On The Upgrade of Wide Swath Significant Wave Height of HY2B-2C-2D and Directional Wave Spectra From Sentinel-1 and CFOSAT : Focus on Extreme Wave Conditions

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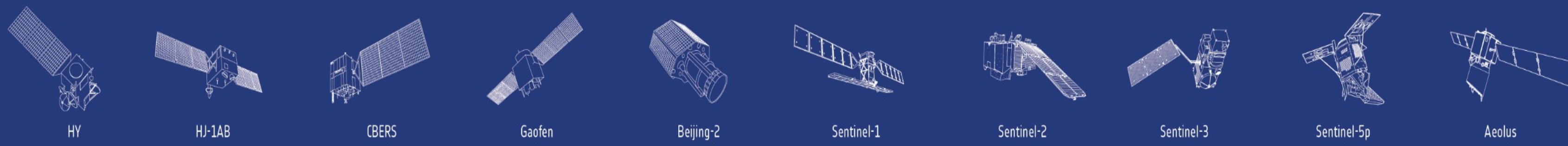
DRAGON-5 Symposium, Hohhot 11-15 September 2023



2023 DRAGON 5 SYMPOSIUM

3rd YEAR RESULTS REPORTING

11-15 SEPTEMBER 2023

[PROJECT ID. 59329]

[RESEARCH AND APPLICATION OF DEEP LEARNING FOR THE IMPROVEMENT OF SIGNIFICANT WAVE HEIGHT AND DIRECTIONAL WAVE SPECTRAFROM MULTI-MISSIONS]

THURSDAY 14/09/2023

ID. 59329

PROJECT TITLE: RESEARCH AND APPLICATION OF DEEP LEARNING FOR THE IMPROVEMENT OF SIGNIFICANT WAVE HEIGHT AND DIRECTIONAL WAVE SPECTRAFROM MULTI-MISSIONS

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PRESENTED BY: LOTFI AOUF (METEO FRANCE - CNRM)

Data use

ESA /Copernicus Missions	
1.Sentinel-1	Wave spectra
2.Sentinel-3	SWH

ESA Third Party Missions	
1. CFOSAT	Wave spectra SWH

Chinese EO data	
1.HY2B-HY2C-HY2D	SWH
2.CFOSAT	SWH

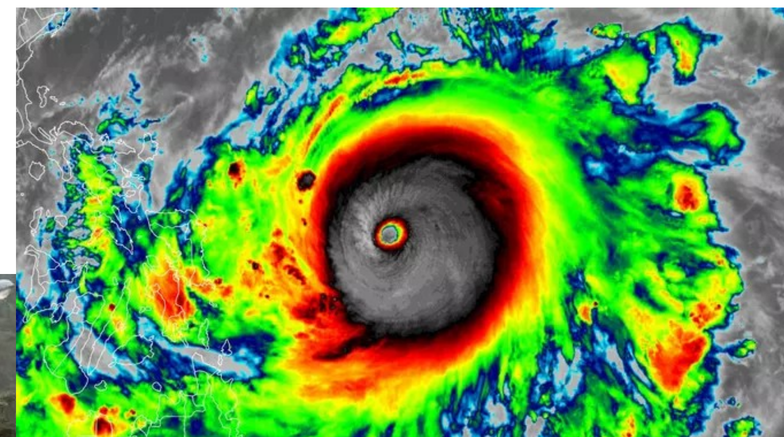
ESA/Copernicus and CFOSAT data from operational archived Meteo France operational data base

Motivation

- **Improvements of wide swath SWH from multi-missions (CFO-HY2B-HY2C), and assessement of the impact for long period.**

- **Synergy between directional wave observations from CFOSAT and Sentinel-1, and wide swath SWH.**
  → Better scaling of swell propagation and wind-waves in extreme conditions.

- **Estimate of maximum wave height from altimetry : rogue wave prediction**



Super typhoon Surigae 2021 Hiting Philippines

Dragon 5 3rd Year implementation

- 3 years (2019-2020) of wide swath Significant wave height have been processed from CFOSAT, HY2B, HY2C, HY2D missions

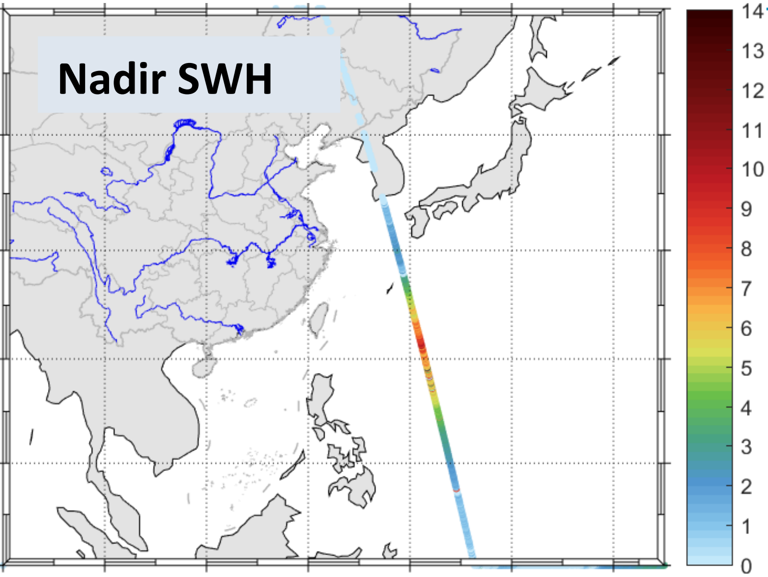
- Evaluation of wide swath data in the assimilation system of the model MFWAM : Global scale

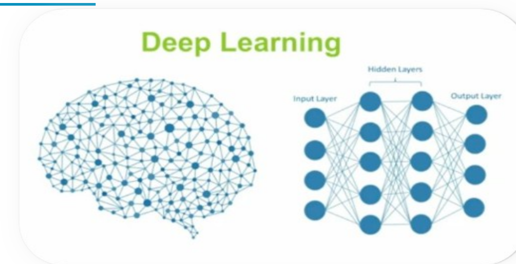
- Improvement of deep learning scheme by using reprocessed Wave data from CFOSAT mission

- Upgrade deep learning scheme of Hmax by including more buoys (Campbell Island)

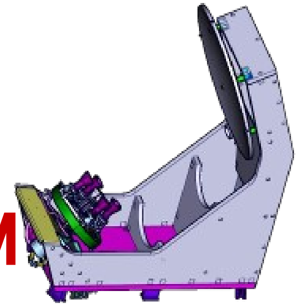
- Complementary use of wide swath and directional wave spectra from CFOSAT and Sentinel-1 : analysis for extreme wave conditions

