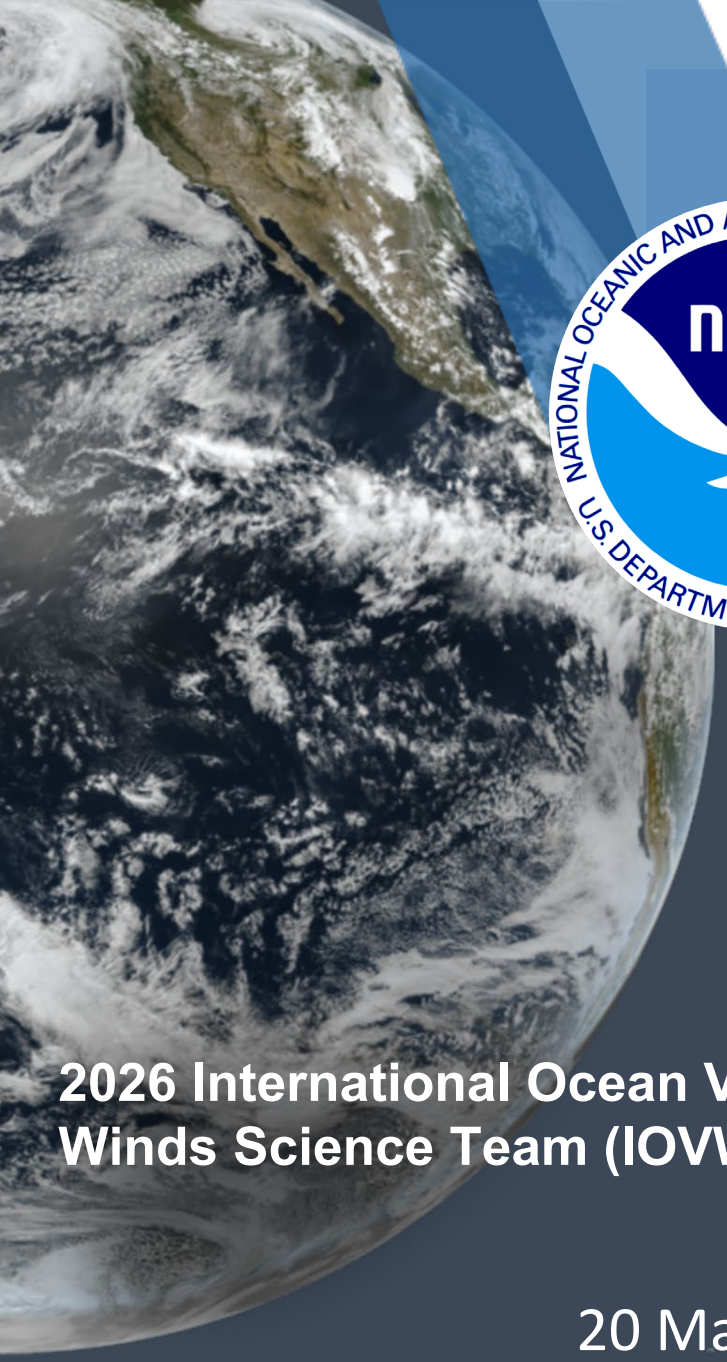


Buoy Validation of Synthetic Aperture Radar (SAR) Derived Ocean Surface Winds using CMOD4 / CMOD7

Christopher R. Jackson[1,2,3]
Jessie C. Moore Torres[2,3]
Rachel Lazzaro[2,3]
Tyler W. Ruff[2,3]
Marilyn Yuen Murphy[3]

[1]Global Ocean Associates
[2]Global Science and Technology Inc
[3]NOAA / NESDIS / STAR

2026 International Ocean Vector Winds Science Team (IOVWST)

20 May 2026

NOAA STAR Synthetic Aperture Radar Science Team

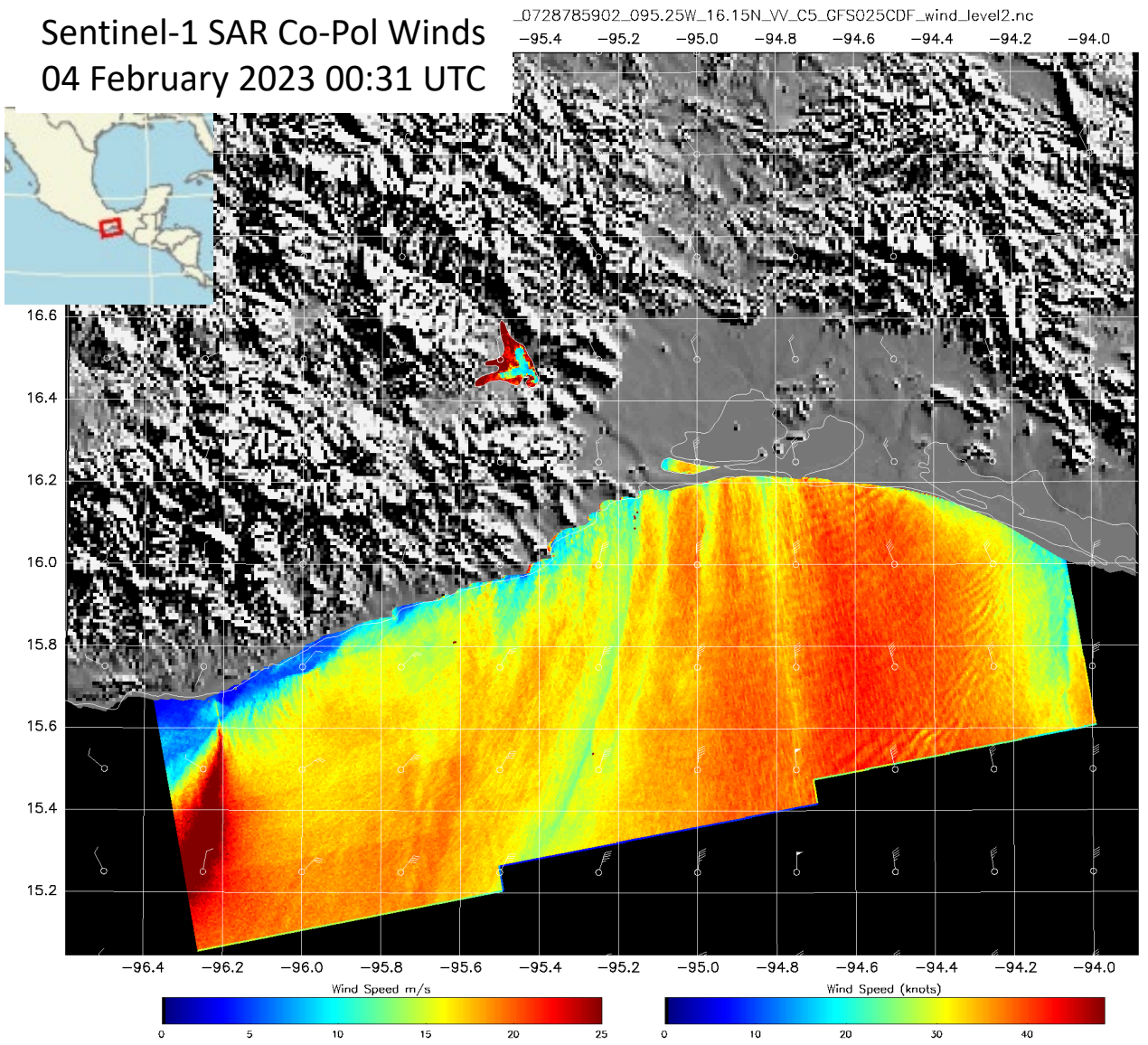
The Center for **Satellite Applications and Research (STAR)** is the science arm of National Environmental Satellite, Data, and Information Service (NESDIS).

STAR's mission is to accelerate the transfer of satellite observations of the land, atmosphere, ocean, and climate from scientific research and development into routine operations, and offer state-of-the-art data, products, and services to decision-makers.

