Post-launch performance evaluation of EOS-06/Oceansat-3 Scatterometer winds using HY-2D, In-situ and NWP model fields

By

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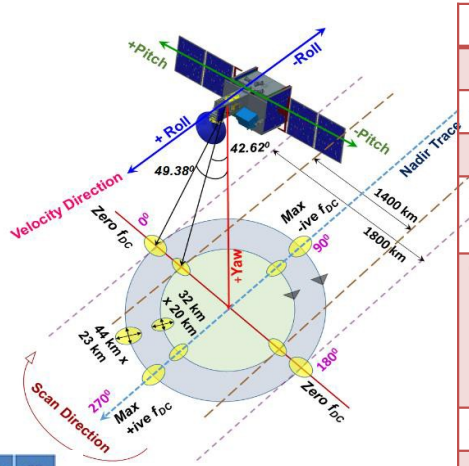
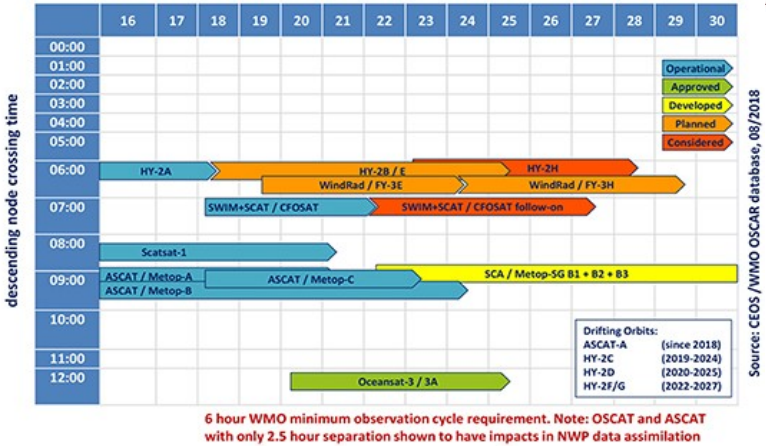
Outline:

- EOS-06/Oceansat -3 Scatterometer
- Types of products
- Different Versions of products released so far
- Evaluation with in-situ data
- Evaluation with ASCAT & HY-2D data
- Evaluation with ECMWF Analysis winds
- Comparison of ISRO & KNMI Wind Processing
- Summary

EOS-06 Scatterometer Mission

- EOS-06 Scatterometer (SCAT-3):
  - An advanced version of SCATSAT-1.
  - Co-passengers onboard Oceansat-3:
    1) OCM-3 2)SSTM 3) ARGOS
  - Nominal mode to be similar as SCATSAT-1, with few enhancements.
  - High resolution mode (5 km x 5 km) as an experimental feature





6 hour WMO minimum observation cycle requirement. Note: OSCAT and ASCAT with only 2.5 hour separation shown to have impacts in NWP data assimilation

EOS-06 Scatterometer System Parameters

Parameter	Inner Beam	Outer Beam
Spacecraft Altitude	750 km	
Frequency	13.51 GHz	
Swath / Polarization	1400 km / HH	1800 km / VV
One Way 3dB Foot Print at Equator (Azimuth x Elevation)	29.5 km X 20 km	38 km X 22 km
Scan Rate	16 rpm	
Antenna Diameter	1.4 m	
Wind speed range	3 to 30 m/s	
Wind direction range	0° to 360°	
Wind speed accuracy	1.6 m/s rms or 10% whichever is higher	
Wind direction accuracy	20° rms	
Wind vector cell size	25 km x 25 km and 12.5 km x 12.5 km	

EOS-06/Oceansat-3 Scatterometer Mission

Parameters	SCATSAT-1		EOS-06 Scatterometer			
	HH	VV	HH		VV	
Look Angle	42.62°	49.38°	42.62°		49.38°	
Incidence Angle	48.9°	57.6°	48.9°		57.6°	
Swath (Km)	1400	1800	1400		1800	
Beam Width (El X Az)	1.63° X 1.47°	1.72° X 1.39°	1.12° X1.05°		1.08° X1.08°	
FP Dimensions (Range X Az) Km	46 X 27	70 X 30	31.7 X 19.4		44 X 23.4	
Scan Loss (dB)	2	2.5	1.15		1.4	
Slice Bandwidth (KHz)	9.54	9.54	9.54	4.5	9.54	4.5
Range-Slice Resolution(Km)	6.5	5.7	6.5	3.0	5.7	2.7
NEσ° (dB) (Slice)	-30	-27.3	-34.6	-31.7	-34.5	-31.8
Main Reflector Diameter (meter)	1		1.4			
Antenna Gain (dBi)	40		42.3 ± 0.5			
Side lobe ratio (dB)	≤ -16		≤ -16			
Cross Pol (dB)	≤ -20		≤ -20			
Speed of Rotation (rpm)	20.5		16			

Reference

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An Advanced Ku-Band Fine-Resolution and High-Sensitivity Wind Scatterometer

Prantik Chakraborty, Priyanka Gupta, Ch V. Narasimha Rao, *Senior Member, IEEE*, Rajeev Jyoti, *Senior Member, IEEE*, and Nilesh M. Desai

***Abstract*— An advanced Ku-band pencil-beam scatterometer has been developed having a scanning 1.4 m diameter Cassegrain antenna, for providing 3 × 20 km [for horizontal-transmit and horizontal-receive (HH) beam] and 3 × 23 km (for VV beam) fundamental range-slice resolution, a marked improvement over its predecessor Scatsat-1, which provided 6 × 46 km (for HH beam) and 6 × 70 km [for vertical-transmit and vertical-receive (VV) beam]. This instrument will carry forward the legacy of data services from the Indian Space Research Organization's OScat (Oceansat-2 Scatterometer, which operated in orbit from 2009 to 2014) and Scatsat-1, which operated from September 2016 to April 2021, with improved spatial resolution, noise-equivalent normalized radar cross section (NEσ^0), and the sensitivity parameter K_p. The improvement in NEσ^0 and the signal-to-noise ratio (SNR) is of the order of 4.5 dB, and of K_p by 2.5 dB over a Scatsat-1 equivalent resolution cell. Equivalently, over its own range-slice resolution, the new sensor will match Scatsat's measurement sensitivity. This article elaborates on the system design of the instrument, the performance improvements over Scatsat-1 and the payload characterization methods.**

***Index Terms*— K_p, Ku-band scatterometer, noise-equivalent σ^0(NEσ^0), normalized radar backscatter cross section (σ^0), pulse repetition interval (PRI), scanning loss, signal-to-noise ratio (SNR), spatial resolution.**

I. Introduction

SCATSAT-1 has proven to be extremely useful in predicting and tracking cyclones all over the globe [1], [6]. With Scatsat-1 operations discontinued since April 2021, a new advanced scatterometer has been conceived and developed with the aim of providing finer spatial resolution and improved sensitivity for ISRO's forthcoming EOS-06 satellite. There is a demand for fine-resolution imaging for coastal, land, inland hydrological, and polar ice-cap applications. The new scatterometer will provide 12.5 km gridded σ^0 and wind products in addition to the legacy 25 km products like those from Scatsat-1 [1]. The fundamental resolution bin of the

in resolution is complemented by an improvement in noise-equivalent σ^0 (NEσ^0) by ~4.5 dB, because of which, over a Scatsat-1 equivalent resolution cell, the signal-to-noise ratio (SNR) improves by a factor of 4.5 dB and the sensitivity K_p by 2.5 dB. Over a finer range-slice resolution from the new sensor, this SNR improvement compensates for the reduced integration interval and consequently, one can achieve Scatsat-1 equivalent sensitivity over half the range resolution.

A brief description of the instrument is given in Section II. The advancements in the new scatterometer with respect to its predecessor Scatsat-1 by virtue of exploiting the benefits of a larger dimension Cassegrain antenna are discussed in Section III. The payload characterization methods and analysis are presented in Section IV.

II. Brief Description of the Sensor

The Ku-band scatterometer is designed to measure near-surface wind vectors over the ocean at a global scale. It is a conically scanning pencil-beam radar, which uses a single paraboloid reflector to emanate two beams in the incidence plane at horizontal and vertical polarizations and at look angles of 42.62° and 49.38°, respectively. This translates from a nominal altitude of 740 km to an inner qualified swath of 1400 km, in which measurements at both polarizations are available, and beyond which only the outer V-polarized beam is available up to 1800 km. The scatterometer measures the backscatter from the ocean surface in the Bragg-scattering zone. There are either four or two observations of a geo-location depending upon its position in the swath, which are used to resolve wind vectors. The predicted wind speed and direction accuracies from the new sensor within the 1400-km swath are 1.4 m/s and 15° rms, respectively. The major system parameters are provided in Table I.

By virtue of a shaped axis-symmetric Cassegrain antenna

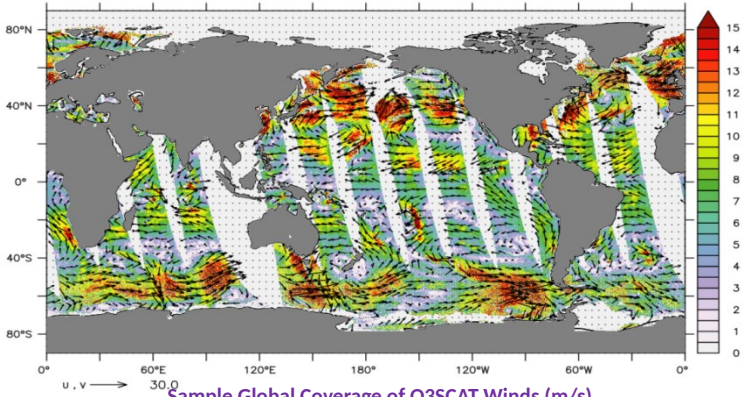
EOS-06 Scatterometer Data Products

Levels of Products corresponding to LRScat Mode (Primary mode)					
Product	Level-1B	Level-2A	Level-2B	Level-3S	Level-3W
Swath	1800 Km			Global	Global
Definition	Half Revolution	Half Revolution	Half Revolution	Full Globe	Full Globe
WVC Size	Scan mode data, WVC size not applicable	12.5 km x 12.5 km & 25 km x 25 km	12.5 km x 12.5 km & 25 km x 25 km	0.125° x 0.125° & 0.25°x0.25°	0.125° x 0.125° & 0.25°x0.25°
Parameter	σ°	σ°	Wind Vector	σ°	Wind Vector
All products will be generated in HDF5 format					

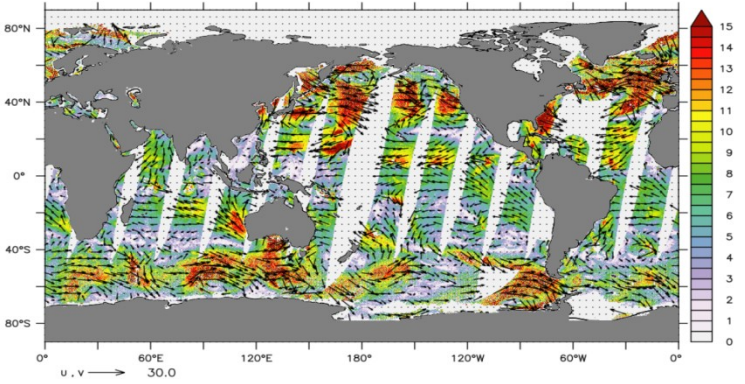
Note: Apart from Low Resolution (Nominal Mode) there is an experimental high-resolution mode which will provide 5km resolution sigma0 products.

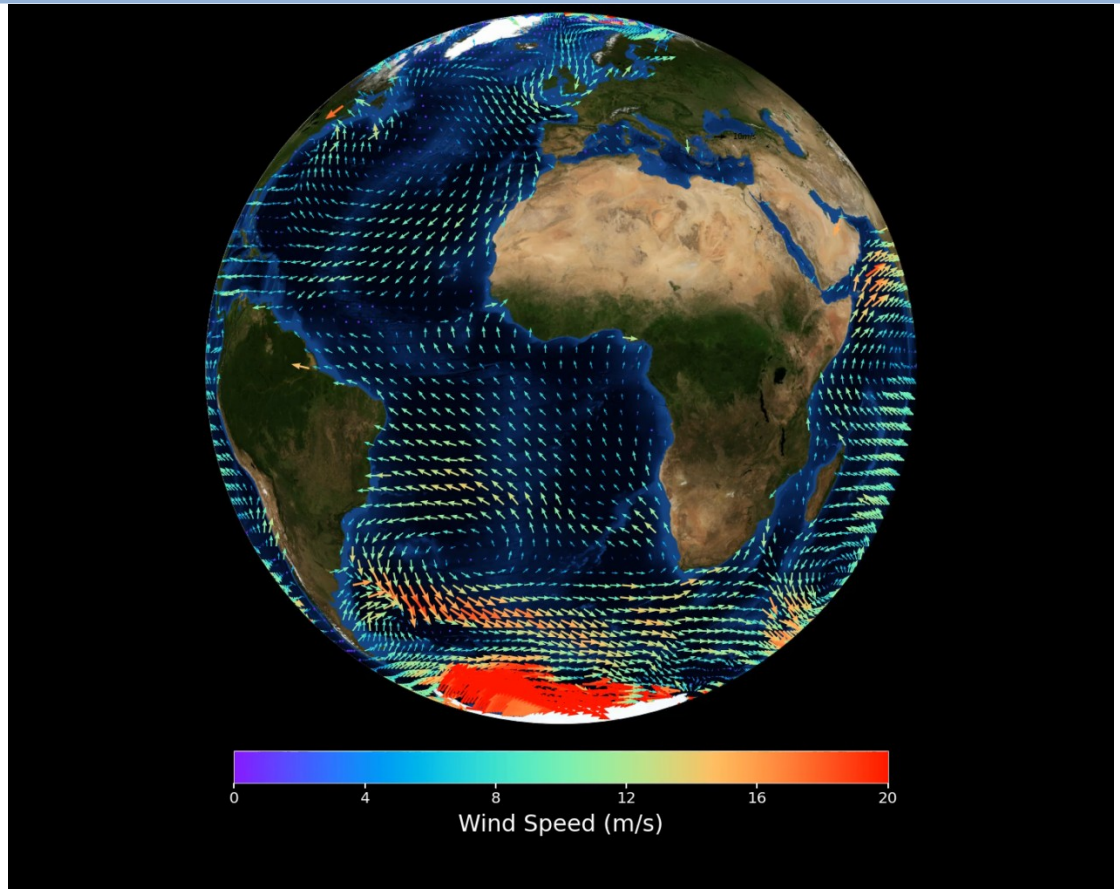
EOS-06 Scatterometer PRODUCTS

Sample Global Coverage of O3SCAT Winds (m/s)
(Data from 14th January 2023) (Ascending Passes)



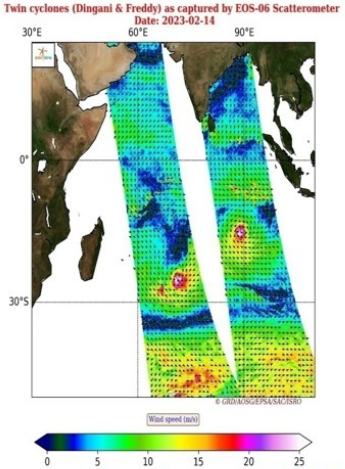
Sample Global Coverage of O3SCAT Winds (m/s)
(Data from 14th January 2023) (Descending Passes)