Synergy between wind and wave (nadir+ directional) observations

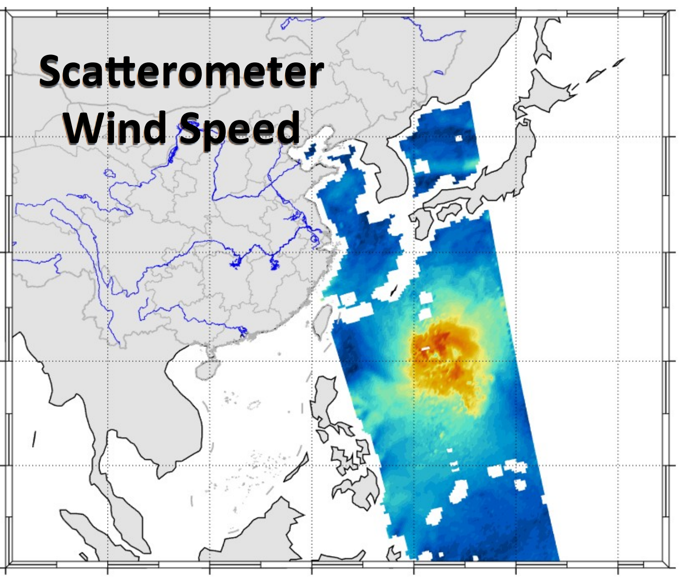




- **SWIM**

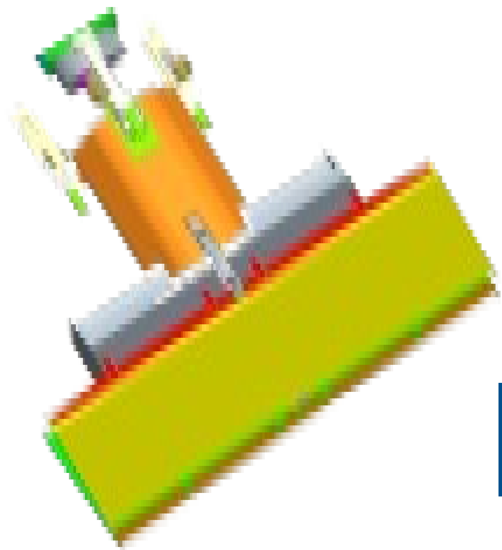


Nadir SWH and wave spectra from beam measured by SWIM



- **SCAT**

Wind vector on Swath from scatterometer



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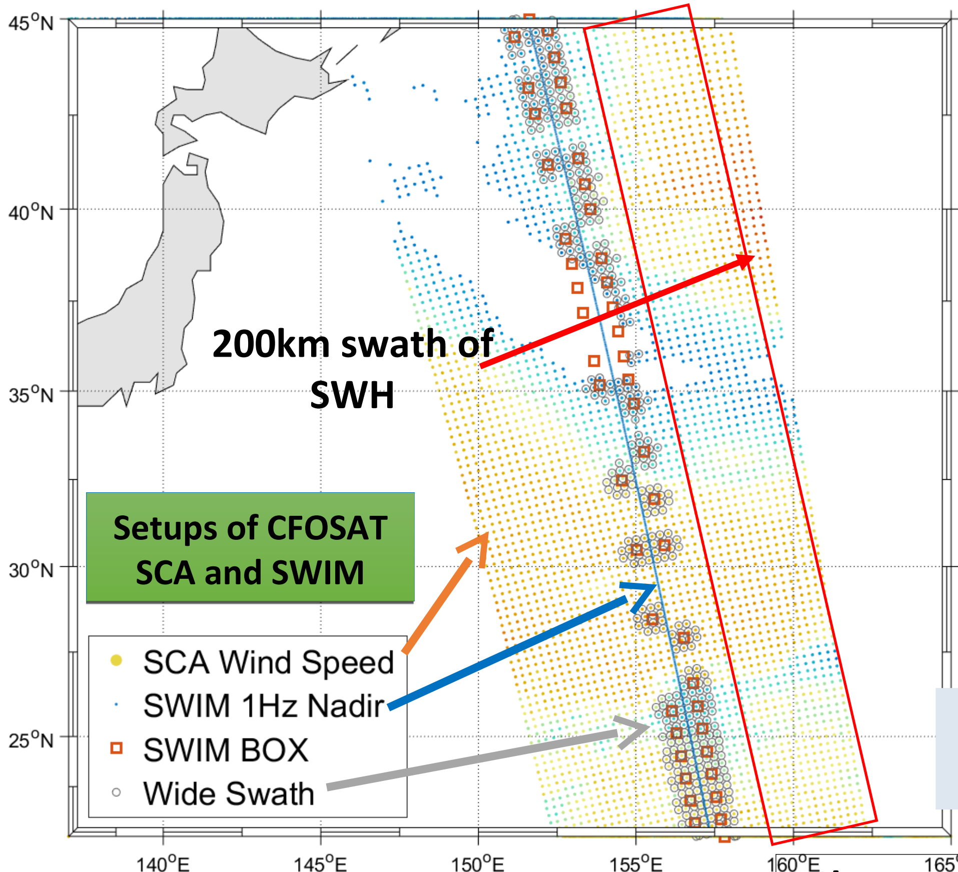
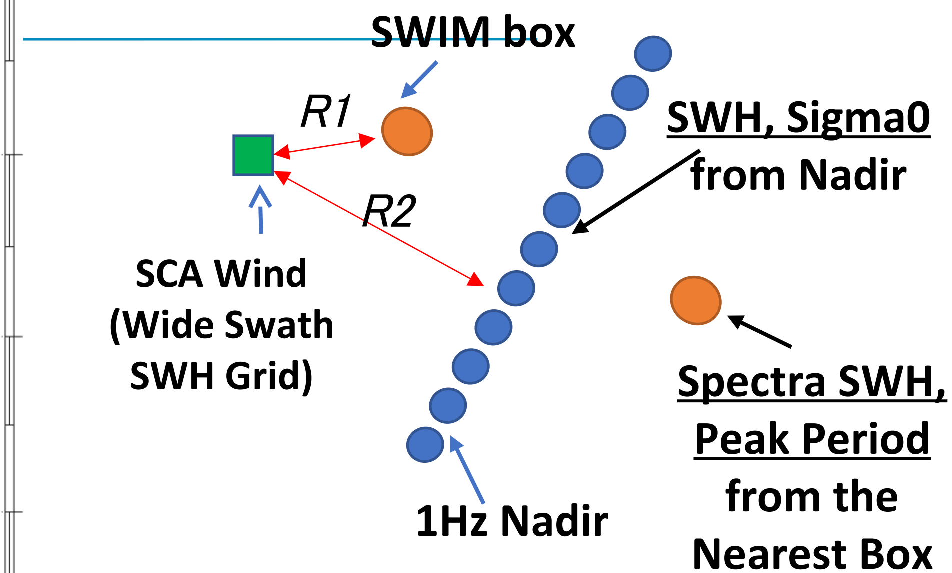
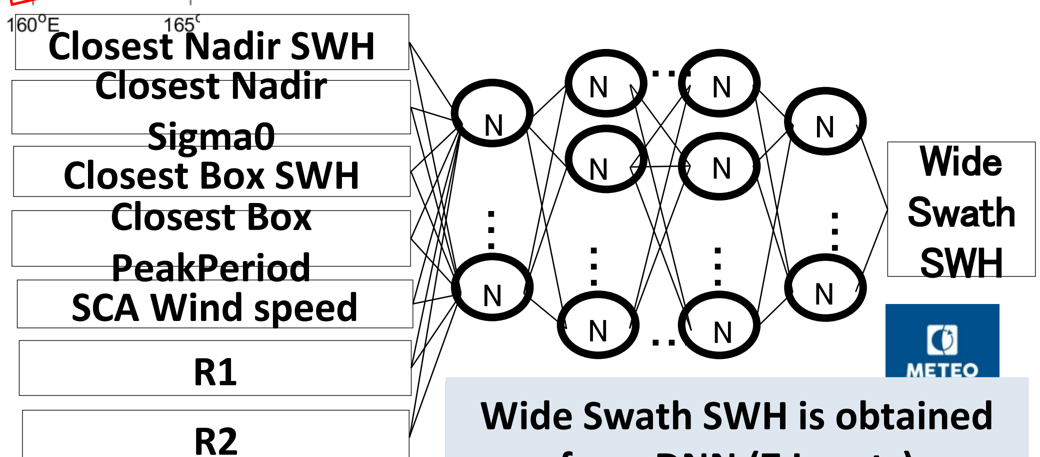
Deep neural network based retrieval of wide swath SWH (Wang et al. 2021)