Synthetic Aperture Radar Science Team has programs to produce

- **Ocean Surface Wind Speeds**
- Tropical Cyclone Wind Speeds
- Flooding and Inundation Maps
- Sea Ice Extent and Characterization

Products Support Operational Customers



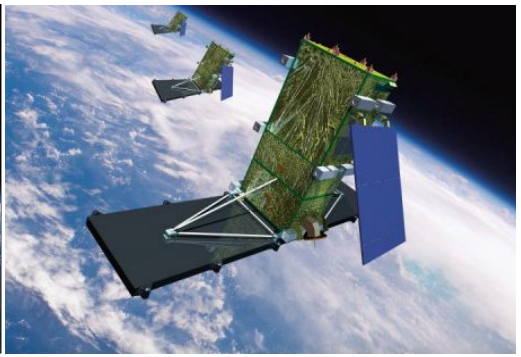
SAR Satellites Background

Coverage Limitation

- Satellite-based SAR acquires data with a limited footprint and only over a portion (~25%) of every orbit

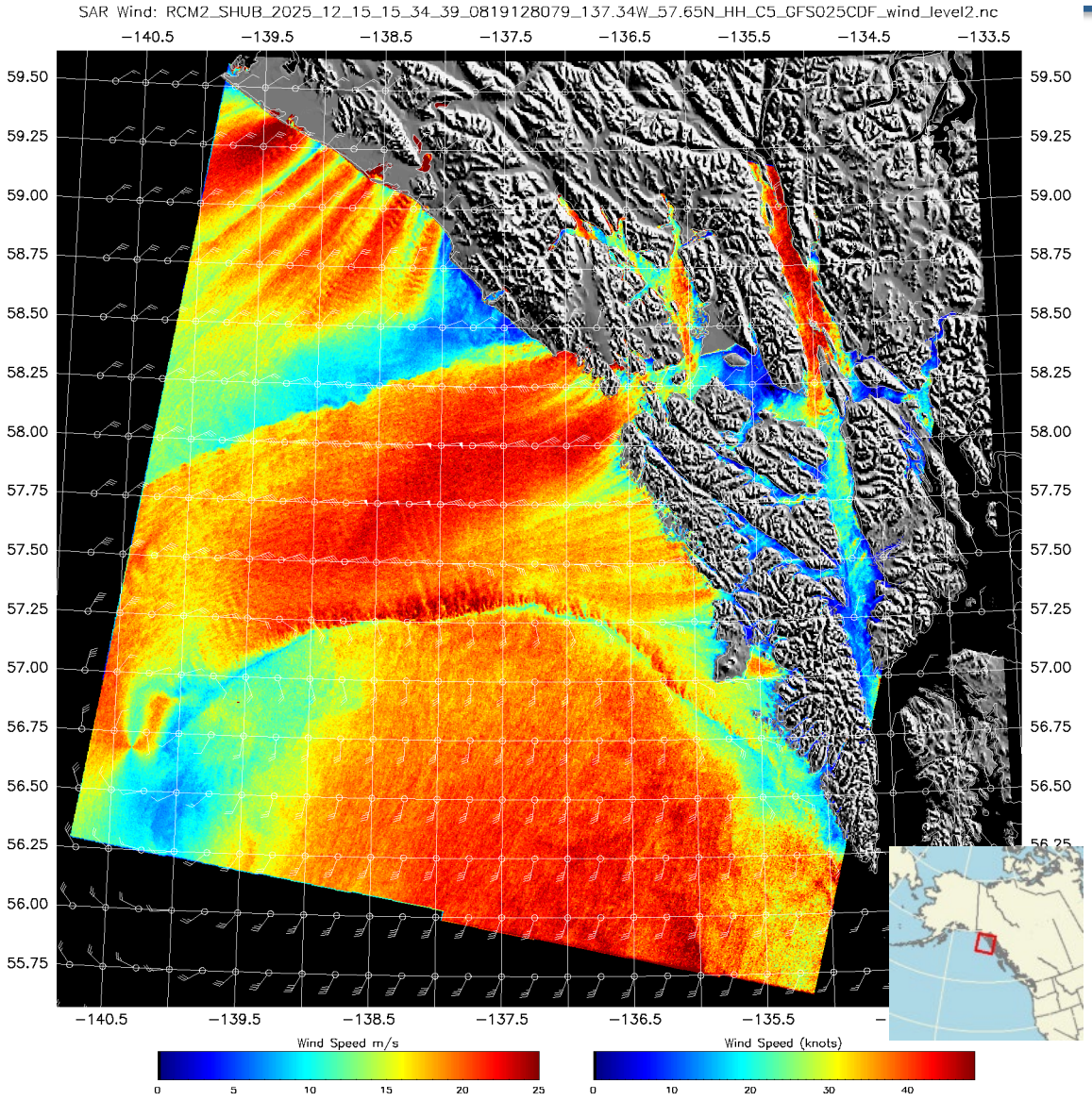
- NOAA STAR processes between 500 and 1000 images per day principally in the US EEZ (including Alaska and Hawaii), the North Atlantic , the Caribbean, the North Pacific





	Sentinel-1	RCM
Launch	2014 (A) / 2024 (C) / 2025 (D)	2019 (1,2,3)
Altitude	693 km	593 km
Repeat	12 Day	12 Day
LT Ascending Node	18:00	18:00
Center Frequency	5.405 GHz	5.405 GHz
Polarization	VV,VH (HH,HV)	HH,VV,HV, VH, Compact
Swath Width	80,240,400	30,125,350,500
Resolution (Wideswath)	40/80 m	30/50/100 m