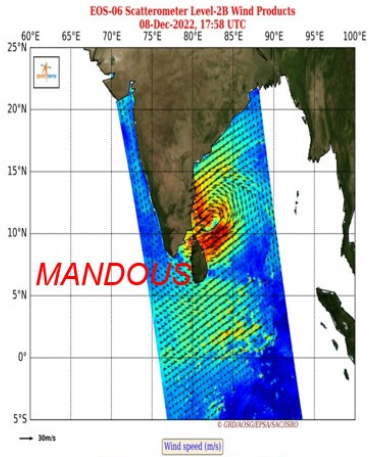


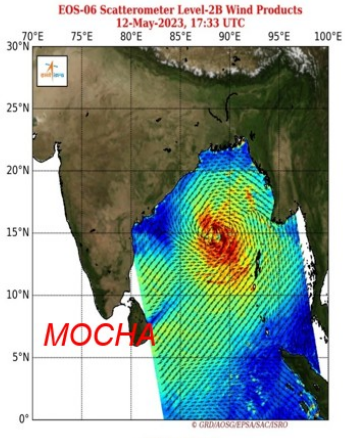


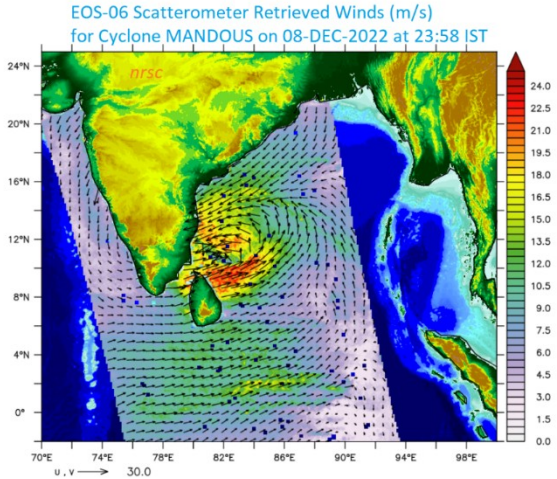
EOS-06 Scatterometer PRODUCTS

Global cyclones as captured by EOS-06 Scatterometer

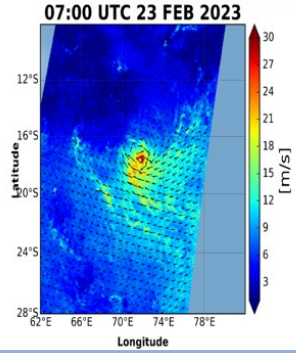




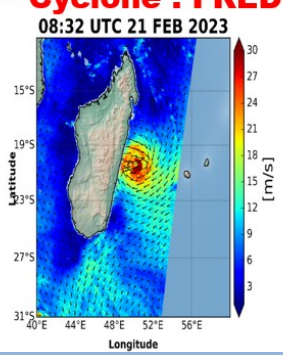




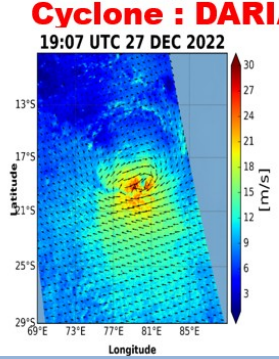
Cyclone : ENALA



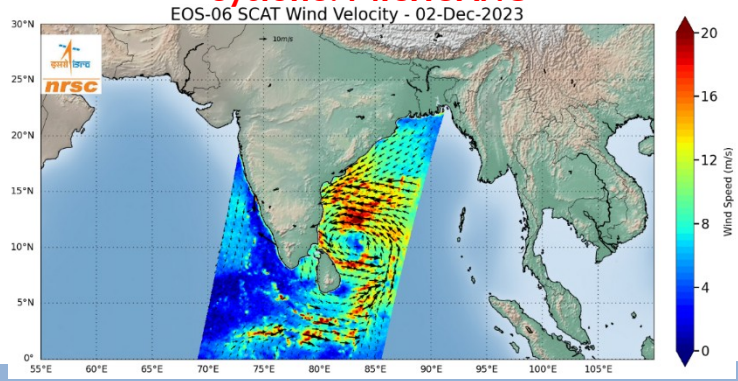
Cyclone : FREDDY



Cyclone : DARIAN



Cyclone: MICHUANG



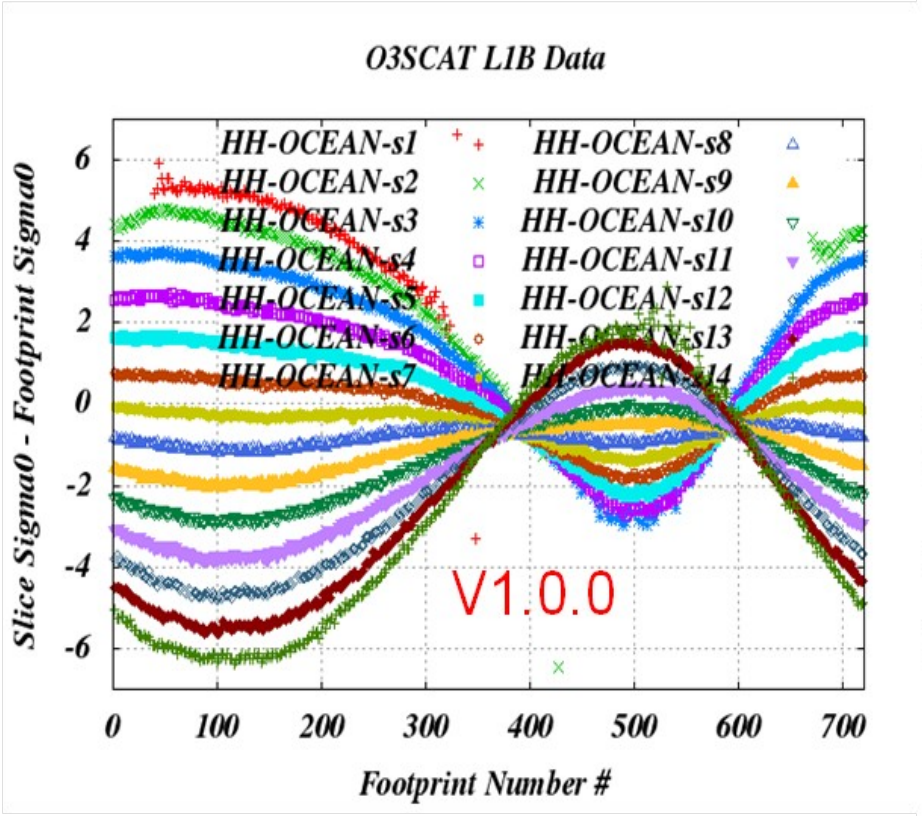
EOS-06 SCATTEROMETER PRODUCTS

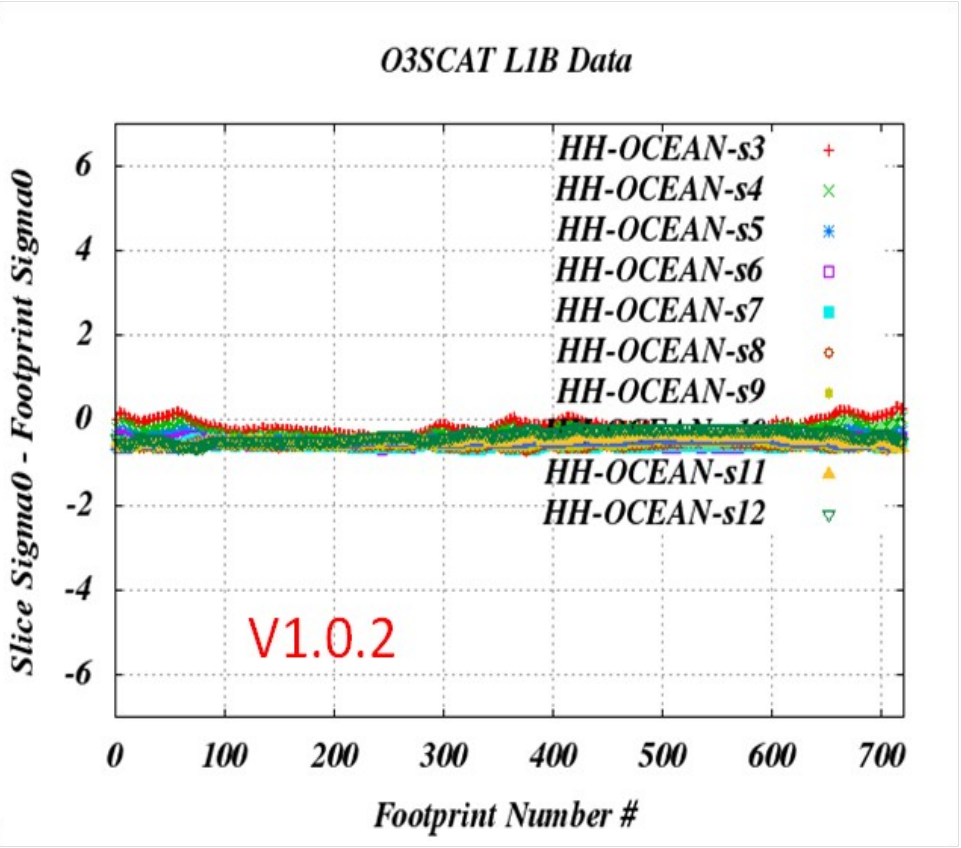
EOS-06 Scat Status: Completion of IOT Phase and Operational (Since April 2023)products (L1B, L2A, L2B, L3W) are now routinely disseminated through Bhoonidhi.

EOS-06 Scat Data Product Versions:

1) **Version 1.0.0** - Pre operational (First Day Product) version up to 08th Feb 2023 (ALL SCATSAT Algorithms)
2) **Version 1.0.1** - Updated on 09th Feb 2023 with improvements in L1B Slice balancing, OAT fine-tuning, updated Noise power computation etc.,
3) **Version 1.0.2** – Updated on 24th April 2023 with improvements such as use of Level-0 output attitude, correction for scan-angle based trend in noise data, L1B slice balancing etc.,
4) **Version 1.0.3** – Updated in May 2024, with EOS-06 Scat specific GMF
5) **Version 1.0.4** – Updated on 2nd April 2025, Bias removal in BT & Sigma0 based on December 2024 Deep Space Cal.

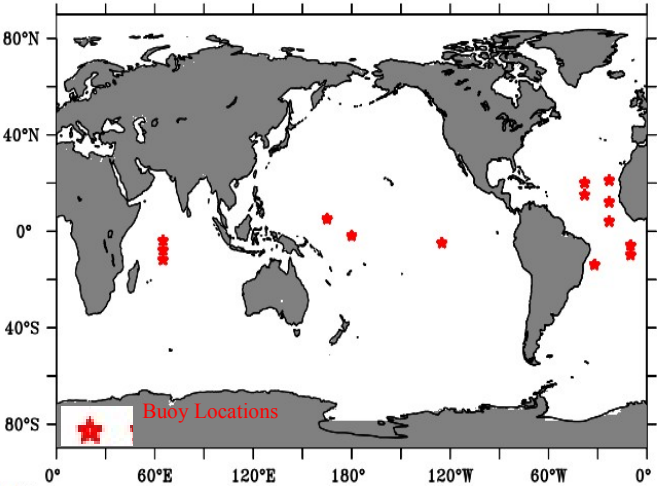
L1B Slice Balancing

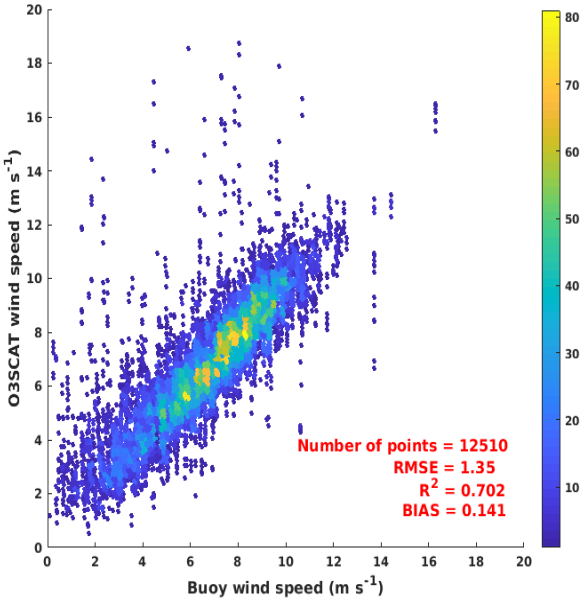


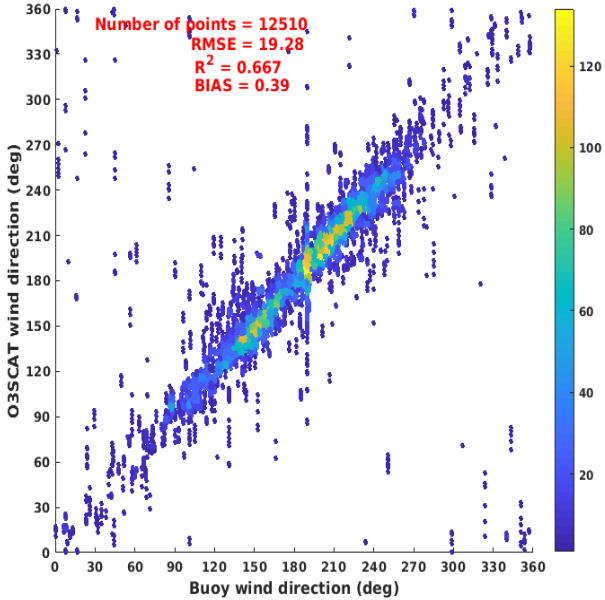


EOS-06 Scatterometer PRODUCTS
Evaluation with *IN-SITU* data

Spatial positions of collocated points of O3SCAT and RAMA/TRITON/TAO Buoys For May-Dec 2023 including 10 minutes data







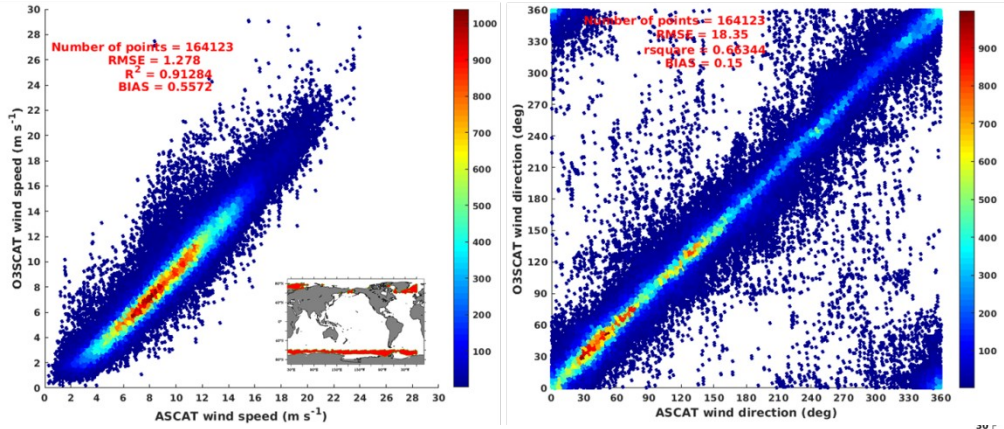
O3-SCAT Validation:

- ✓ Temporal Window: ±30 min
- ✓ Spatial Window: ±25km
- ✓ Data Version: Version 1.0.2
- ✓ Data Period: May – Dec 2023