The distance of Wide Swath SWH grid is limited to 50km from the Box (R1) and 100km from Nadir (R2)

Both wind-wave and swell regimes are captured from SCAT and SWIM

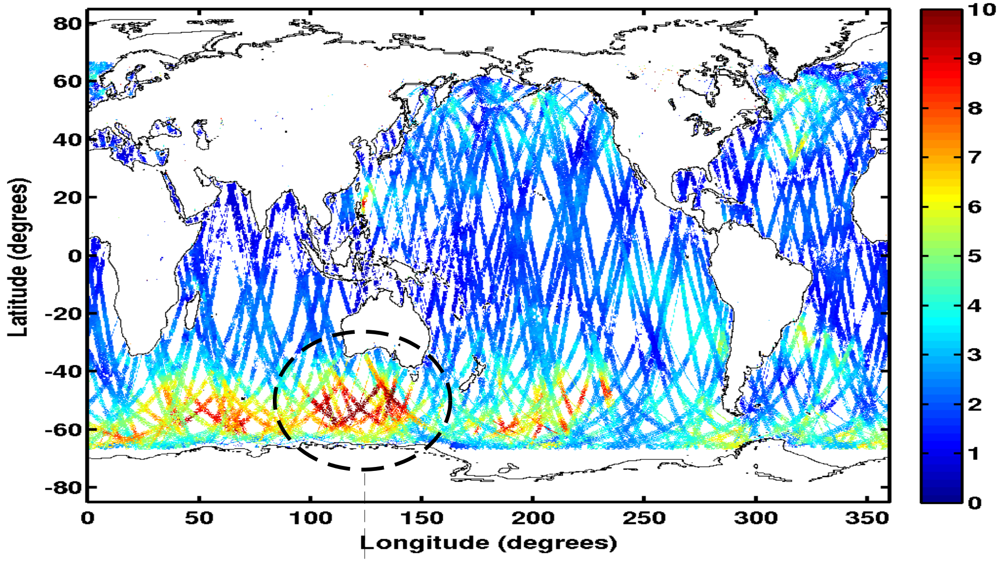


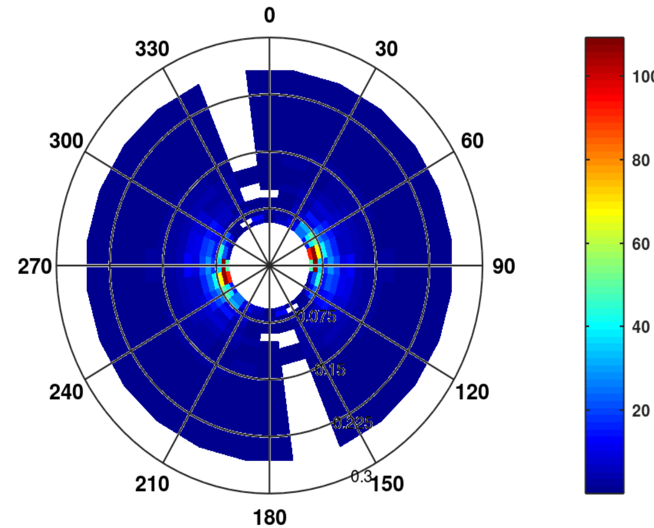
Wide Swath SWH is obtained from DNN (7 Inputs)

Benefit of wide swath SWH and directional wave spectra in tracking fast storm event

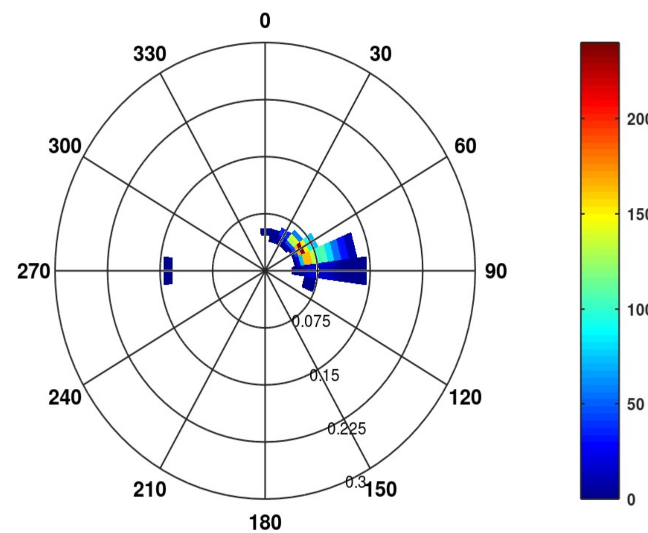
CFOSAT/SWIM : wavelength range 60-500 m)

2-day coverage of multi-missions wide swath SWH CFO-HY2B-2C : 20-22 April 2021

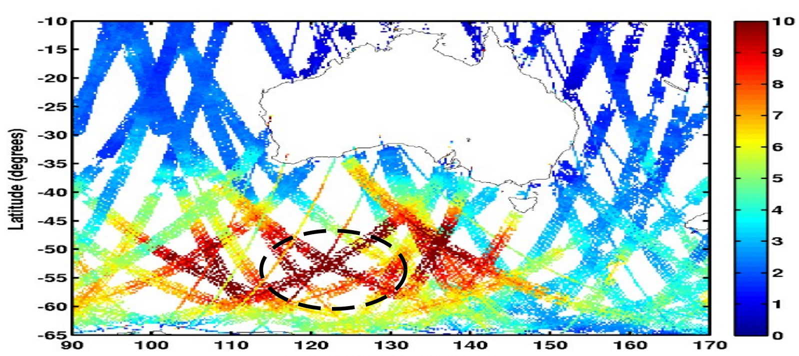




Sentinel-1/SAR : wavelength range 200-800 m



Tracking storms and propagating the best initial Conditions



Model experiments : impact evaluation

■ The wave model MFWAM global configuration grid size of 0.5° and spectral resolution of 24 Directions and 30 frequencies.
The model is driven by 6-hourly atmospheric forcing (winds and ice fraction) from IFS-ECMWF system.

■ Several data assimilation experiments
Period January-June 2021 :

-Run A : DA with Wide swath SWH (multi-missions CFO-HY2B-HY2C) and wave spectra from CFO and Sentinel-1
-Run B : DA of Wide swath SWH (1 mission : CFO)
-Run C : Control run without assimilation

■ Validation of the results in comparison with independent altimeters SWH (Jason-3, Saral and Sentinel-3)

