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

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NOAA STAR Synthetic Aperture Radar Science Team

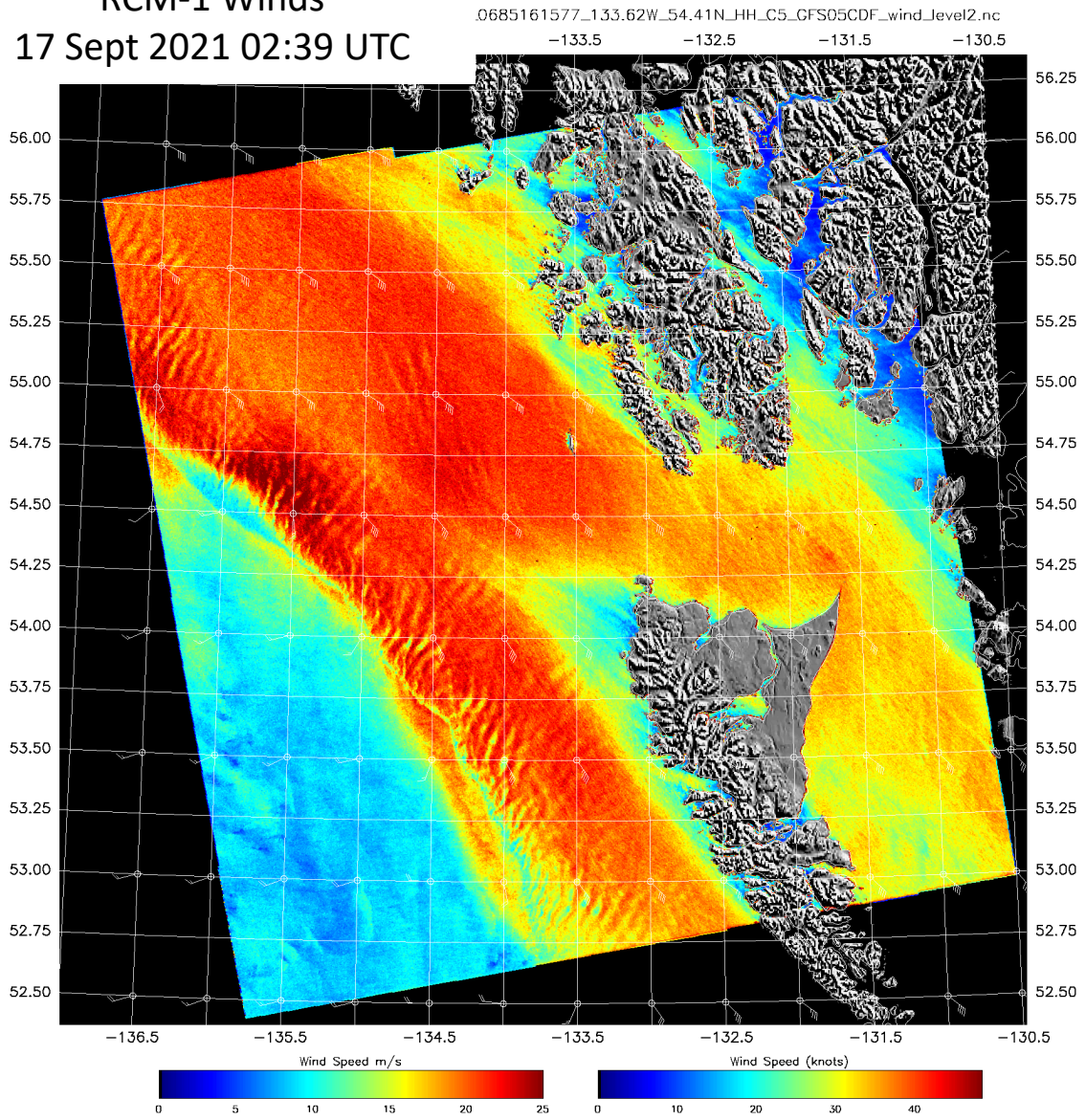
The Center for **Satellite Applications and Research (STAR)** is the science arm of National Environmental Satellite, Data, and Information Service (NESDIS).

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

RCM-1 Winds
17 Sept 2021 02:39 UTC

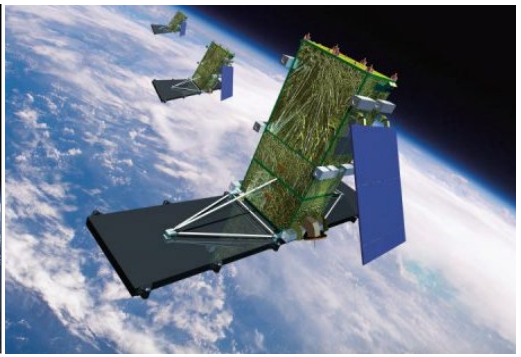


SAR Satellites Background

Coverage Limitation

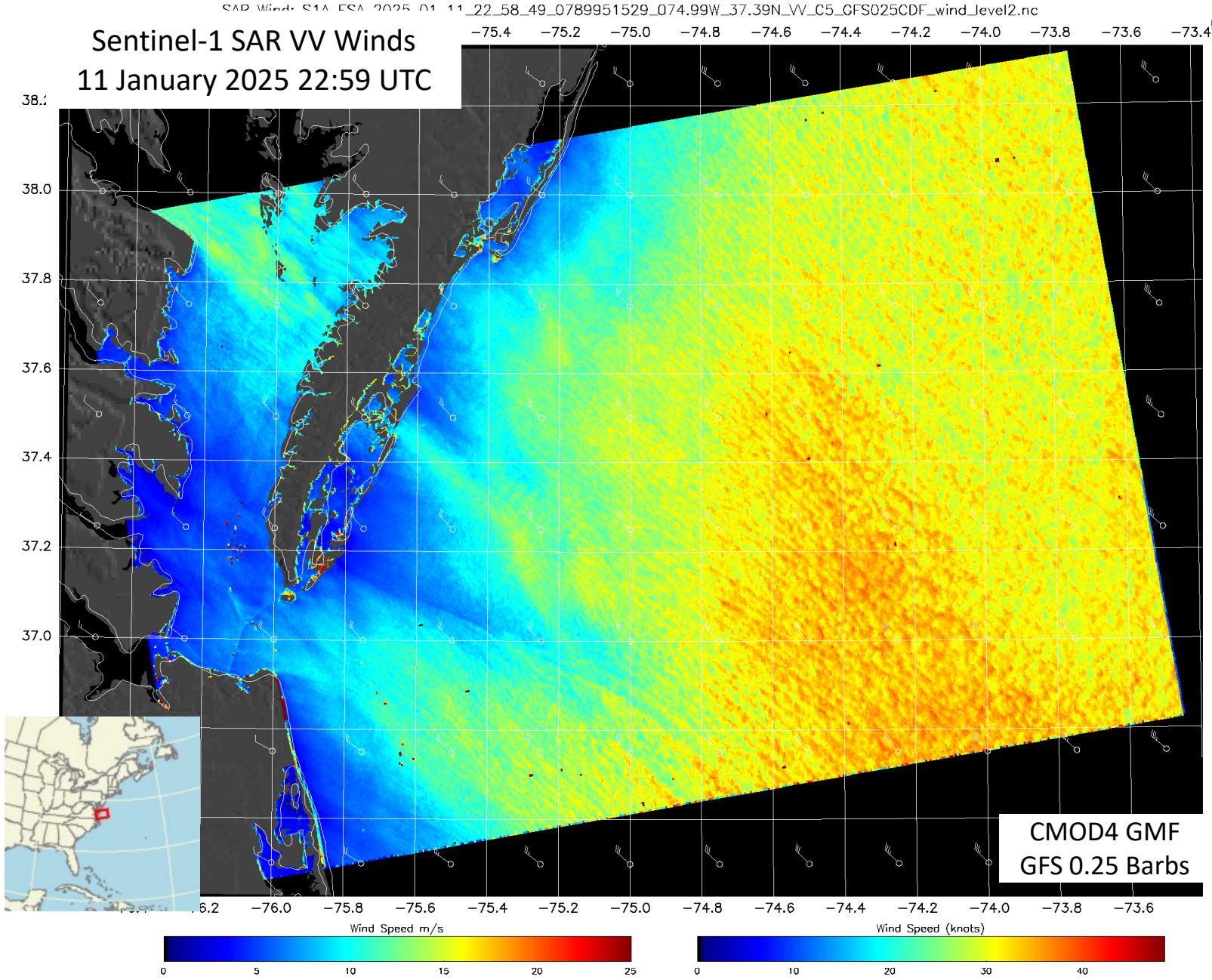
- Satellite-based SAR acquires data with a limited footprint and only over a portion (~25%) of every orbit

