Analysis of Wind and Waves from SWIM on-board CFOSAT: A gen-next altimeter

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Background

Surface winds, currents, and waves interact over a wide range of spatio-temporal scales, which ranges from centimeters to global scales and from seconds to decades.

High-resolution satellite observations of sea surface temperature (SST) reveal oceanic fronts, vortices, and filaments at scales below 10 km, measurements of ocean surface dynamics at this scales are rare

Studies shows variability of significant wave height at scales shorter than 100 km is primarily governed by wave-current interactions.

Currently there are fundamental gaps in our observations of these quantities.

Observational gap in coastal, shelf, and marginal ice zones are noteworthy. In these regions, exchange between land, ocean, cryosphere and atmosphere takes place which impacts important processes like wind-wave-current interactions resulting in beach erosion, dispersion of pollutants and extreme sea level events.

Ocean process studies are required for improving parameterization in our models for a better prediction of weather and oceans. Understanding them results in

- **Better implementation of adaptation and mitigation strategies**
- **Increase resilience to natural hazards and environmental changes.**

Hence more and more space-based instruments dedicated for synergistic and simultaneous measurements of wind, waves, ice and currents are next frontier for earth observing satellites.

CFOSAT (the China France Oceanography Satellite) is a joint China and France mission, dedicated to the simultaneous observation ocean surface wind and surface gravity waves. This mission is unique in the sense that it would have a synergistic realization of both wind and waves at the same time.

It aims to improve

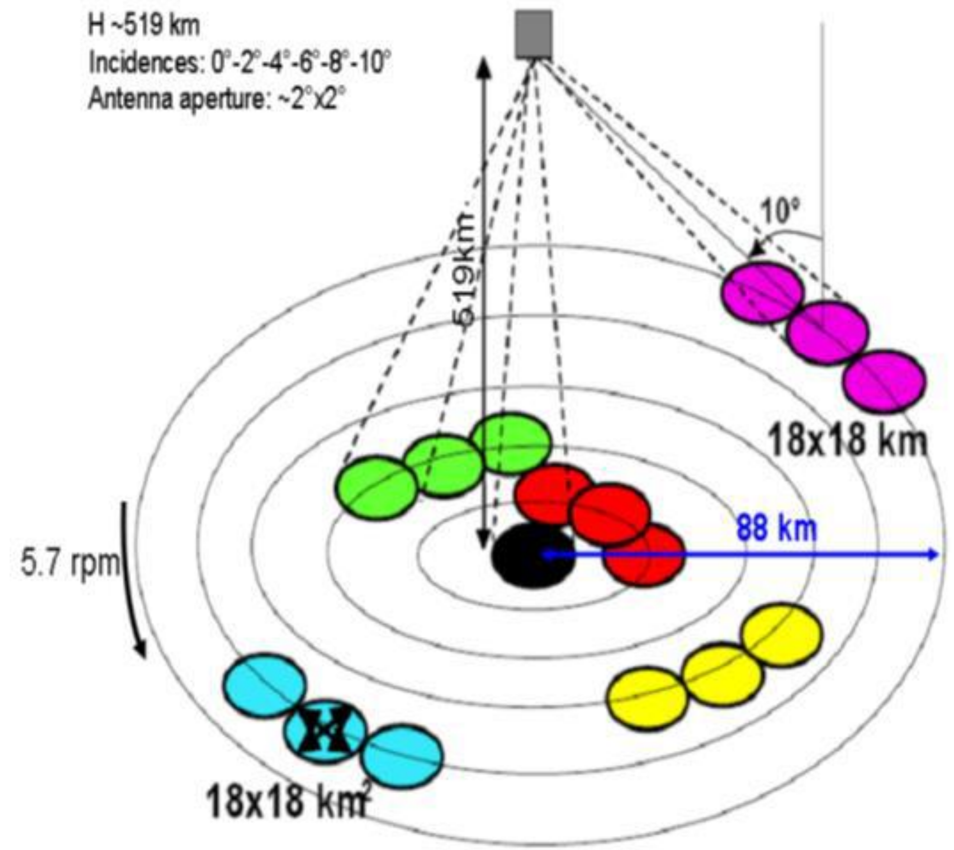
- Numerical Weather Prediction (NWP)
- Ocean State Forecast (OSF)
- Ocean process studies and modelling ocean dynamics
- Prediction of climate variability
- Suffice to fundamental understanding the surface processes

The CFOSAT carry two Ku-Band radars.

- ✓ Wave Scatterometer known as Surface Waves Investigation and Monitoring instrument (SWIM)
- ✓ Dual Polarized Rotating Fan-Beam Scatterometer (SCAT) for wind measurements.

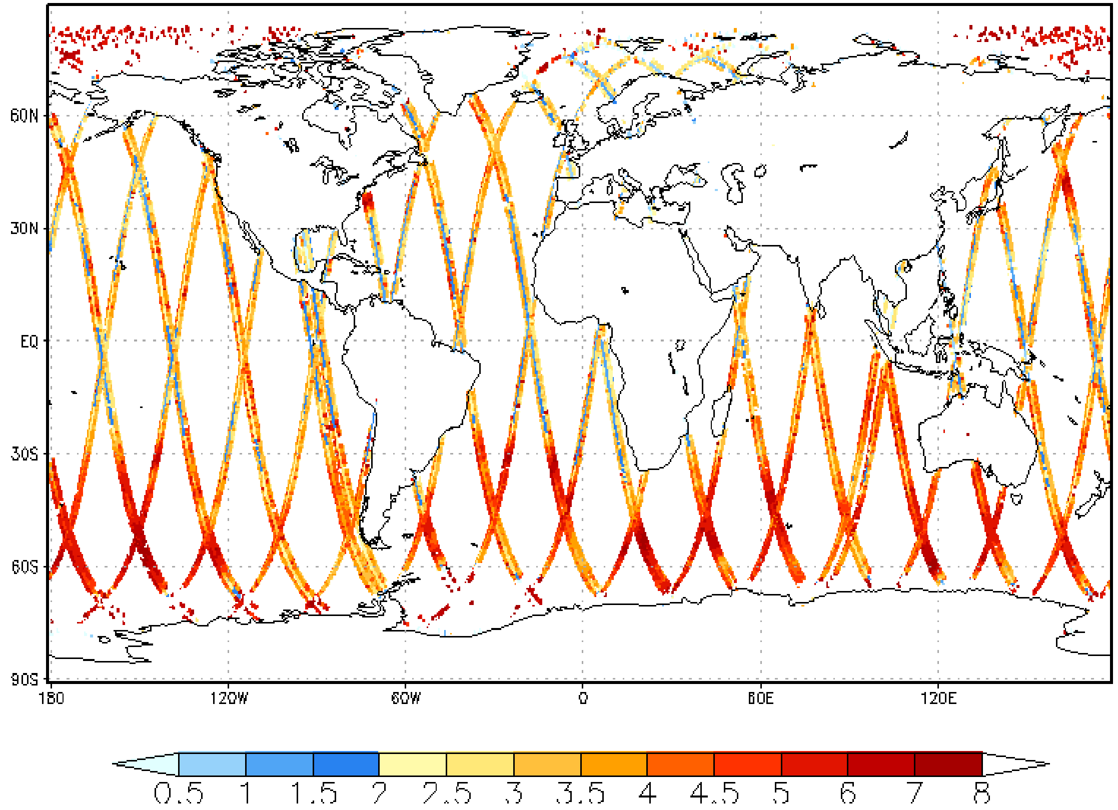
SWIM Specifications and Geometry

System parameters	Specifications
Frequency	13.575 GHz
Useful bandwidth	320 MHz
Useful pulse duration	50 µs
Peak power	120 W
Incidence angles (on ground)	0º, 2.43º, 4º, 6º, 8º, 10º
PRF (Pulse Repetition Frequency)	from 5 to 5.4 kHz
Antenna rotation speed	5.6 rpm
Antenna diameter	90 cm
Antenna 3 dB aperture	>1.5º (0º and 2º); >1.7º (from 4º to 10º)
Polarization	Linear (VV in rotation)