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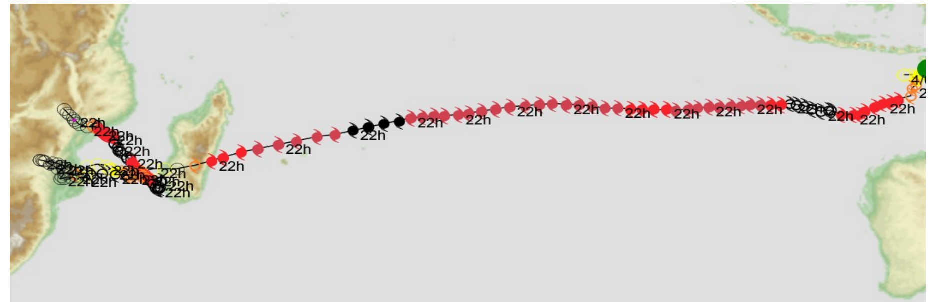
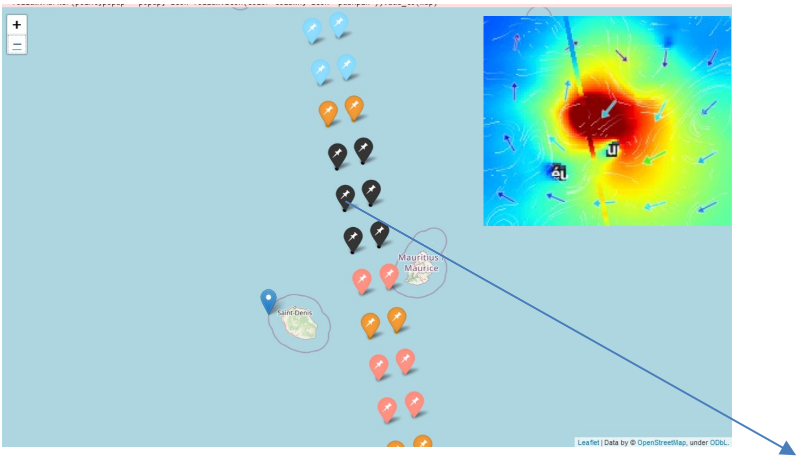
Directional wave description observed by SWIM at the front of cyclone Freddy (Feb. 2023)

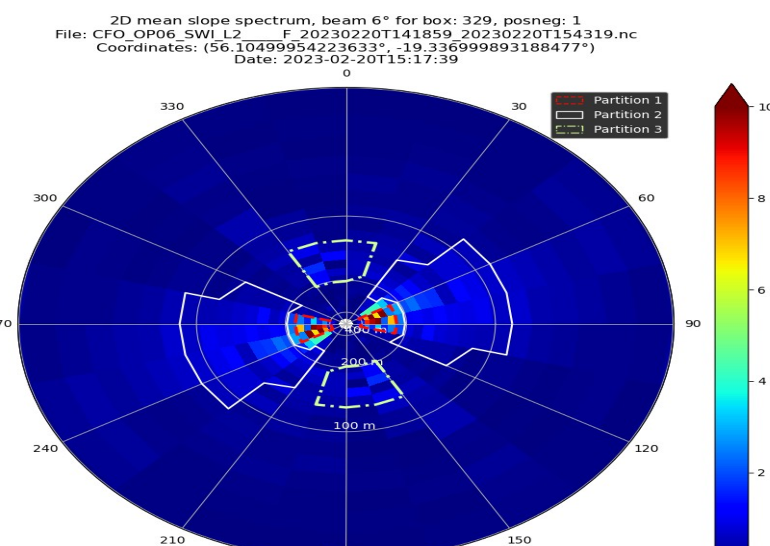
Trajectory of cyclone Freddy



SWIM passage 20 Feb. 2023 15:00UTC



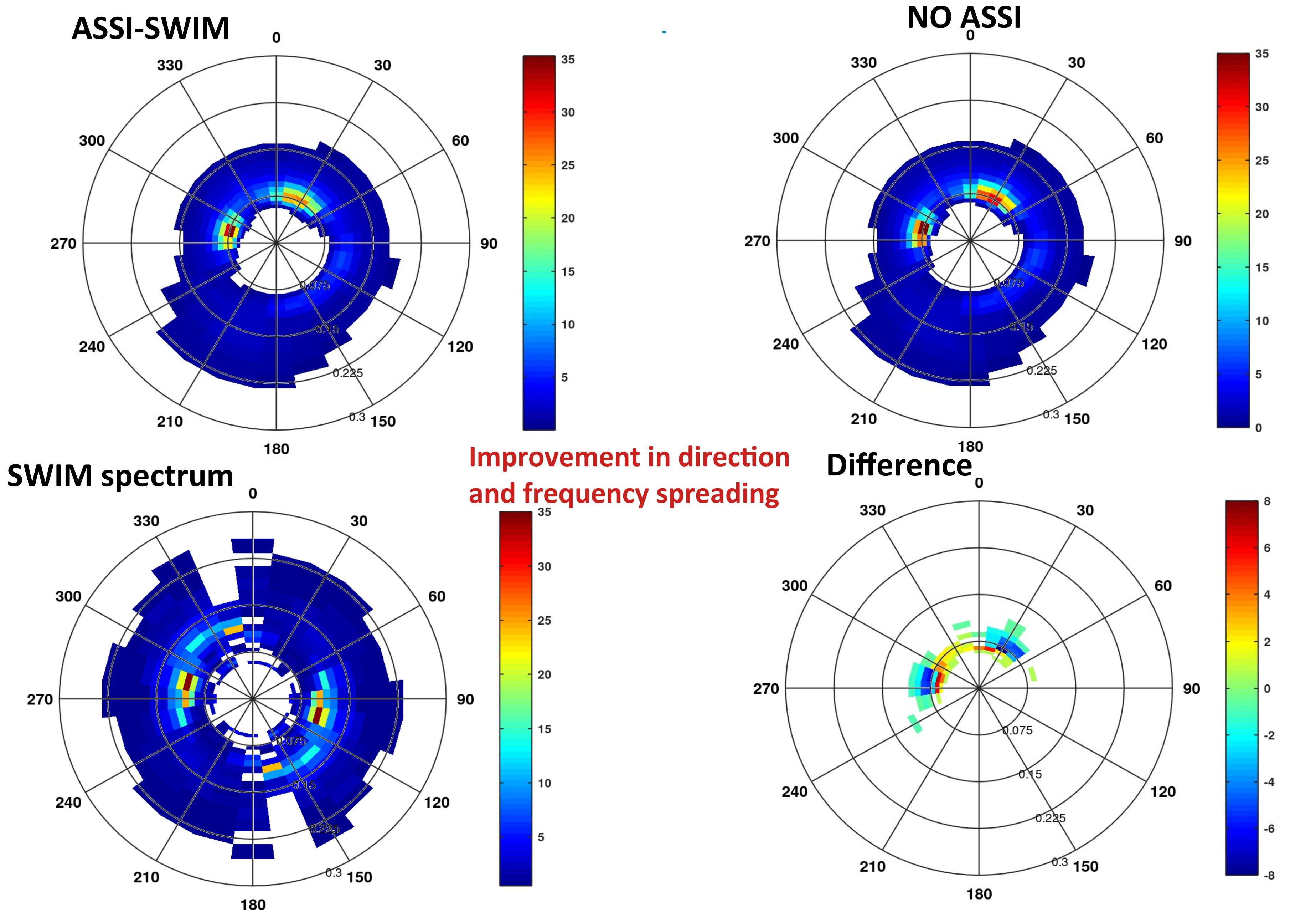
Long swell at ~80° and wavelength of ~350m, with wind-wave partition in the same direction, and other wind-wave in perpendicular direction



partition	SWH(m)	wavelenth(m)	direction (°)
1	7.286	314.087	74.515
2	4.332	171.303	69.401
3	–	–	–

Capturing directional properties of waves during growth phase and providing the Best initial conditions to the wave model