- 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)	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

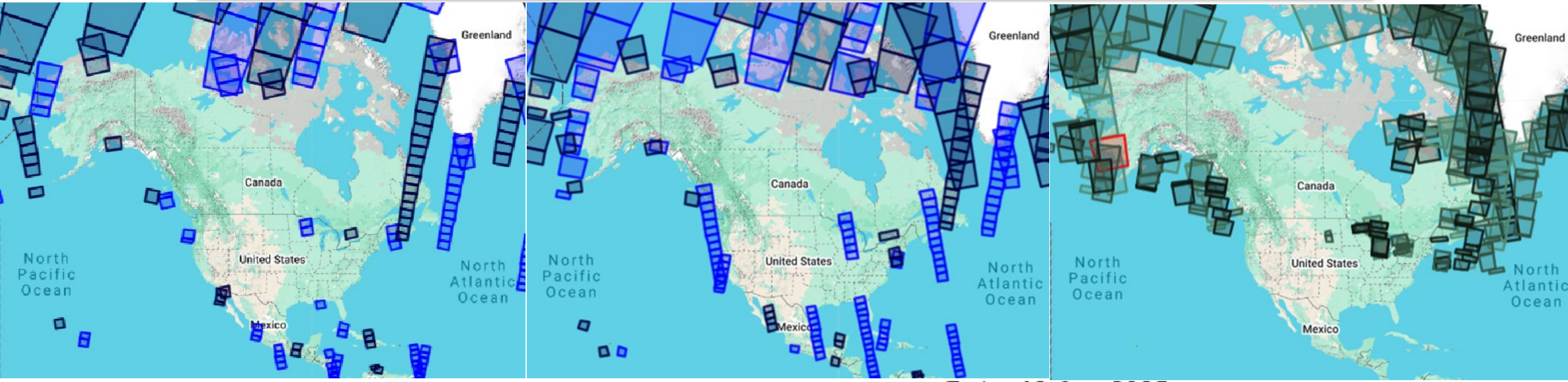
SAR Wind Image



Characteristics

- 500 m sampling
  - Available adjacent to coastlines
- Reported at a 10-m height above the surface (CMOD4)
- Accuracy < 2 m/s (up to 15 m/s),
- Near Real Time with 2-6+ 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

SAR Coverage – US EEZ



Date: 16-Apr-2025

Date: 18-Apr-2025

Limited daily geographic coverage

- S1 and RCM have a regular collection pattern with a 12 day exact repeat

STAR S1 Winds

https://coastwatch.noaa.gov/SAR/sar_winds_s1.html

STAR Radarsat-2/RCM Winds

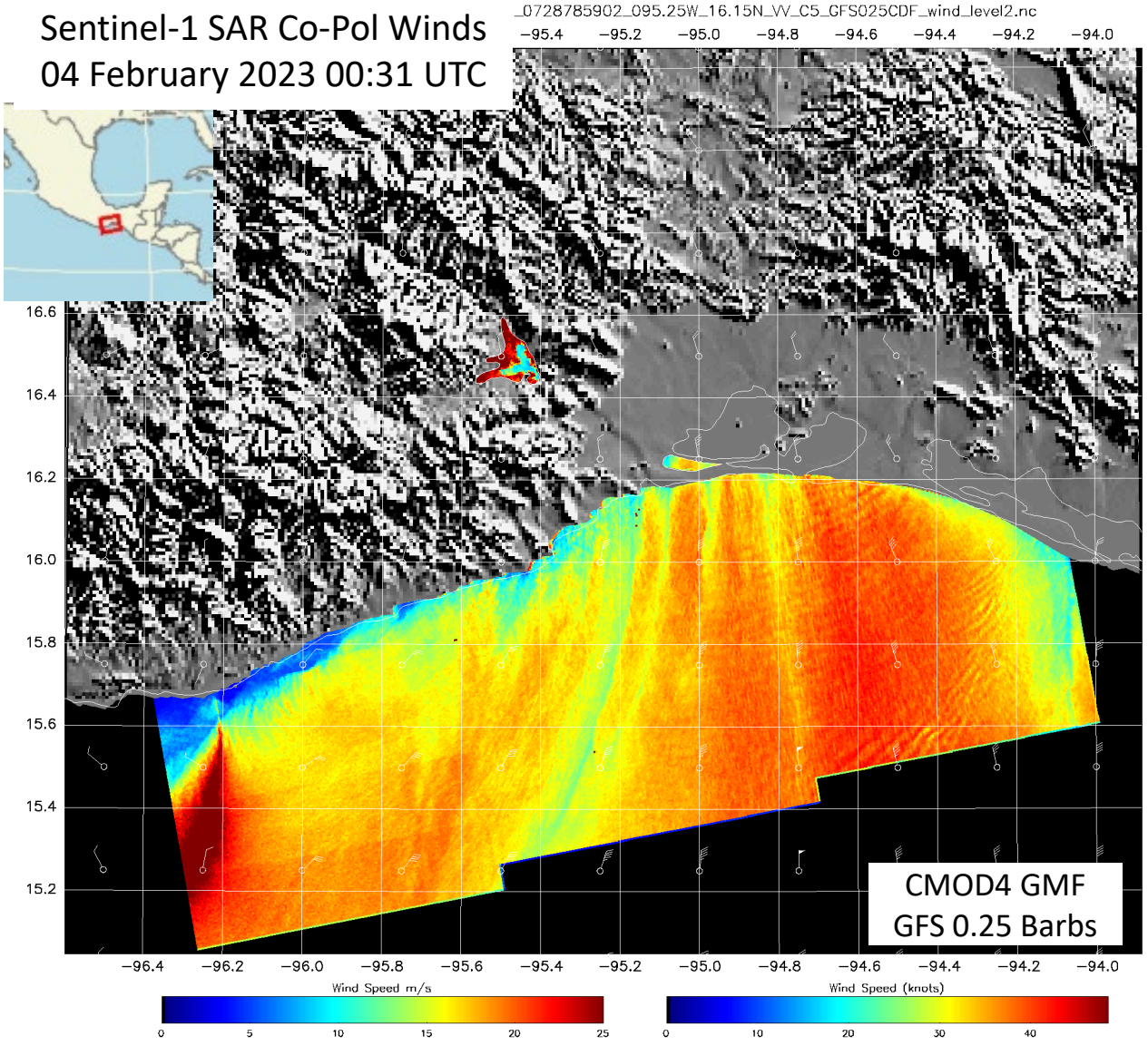
https://coastwatch.noaa.gov/SAR/sar_winds_rcm.html

Revisit is location dependent.