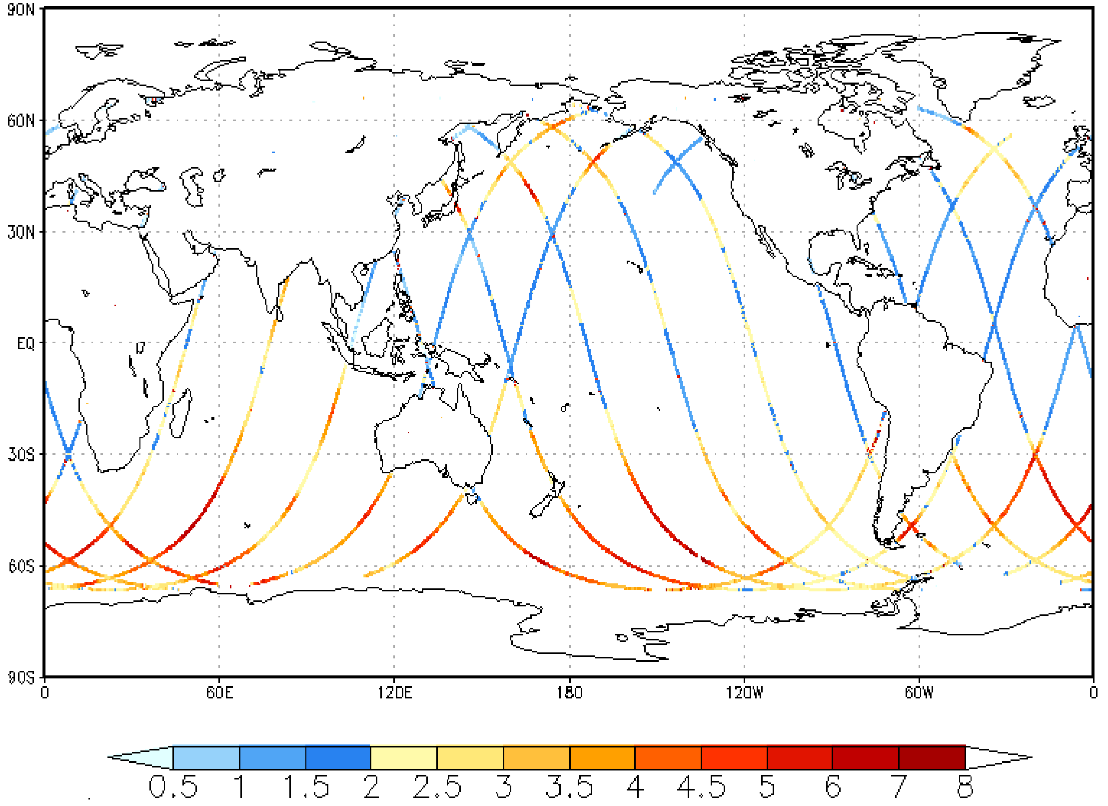


Advantage of SWIM geometry on applications

Typical Observation on May 19, 2020



CFOSAT

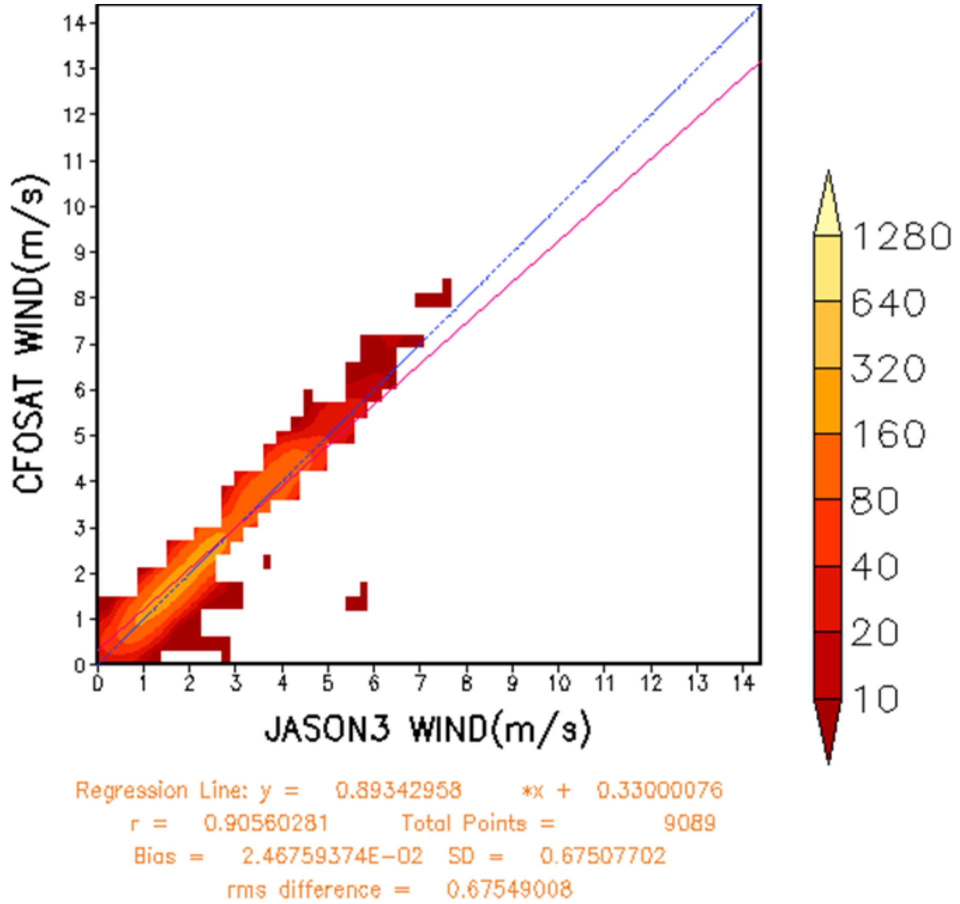


Jason-3

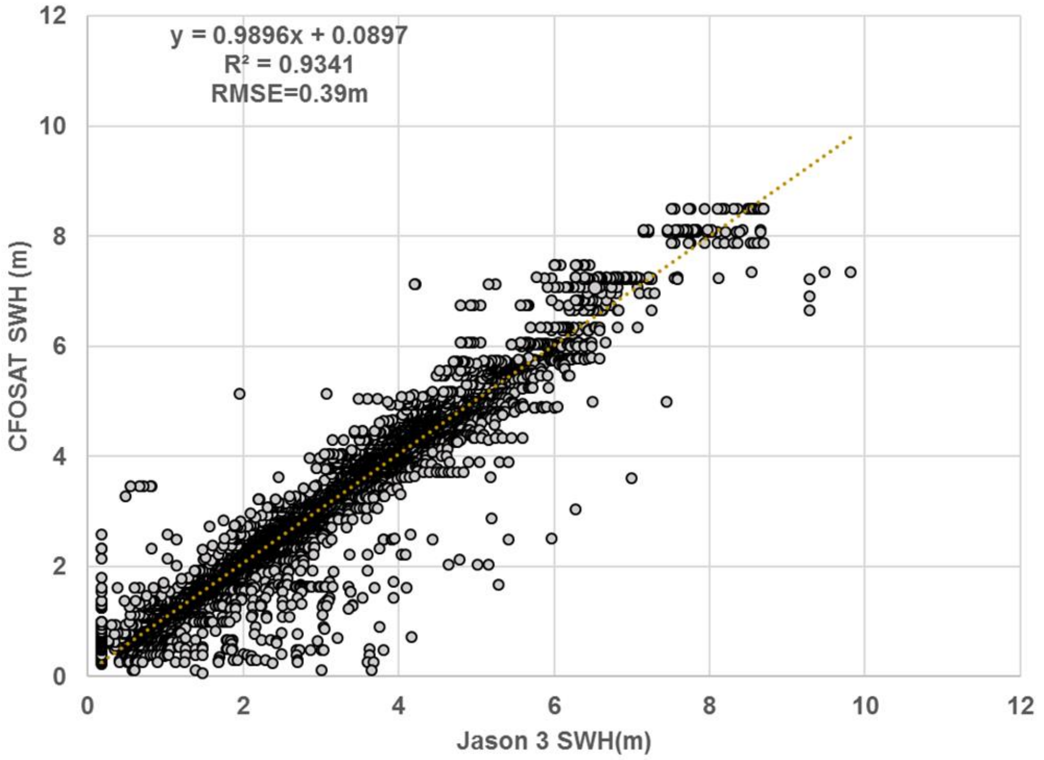
The SWH from SWIM on-board CFOSAT and Jason-3

SWIM provides excellent opportunity with enhanced data availability over the traditional nadir altimetry.