EOS-06 Scatterometer PRODUCTS
Evaluation with HY-2D data

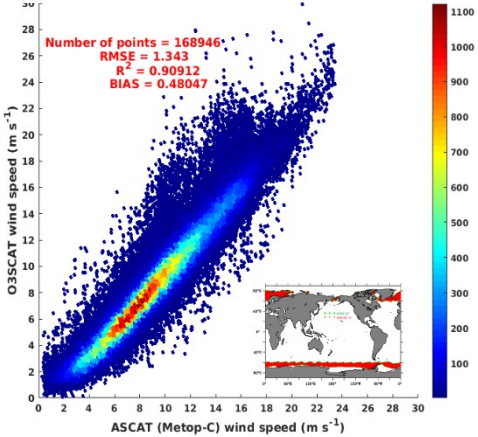
O3SCAT v/s ASCAT- B

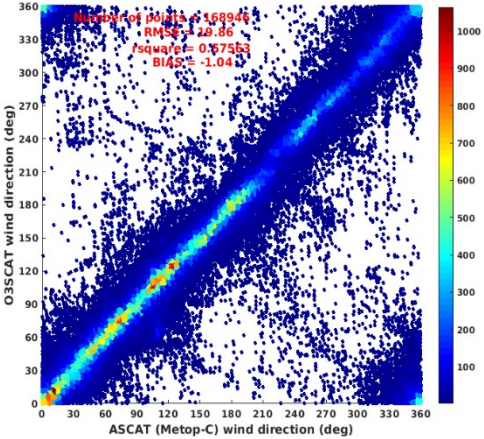
O3SCAT v/s ASCAT-B Wind Speed



O3SCAT v/s ASCAT-B Wind Direction

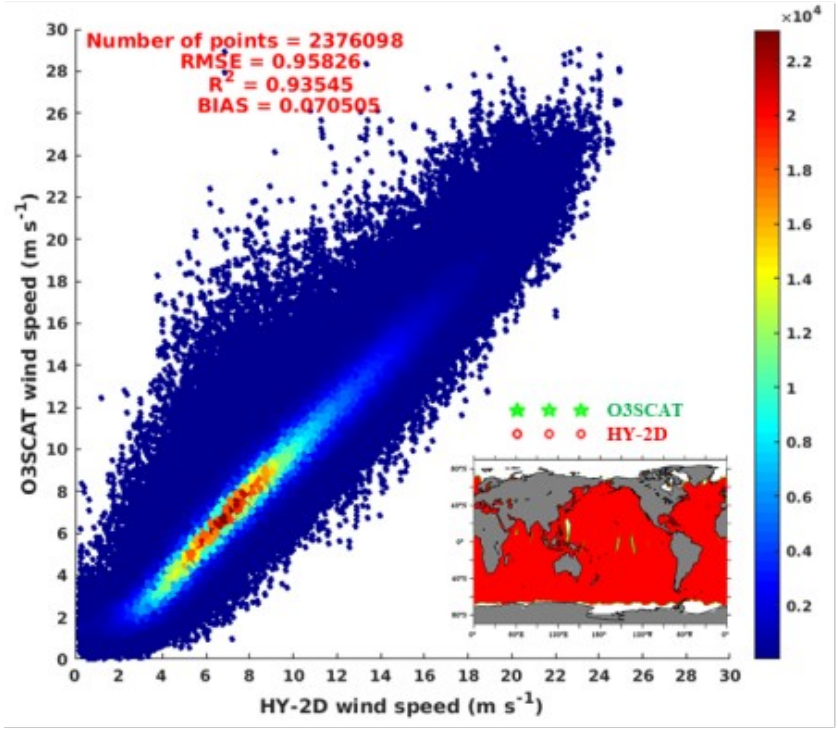
O3SCAT v/s ASCAT-C



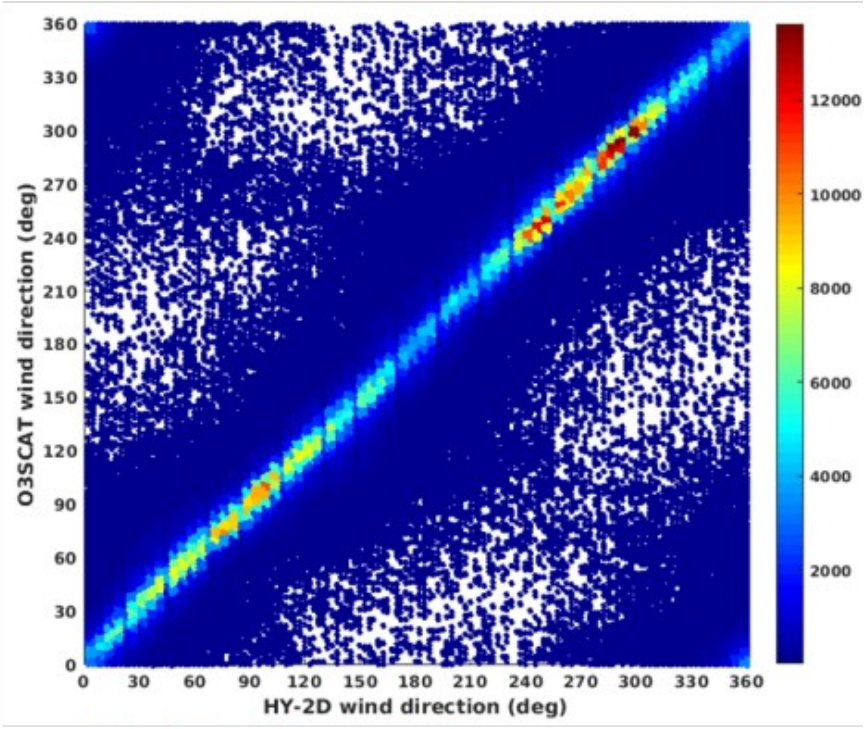


EOS-06 Scatterometer PRODUCTS
Evaluation with HY-2D data

O3SCAT v/s HY-2D Wind Speed

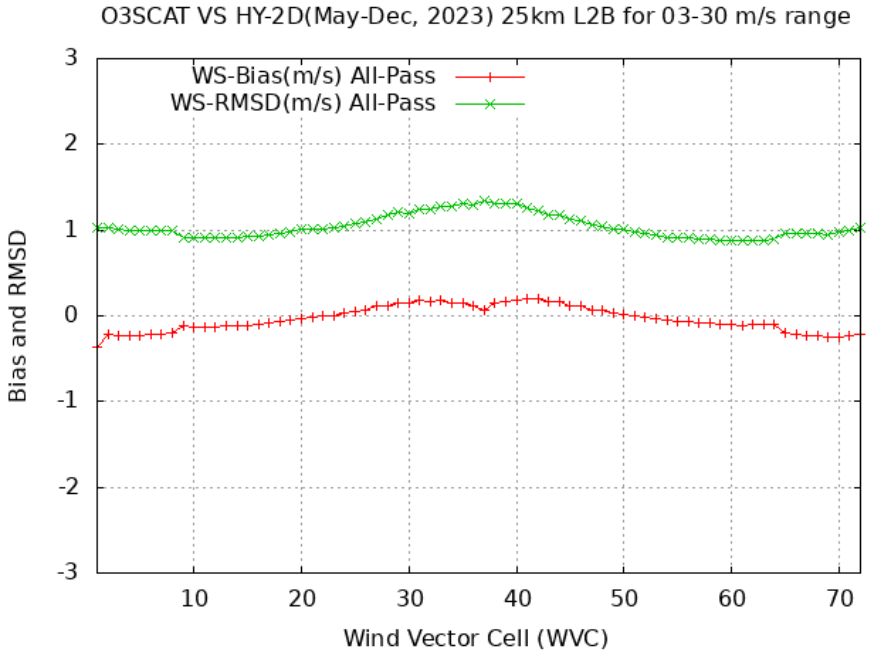


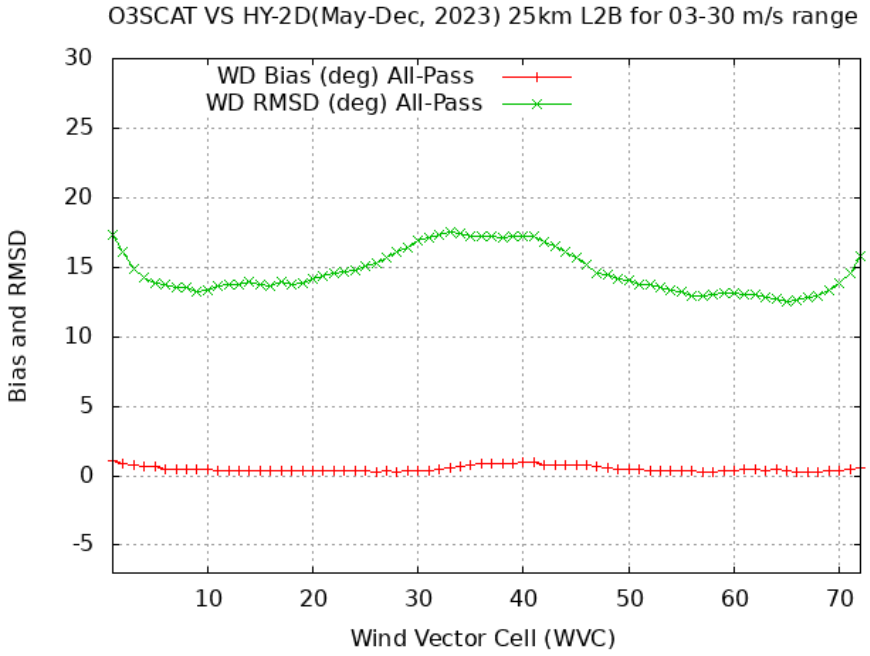
O3SCAT v/s HY-2D Wind Direction



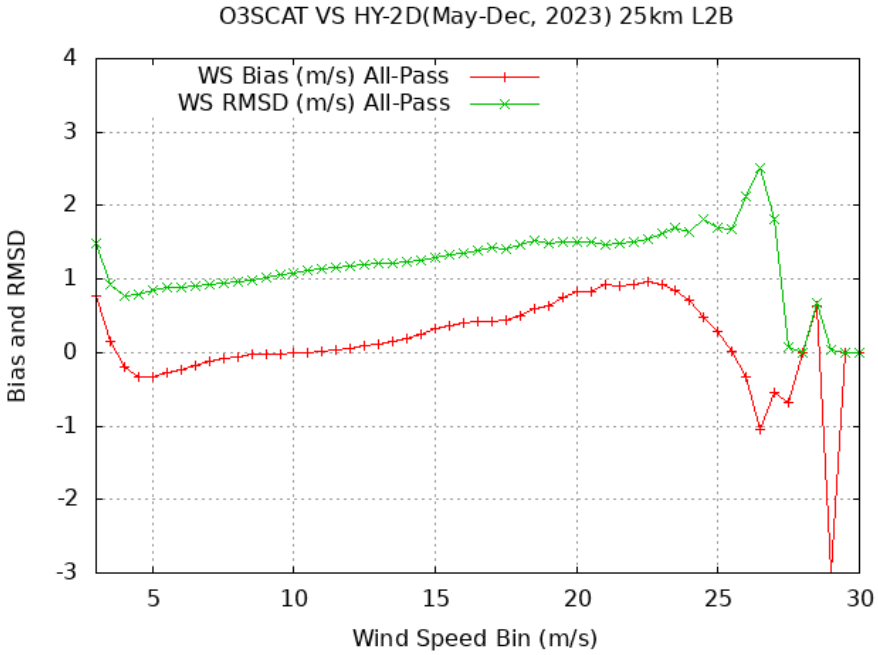
Numb of points: 2376098
RMSE: 13.77 deg
R-square: 0.78
Bias: 0.60

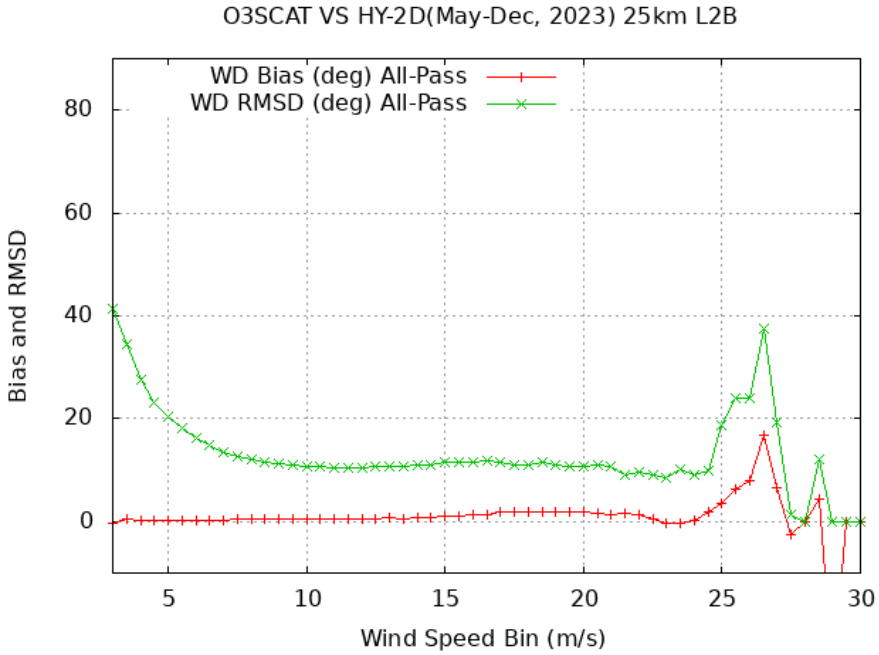
EOS-06 Scatterometer PRODUCTS
Evaluation with HY-2D data



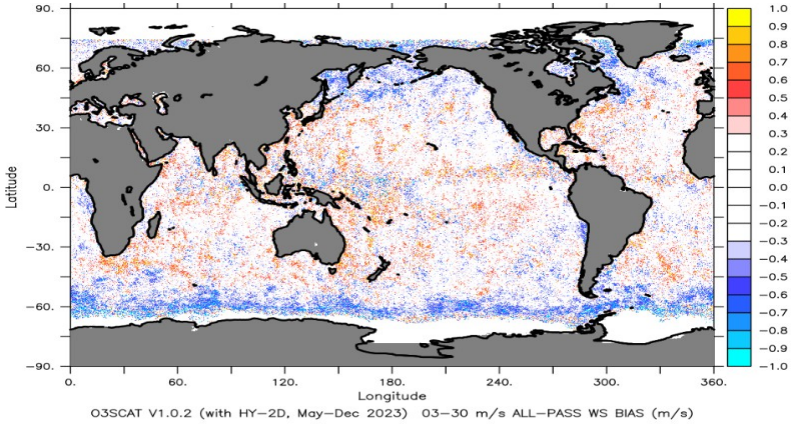


EOS-06 Scatterometer PRODUCTS
Evaluation with HY-2D data

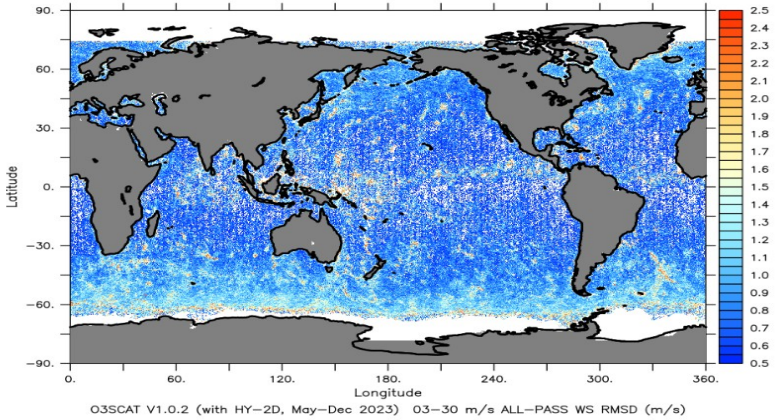




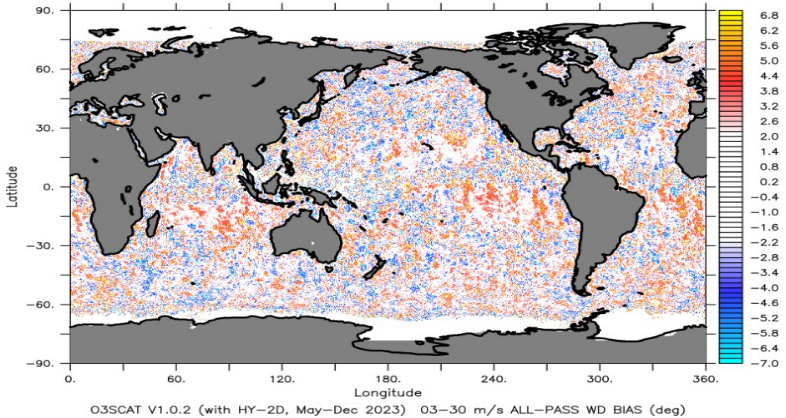
EOS-06 Scatterometer PRODUCTS
Evaluation with HY-2D data