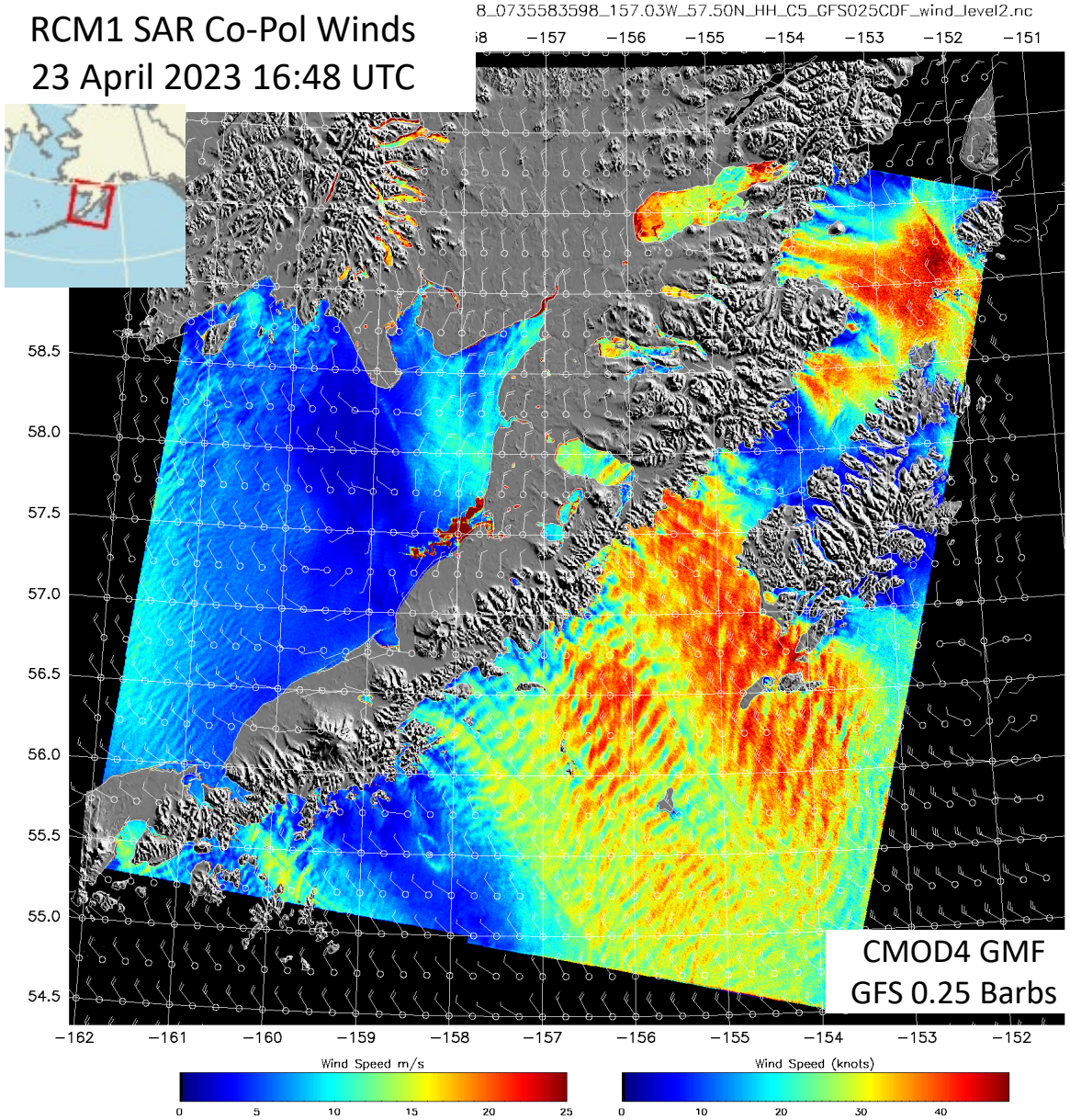
- Alaska (daily)
- Great Lakes (near daily)
- North America Coastal (north of 49N) (near daily)
- CONUS/Hawaii – 6 to 12 days for exact repeat
- Limited “Open Ocean” coverage