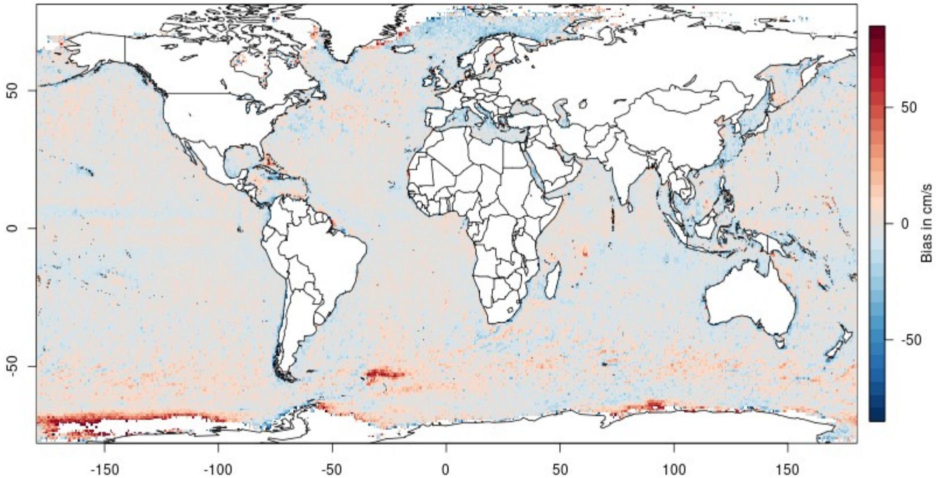
Impact of the spectral assimilation on the north part of the trajectory of cyclone Freddy : long=56.8°E & Lat=18°S

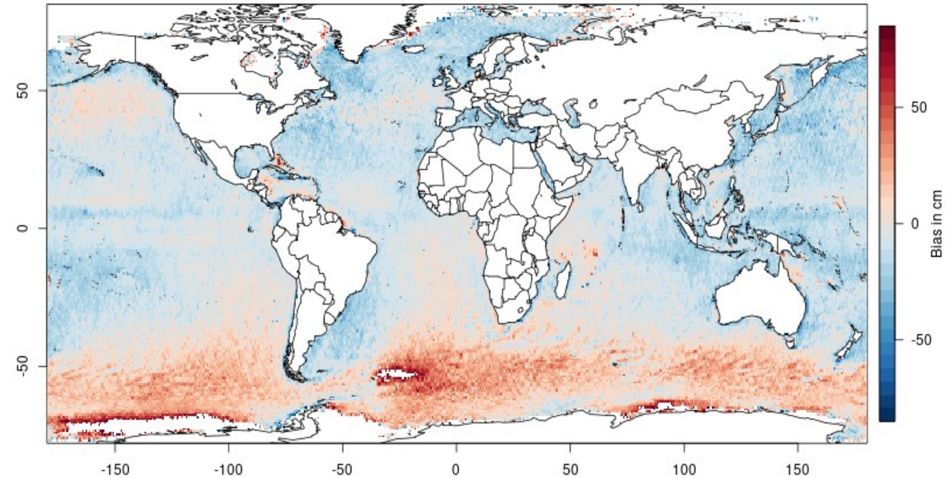


Impact of the assimilation of wide swath (CFO-HY2B-HY2C) and wave spectra (SAR & SWIM) : Jan-Jun 2021

Bias map (max. 60 cm)

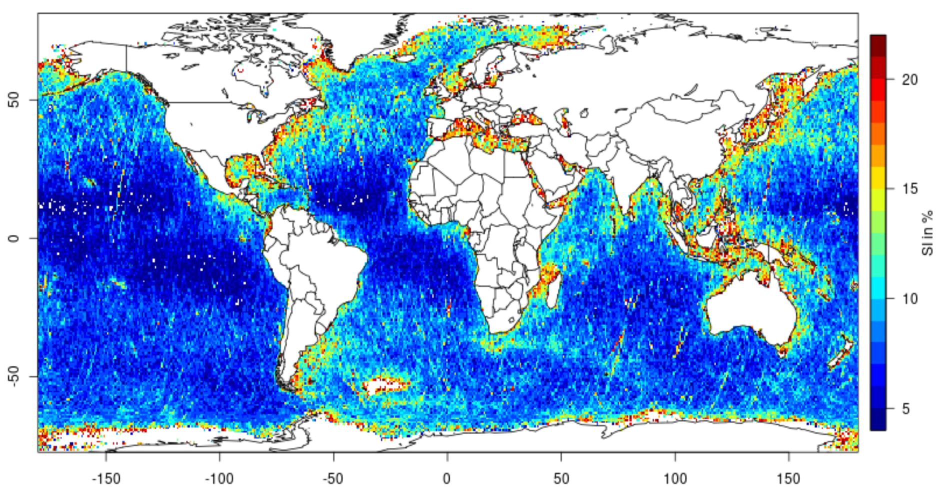
With DA | **Without DA**

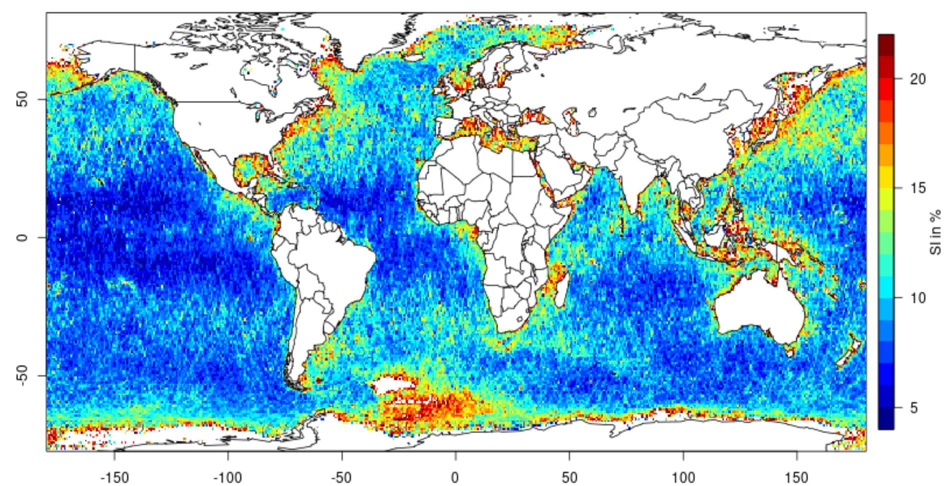




Remarkable bias reduction Induced by DA (SO and mid lats)

Scatter index map (%)





The smaller scatter index is, the better

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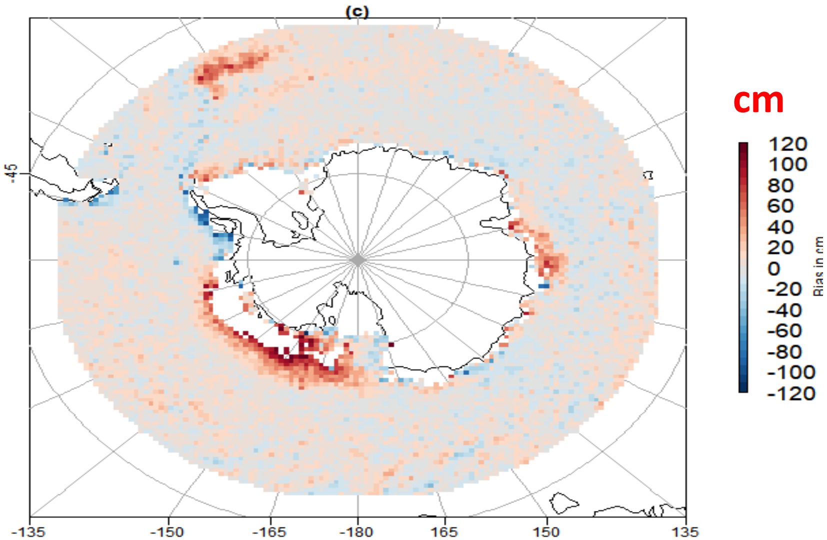
Validation with independent altimeters (Jason-3, Saral, S3)