SAR Wind Image

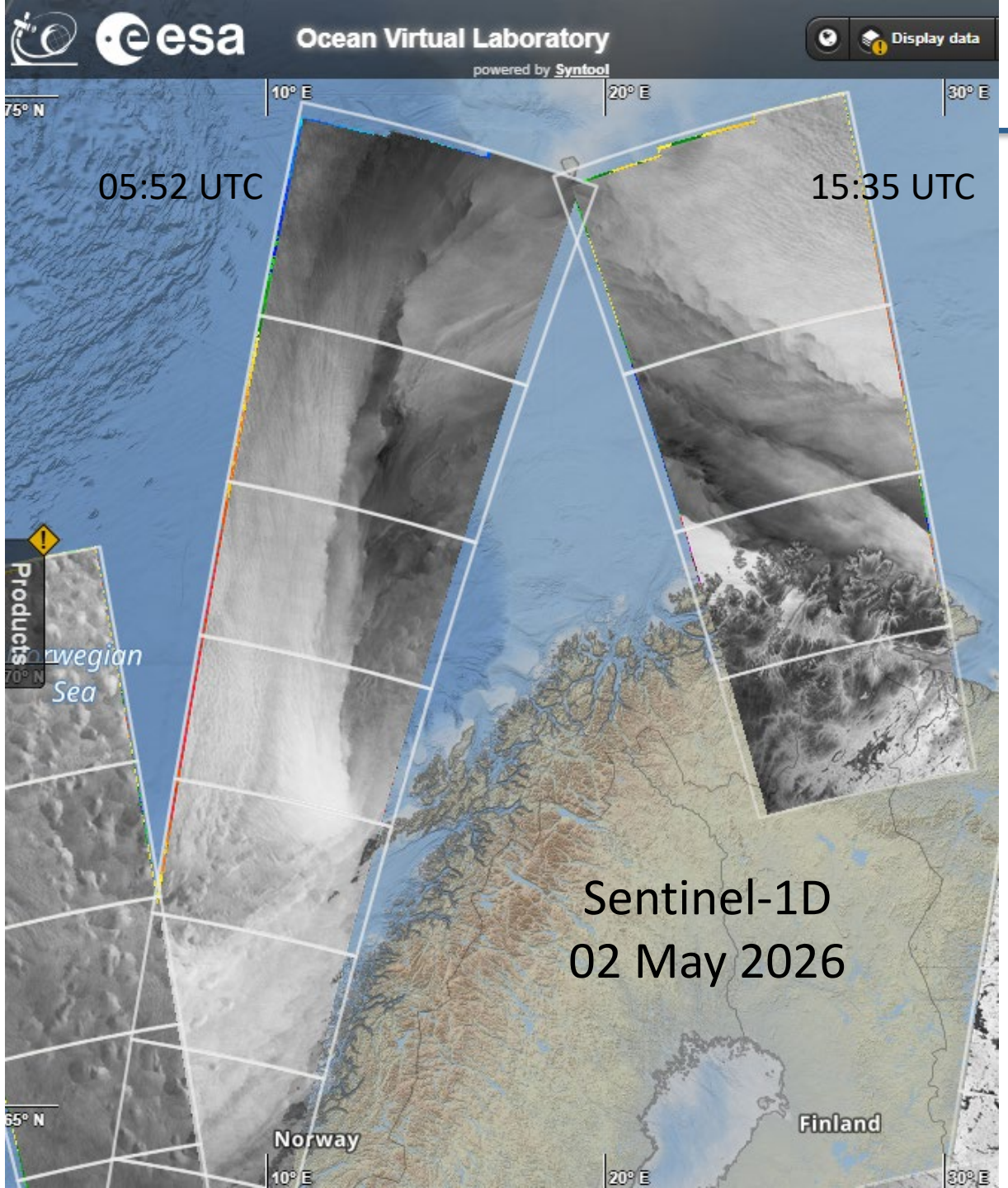


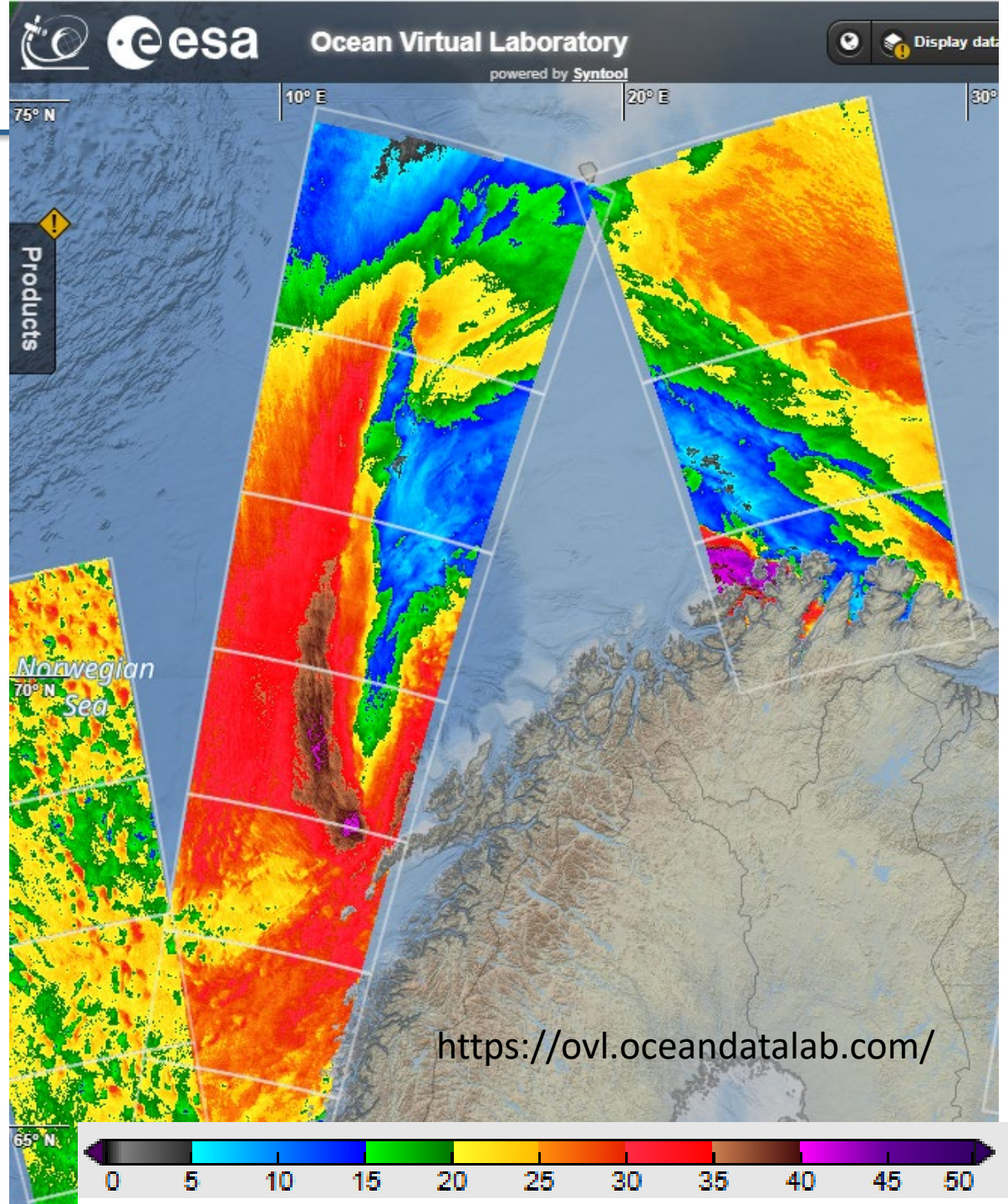
Characteristics

- 500 m sampling
  - Available adjacent to coastlines
- Reported at a 10-m height above the surface (CMOD4)
- Accuracy < 2 m/s (up to 20 m/s),
- Near Real Time with 2-4+ hours latency
- Wind speed only
- Wind directions are obtained from weather models
  - GFS 0.25° or HRRR 3km (Great Lakes)
  - Inaccurate wind direction equals inaccurate wind speed
- Non-ocean surface scattering produces false wind measurements
  - The GMF just converts NRCS to wind speed

:MOD4 GMF
FS 0.25 Barbs

RADARSAT Constellation Mission Imagery Copyright Government of Canada 2025
RADARSAT is an official mark of the Canadian Space Agency
Processed at NOAA/NESDIS/STAR/SOCD 2025 Dec 15 16:48:17 UTC


esa
Ocean Virtual Laboratory
powered by Syntool
Display data
10° E
20° E
30° E
75° N
05:52 UTC
15:35 UTC
Products
Norwegian Sea
70° N
65° N
Norway
Finland
Sentinel-1D
02 May 2026


esa
Ocean Virtual Laboratory
powered by Syntool
10° E
20° E
75° N
Products
Norwegian Sea
70° N
65° N
https://ovl.oceandatalab.com/
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SAR Wind Speed Validation

Ocean buoys provide in-situ measurements of wind speed and direction useful for SAR wind speeds validation

- SAR collects a near instantaneous measurement (0.5 sec) over a large spatial area
- Buoy collects 8 min average wind speed and direction at a single location

Both the SAR and the buoy can measure the wind perfectly but still produce different results.

Are the buoy / SAR wind comparisons meaningful?

- Yes… but the expected differences and their impacts on the measurements/comparisons need to be understood*

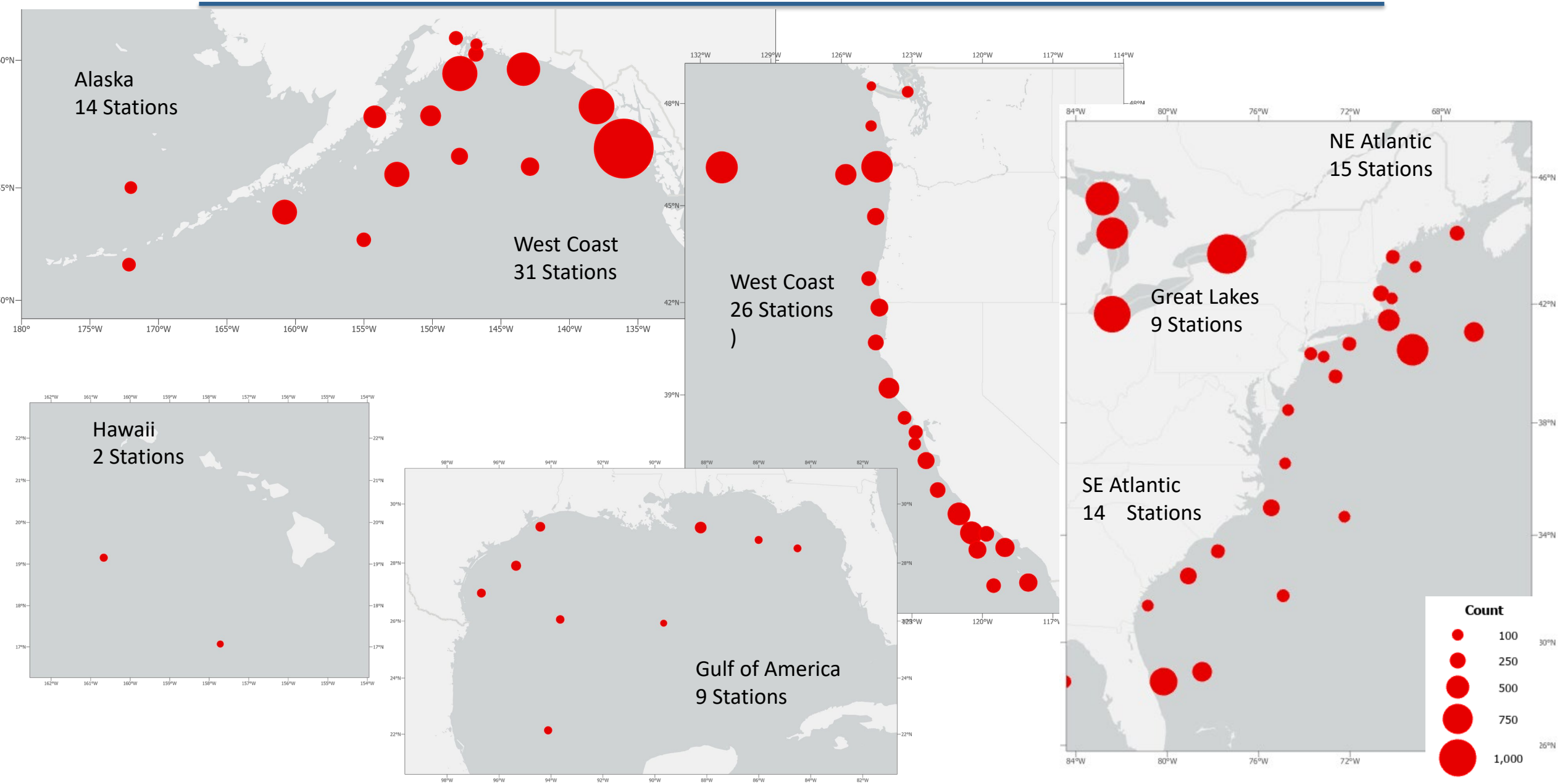
SAR winds vs Buoy

- SAR processed to 500 meter pixel using both CMOD4 and CMOD7 (10 m height)
  - Closest pixel to mooring location
  - Examine VV and HH separately
- Quality controlled standard meteorological data from NBDC owned “numbered “buoys in US Coastal waters. Corrected to 10 m height
  - Wind Dir Accuracy +/- 10 deg
  - Wind Speed Accuracy +/- 1 m/s or 10%

