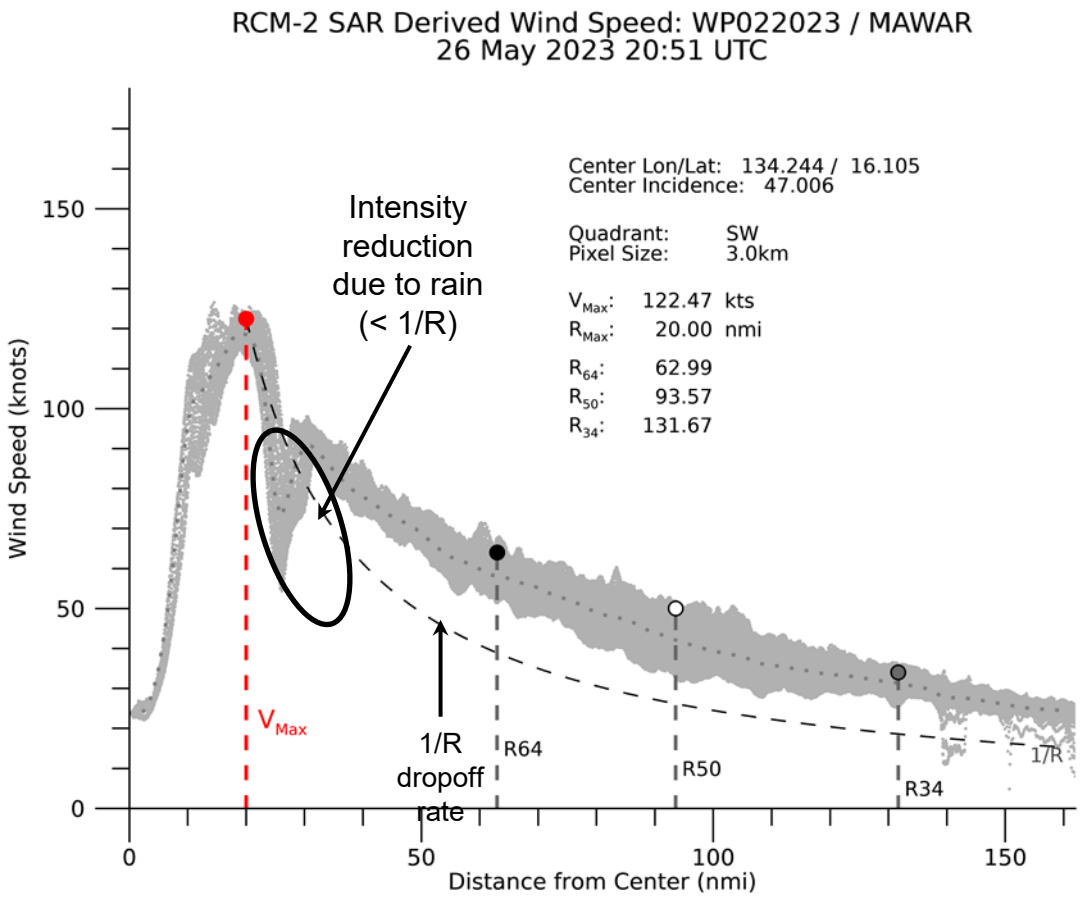


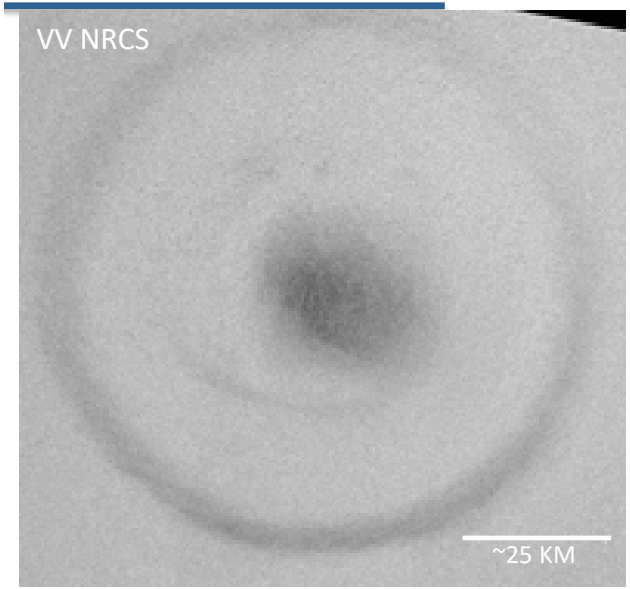
FIG. 19. Schematic cross section depicting the locations of the clouds and precipitation, RMW, and radial–vertical airflow through the eyewall of Hurricane Allen on 5 August 1980. The downward motion in the eye is based on estimates of radial divergence, while the downdrafts within the high rainfall rate region are inferred from vertical velocity time series from the individual passes. Radar reflectivity (dBZ) contours are based on a composite using 15 passes, although there is considerable pass-to-pass variability. The slope of the cloudy region on the inside edge of the eyewall is based on radar minimum detectable signal analysis, aircraft altimeter readings, handheld photography and observer notes. Darker shaded regions denote the location of the largest radial and vertical velocity.