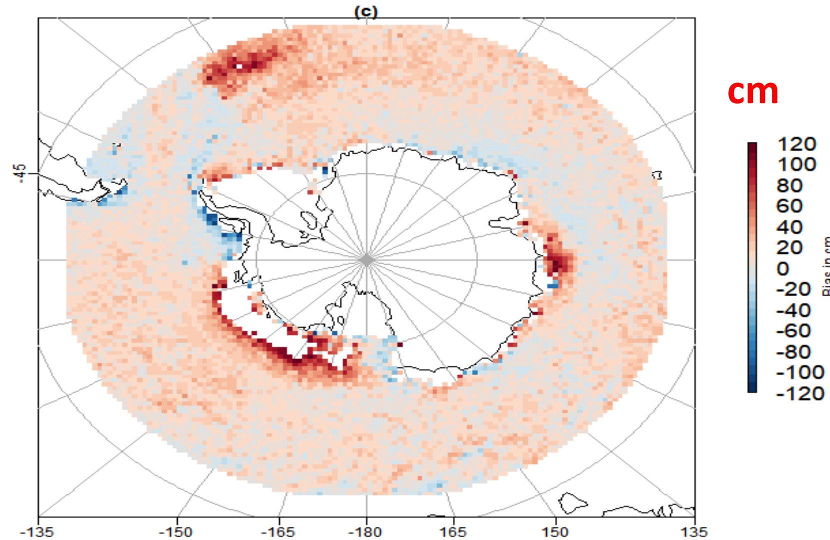
Performance in Southern Ocean and complementary use of SWIM and SAR directional wave spectra : Jan-Jun 2021

Bias maps (max. 80 cm)

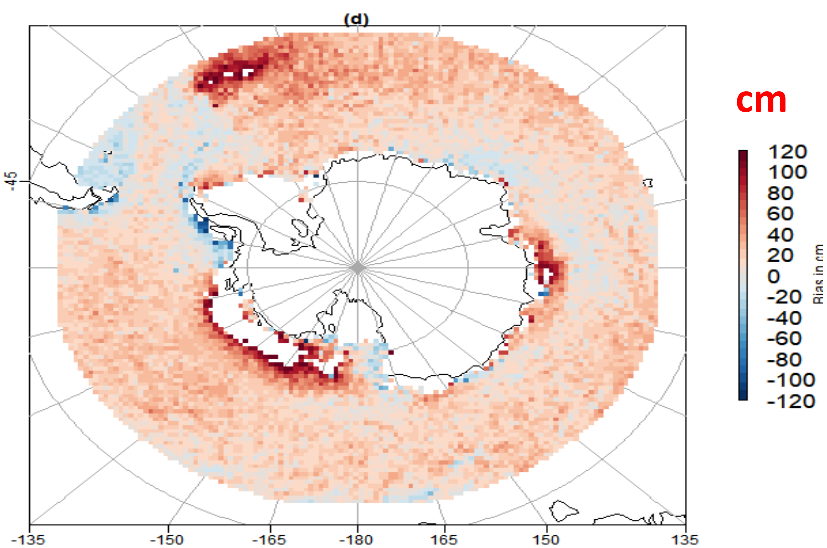
With DA multi-missions wide+SWIM+SAR



With DA CFOSAT wide+SWIM

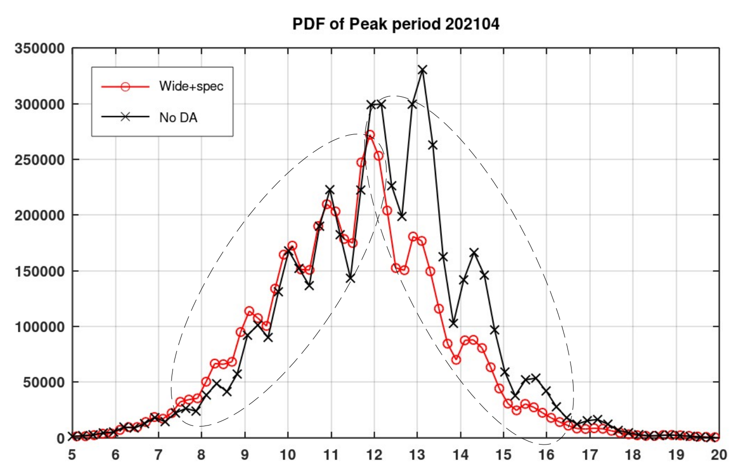


Without DA



Complementary use of SAR and SWIM wave Spectra enhances SWH bias reduction in SO

Improvement of peak period Tp PDF with DA

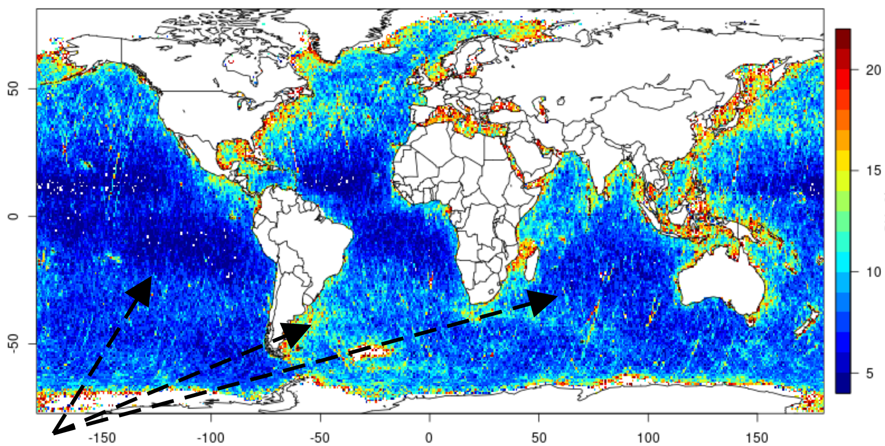


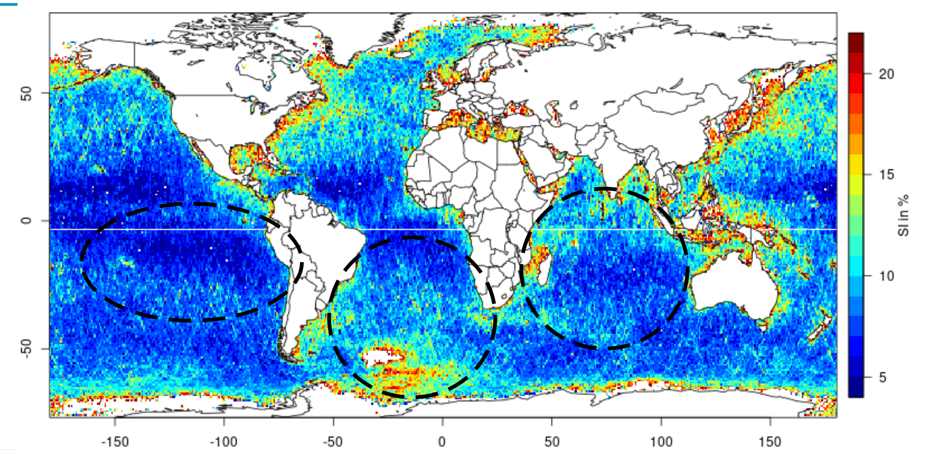
Performance of synergy between satellite missions (Jan. & Jun. 2021)

wide swath CFO-HY2B-2C+spectra)