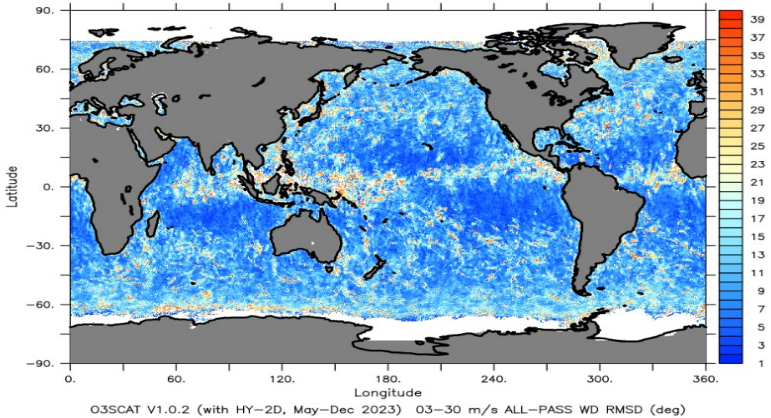
O3SCAT V1.0.2 (with HY−2D, May−Dec 2023) 03−30 m/s ALL−PASS WS BIAS (m/s)



O3SCAT V1.0.2 (with HY−2D, May−Dec 2023) 03−30 m/s ALL−PASS WS RMSD (m/s)



O3SCAT V1.0.2 (with HY−2D, May−Dec 2023) 03−30 m/s ALL−PASS WD BIAS (deg)

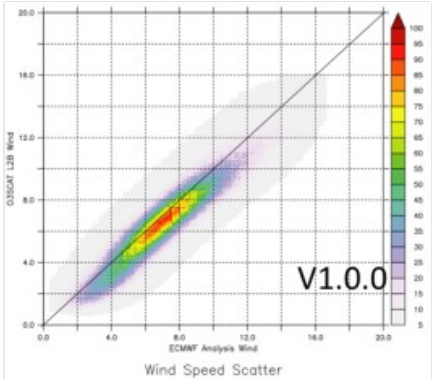


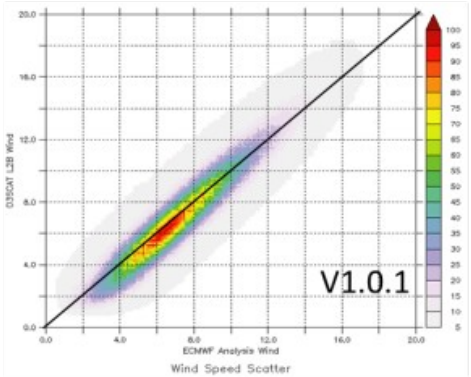
O3SCAT V1.0.2 (with HY−2D, May−Dec 2023) 03−30 m/s ALL−PASS WD RMSD (deg)

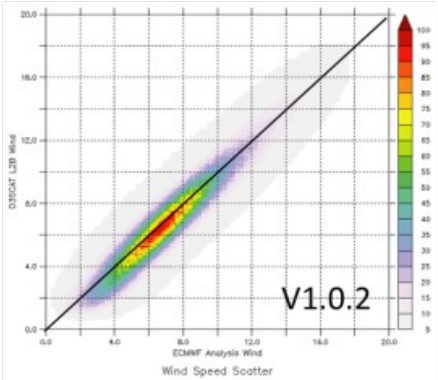
Evaluation with ECMWF Analysis Winds

EOS-06 Scatterometer PRODUCTS

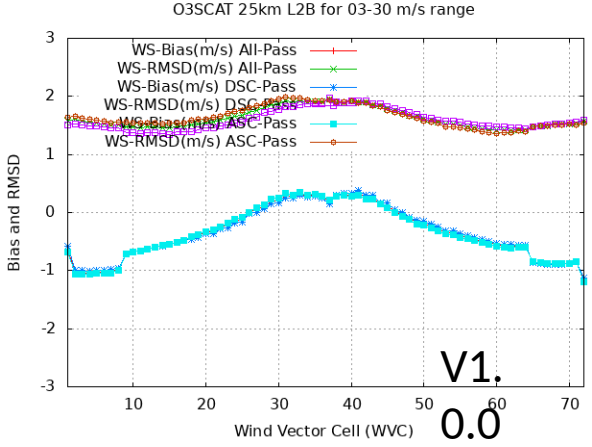
O3SCAT 25km (JD:2024091 to 2024101 data)	Wind Speed Bias (m/s)	Wind Speed RMSE (m/s)	Wind Speed URMSE (m/s)	Wind Direction Bias (deg)	Wind Direction RMSE (deg)	Wind Direction URMSE (deg)	#No.Of points
L2B 25km Data (V1.0.1)	-0.35	1.64	1.61	0.03	18.08	18.08	35420676
L2B 25km Data (V1.0.1)	0.07	1.62	1.62	0.77	15.81	15.80	14226365
L2B 25km Data (V1.0.2)	-0.27	1.61	1.59	0.22	15.43	15.43	16323756
L2B 25km Data (V1.0.3)	-0.19	1.58	1.57	0.48	15.47	15.47	14499760
L2B 25km Data (V1.0.4)	-0.02	1.58	1.58	0.24	15.35	15.35	13749524