Analysis of the Nadir Data: SWH and Wind Speed Validation for Mar- May 2020 using Jason-3



Comparison of CFOSAT Nadir Wind and Jason-3 Wind from March, 01 –May, 26, 2020

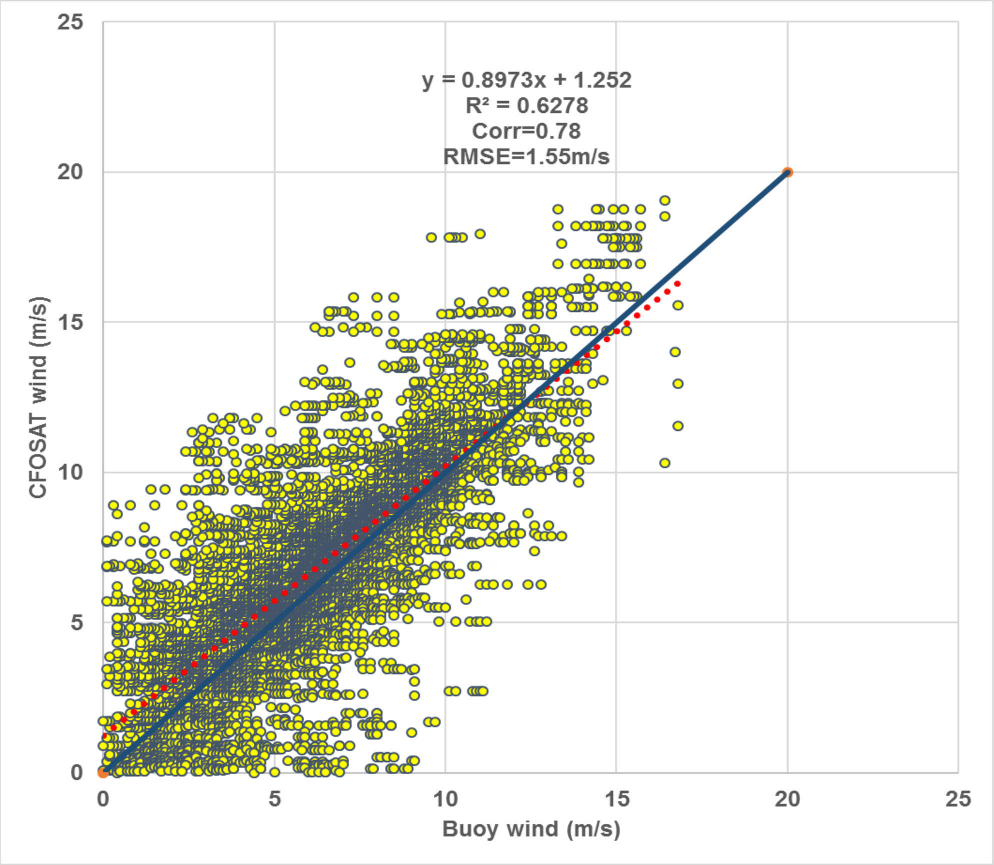


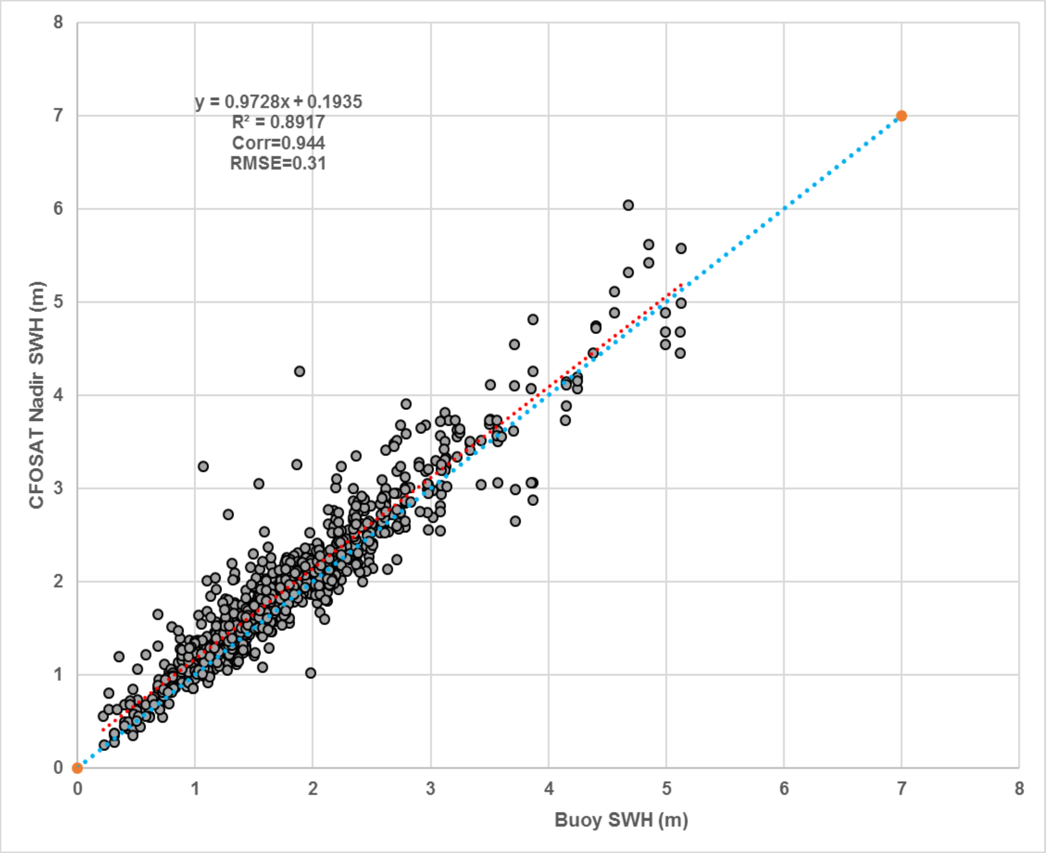
Comparison of CFOSAT Nadir SWH and Jason-3 SWH from March, 01 –May, 26, 2020 (after applying 3-sigma criteria). Collocated points within 50 km are used for making the plot.