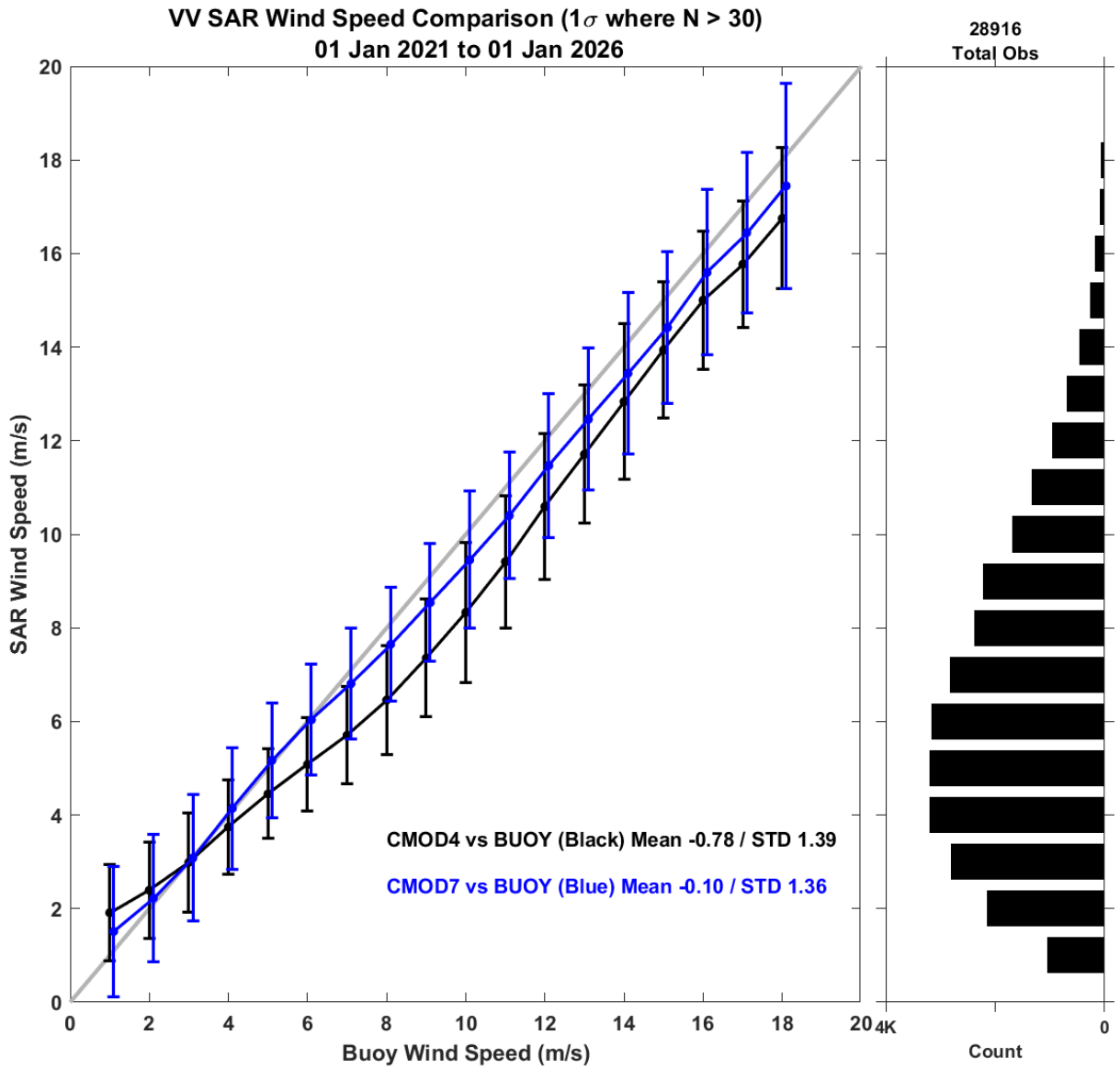
*See Monaldo JGR Vol. 93 No. C3, 2285-2303, March 1988

National Buoy Data Center Buoys

VV 99 Buoys (57% Obs)
HH 62 Buoys (43% Obs)



SAR VV Wind Validation Buoy



SAR winds vs Buoy

Data Span: 01-Jan-2021 to 01-Jan-2026

104 (up from 97 Buoys)

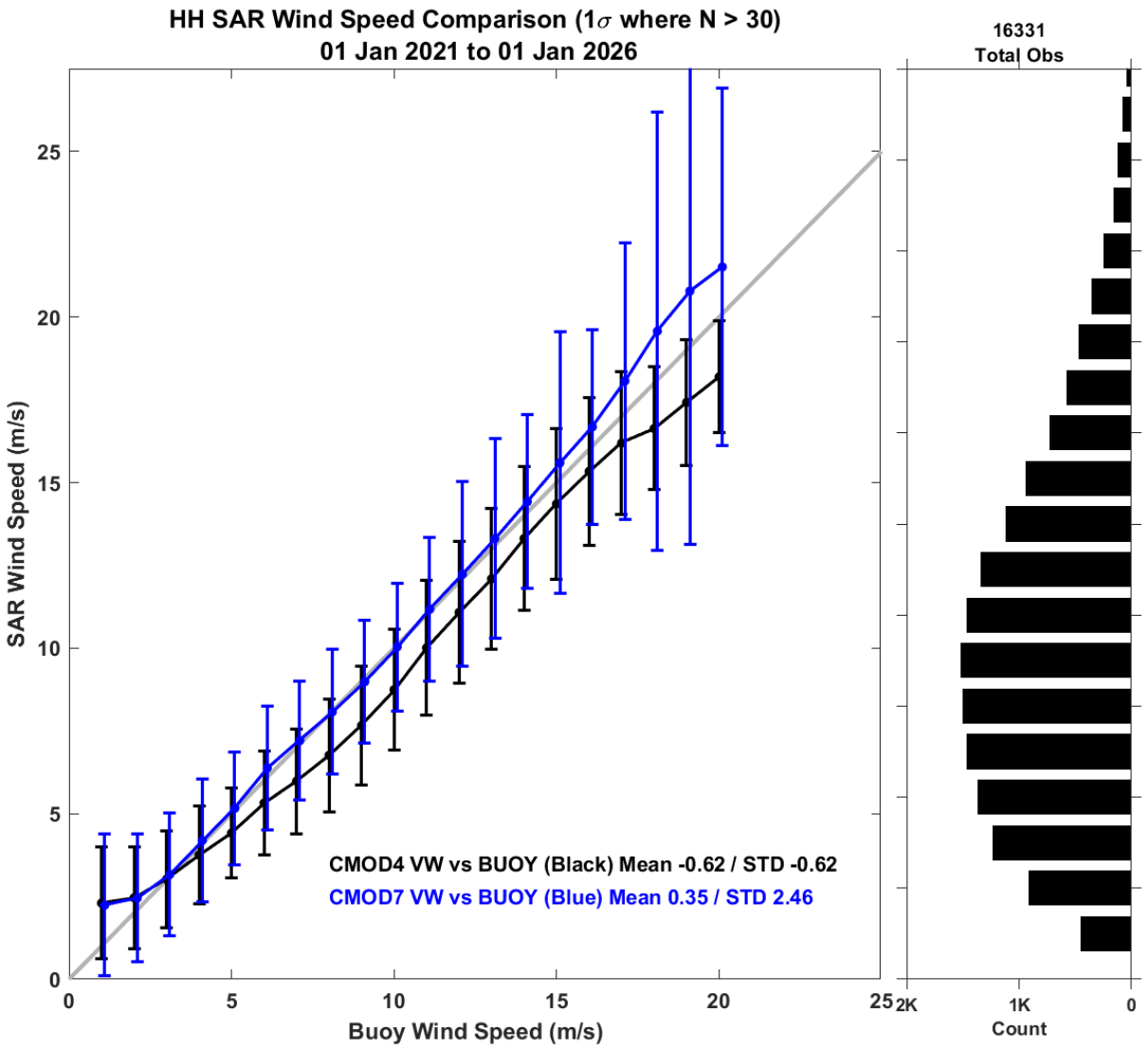
VV Observations: 28970 (up from 19251)