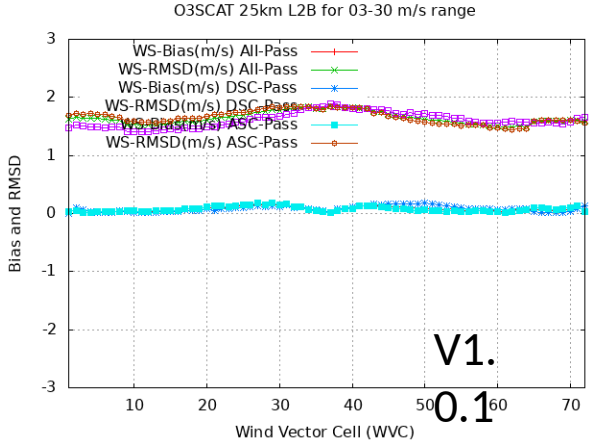


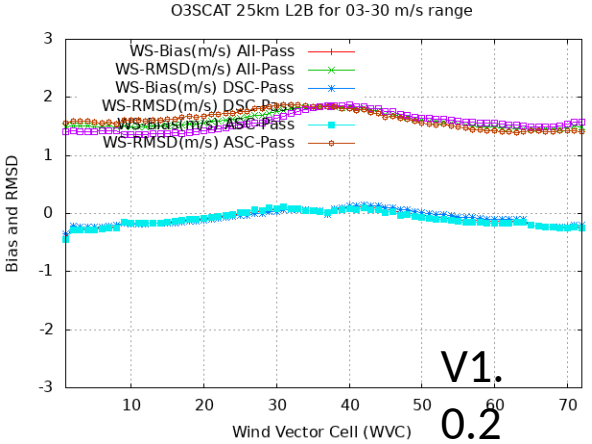


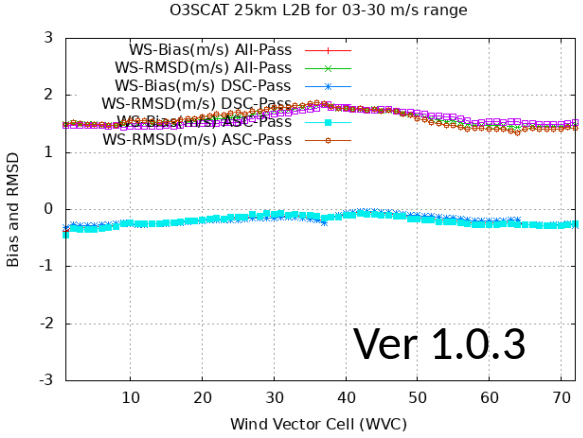


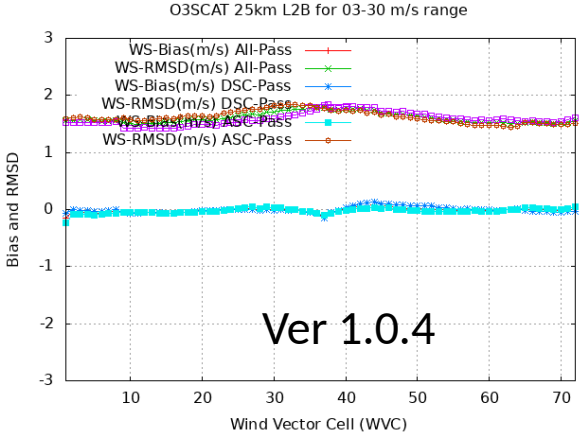
EOS-06 Scatterometer PRODUCTS



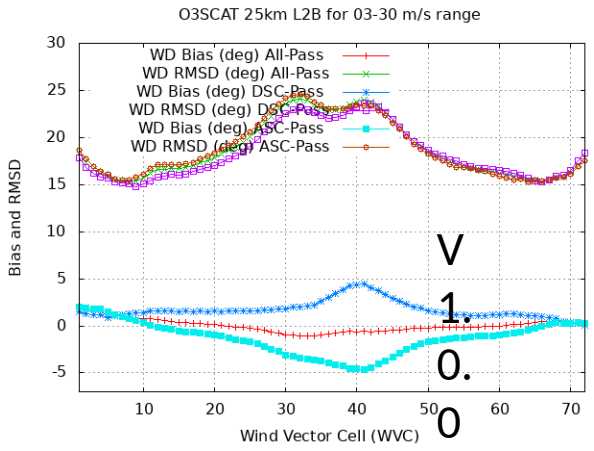


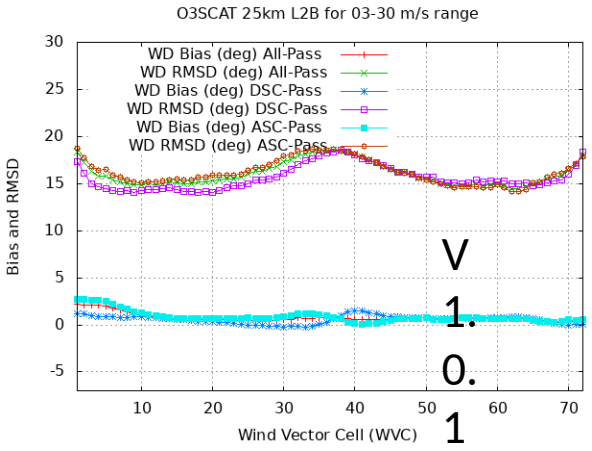


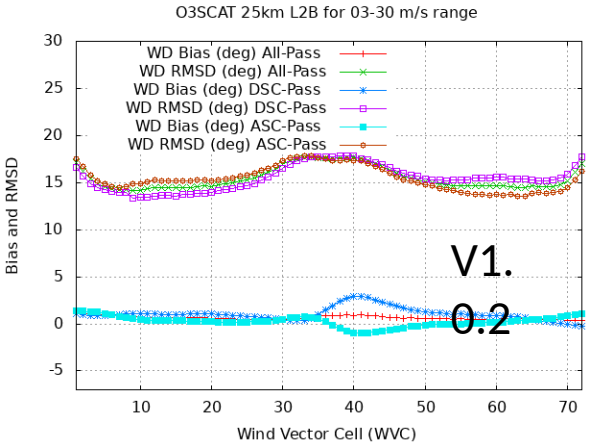


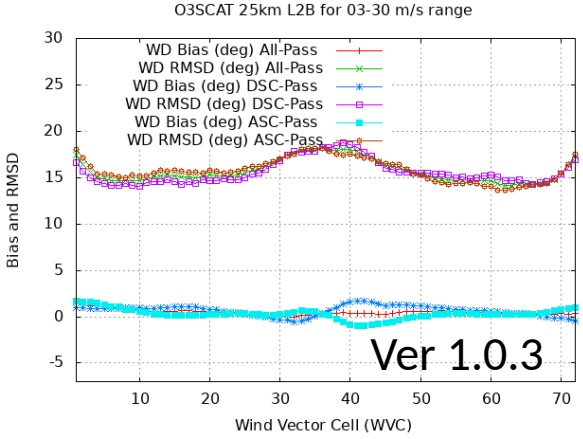


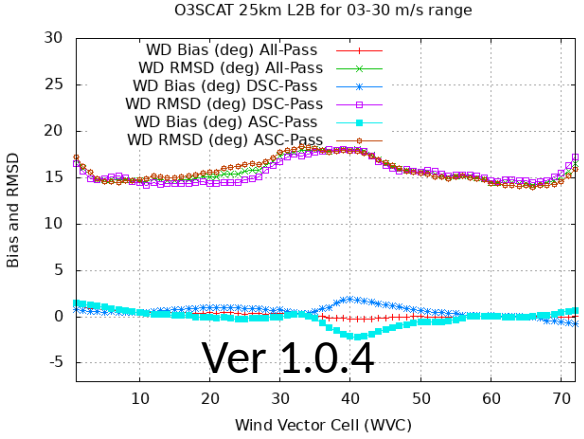
EOS-06 Scatterometer PRODUCTS



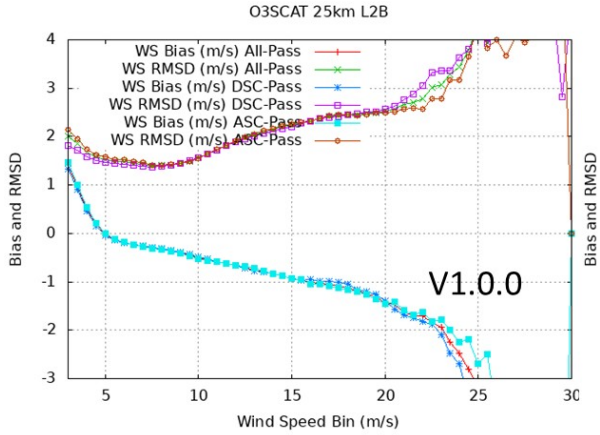


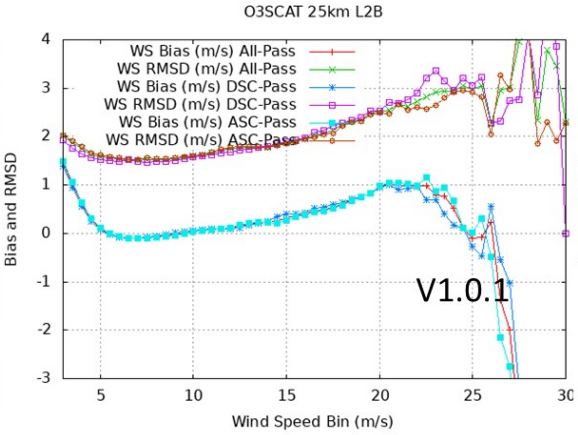


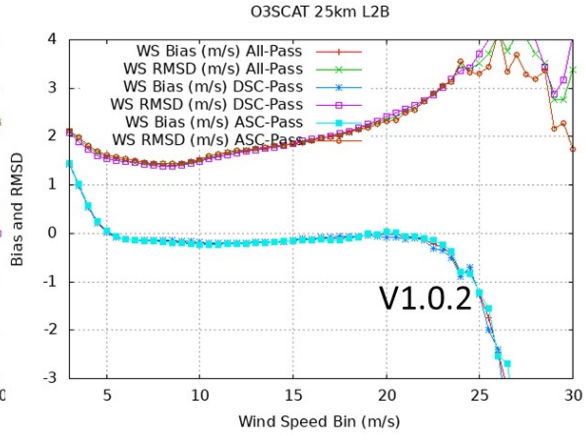


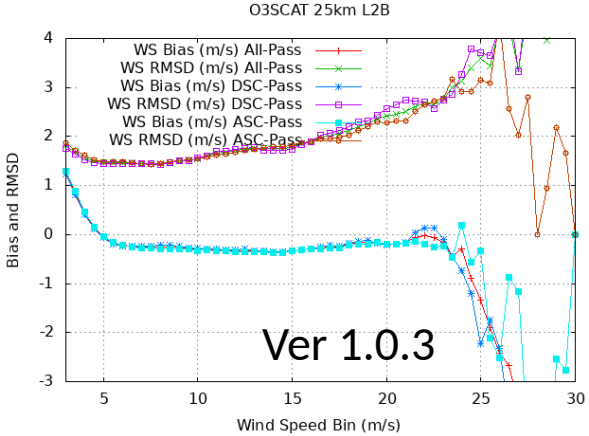


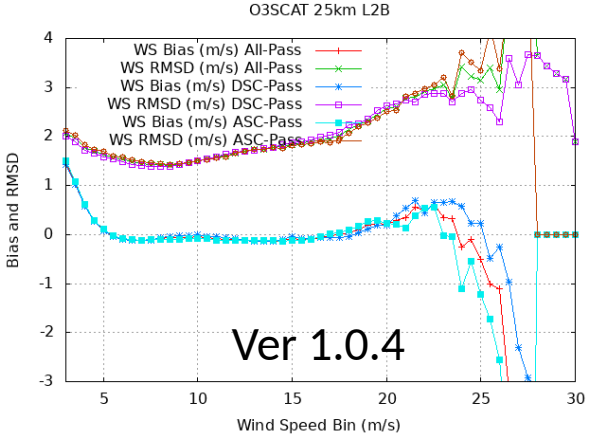
EOS-06 Scatterometer PRODUCTS



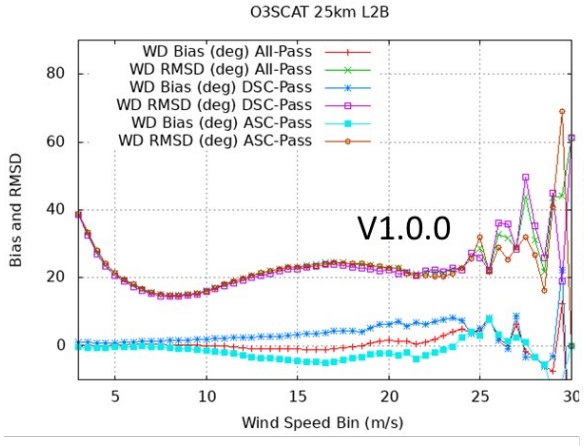


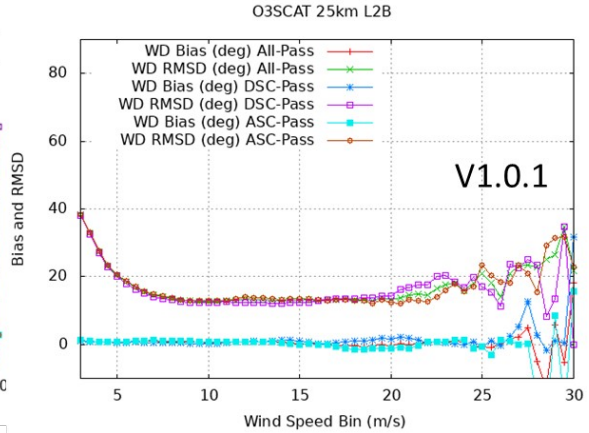


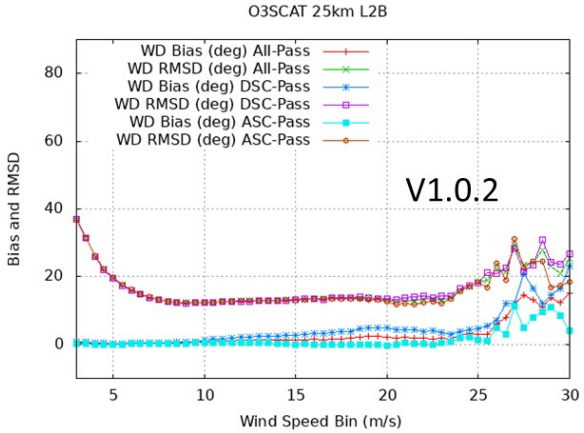


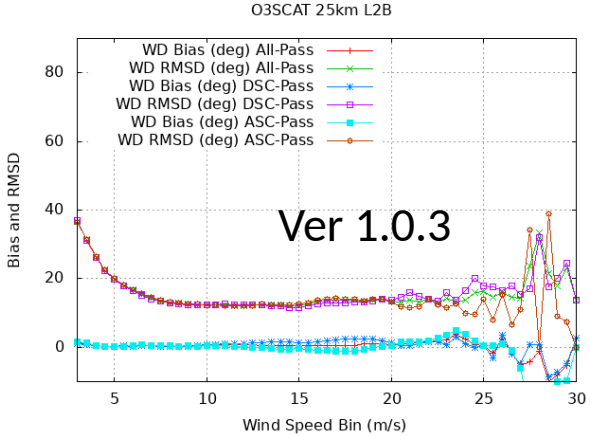


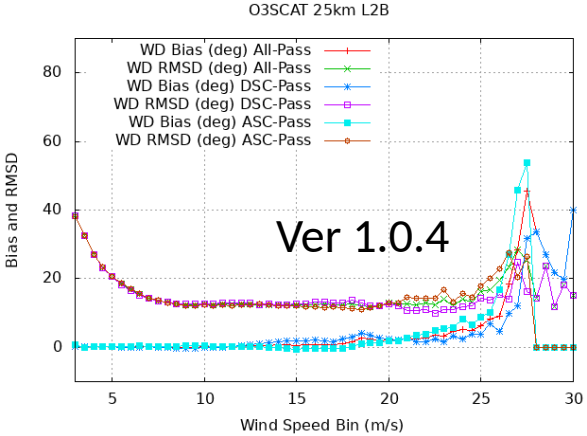
Comparison of April-2025 (V1.0.4) L2B V/S ECMWF Analysis Data



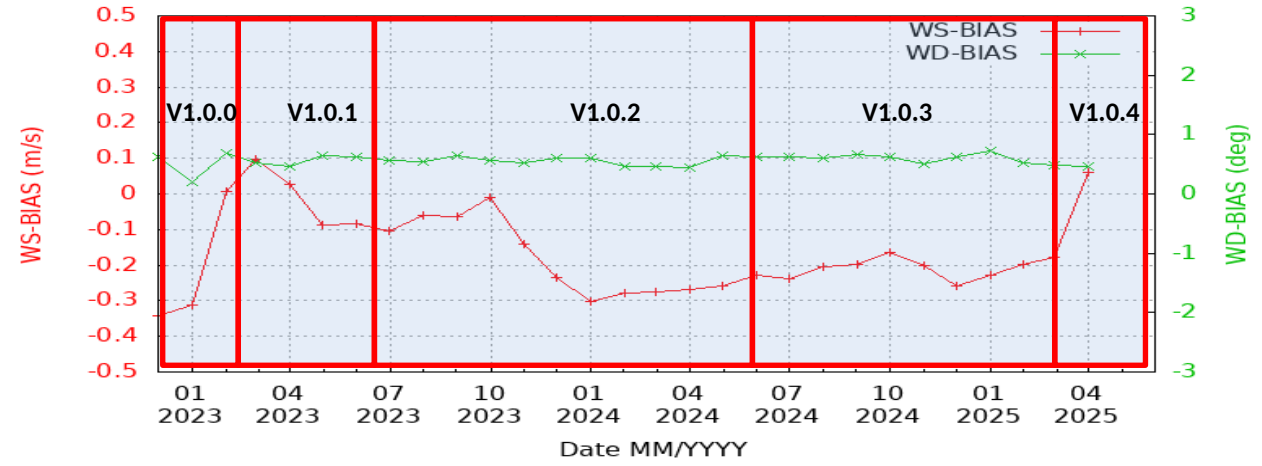


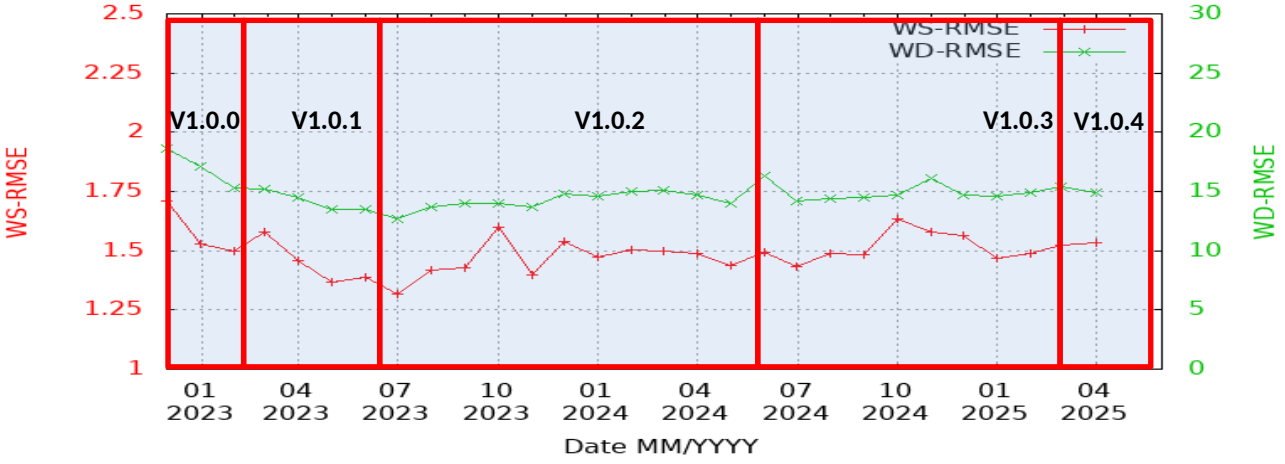






Current Status (Till April 2025) of EOS-06 Scat Wind Product Quality





Summary:

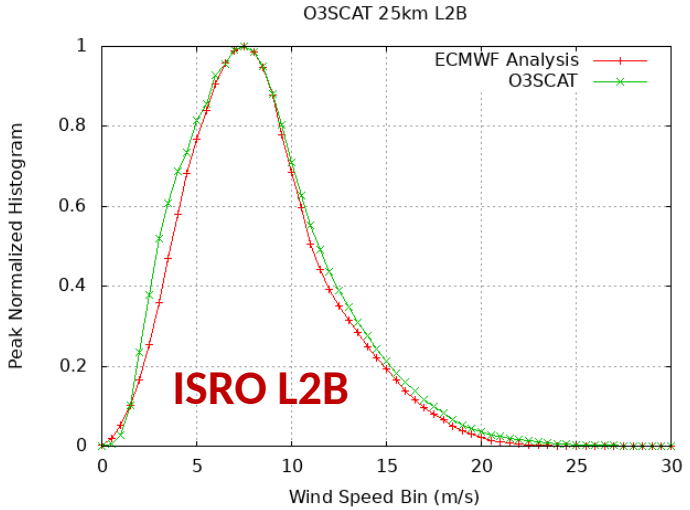
- From Day -1 of TWTA on (03-Dec-2022) O3SCAT started providing wind products continuously.
- L1B slice balancing analysis clearly shows a systematic anomalous trends as a function of foot print number for the V1.0.0 and were significantly improved in the subsequent versions.
- Validation of O3SCAT winds with ASCAT & HY-2D satellite winds, In-situ and ECMWF analysis winds is carried out.
- Due to observational local time differences (ASCAT 9:30 AM/PM orbit and O3SCAT 12:00 AM/PM orbit) limited colocations with ASCAT are observed only at higher latitude regions. The observed RMSE with limited ASCAT collocated is around 1.30 m/s and 19.8 deg for wind speed and direction respectively.
- The validation with HY-2D having good global collocation data shows an RMSE of 0.9 m/s and 13.7 deg for wind speed and direction respectively demonstrating the excellent performance of EOS-06 with other global standards.
- Validation with ECMWF analysis winds showed a global mean bias of 0.02 m/s, 0.24 deg and RMSE of 1.5 m/s 15.04 deg for wind speed and direction respectively.
- Time series of wind speed Bias clearly conforms the sudden dip (observed also in BT data) since October 2023 which got rectified with the latest version (V1.0.4) after Deep Space Cal correction implementation.
- Further fine-tuning of EOS-06 Scat specific GMF and reprocessing of full mission data is in progress.
- The current version of EOS-06 scat data very well meets the accuracy requirements for all operational applications.