Methods: For the nadir observations from SWIM we consider a spatio-temporal window of maximum 70 km and 30 min within which the Jason-3 and SWIM measurements are located and we compare them with one another.

SWIM provides nadir measurements at par with traditional altimeters

Analysis of the Nadir Data: SWH and Wind Speed Validation for Mar- May 2020 using global NDBC buoys



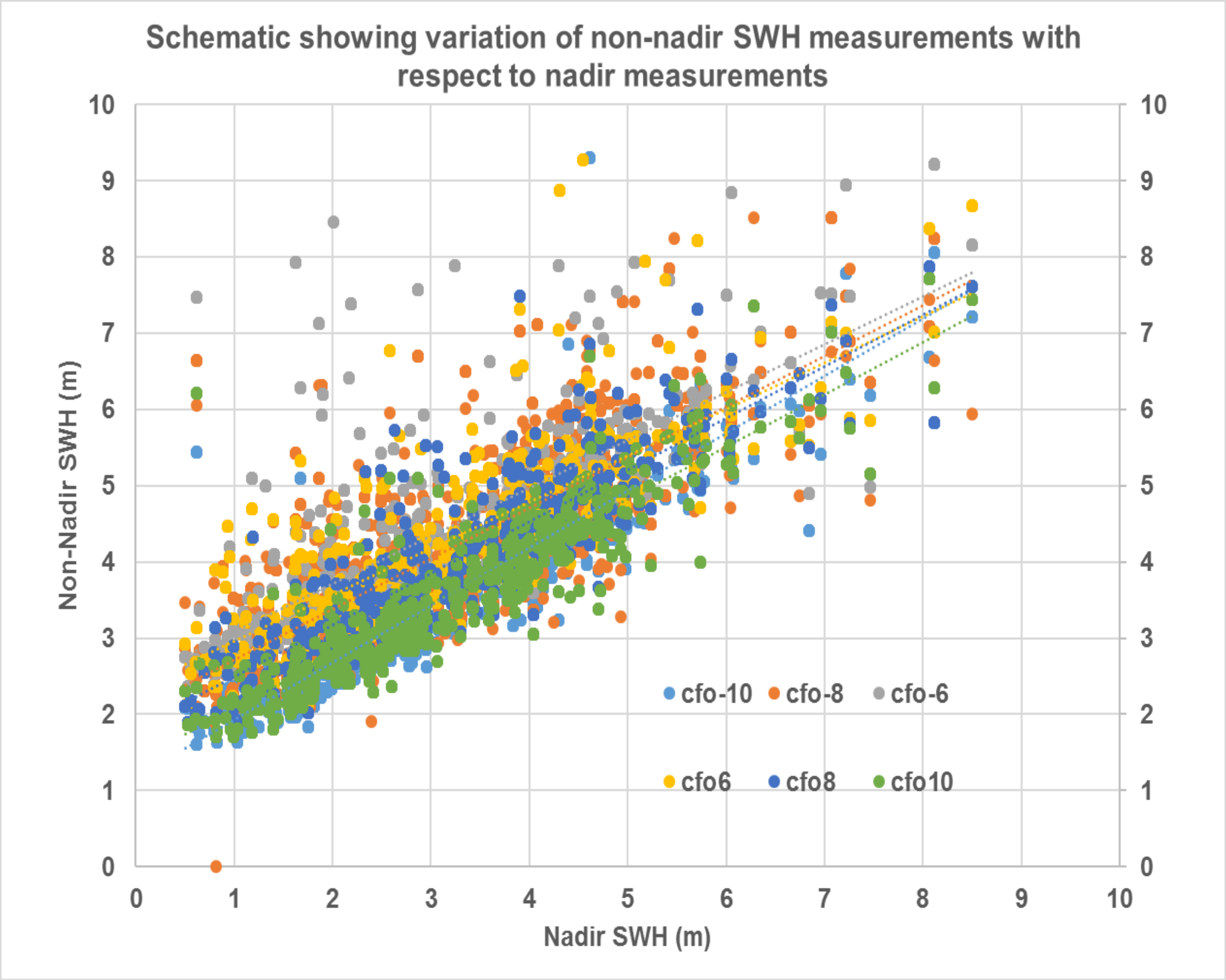


Comparison of CFOSAT Nadir SWH and NDBC buoy observations from March, 01 –May, 26, 2020

Methods: For the nadir observations from SWIM we consider a spatio-temporal window of maximum 70 km and 30 min within which the Buoy and SWIM measurements are located and we compare them with one another.

SWIM provides nadir measurements matches well with in-situ buoys

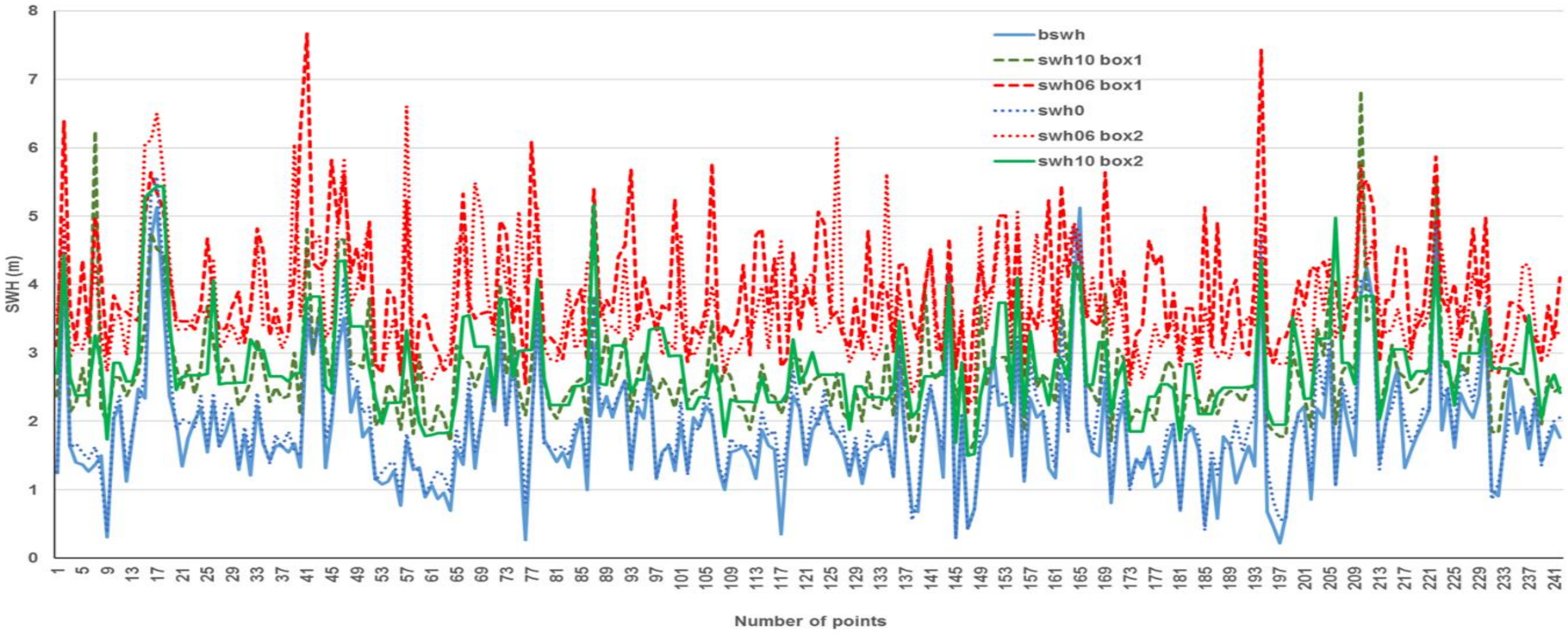
Analysis of Off-Nadir Data: Comparison of SWH from off-nadir beams and Nadir measurements for Mar- May 2020