HH Observations: 16520 (9652)

Residual- VV	Mean (m/s)	STD (m/s)	R^2
CMOD4-Buoy	-0.79	1.39	0.81
CMOD7-Buoy	-0.10	1.37	0.85
CMOD4-GFS	-0.72	1.89	
CMOD7-GFS	-0.04	1.97	

- NDBC Wind Speed Accuracy +/- 1 m/s or 10%

SAR HH Wind Validation Buoy / GFS



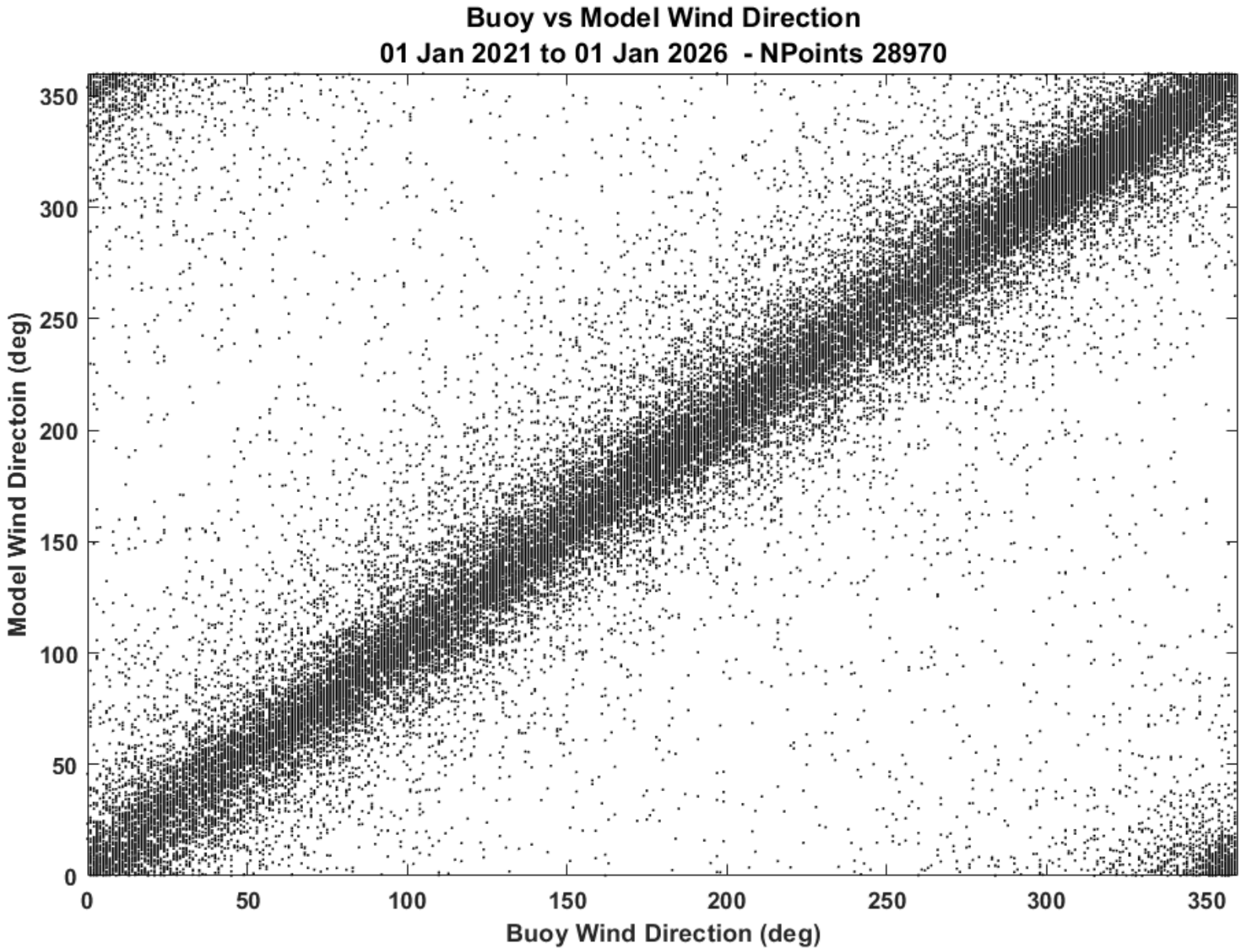
SAR winds vs Buoy

Data Span: 01-Jan-2021 to 01-Jan-2026

HH Observations: 16520 (9652)

Residual- HH	Mean (m/s)	STD (m/s)
CMOD4-Buoy Alpha 1	-0.28	2.16
CMOD7-Buoy Alpha 1	0.84	3.40
CMOD4-Buoy V&W	-0.62	1.97
CMOD7-Buoy V&W	0.35	2.47
CMOD4-GFS V&W	-0.73	2.20
CMOD7-GFS V&W	0.24	2.61