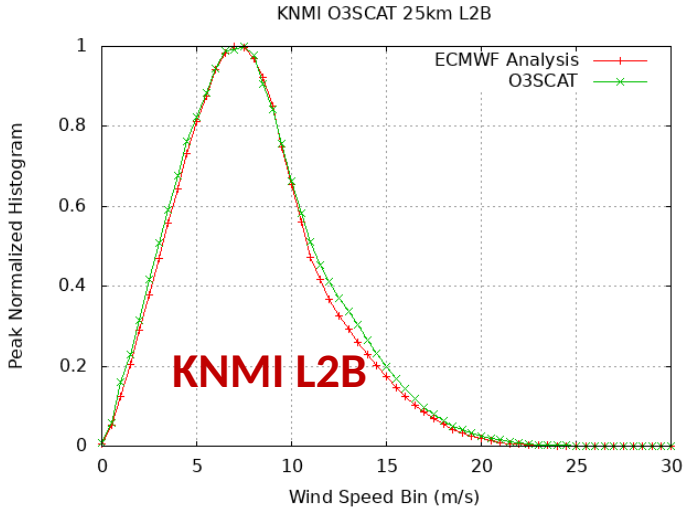
Comparison of ISRO v/s KNMI Processing

EOS-06 SCATTEROMETER PRODUCTS

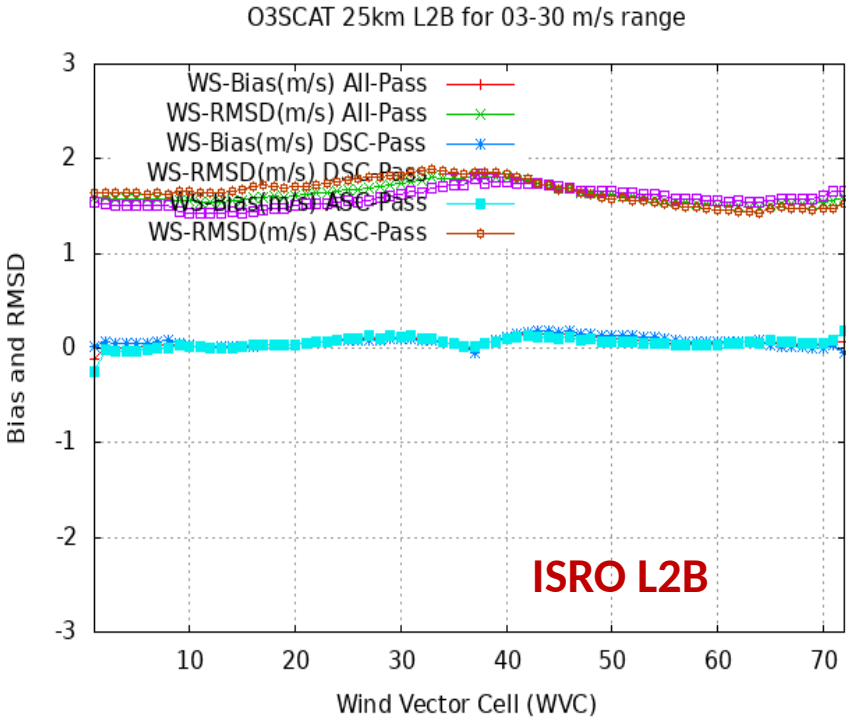
Comparison of V1.0.4 with ECMWF Analysis winds
Data for April 2025 (Full One Month Data)

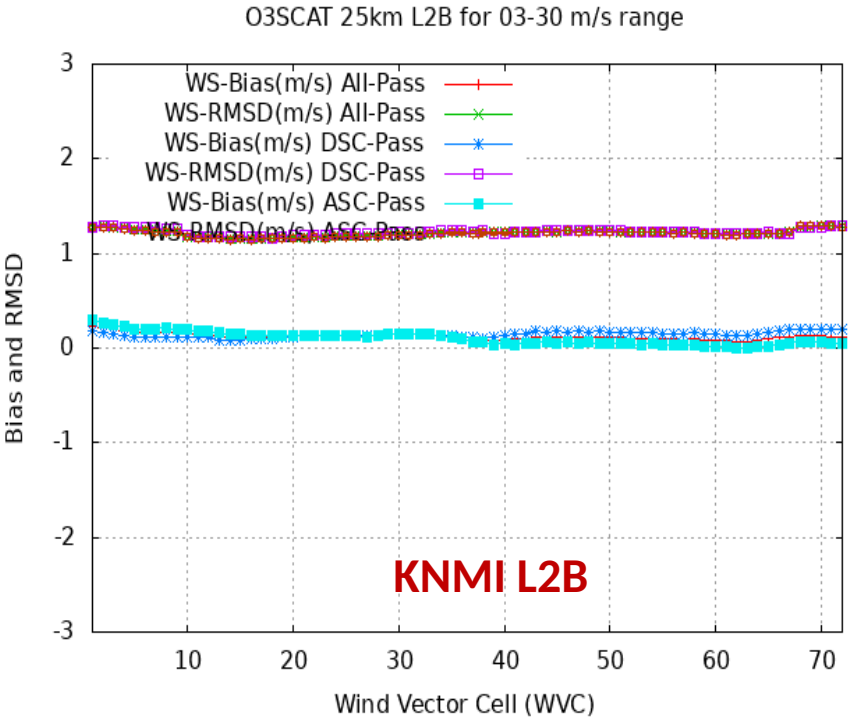
O3SCAT Version 1.0.4 25km (April 2025 data) L2B Data	Wind Speed Bias (m/s)	Wind Speed RMSE (m/s)	Wind Speed URMSE (m/s)	Wind Direction Bias (deg)	Wind Direction RMSE (deg)	Wind Direction URMSE (deg)	#No.Of points
L2B 25km Data (ISRO L2B)	0.060	1.536	1.534	0.47	14.91	14.90	39016162
L2B 25km Data (KNMI L2B)	0.124	1.213	1.207	0.51	14.41	14.40	14533159



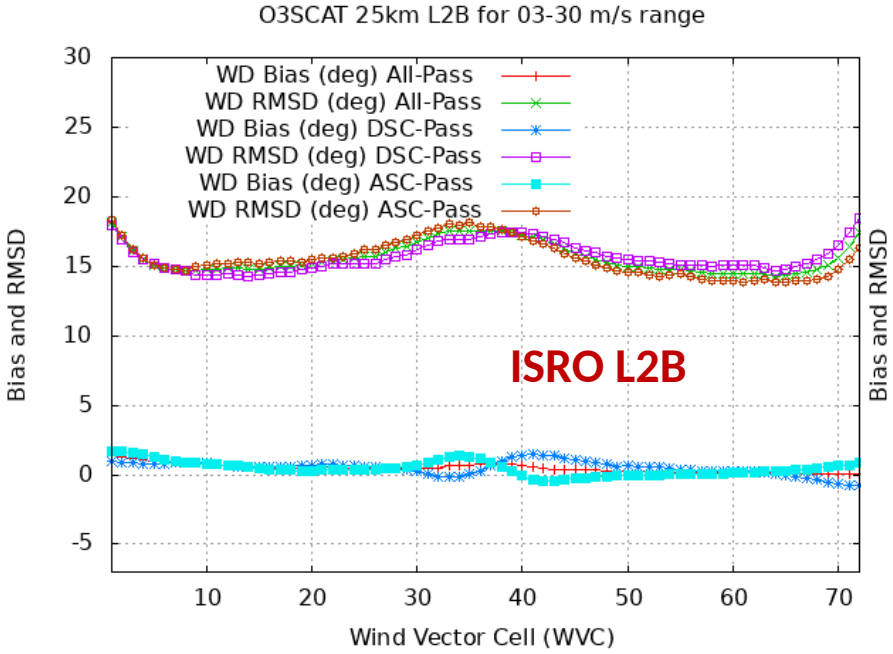


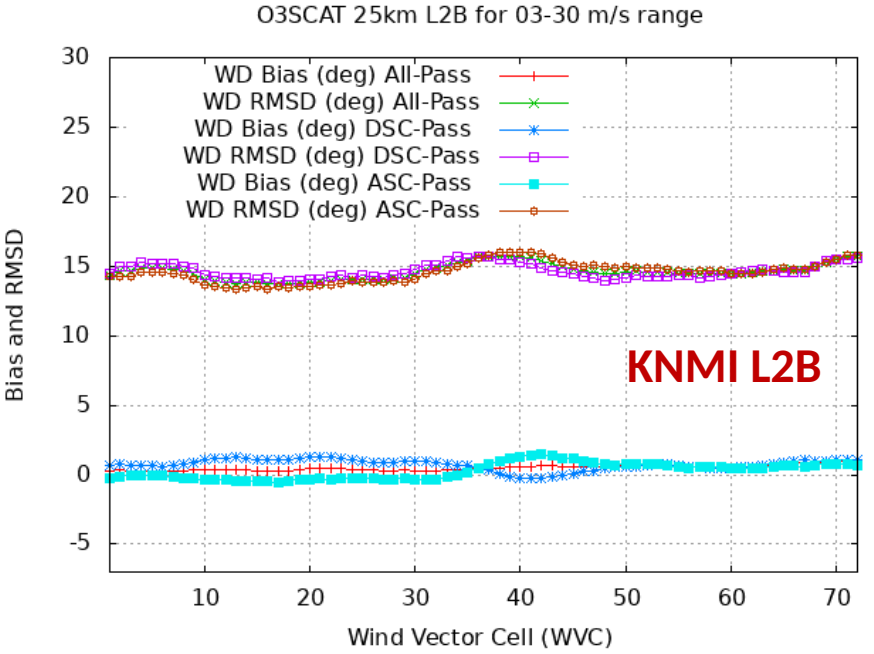
Comparison of April-2025 (V1.0.4) L2B V/S ECMWF Analysis Data



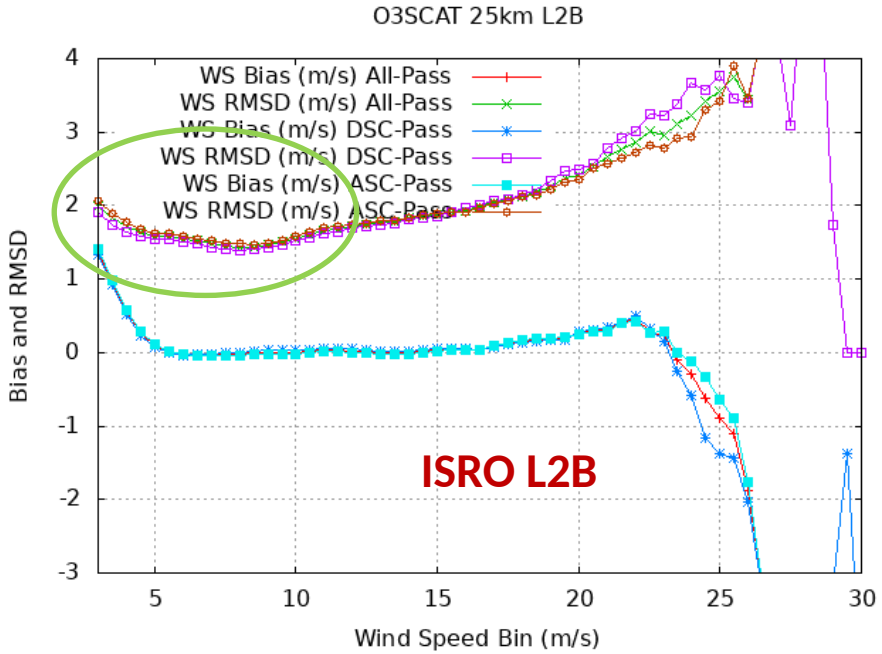


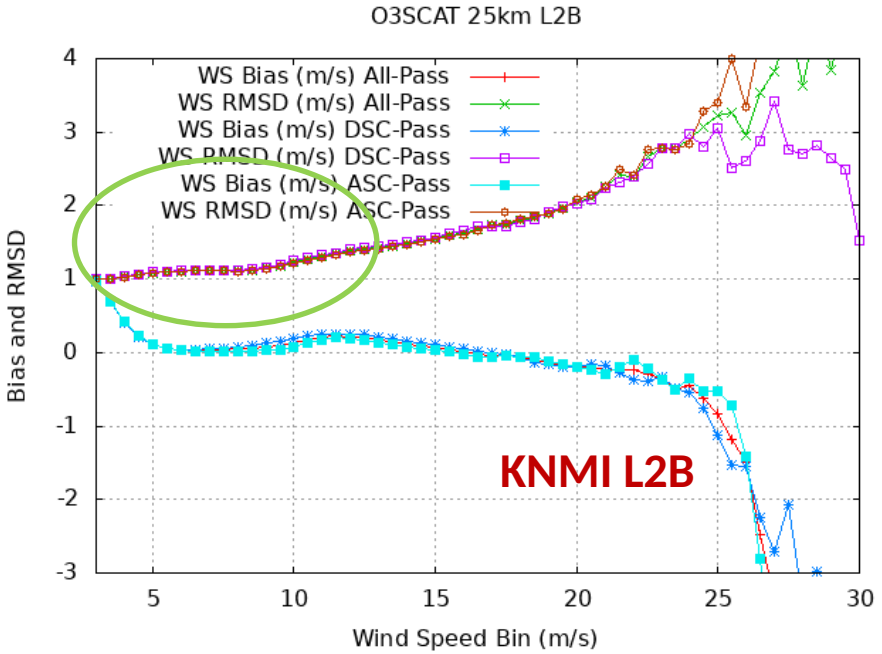
Comparison of April-2025 (V1.0.4) L2B V/S ECMWF Analysis Data



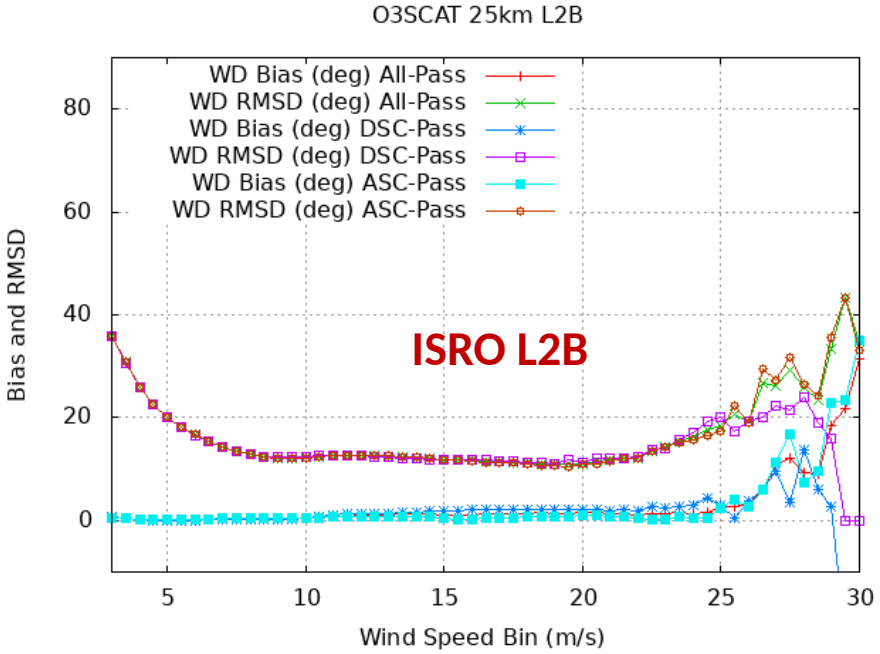


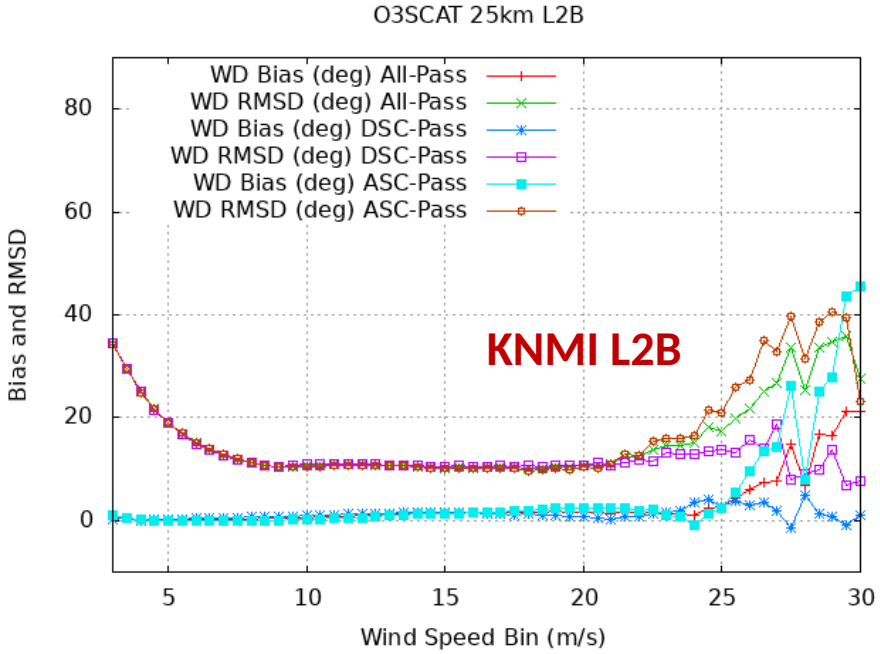
Comparison of April-2025 (V1.0.4) L2B V/S ECMWF Analysis Data