Gap Flow Winds - Gulf of Tehuantepec and Southeast Alaska

Sentinel-1 SAR Co-Pol Winds
04 February 2023 00:31 UTC

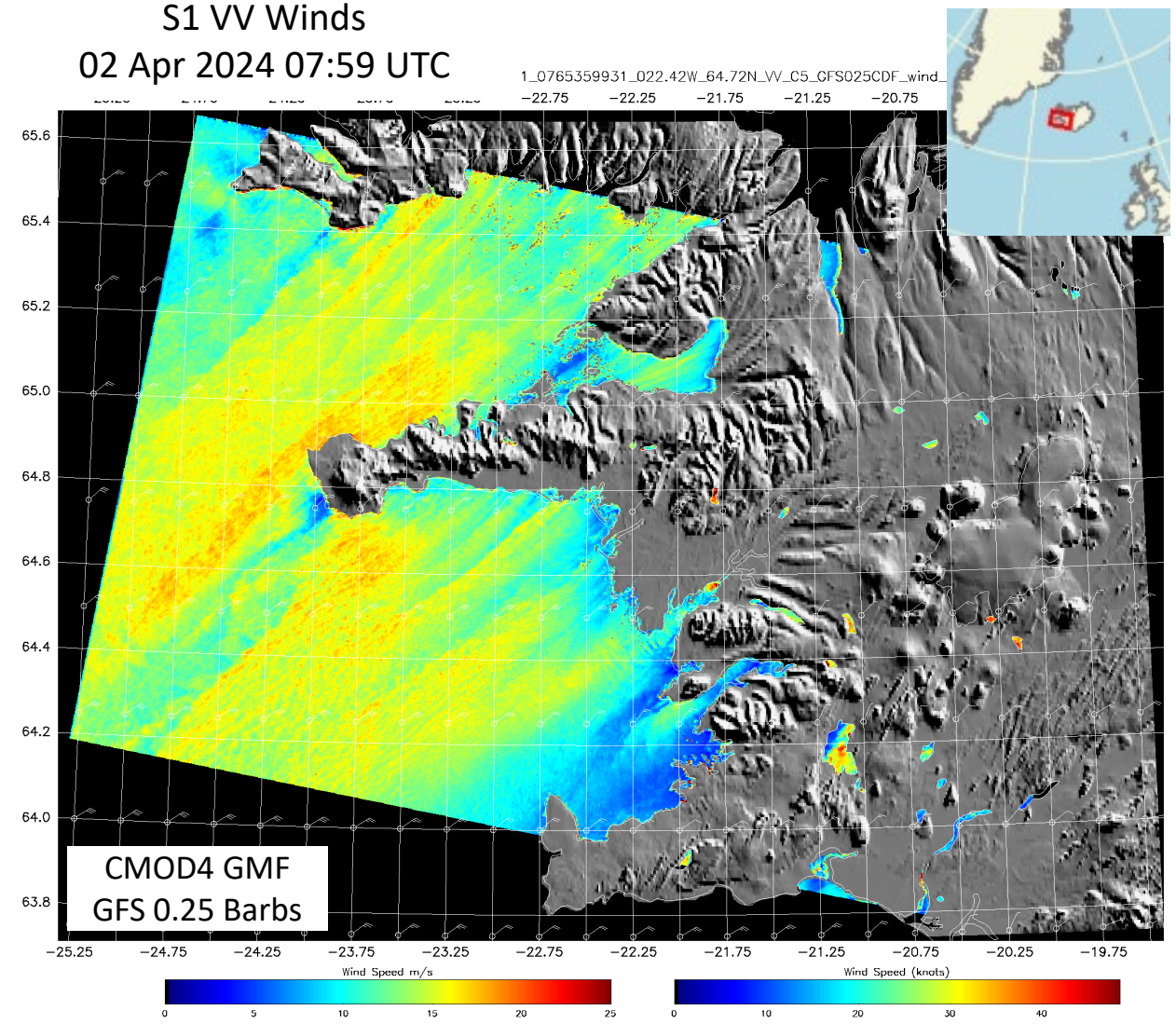


RCM1 SAR Co-Pol Winds
23 April 2023 16:48 UTC



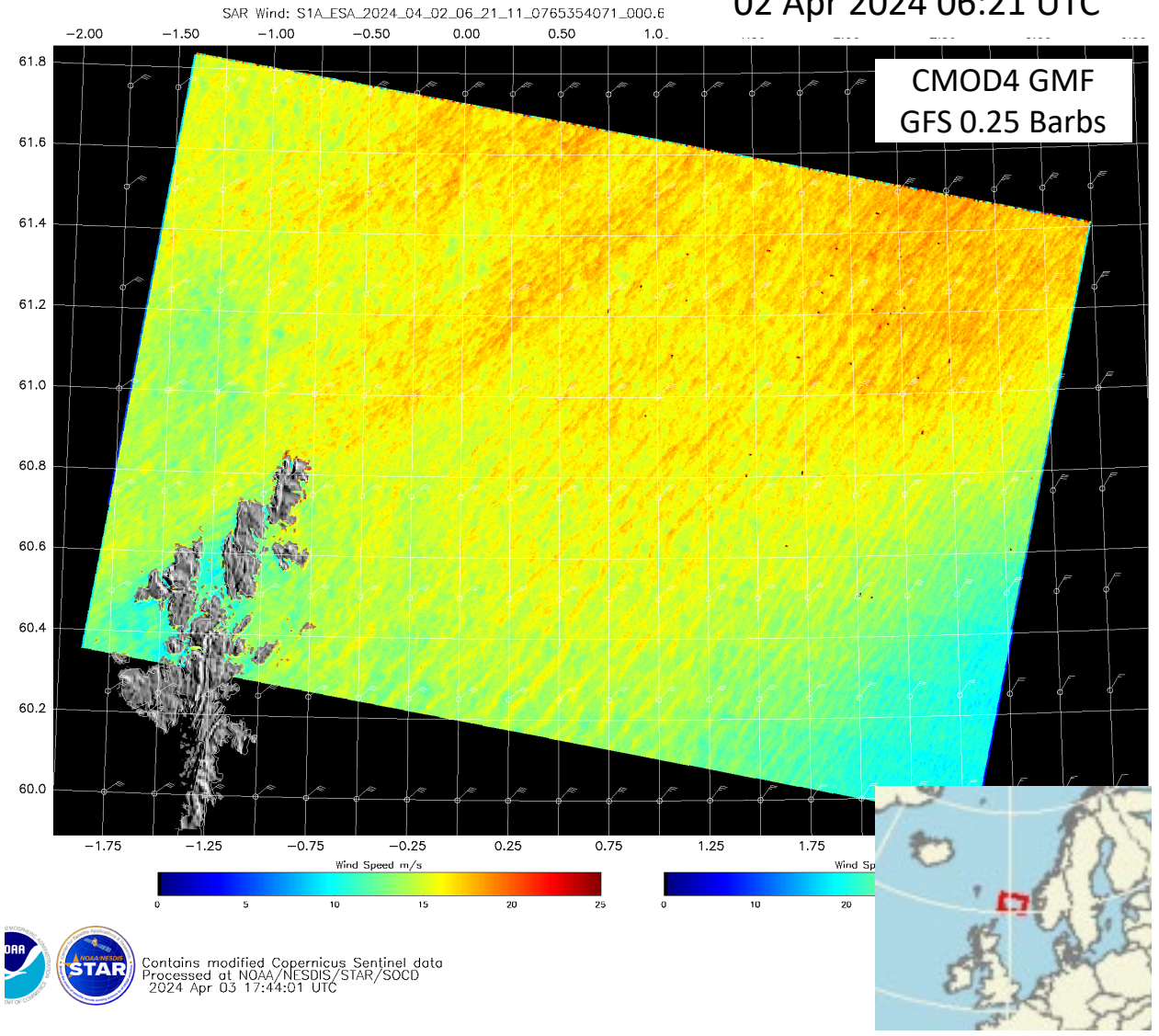
High Winds – North Atlantic

S1 VV Winds
02 Apr 2024 07:59 UTC



Contains modified Copernicus Sentinel data
Processed at NOAA/NESDIS/STAR/SOCD
2024 Apr 02 11:04:50 UTC

S1 VV Winds
02 Apr 2024 06:21 UTC



Contains modified Copernicus Sentinel data
Processed at NOAA/NESDIS/STAR/SOCD
2024 Apr 03 17:44:01 UTC

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?