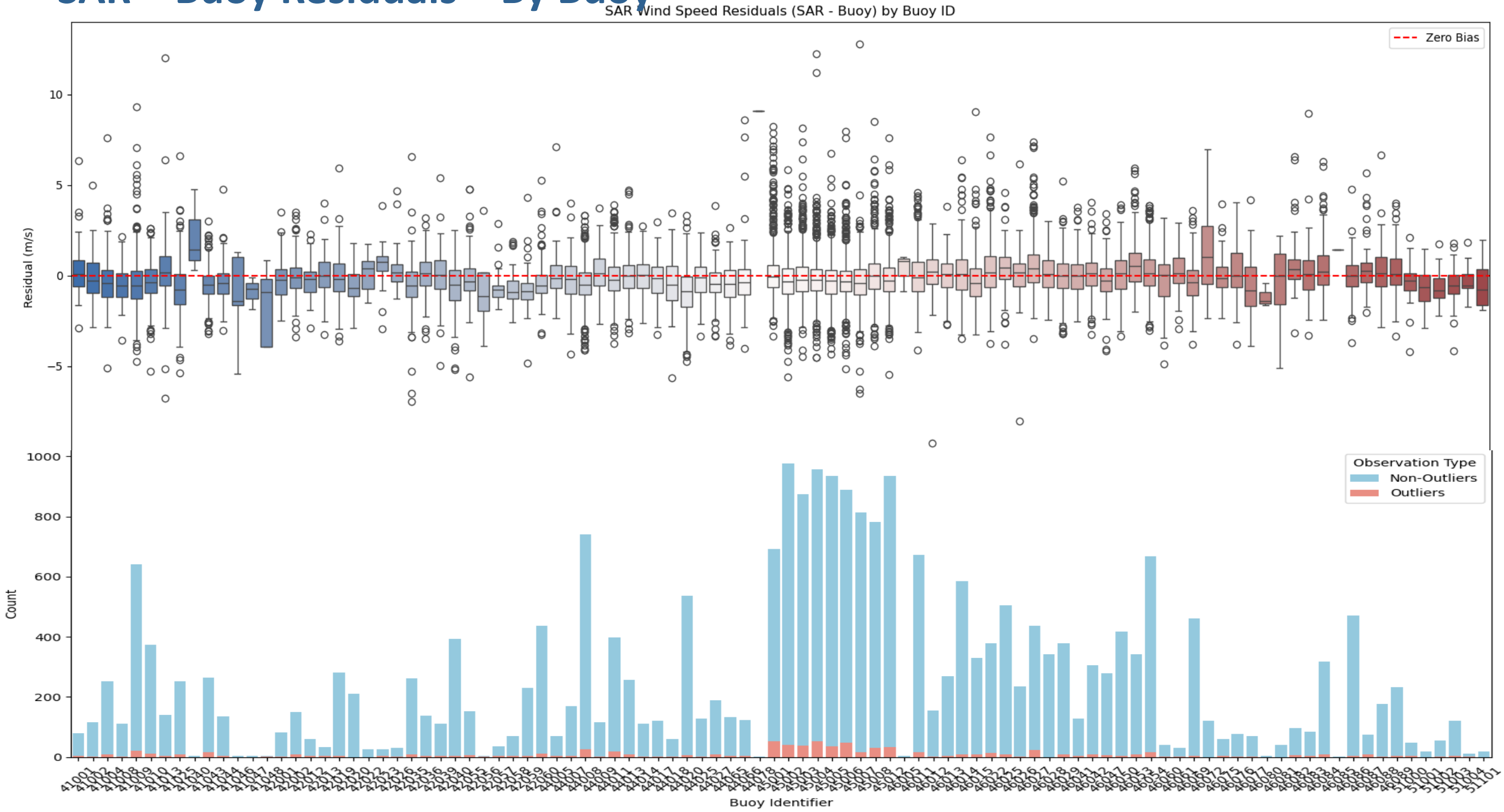
Buoy vs GFS 0.25 Model Directions



A sensitivity analysis can be done using Buoy wind directions as input for SAR

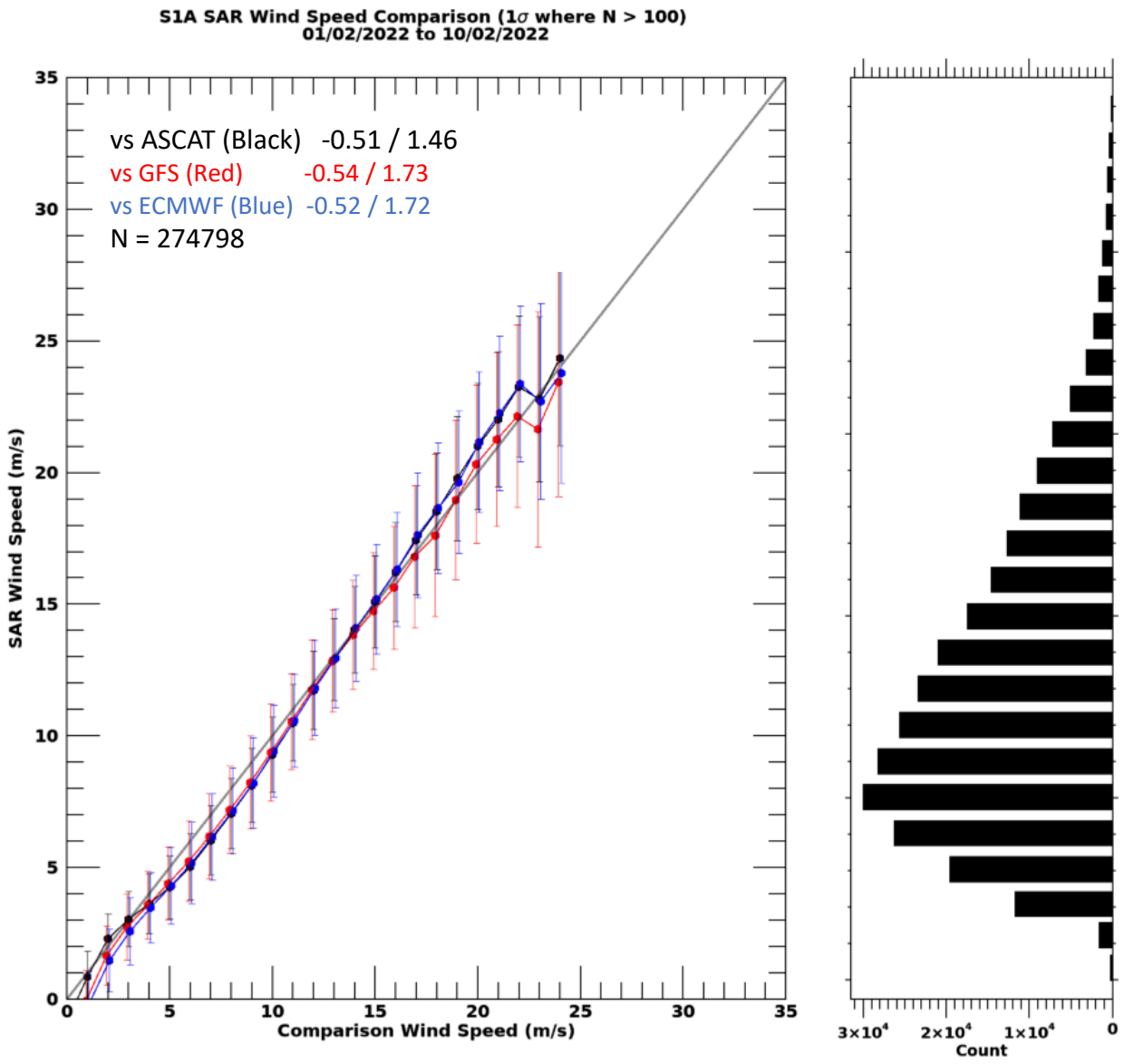
- NBDC Wind Dir
- Accuracy +/- 10 deg

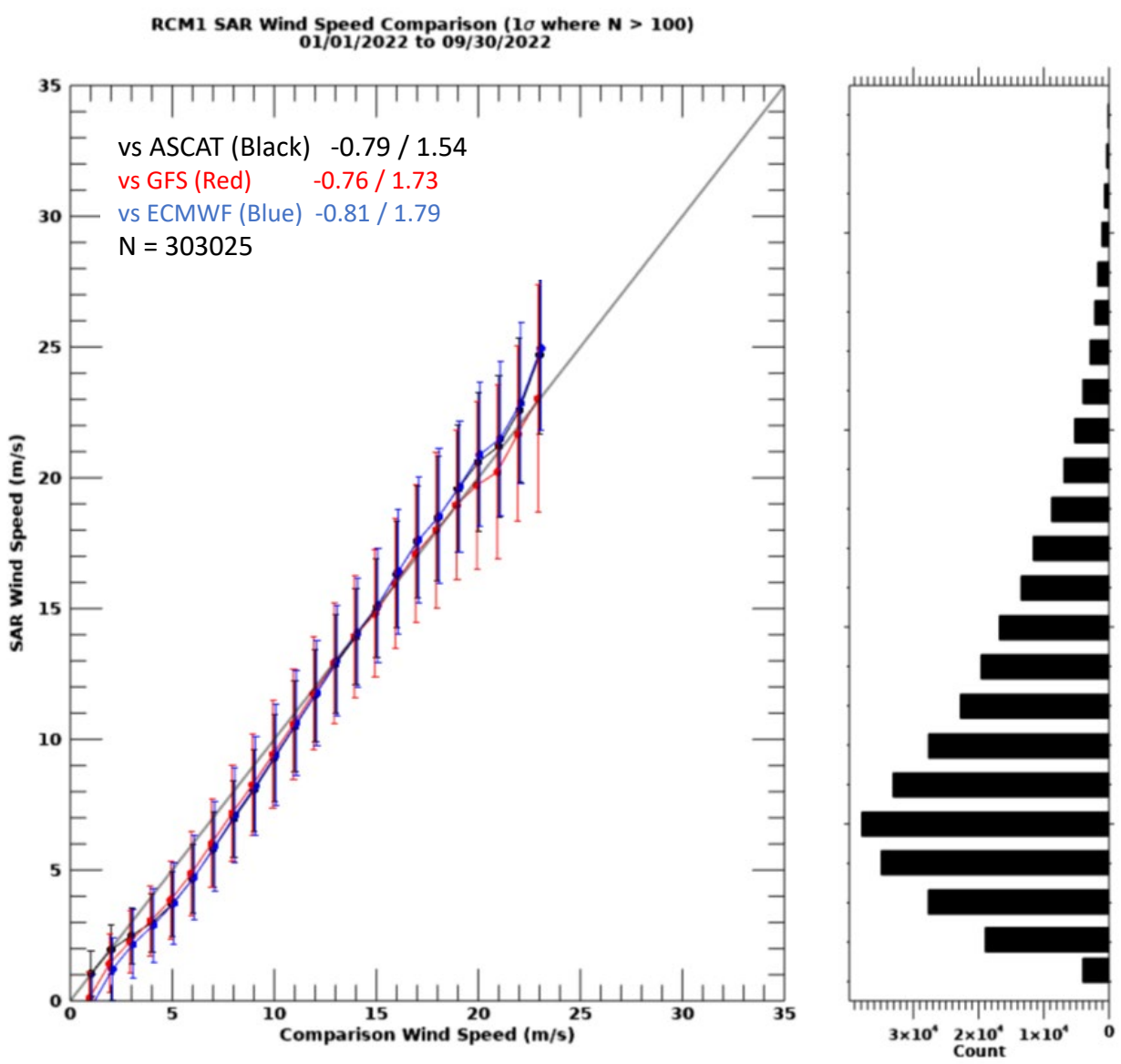
SAR – Buoy Residuals – By Buoy



ASCAT Validation (25 km)

ASCAT / SAR +/- 2 hours





ASCAT KNMI files from JPL PODAAC.