Comparison of CFOSAT Nadir SWH and Off-Nadir SWH measurements from March, 01 – May, 26, 2020

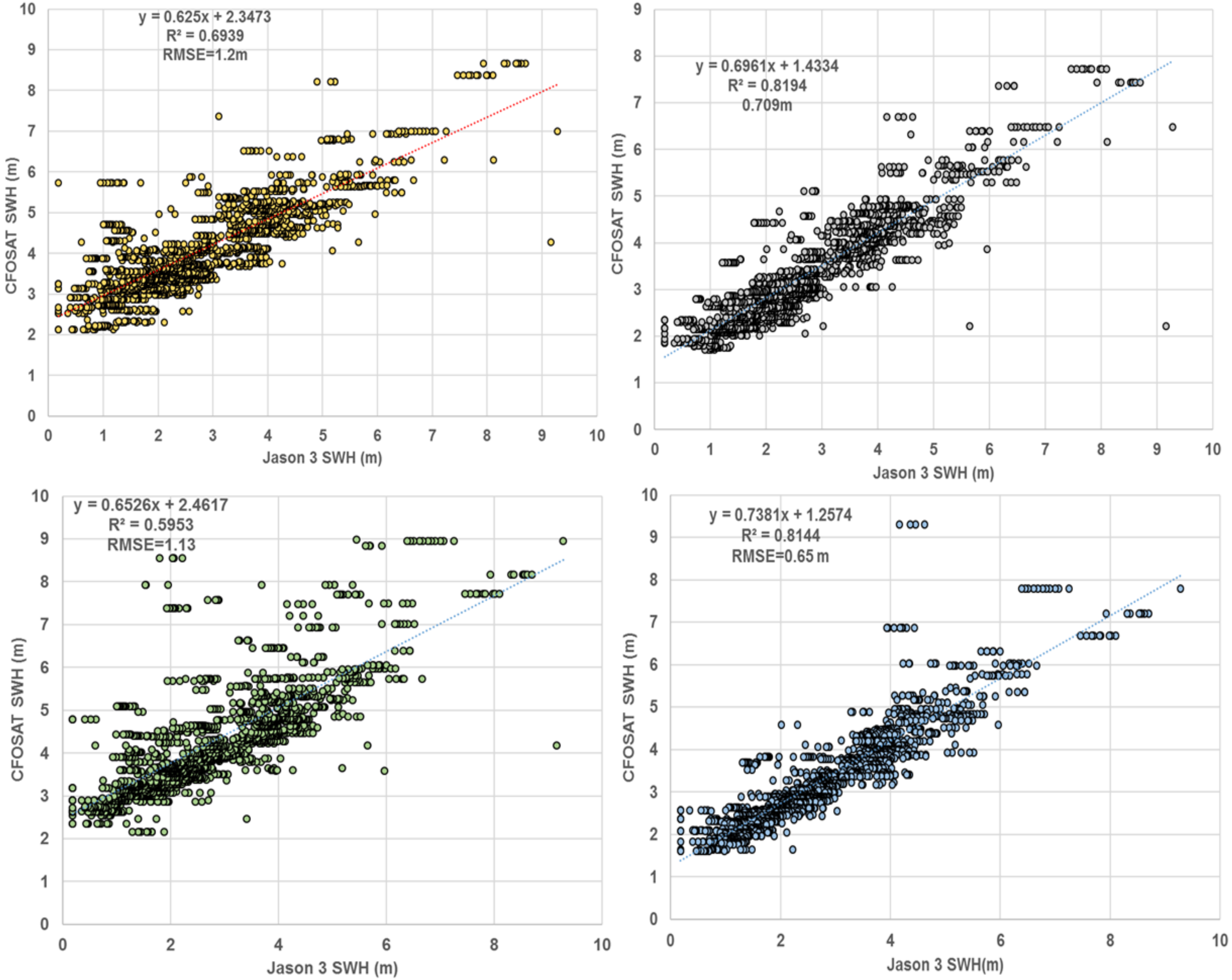
At 10° at either side of nadir the spread in SWH is much less as compared to the 6° and 8°

Analysis of Off-Nadir Data: Comparison of SWH time-series from off-nadir beams and Nadir measurements and Buoys



Variation of SWIM off Nadir SWH measurements computed from spectra along with buoy measurements from March, 01 –May, 30, 2020. The green lines are the far range observations while red lines are near range. Blue dotted and solid lines are nadir and buoy observations respectively.