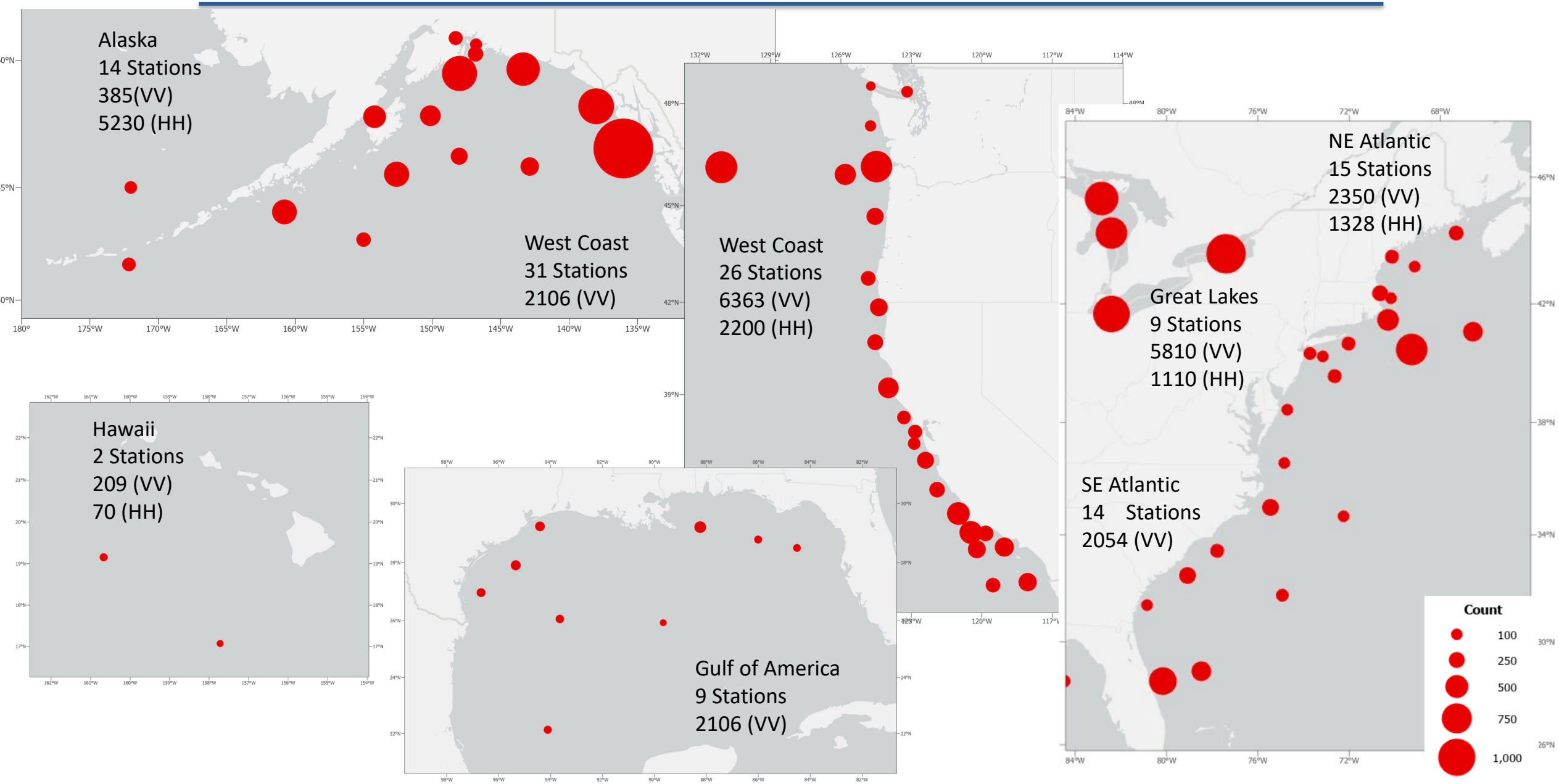
- Yes… but the expected differences and their impacts on the measurements/comparisons need to be understood*

SAR winds vs Buoy

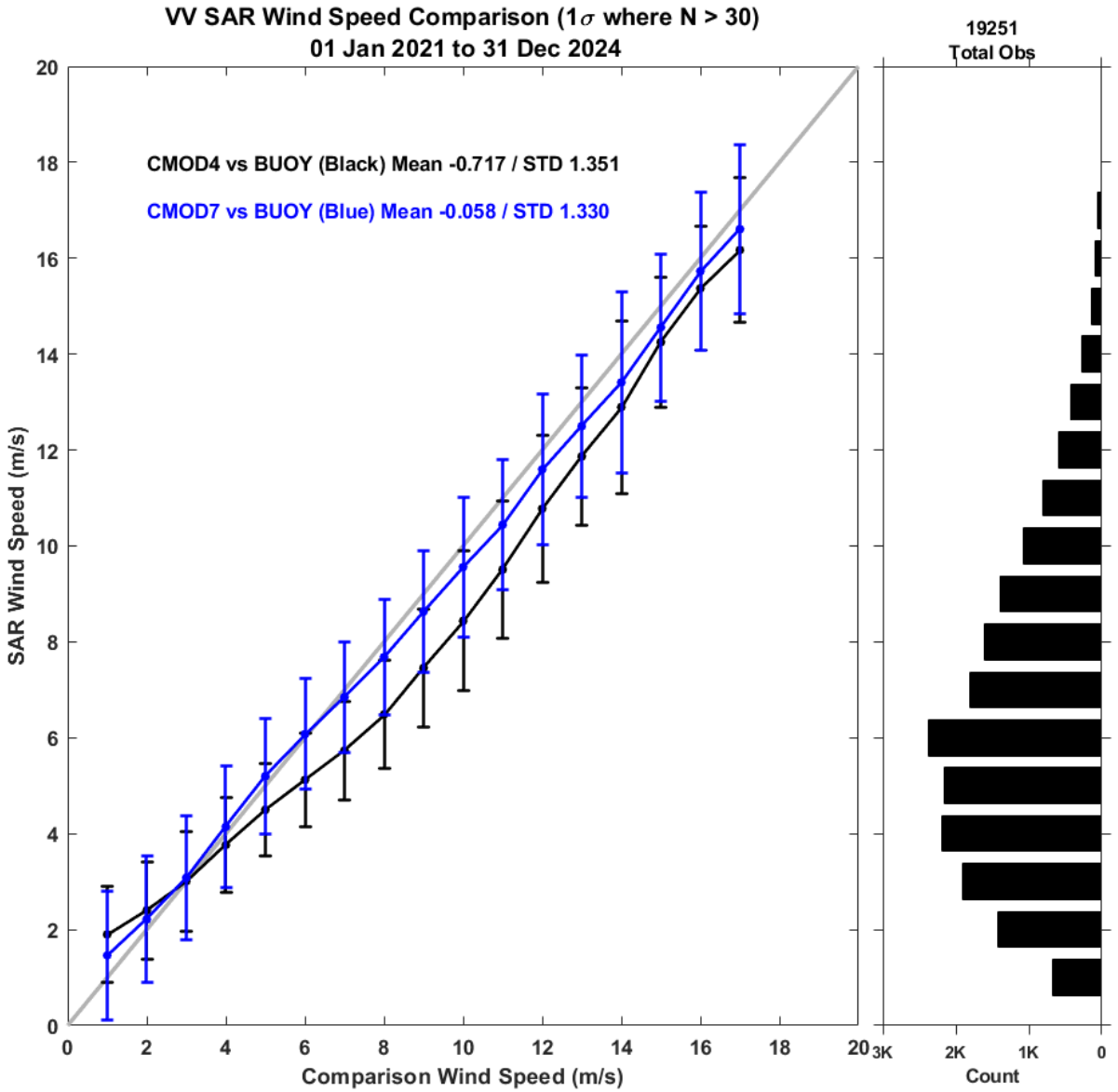
- SAR processed to 500 meter pixel using both CMOD4 and CMOD7 (10 m height)
  - Closest pixel to mooring location
  - Examine VV and HH separately
- Quality controlled standard meteorological data from NBDC owned “numbered “buoys in US Coastal waters. Corrected to 10 m height
  - Wind Dir Accuracy +/-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