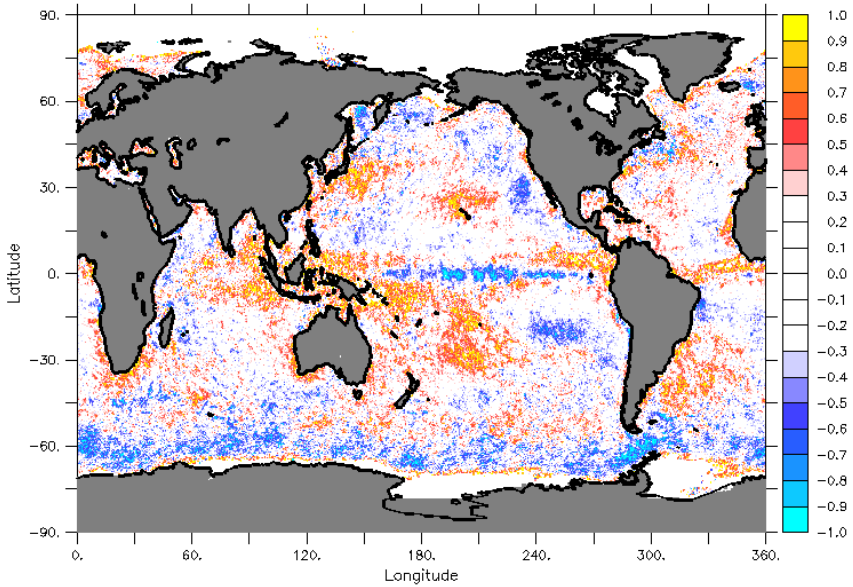
Comparison of April-2025 (V1.0.4) L2B V/S ECMWF Analysis Data





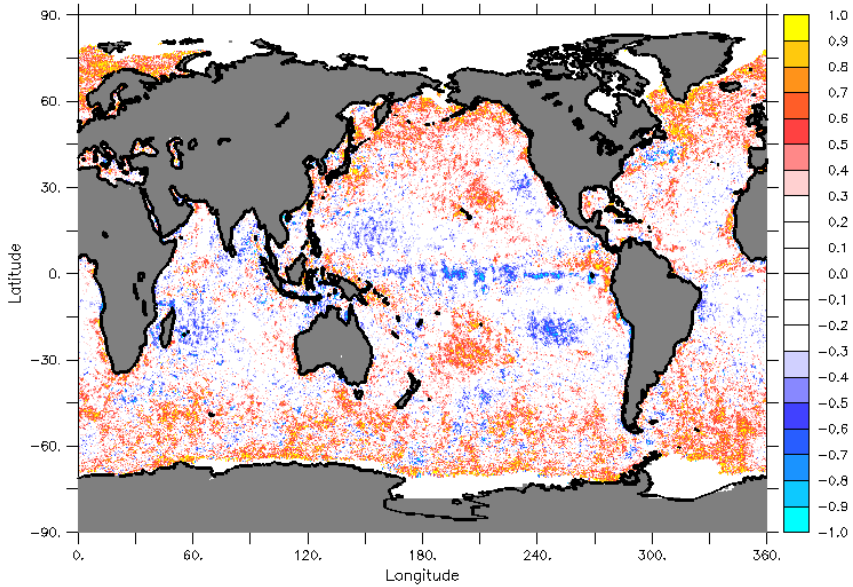
Comparison of April-2025 (V1.0.4) L2B V/S ECMWF Analysis Data

ISRO L2B



O3SCAT L2B 25km 03–30 m/s ALL–PASS WS BIAS (m/s)

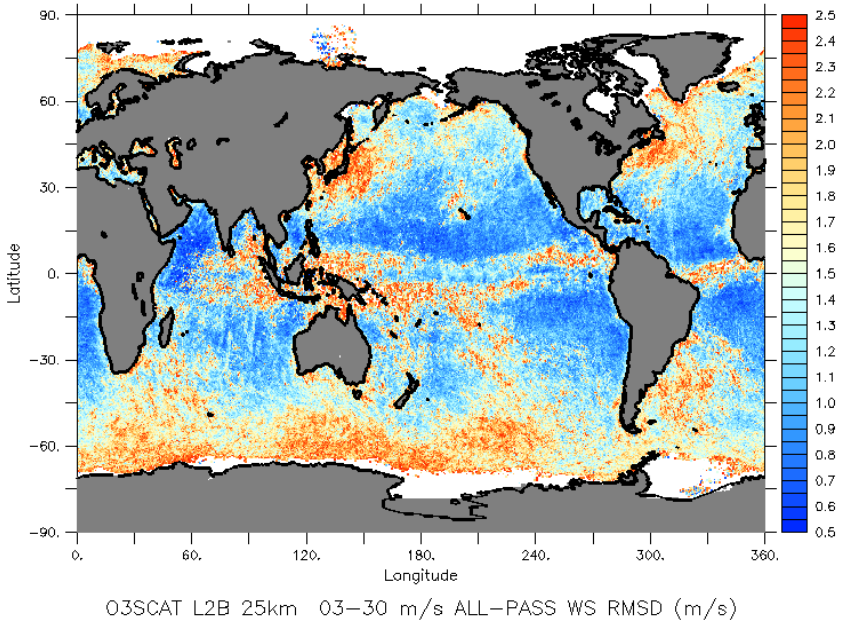
KNMI L2B



O3SCAT L2B 25km 03–30 m/s ALL–PASS WS BIAS (m/s)

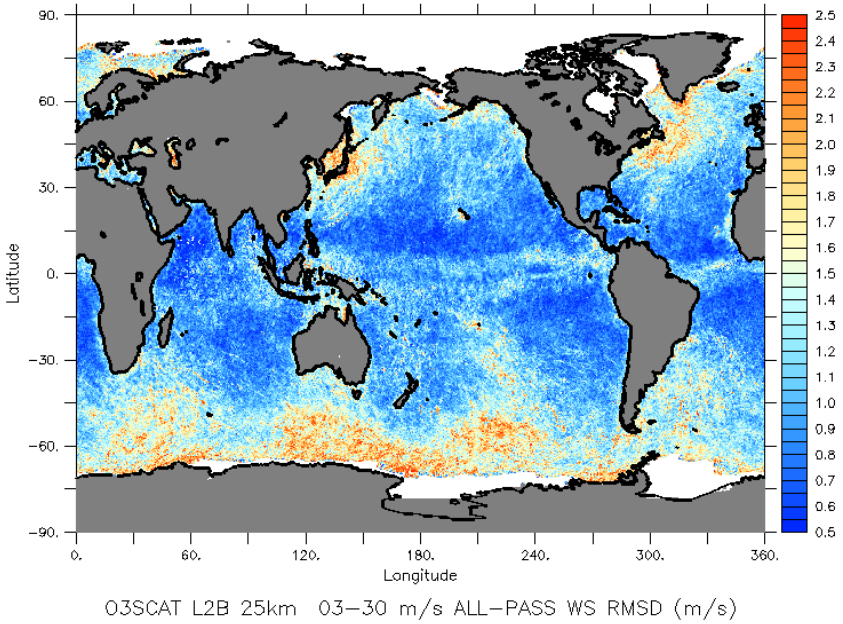
Comparison of April-2025 (V1.0.4) L2B V/S ECMWF Analysis Data

ISRO L2B



03SCAT L2B 25km 03–30 m/s ALL–PASS WS RMSD (m/s)

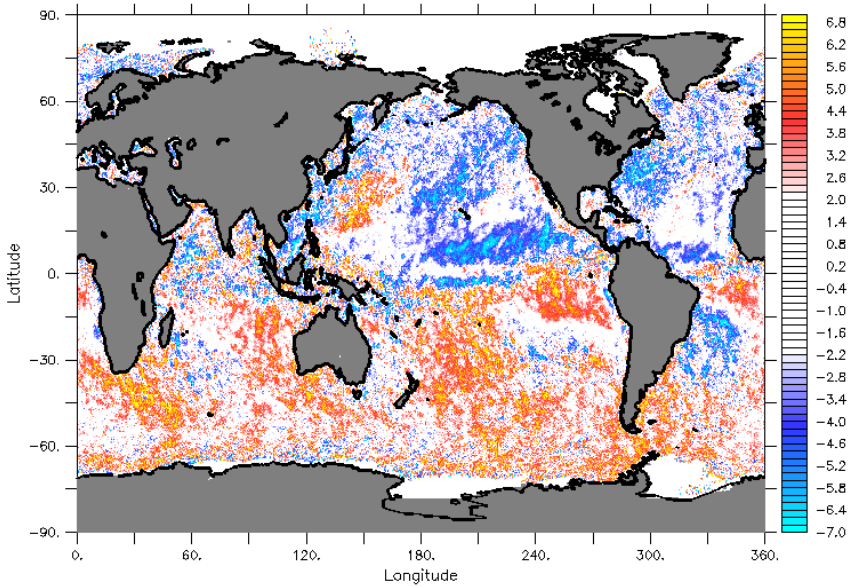
KNMI L2B



03SCAT L2B 25km 03–30 m/s ALL–PASS WS RMSD (m/s)

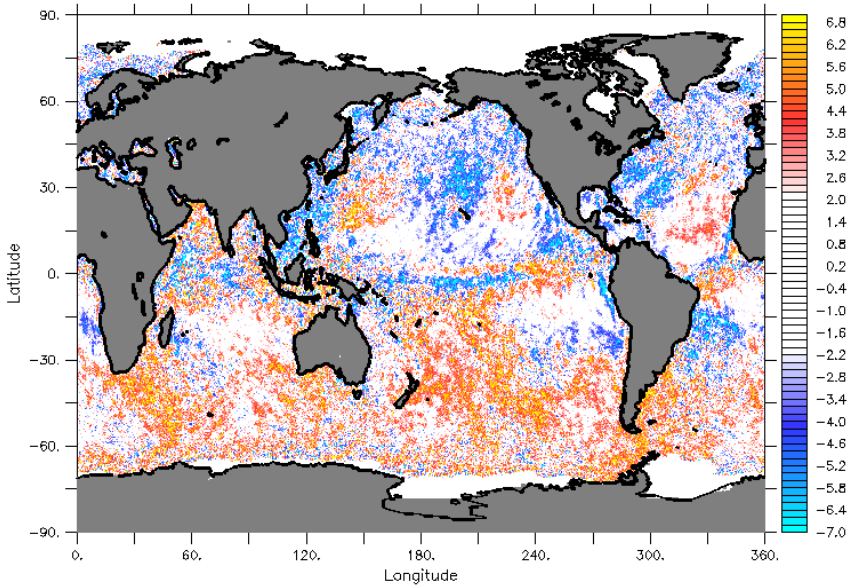
Comparison of April-2025 (V1.0.4) L2B V/S ECMWF Analysis Data

ISRO L2B



03SCAT L2B 25km 03–30 m/s ALL–PASS WD BIAS (deg)

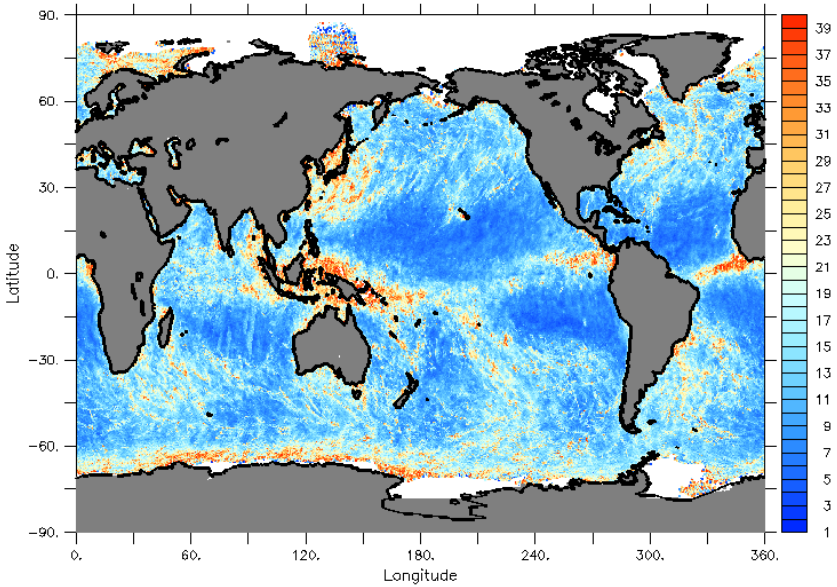
KNMI L2B



03SCAT L2B 25km 03–30 m/s ALL–PASS WD BIAS (deg)

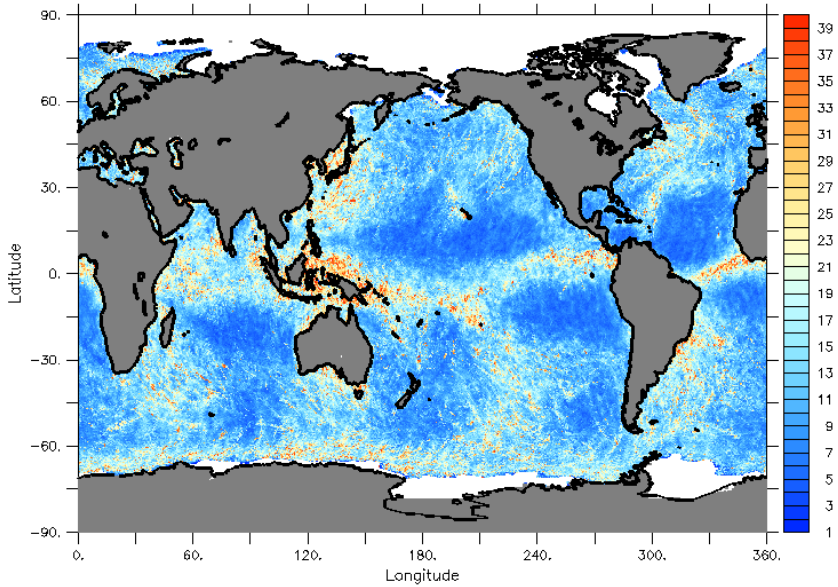
Comparison of April-2025 (V1.0.4) L2B V/S ECMWF Analysis Data

ISRO L2B



O3SCAT L2B 25km 03–30 m/s ALL–PASS WD RMSD (deg)