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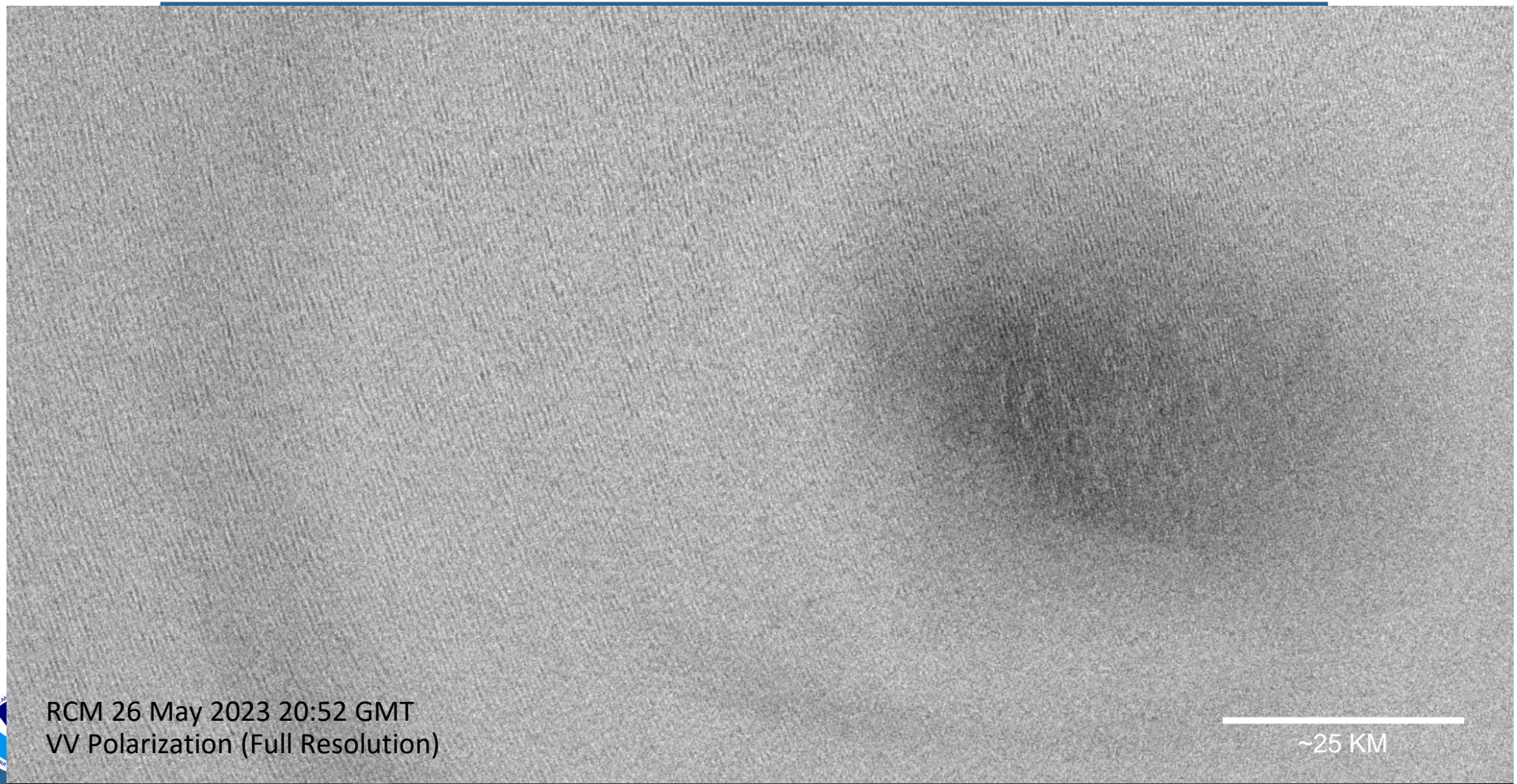
Rain Identification / Contamination





Continued effort to filter rain, detect rain and use the information to better understand rain rate