SAR VV Wind Validation Buoy



SAR winds vs Buoy

Data Span: 01-Jan-2021 to 30-Dec-2024

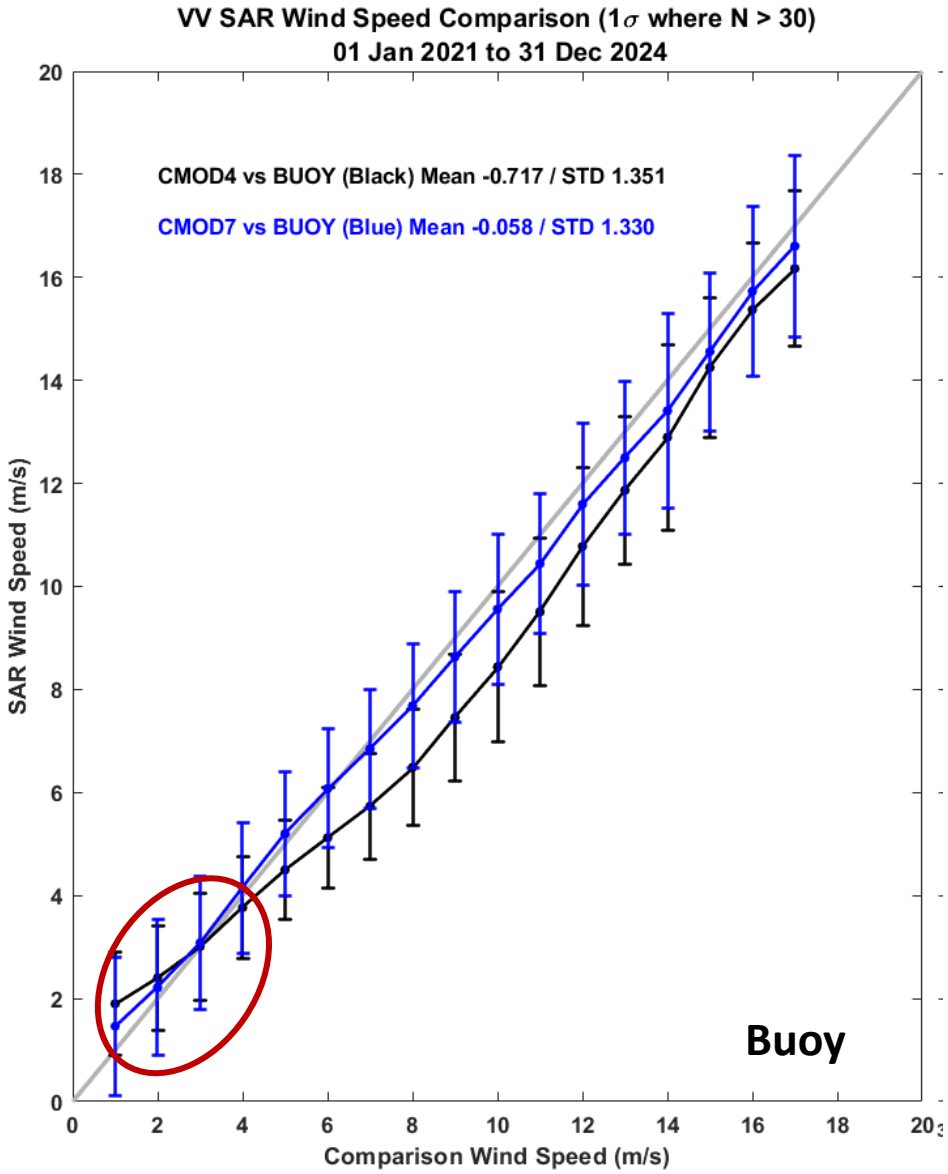
97 Buoys

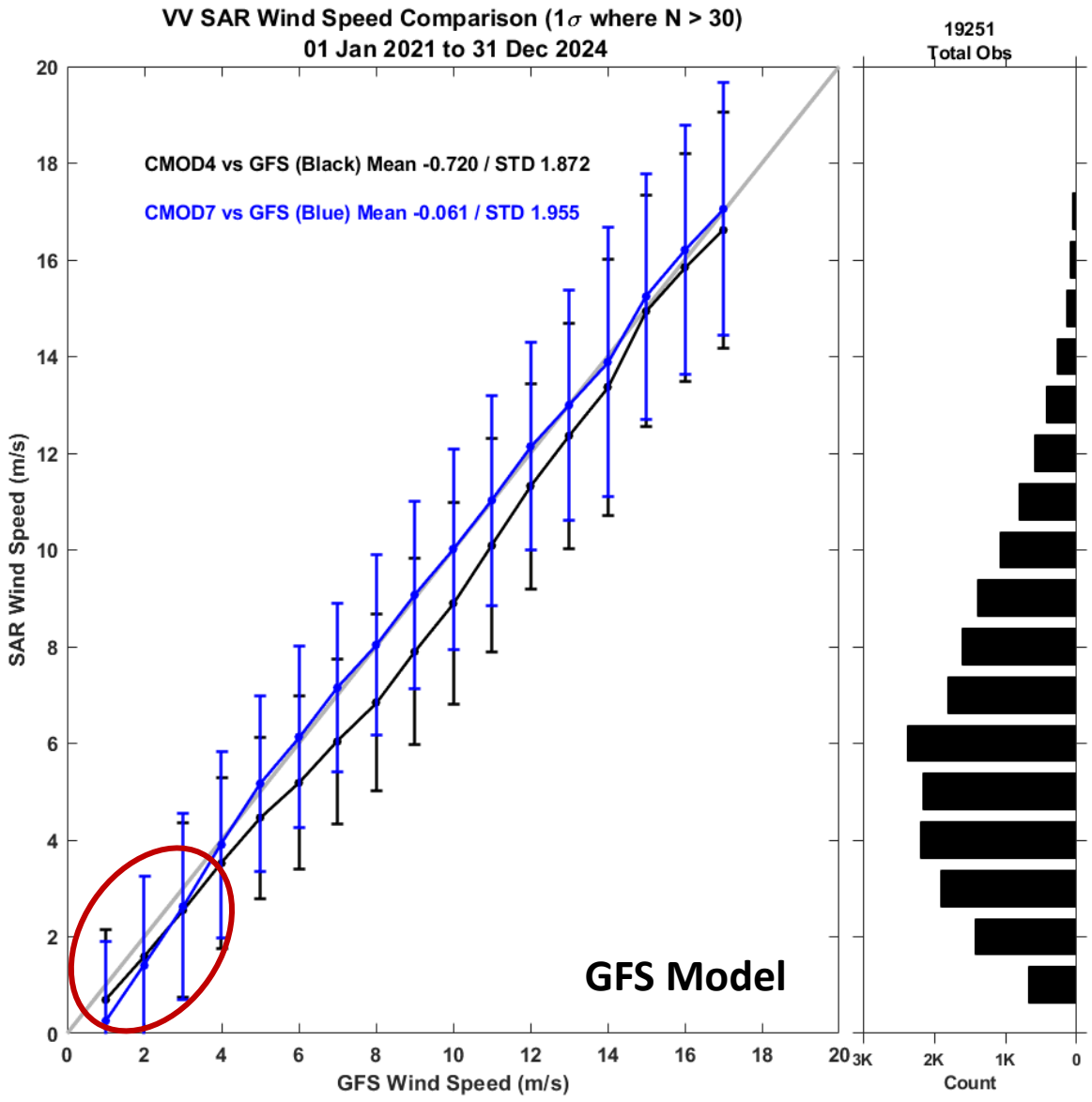
VV Observations: 19251

HH Observations: 9652

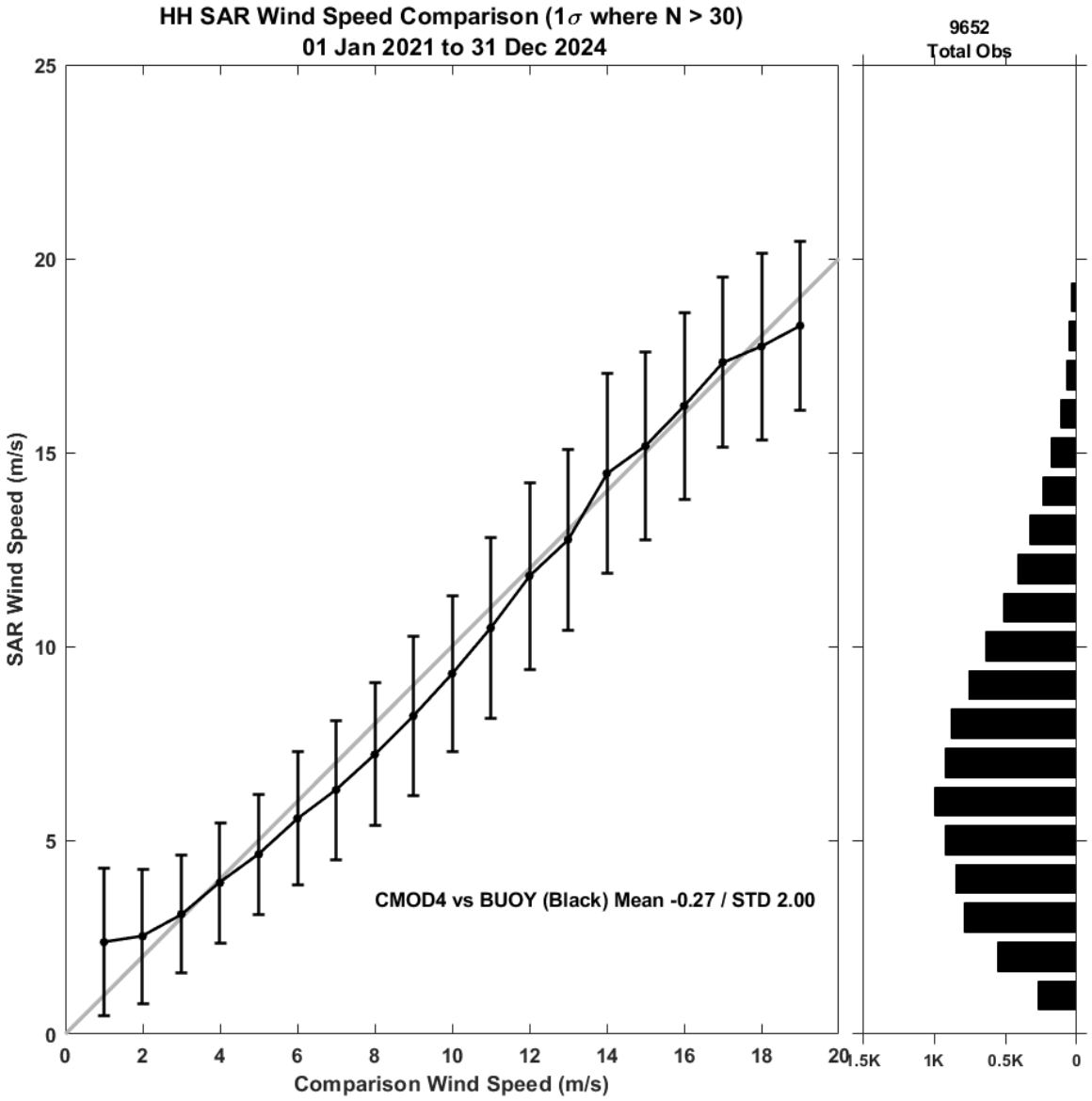
Residual- VV	Mean (m/s)	STD (m/s)	R^2
CMOD4-Buoy	-0.72	1.35	0.81
CMOD7-Buoy	-0.06	1.33	0.85
CMOD4-GFS	-0.72	1.87	