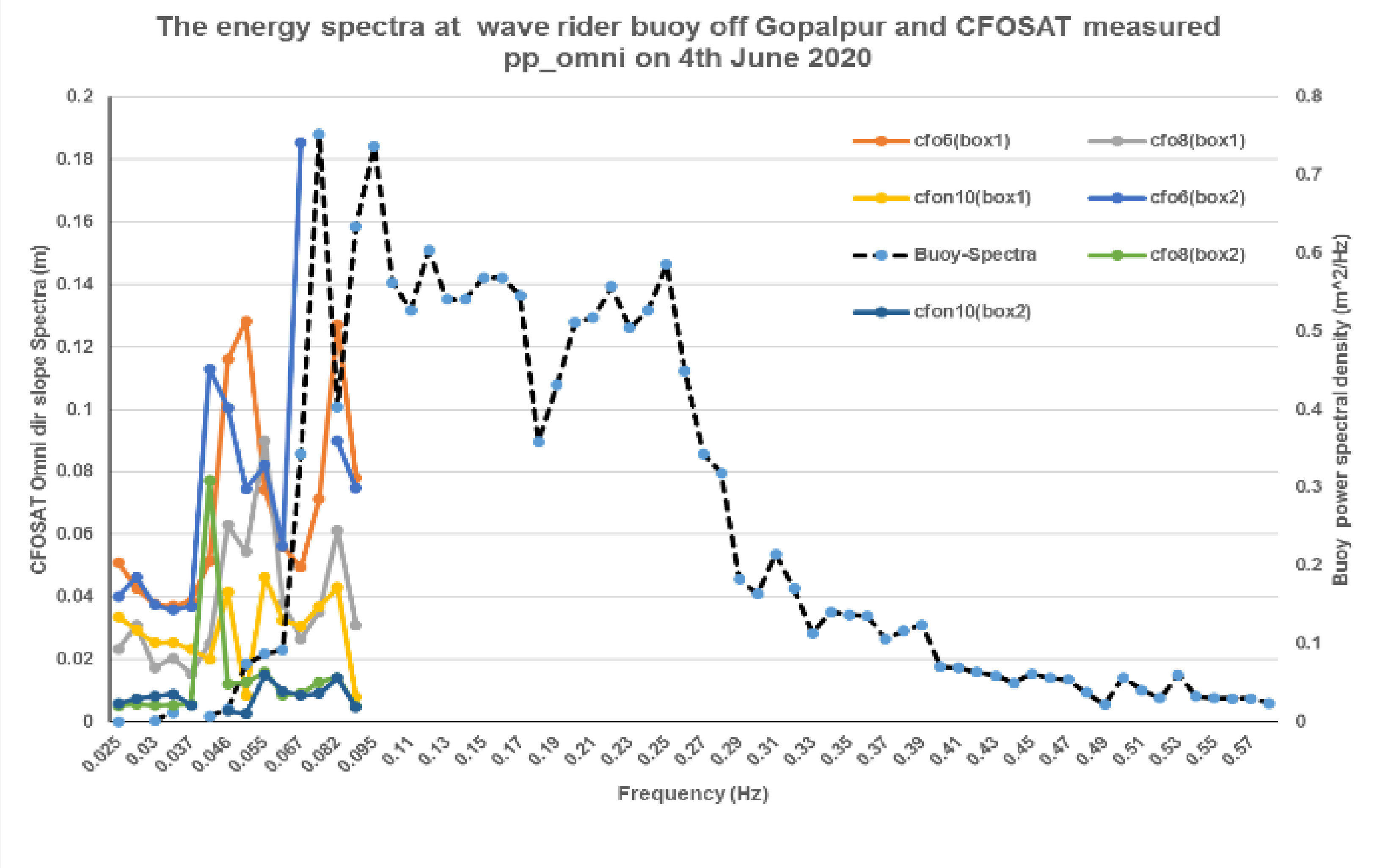
If we compare the non-nadir measurements of SWIM with the Buoy data we can see the nadir measurements are best match and far range measurements are better match to the observations as compared to the near range.



Comparison of CFOSAT off Nadir SWH measurements computed from spectra with Jason-3 measurements from March, 01 –May, 26, 2020

This figure shows the 6° and 10° incidence angle measurements at either side of the nadir. With respect to Jason-3 we can observe the RMSE at far range is around 0.70m and 0.65m on each side of nadir, while at near range the RMSE is much more i.e. 1.2 m and 1.13m respectively. The reason as discussed by few studies may be due to increased speckle noise at near range.

Analysis of Spectra Data: Comparison of wave spectra from off-nadir beams and Indian Ocean Buoys

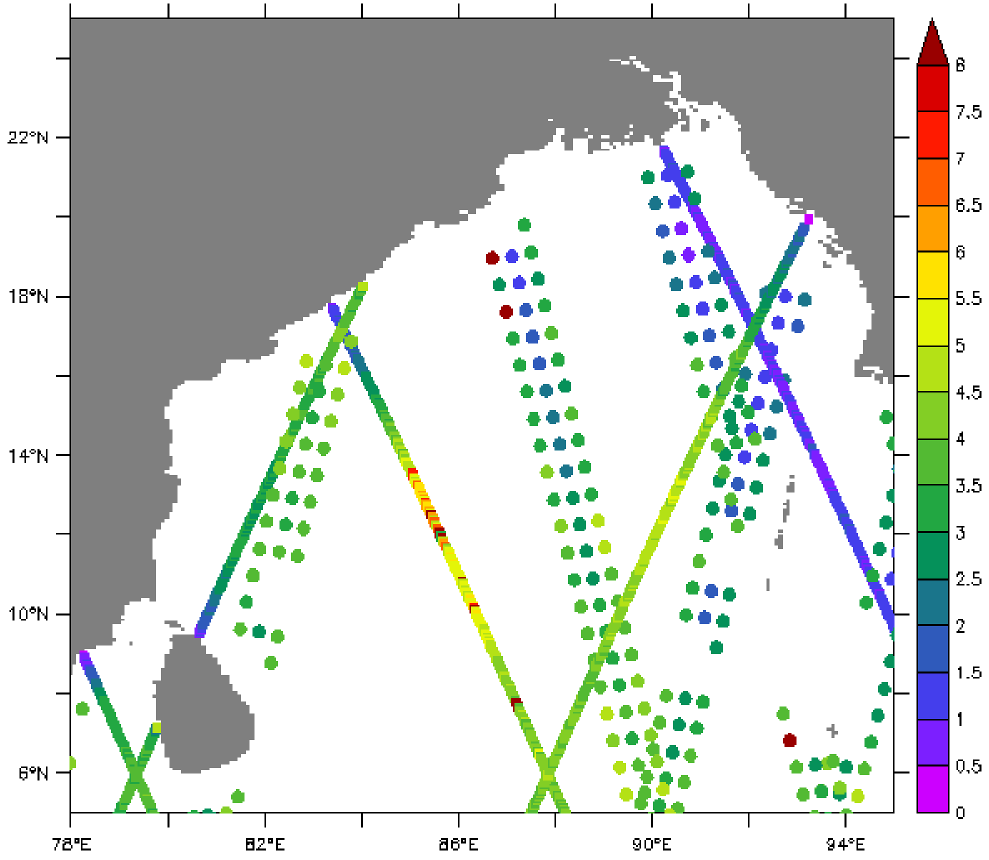


The comparison of the spectra from buoy and all non-nadir SWIM measurements

- The wave rider buoys over Indian coastal region provide the power spectra density with respect to the frequency,
- SWIM measures spectral energies with respect to the wave number.
- Wave rider buoy data at Gopalpur used for validating the SWIM measured spectra.
- Dispersion relation at shallow water is used to convert the wave number into frequency by taking the water depth= 15m at off Gopalpur location.

- **SWIM does not have valid observations a high frequency beyond 0.1 Hz. This poses a limitation for spectra validation.**
- **However, at lower frequency part the peak energy frequency is correctly captured by SWIM.**