Final Notes

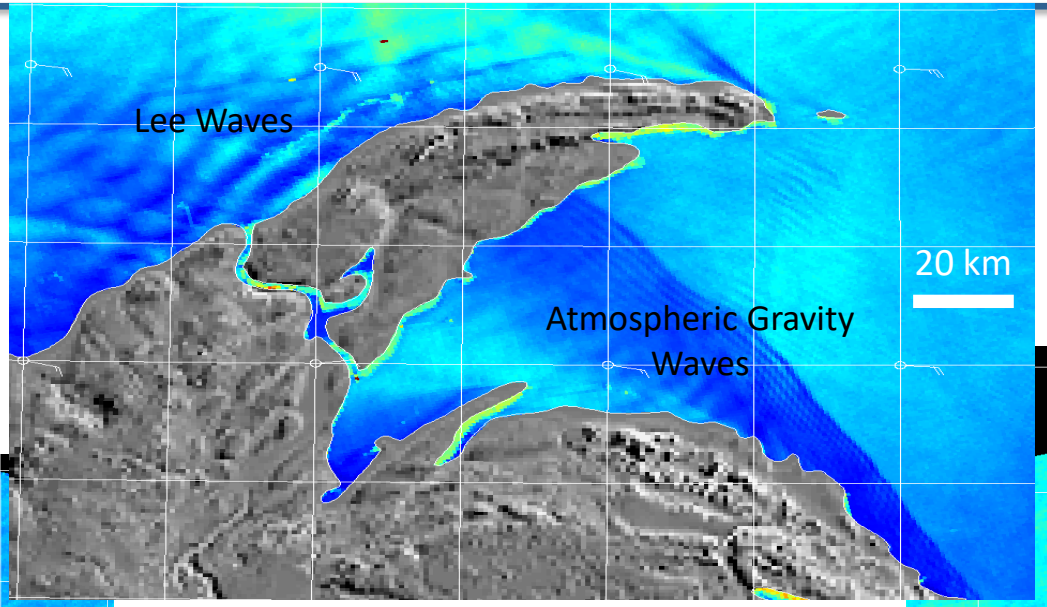
SAR Synthetic Aperture Radar (SAR) derived wind speeds produce accurate ocean surface wind speeds using model wind directions (using GFS 0.25 deg Model Wind)

- VV wind speed accuracy for CMOD4 and CMOD7 are comparable (~ 1.4 m/s STD) but CMOD7 has a smaller bias (-0.1 vs -0.8) (Wind speeds < 20 m/s)
- HH wind speed accuracy is lower then VV (using the Vachon and Wolf Polarization Ratio) (CMOD4 ~2 .0, CMOD7 2.5 m/s) . Its unclear why CMOD4 is performing better for HH SAR observations
- Comparable results were obtained against (25 km) ASCAT (-0.5 m/s (bias) / 1.5 m/s (STD))

Future work:

- Reprocess the SAR wind speeds using buoy directions (look at the sensitivity to direction)
- Extend the analysis beyond “All Buoys vs All SAR to look at the performance across buoys , an individual SAR vs Particular Buoy (particular SAR beam Mode)

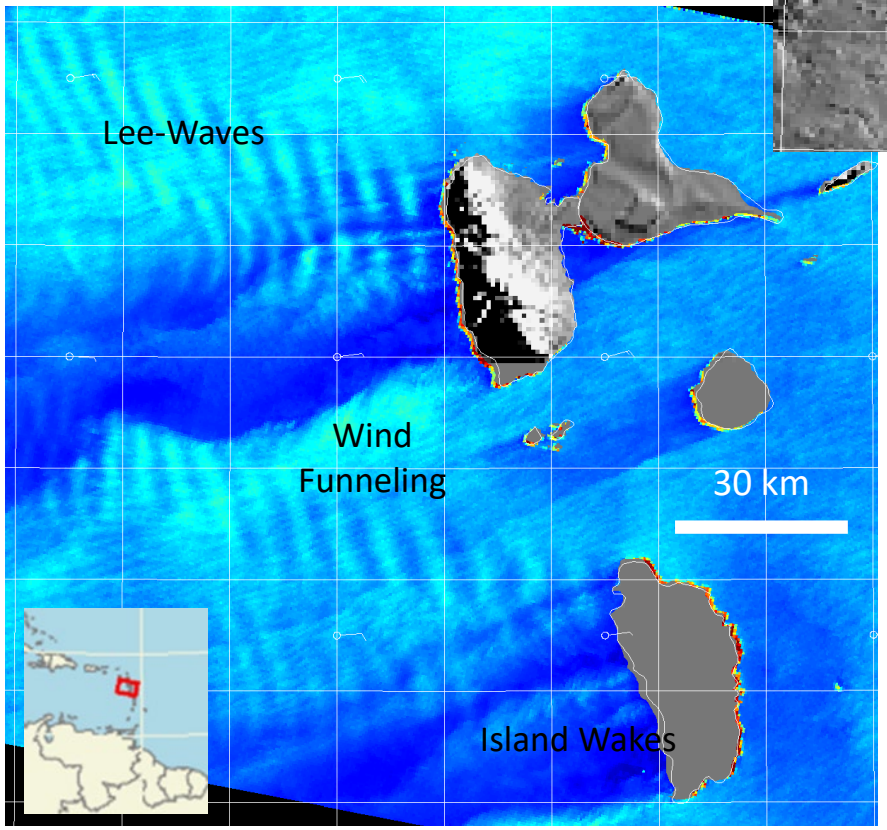
SAR Wind Features at the Marine Atmospheric Boundary Layer