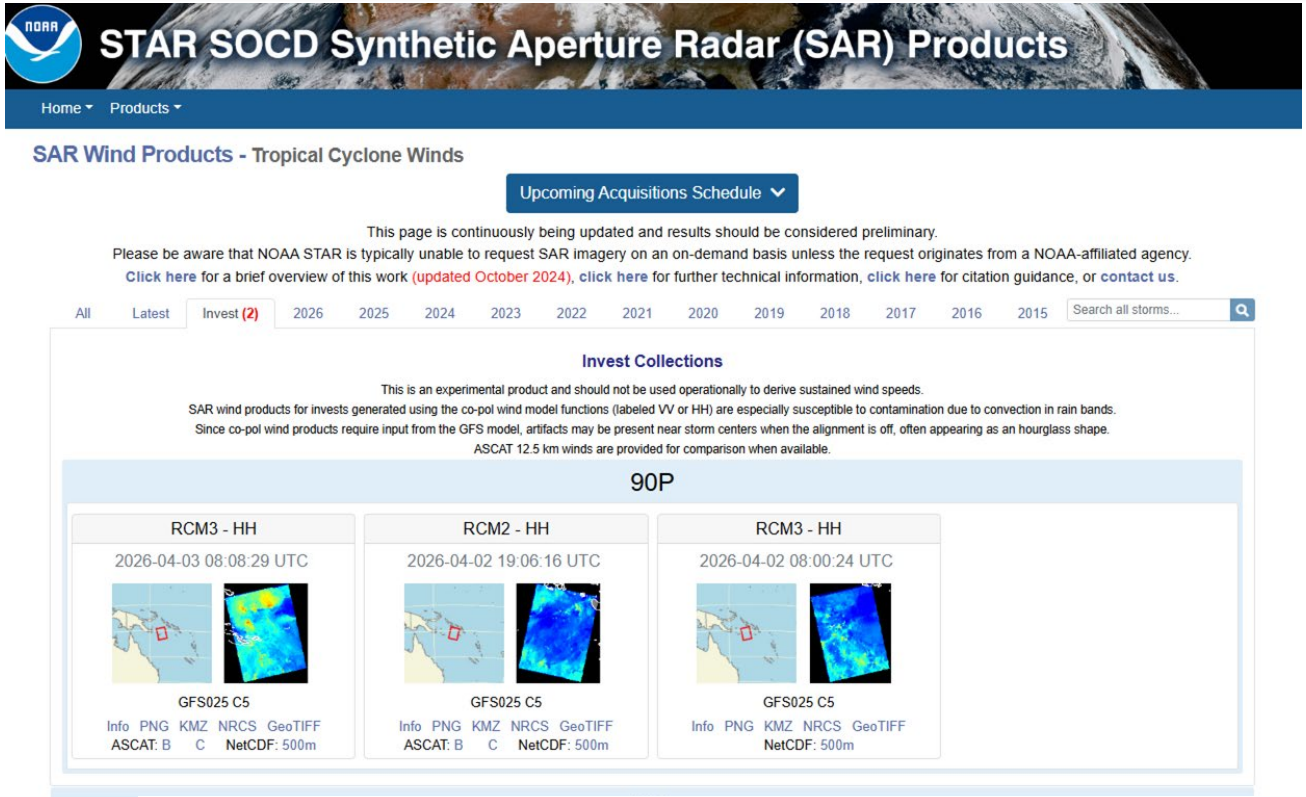
Ocean Swell Field – Typhon Mawar (WP022023)



Conclusions

- SAR provides fine-resolution imagery that captures details of the eye and surface wind structures and other features not observed by other sensors.
- Validation is challenging and ongoing – still work to do
  - In situ: Buoys, Saildrones, Aircraft (Flight Level Data, SFMR, Dropsondes) (Spatial limitations)
  - Satellite Imagery: Scatterometers (ASCAT), Radiometers (SMAP/SMOS), Altimeters (Issue with Spatial Resolution and Timing)
  - Analysis Products (Best-Track, SATCON)
- Find effective method to filter/flag “non-ocean surface” scattering features.
  - Need to examine better ways to filter out the scattering by precipitation, hydrometers in rain cells (also important for Invests)
  - Might need to leverage AI/ML to detect anomalous features that may be affecting some of the estimates.
- Possible to extract information about the swell field

SAR TC Winds Website



https://www.star.nesdis.noaa.gov/socd/mecb/sar/sarwinds_tropical.php

Web Resources

STAR Tropical
https://www.star.nesdis.noaa.gov/socd/mecb/sar/sarwinds_tropical.php

ESA Project on SAR Tropical Cyclones
https://www.esa-cyms.org/

CyclObs (CYMS archive of SAR data)
https://cyclobs.ifremer.fr/app/

STAR S1 Winds
https://coastwatch.noaa.gov/SAR/sar_winds_s1.html

STAR Radarsat-2/RCM Winds
https://coastwatch.noaa.gov/SAR/sar_winds_rcm.html

SAR Marine Users Manual
https://sarusersmanual.com/

High Resolution Wind Monitoring With Wide-Swath SAR: A User's Guide (June2005)
https://www.star.nesdis.noaa.gov/socd/mecb/sar/publications.php

EOS Chasing Cyclones from Space (2021)
https://eos.org/features/chasing-cyclones-from-space

Thank you!