CMOD7-GFS	-0.06	1.96	
Buoy-GFS	0.00	1.64	

SAR VV Wind Validation Buoy / GFS





SAR HH Wind Validation Buoy / GFS



SAR winds vs Buoy

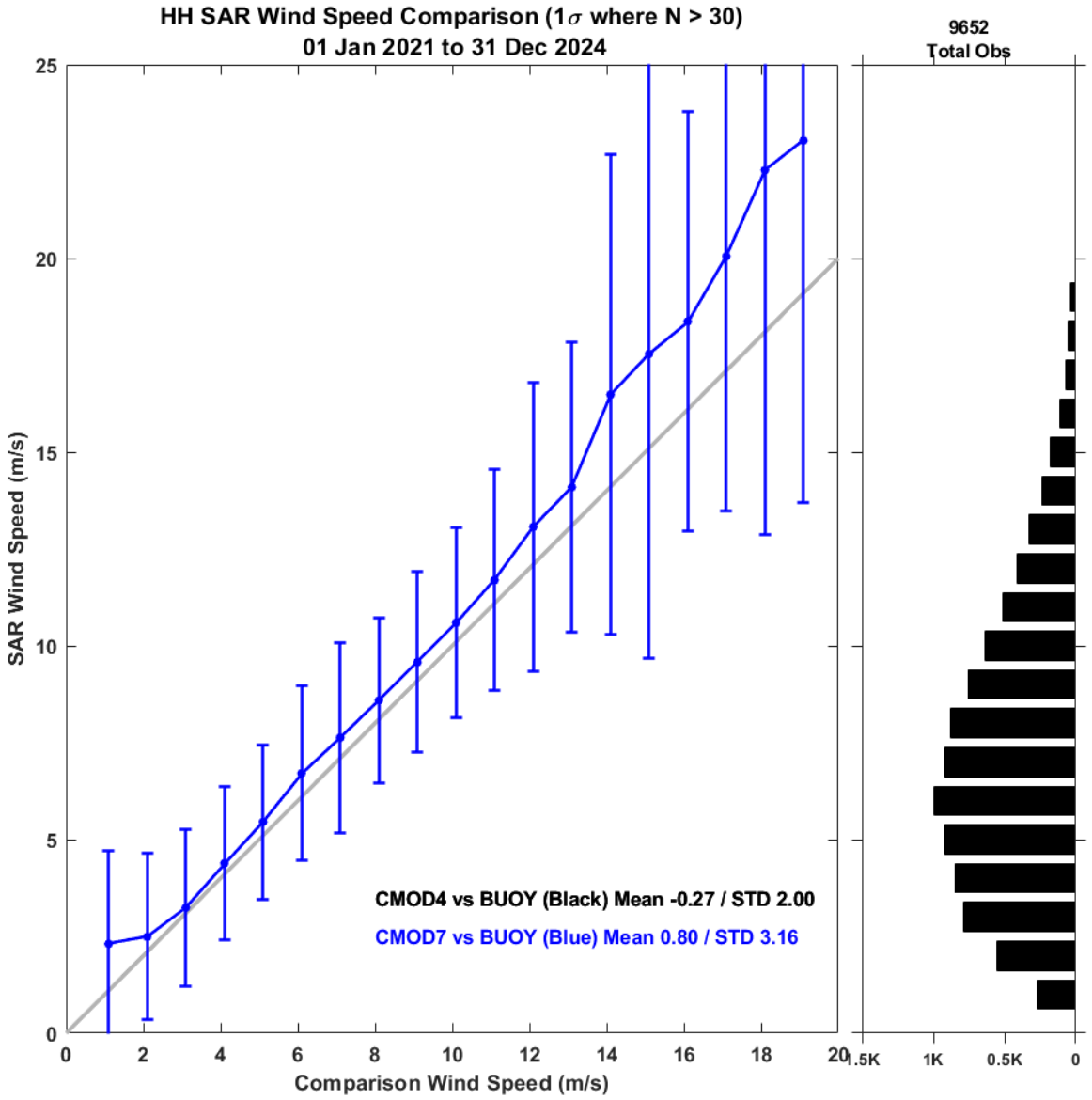
Data Span: 01-Jan-2021 to 30-Dec-2024

HH Observations: 9652

Residual- HH	Mean (m/s)	STD (m/s)	R^2
CMOD4-Buoy	-0.27	2.00	0.78
CMOD7-Buoy	0.80	3.16	0.66
CMOD4-GFS	-0.46	2.31	
CMOD7-GFS	0.62	3.36	
Buoy-GFS	-0.19	1.90	