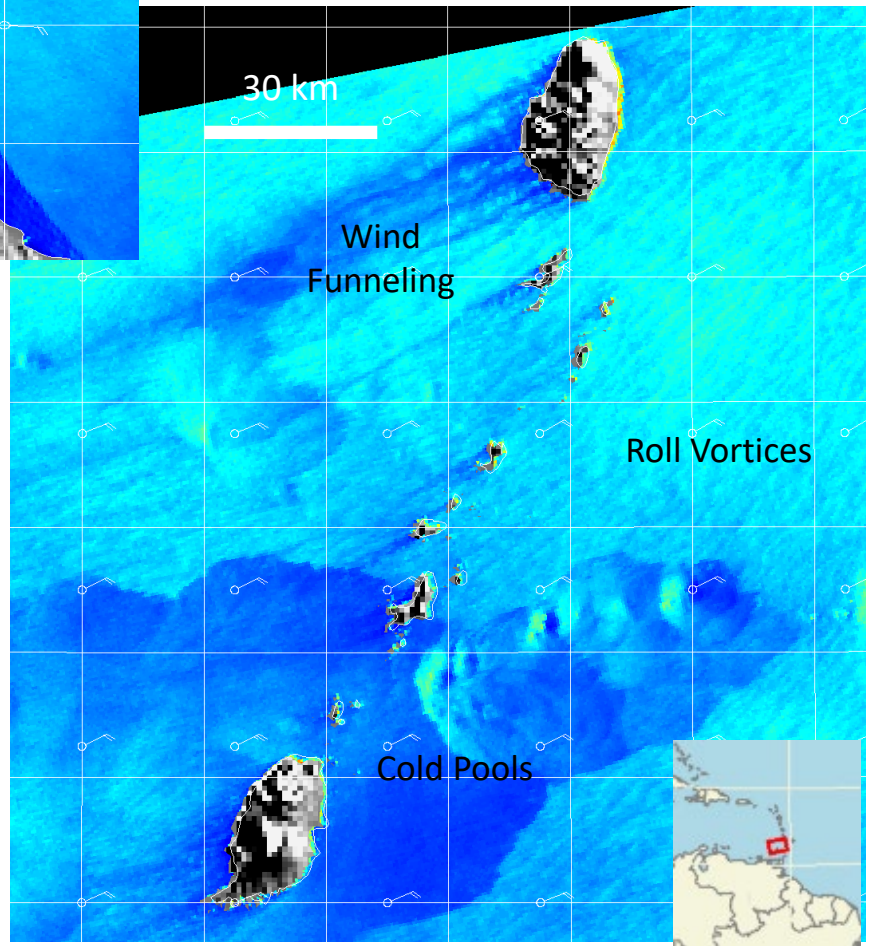


Sentinel-1 22 April 2022 23:42 UTC

Sentinel-1
21 August 2021 09:59 UTC



Sentinel-1
03 April 2025 22:17 UTC



MABL Phenomena

Ocean Surface Wind

Convection Cells / Rolls

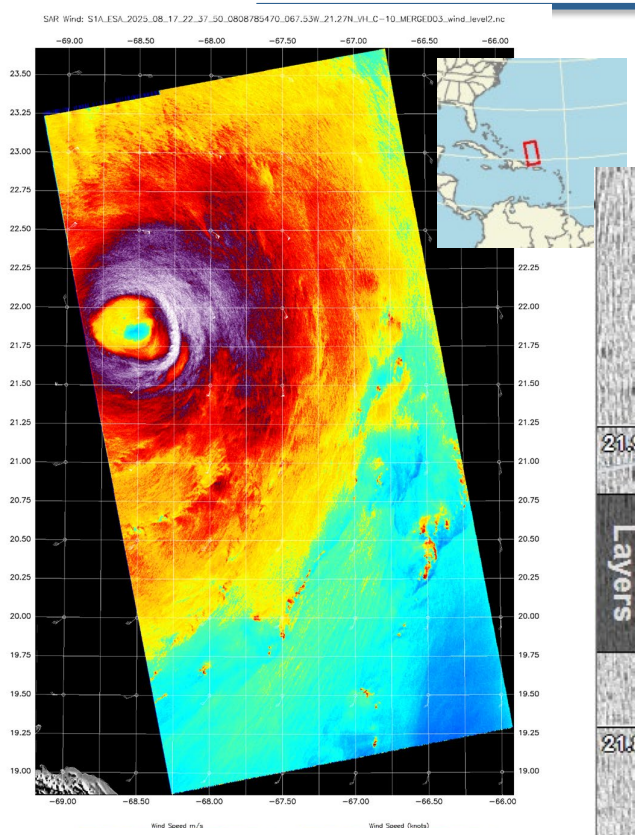
Storm Systems

Vortex Streets

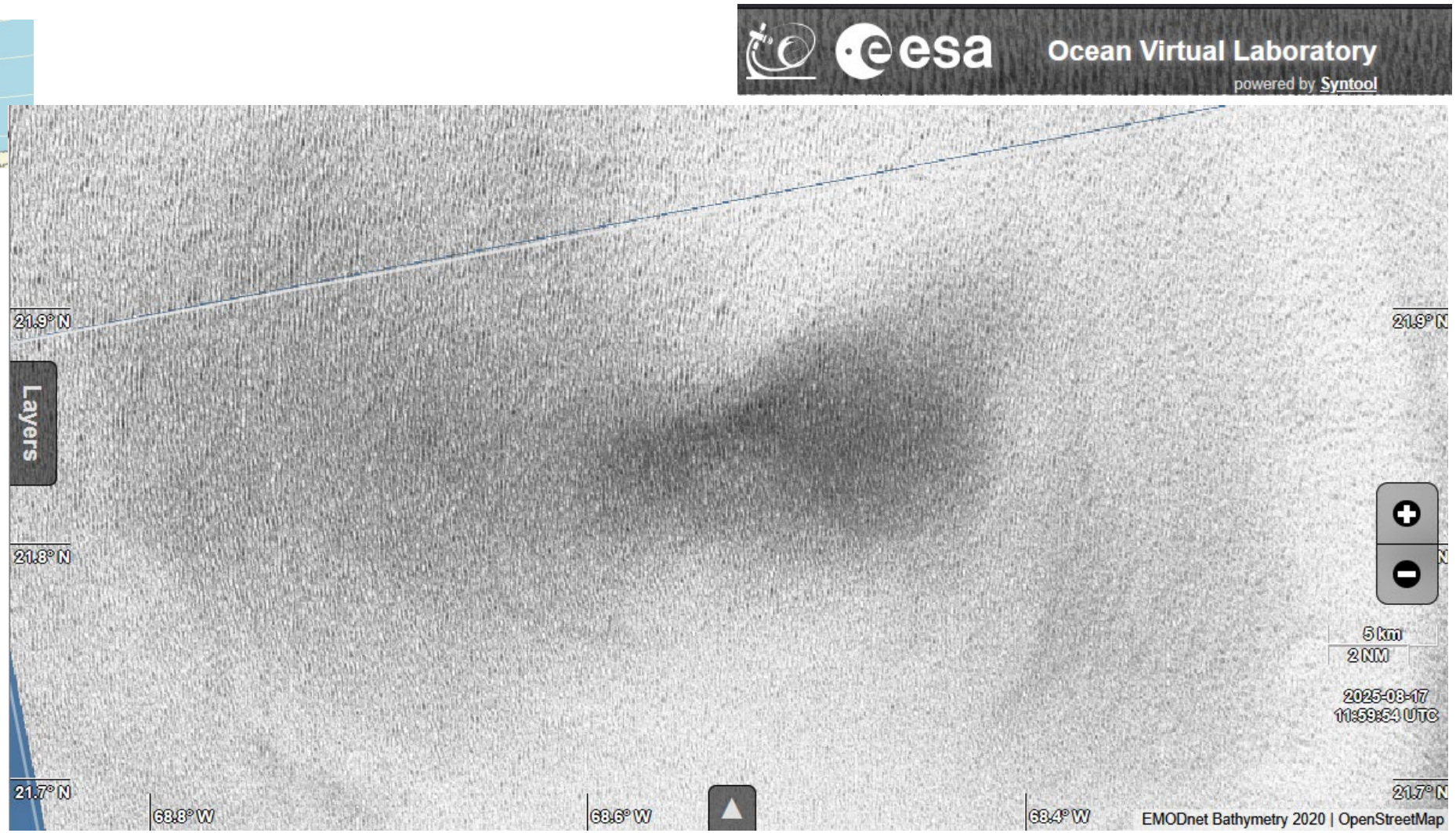
Gravity Waves

Rain Cells / Thunderstorms

AL052025 / ERIN (2025) - Sentinel-1 17 Aug 2025 22:38 UTC



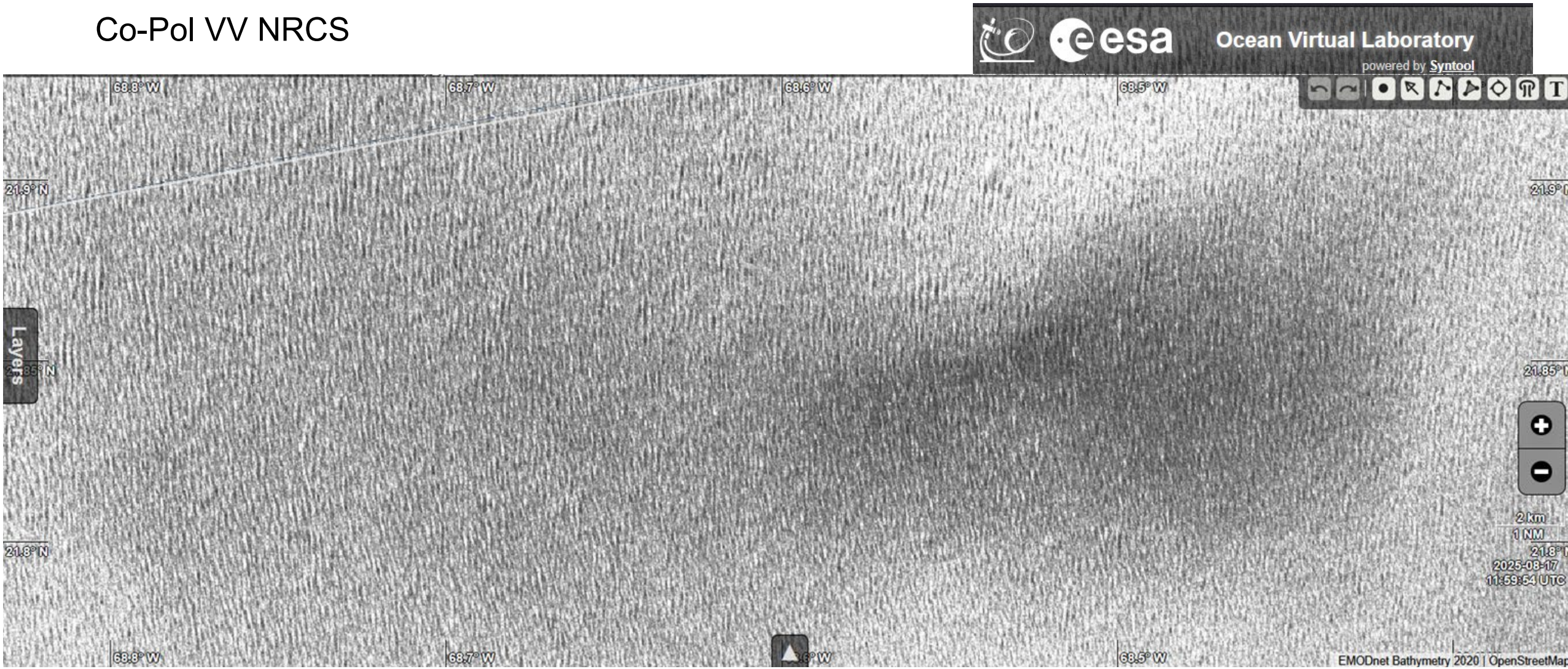
Incidence Angle (Deg): 33.453
NE VMax (kts): 100.06
SE VMax (kts): 101.56
SW VMax (kts): 88.44
NW VMax (kts): 90.75
RMax (nmi): 14.00 - 18.00



Co-Pol VV
NRCS

AL052025 / ERIN (2025) - Sentinel-1 17 Aug 2025 22:38 UTC

Co-Pol VV NRCS



Web Resources

STAR Tropical
https://coastwatch.noaa.gov/SAR/sar_winds_tropical.html
And subscribe to our tropical SAR notification mailing list!

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

STAR Great Lakes
https://www.star.nesdis.noaa.gov/socd/mecb/sar/greatlakes_wind_nrcs.php

SAR Winds Quick Guide
https://rammb2.cira.colostate.edu/wp-content/uploads/2020/01/SAR_Winds_Quick_Guide_v1_final.pdf

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

High Resolution Wind Monitoring With Wide-Swath SAR: A User's Guide (June 2005)
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

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

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

Thank you!

Sentinal-1D

14 May 2026