Scatter index (%) maps

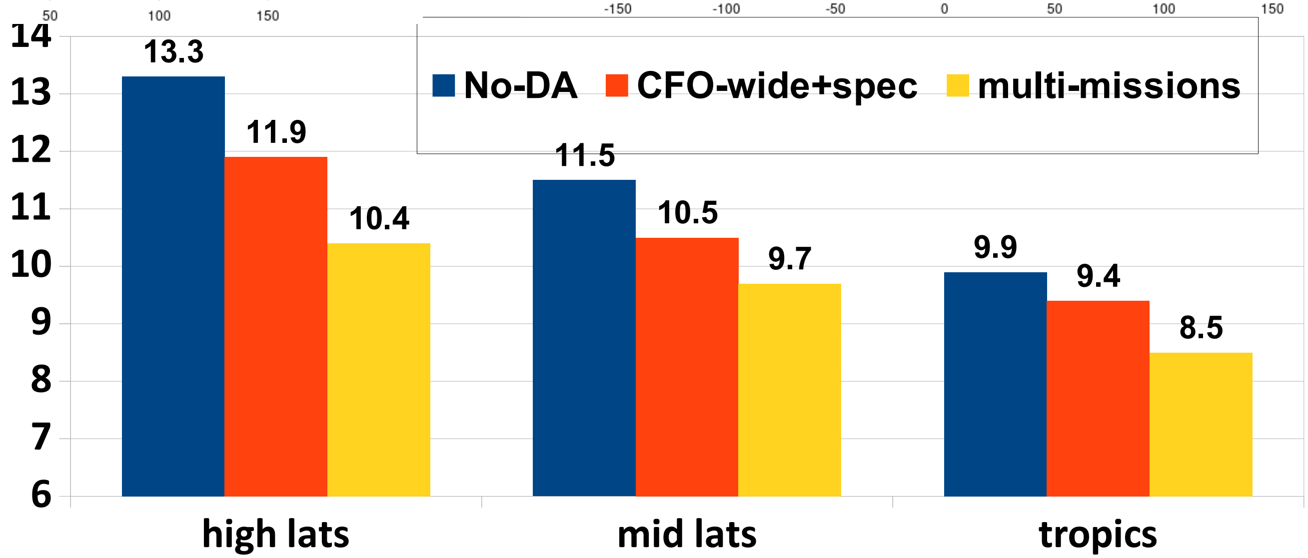
CFO mission (wide swath+spectra)





Enhanced impact in mid and high lats

Scatter index of SWH (%)

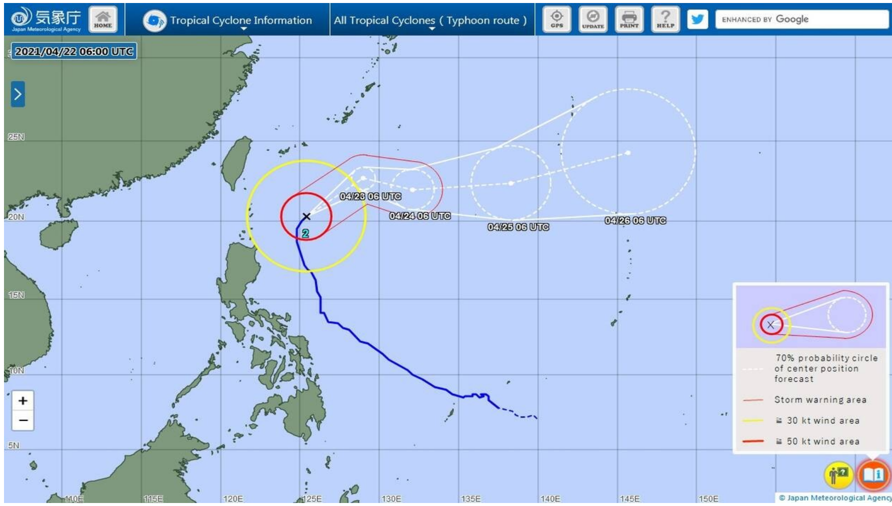


Significant reduction of scatter index of SWH when using CFOSAT spectra and wide swath. The reduction is enhanced by adding wide swath of HY2B and 2C.

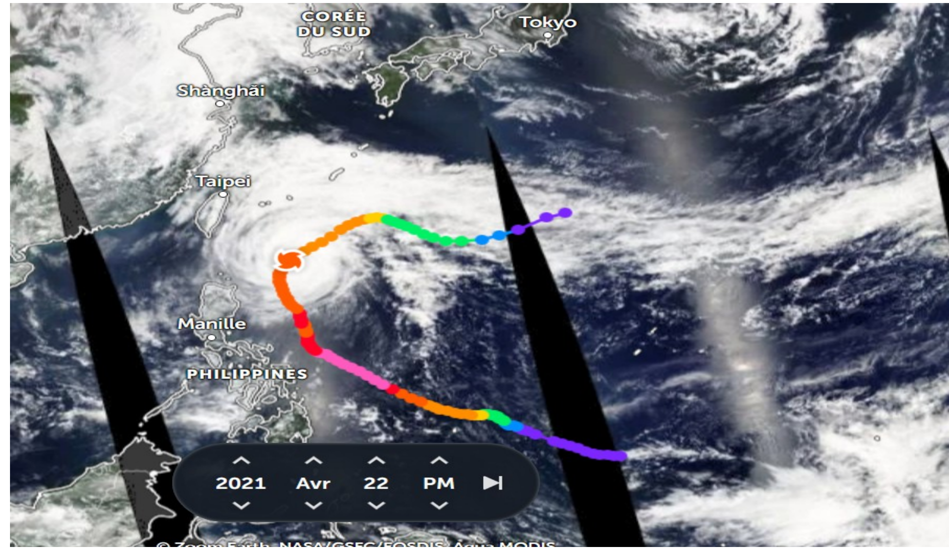
Comparison with SWH from altimeters (Jason-3,Saral,S3)