Assimilation of SWIM SWH data: A preliminary application



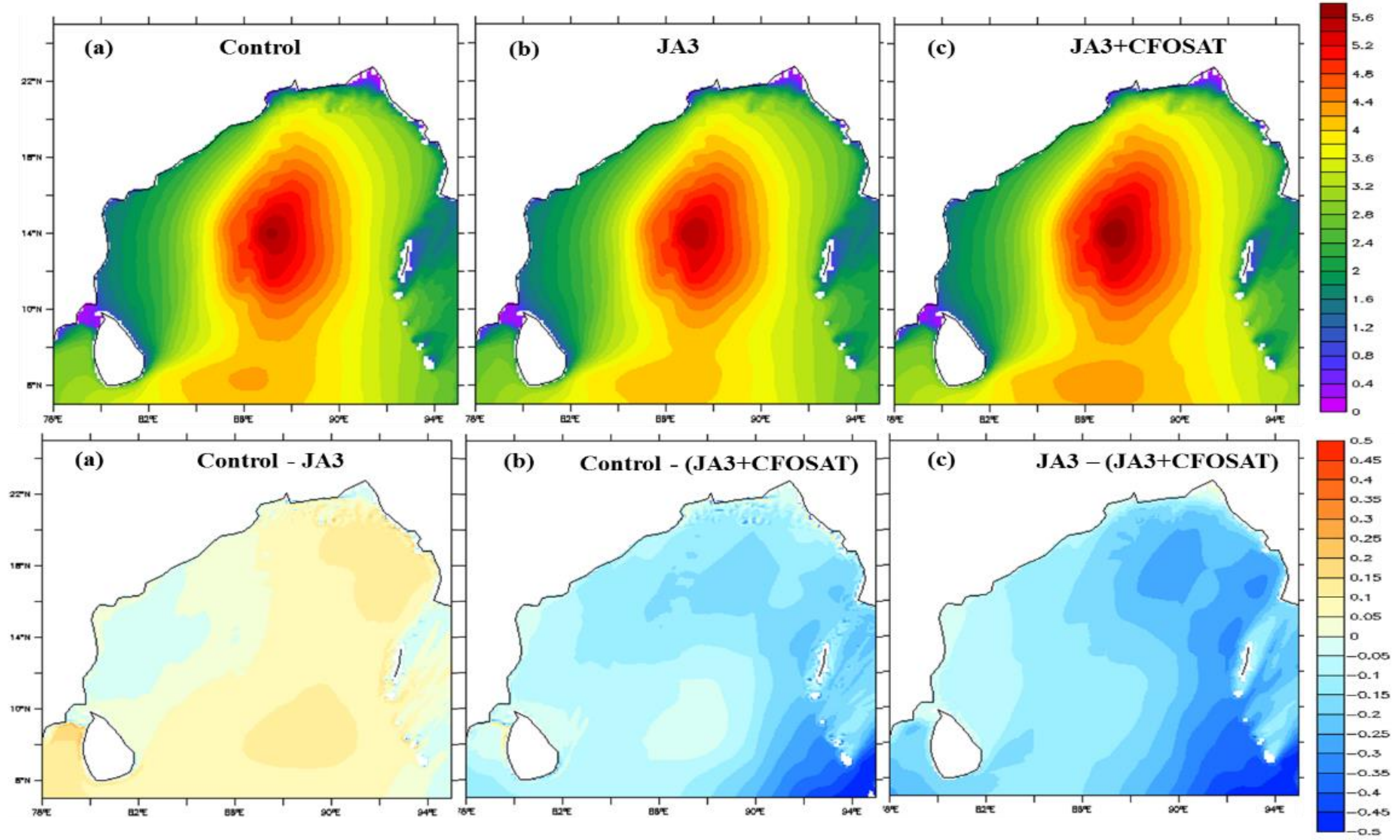
The available Jason-3 and CFOSAT tracks from 16-20 MAY 2020 during occurrence of Amphan. Assimilated tracks of JA3 (square) and CFOSAT (circle) over the period from 16th May 2020 00 UTC to 20th May 2020 12 UTC. Colour indicates the magnitude of SWH (m)

Method:

- **SWIM SWH assimilated into the Wavewatch-III model.**
- **WWIII model is operational at ISRO ingests Jason-3 SWH.**
- **Model is spun-up for 15 days starting from 15th April 2020 to 01st May 2020 without assimilation.**
- **Three sets of model simulations are performed from 01-31 May, 2020**

1. **Analysis run without any assimilation, called the control run.**
2. **Assimilation of only Jason3 SWH**
3. **Both Jason3 and CFOSAT SWH are assimilated.**

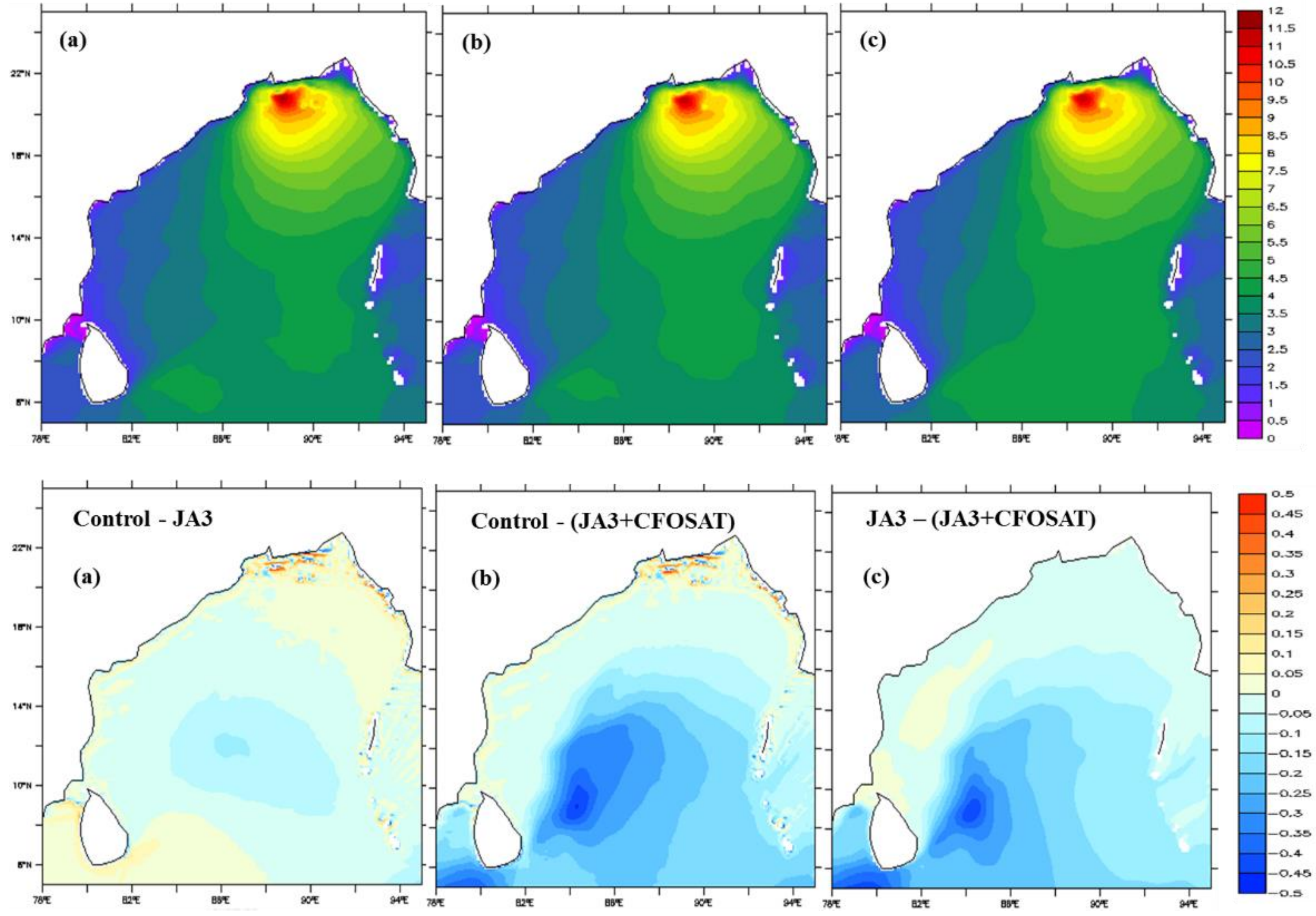
Period of study has a special significance. During this period Bay of Bengal was invaded by a category -5 cyclone named Amphan.