KNMI L2B



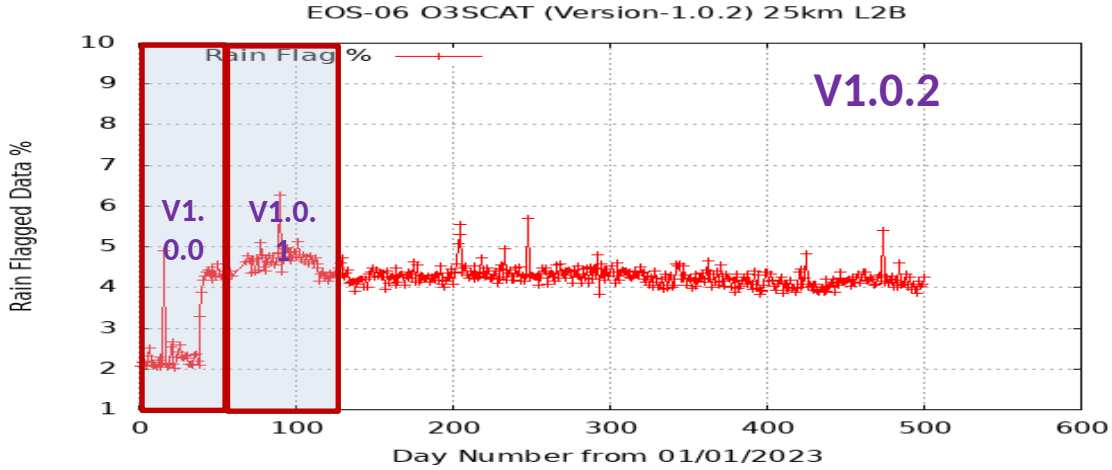
O3SCAT L2B 25km 03–30 m/s ALL–PASS WD RMSD (deg)

Summary:

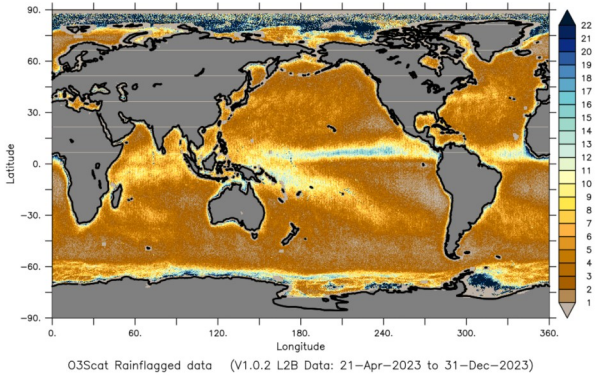
- ✓ Using April 2025 full month of L2B V1.0.4 data a comparison of ISRO V/S KNMI processing is attempted by comparing the L2B data from both agencies V/S ECMWF Analysis winds as reference.
- ✓ KNMI Processing is having better wind speed RMSE (1.2 m/s) compared to ISRO L2B (1.5m/s) (KNMI applies an wind speed dependent bias correction tuned with ECMWF winds after wind retrieval process)
- ✓ In Wind speed Bias ISRO processing is better (0.06 m/s compared to 0.12m/s) (One of the reason could be KNMI has not yet updated their processing from V1.0.3 to V1.0.4)
- ✓ In terms of wind direction both the processing are almost similar
- ✓ Spatial comparison of wind speed Bias and RMSE clearly indicates that ISRO processing needs improvements in SST dependent bias, Ice Screening, Rain flagging (Clearly showing larger Bias and RMSE in Rain Dominated regions, Low SST dominated southern ocean regions)

Thank You

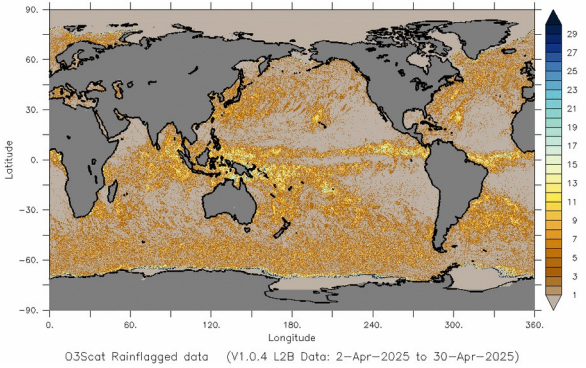
EOS-06 Scatterometer PRODUCTS



ISRO L2B

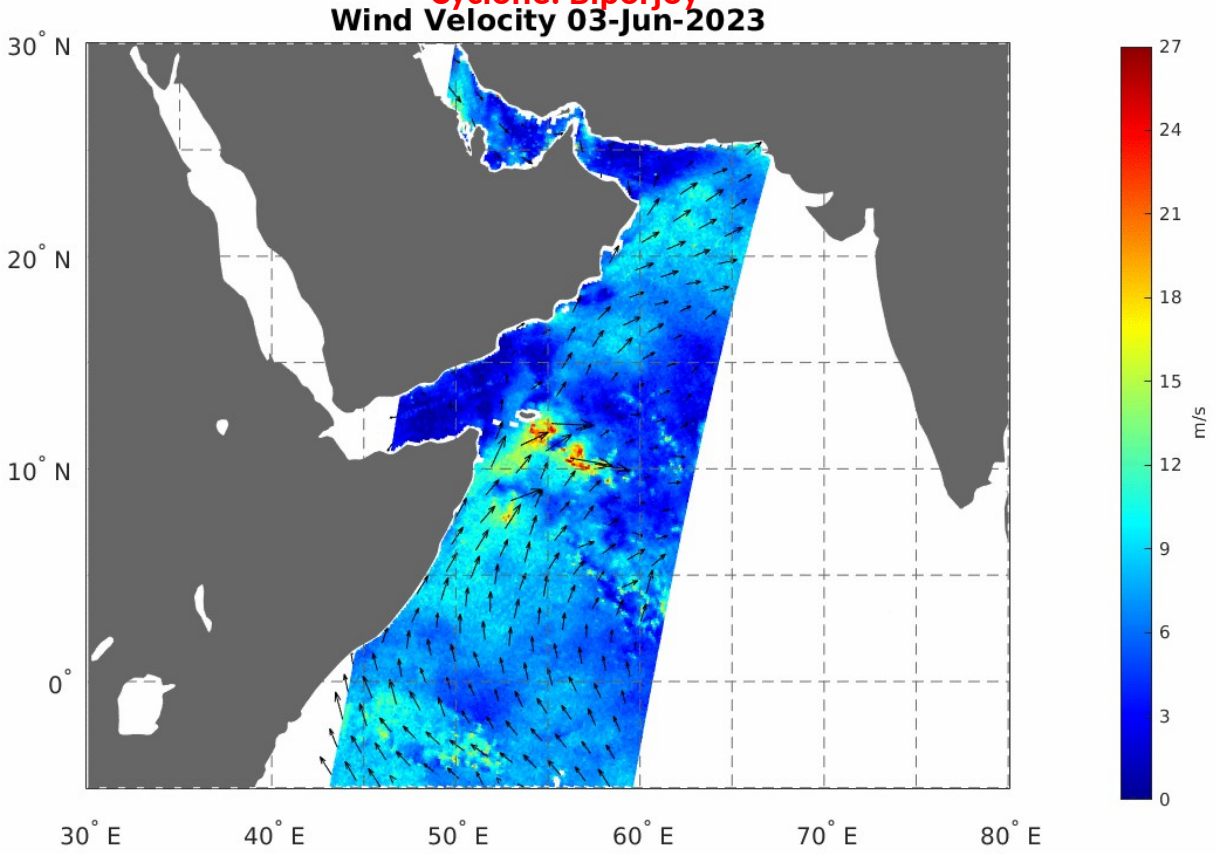


KNMI L2B

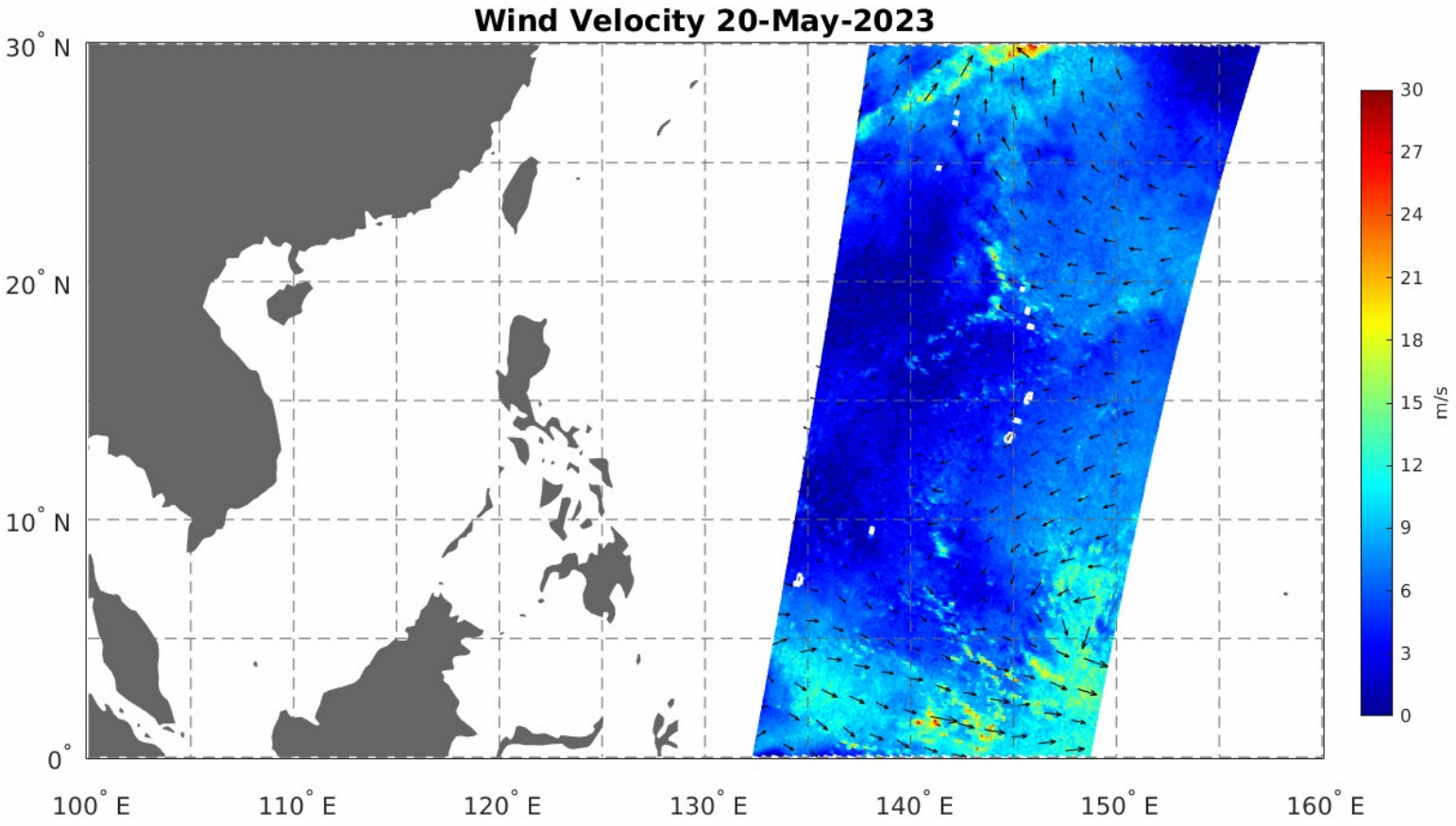


EOS-06 Scatterometer PRODUCTS

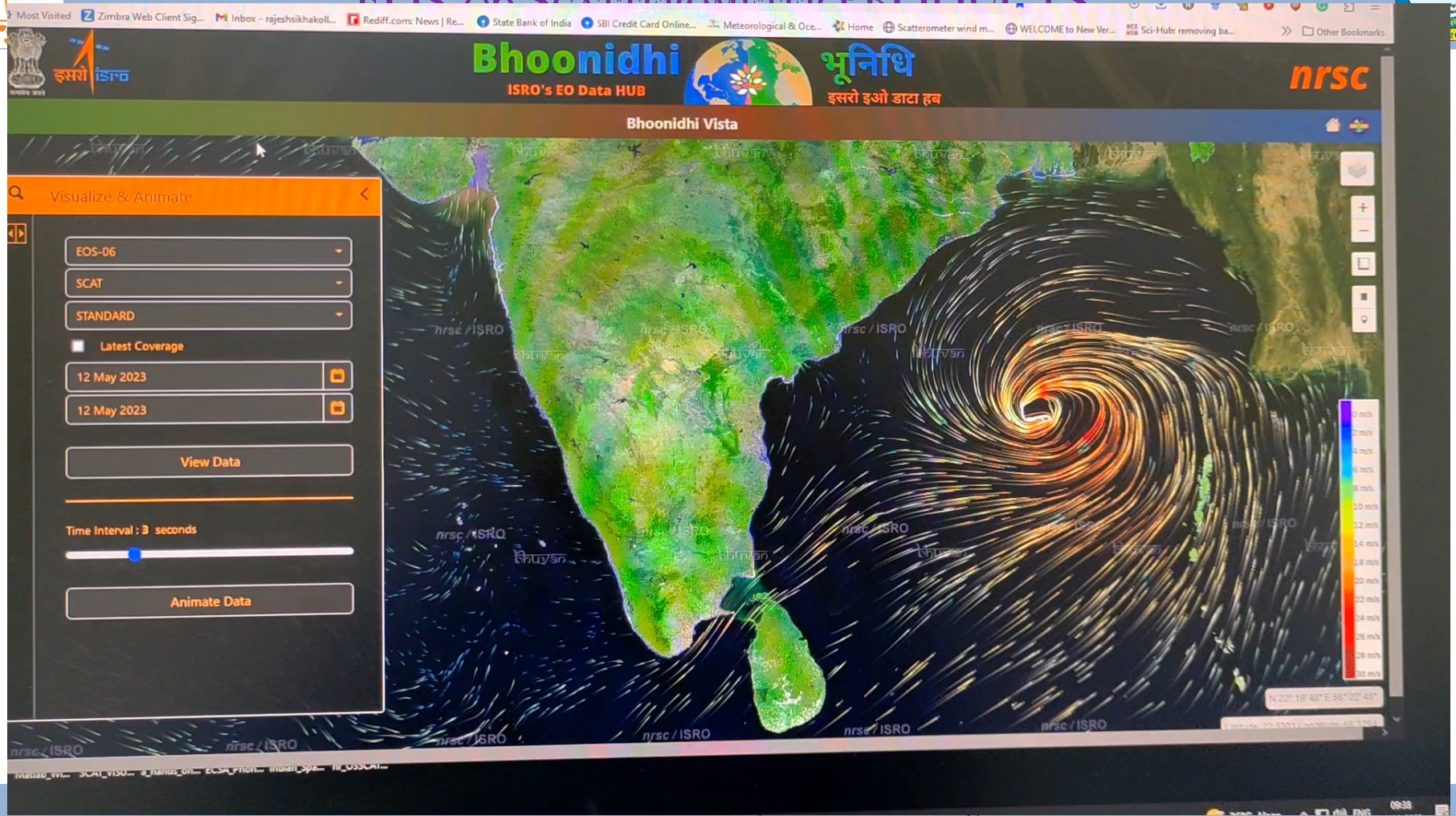
Cyclone: Biporjoy



Cyclone MAWAR in the Western Pacific Ocean



EOS-06 SCATTEROMETER PRODUCTS



EOS-06 Scatterometer PRODUCTS

EOS-06 Oceansat-3 Scatterometer captures simultaneous Twin Cyclones (Tej & Hamoon) in the Indian Ocean