D. R. Thompson, T. M. Elfouhaily, and B. Chapron, Polarization ratio for microwave backscattering from the ocean surface at low to moderate incidence angles,
Proc. IGARSS, Seattle, WA, 1998. (Alpha = 1)

SAR HH Wind Validation Buoy / GFS



SAR winds vs Buoy

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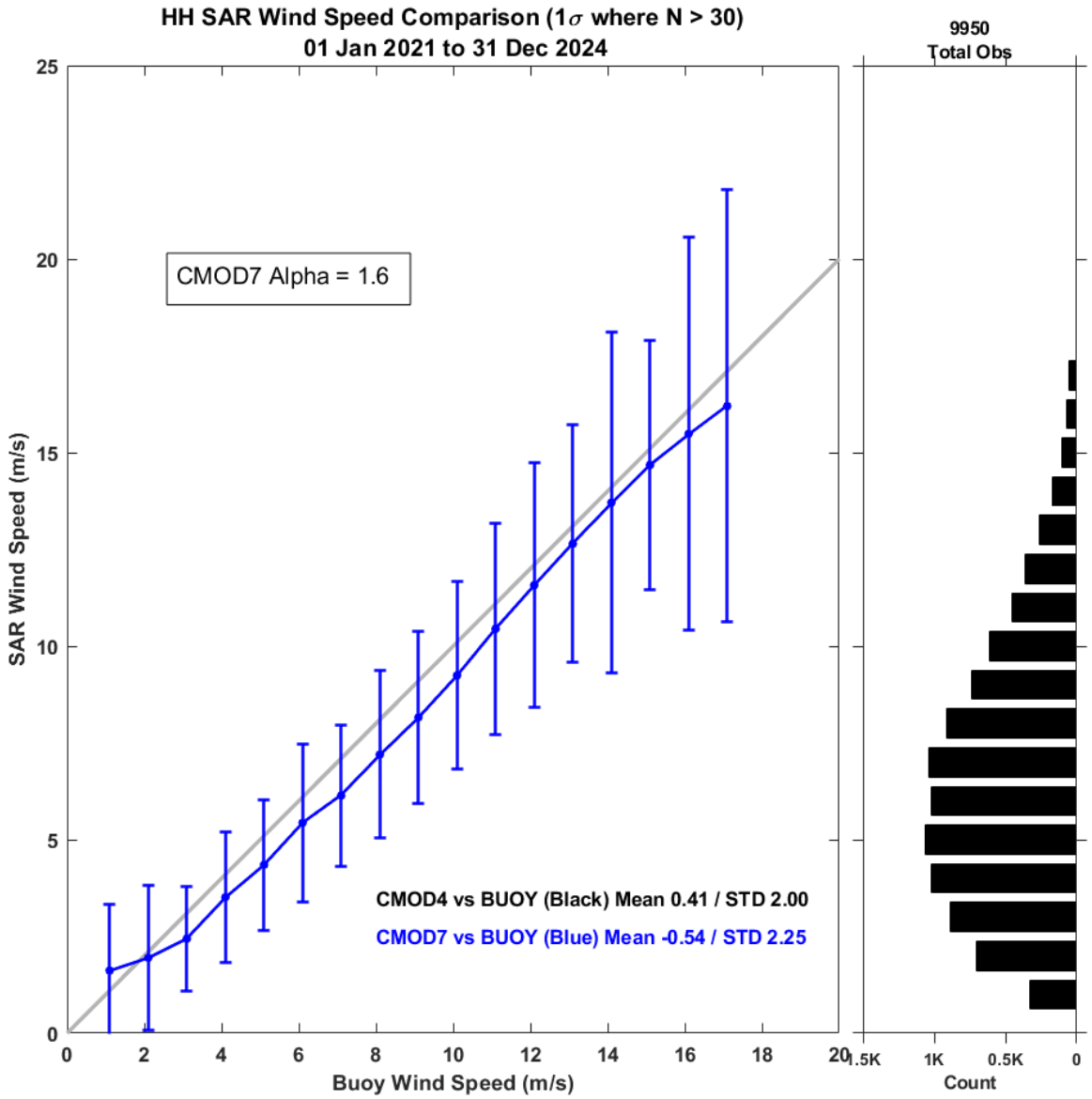
Residual- HH	Mean (m/s)	STD (m/s)	R^2
CMOD4-Buoy	-0.27	2.00	0.78
CMOD7-Buoy	0.80	3.16	0.66
Buoy Wind < 12 m/s (8820)			
CMOD4-Buoy	-0.30	1.94	
CMOD7-Buoy	0.62	2.41	

D. R. Thompson, T. M. Elfouhaily, and B. Chapron, Polarization ratio for microwave backscattering from the ocean surface at low to moderate incidence angles,
Proc. IGARSS, Seattle, WA, 1998. (Alpha = 1)

SAR HH Wind Validation Buoy / GFS



SAR winds vs Buoy

Data Span: 01-Jan-2021 to 30-Dec-2024

HH Observations: 9652

Residual- HH	Mean (m/s)	STD (m/s)	R^2
CMOD4-Buoy	0.41	2.00	
CMOD7-Buoy	-0.54	2.25	

CMOD7 performance is comparable with CMOD4 using Alpha = 1.6

D. R. Thompson, T. M. Elfouhaily, and B. Chapron, Polarization ratio for microwave backscattering from the ocean surface at low to moderate incidence angles, Proc. IGARSS, Seattle, WA, 1998. (Alpha = 1.6)

Final Notes

Synthetic Aperture Radar (SAR) imagery can be used to create fine resolution wind speed maps of the ocean surface

- VV wind speed accuracy for CMOD4 and CMOD7 are comparable (Close to the buoy accuracy itself (1 m/s))
- CMOD7 has better (near zero) bias compared to CMOD4

- HH wind speeds accuracy is lower (compare to VV) for both CMOD4 and CMOD7
- CMOD7 performance improved when Alpha = 1.6 (vs 1.0) in the Thompson et al. polarization ratio

Future work needs to examine other polarization ratio options to improve HH wind speed determination

- Thompson et al. (1988), (Vachon and Wolf (2011), Zhang et al. (2011) all developed before RCM

Residual- VV	Mean (m/s)	STD (m/s)	R^2
CMOD4-Buoy	-0.72	1.35	0.81
CMOD7-Buoy	-0.06	1.33	0.85

Residual- HH	Mean (m/s)	STD (m/s)	R^2
CMOD4-Buoy	-0.27	2.00	0.78
CMOD7-Buoy Alpha = 1	0.80	3.16	0.66
CMOD7-Buoy Alpha = 1.6	-0.54	2.25	

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!