(Top panel) Model simulated mean analysis field of SWH averaged over the period from 16th May 2020 00 UTC to 20th May 2020 12 UTC (a) Control run, (b) JA3 assimilated run and (c) JA3+CFOSAT assimilated run

(Bottom panel) Difference in mean SWH (m) field averaged over the period from 16th May 2020 00 UTC to 20th May 2020 12 UTC (a) Control - JA3 assimilated run (b) Control - JA3 +CFOSAT assimilated run and (c) JA3 – JA3+CFOSAT assimilated run

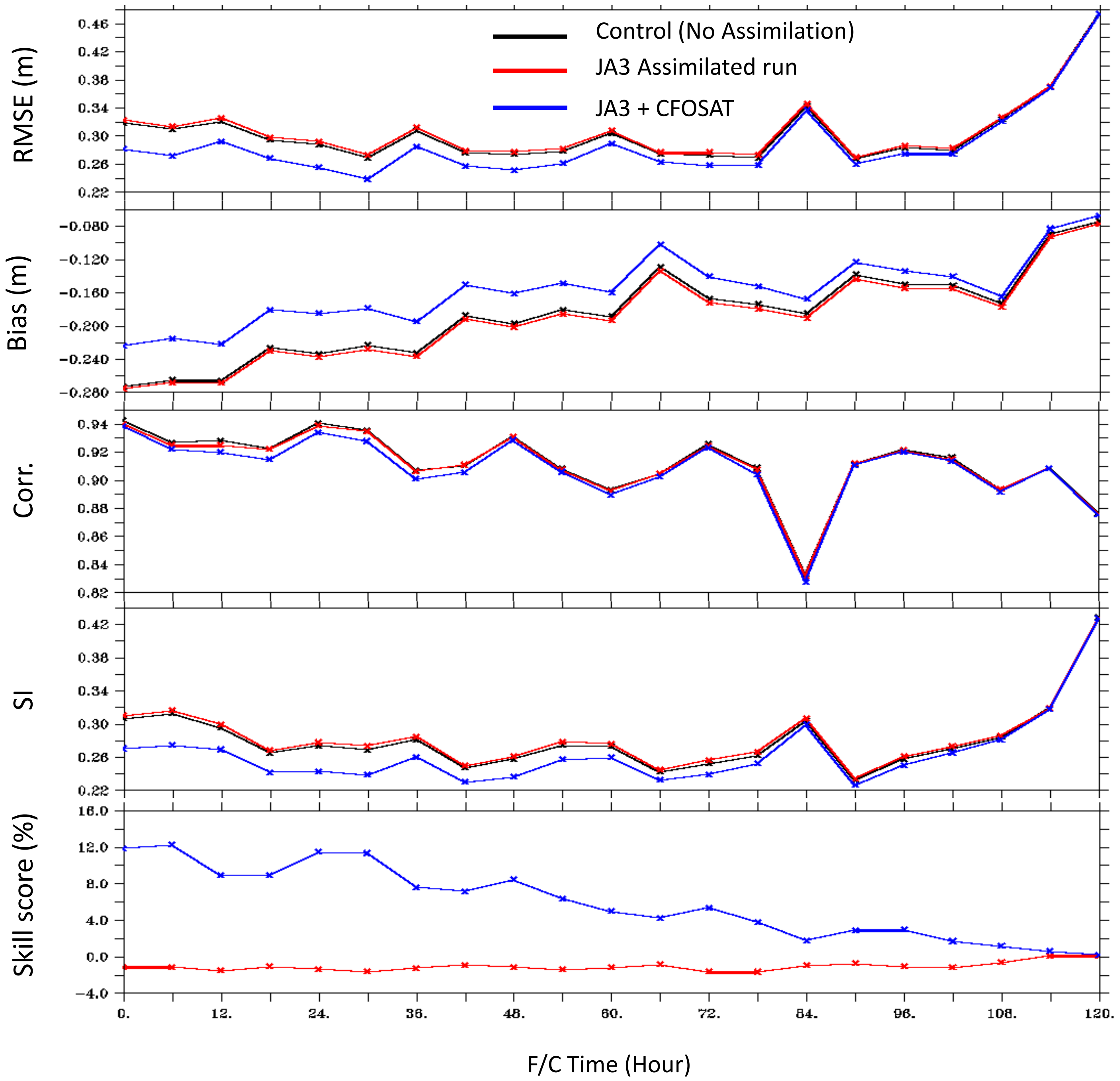
- Differences between Control and JA-3 assimilated runs are positive i.e. reduction of SWH intensity in JA-3 only assimilation.
- Differences between Control and JA-3+CFOSAT assimilated runs are negative i.e. CFOSAT assimilation helped in picking up intensity of the cyclone waves.
- The difference of mean SWH from JA-3 only and JA -3 +CFOSAT assimilation quantifies the impact made by CFOSAT alone.



(Top Panel) Model simulated analysis field of SWH (m) from (a) Control run, (b) JA3 assimilated run and (c) JA3+CFOSAT assimilated run valid for 20th May 2020 06 UTC

(Lower Panel) Difference in SWH (m) field (a) Control - JA3 assimilated run (b) Control - JA3 +CFOSAT assimilated run and (c) JA3 – JA3+CFOSAT assimilated run valid for 20th May 2020 06 UTC

Validation of simulations using wave rider buoys



- **Validation of model forecasted SWH with Wave Rider Buoys along the east coast of India during May 2020**
- **Assimilation of Ja3 alone showed a trivial (~1%) degradation in the SWH f/C along the east coast of India, during May 2020**
- **Assimilation of CFOSAT SWH along with Jason-3 considerably improved (~8-12%) the wave forecast in the initial 48 hours**

Conclusion

- **Detailed validation is carried out for wind/wave measurements by SWIM at nadir using Jason-3 and global NDBC buoy**
- **The results show the SWIM wind and wave measured at nadir is of very high quality and matches fairly with Jason-3 and in-situ buoys**
- **At nadir RMSE of SWH is 0.39 m and 0.31m with respect to Jason-3 and global buoys respectively.**
- **The wind accuracy is 0.67 m/s and 1.55m/s corresponding to Jason-3 and Buoys.**
- **The non-nadir measurements are validated with both Jason-3 and buoy observations. These add on measurements from the oblique look of SWIM shows a better accuracy at far range as compared to the near range. This is due to a less speckle noise at far range.**
- **SWIM data is assimilated into the numerical wave model Wavewatch-III (WWIII) using optimum interpolation technique. Cyclone phase of 16th -20th May 2020 was chosen as study period when the Amphan was active over Bay of Bengal region.**
- **The results suggest CFOSAT is having a positive impact on the improvement of model predictability. The individual contribution of CFOSAT on the improvement of model skill for prediction is around 8-12 %.**

Thus based on the results it can be inferred that geometrical innovation implemented in SWIM on-board CFOSAT is fruitful. At any point of time it can be alternate to the nadir altimeters and for SWIM the nadir measurements are at par with any traditional altimeters. For the oblique look, too CFOSAT has proved its efficiency and far range is found to be very accurate. The SWIM data is applied in wave model and its assimilation is found to be encouraging.

Thanks