Mult-imissions wide swath SWH in typhoon Surigae April 2021

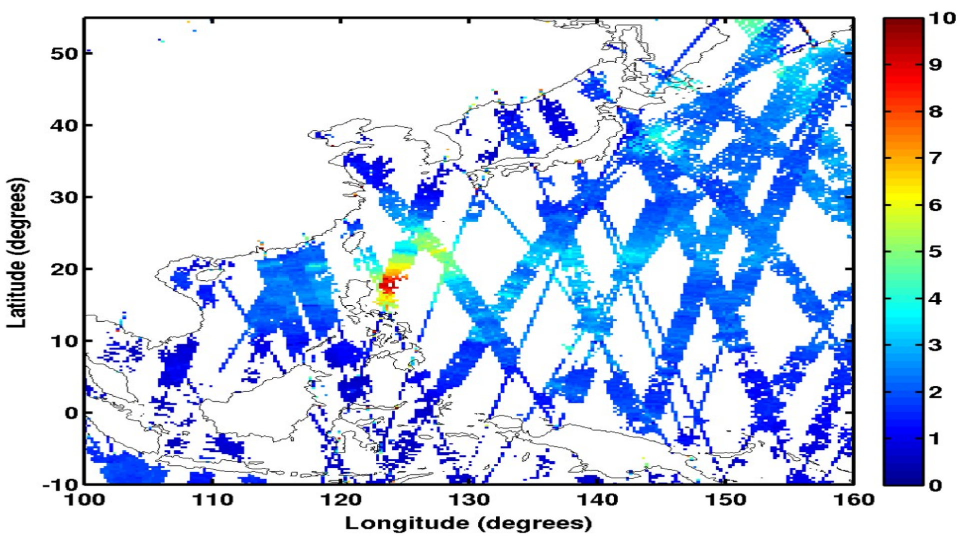
Trajectory of typhoon Surigae



Super typhoon generating long swells



Wide swath SWH from CFOSAT, HY2B and HY2C from 20 to 22 April 2021



Damages at Philippines

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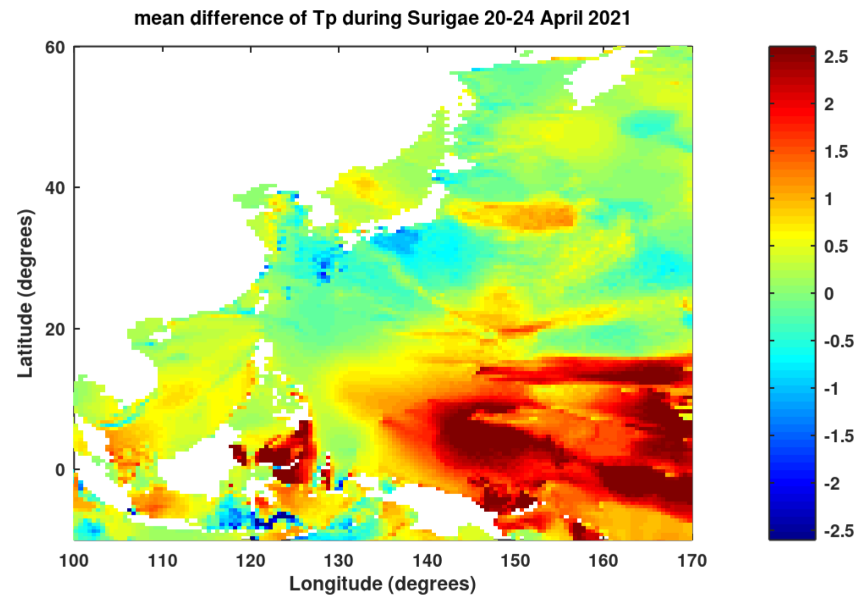
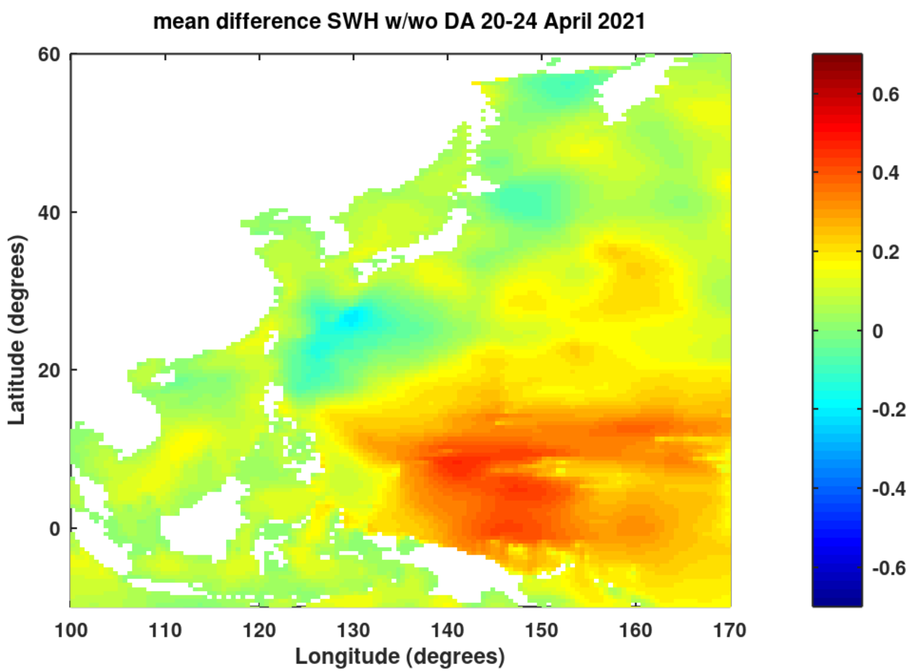
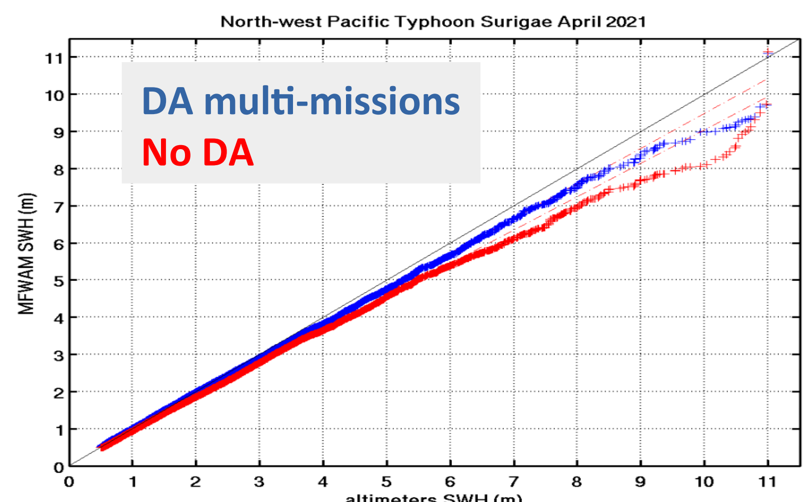
the impact of wide swath SWH and directional wave spectra in typhoon Surigae : 20-24 April 2021

Peak period



Sig. Wave Height





Q-Q plot of SWH indicates better PDF of SWH from DA (wide+spec) in Blue line particularly for high waves.

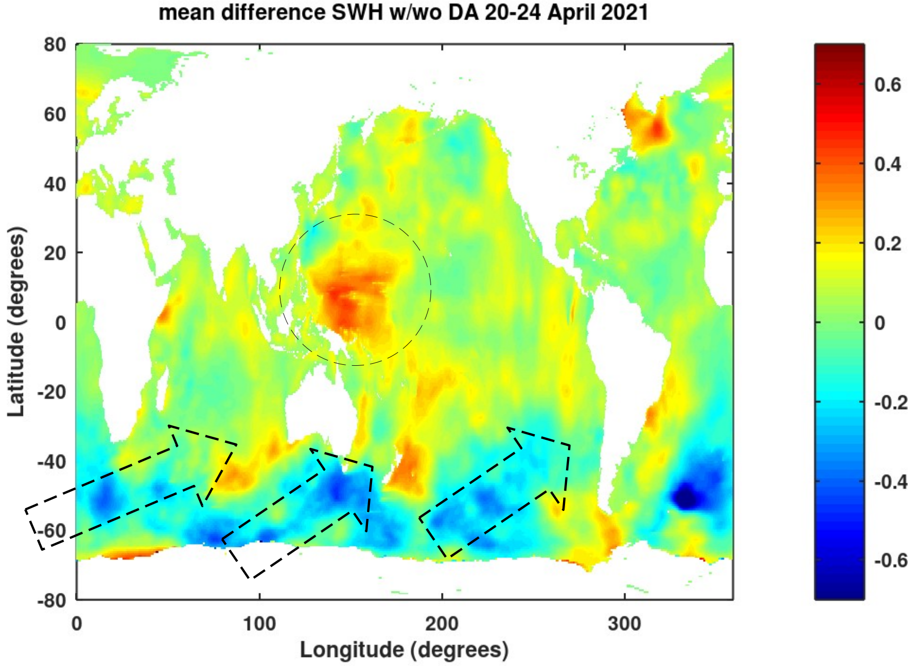
Validation with altimeters (ja3,Saral, S3)

During typhoon SURIGAE SWH is improved by roughly ~13 %

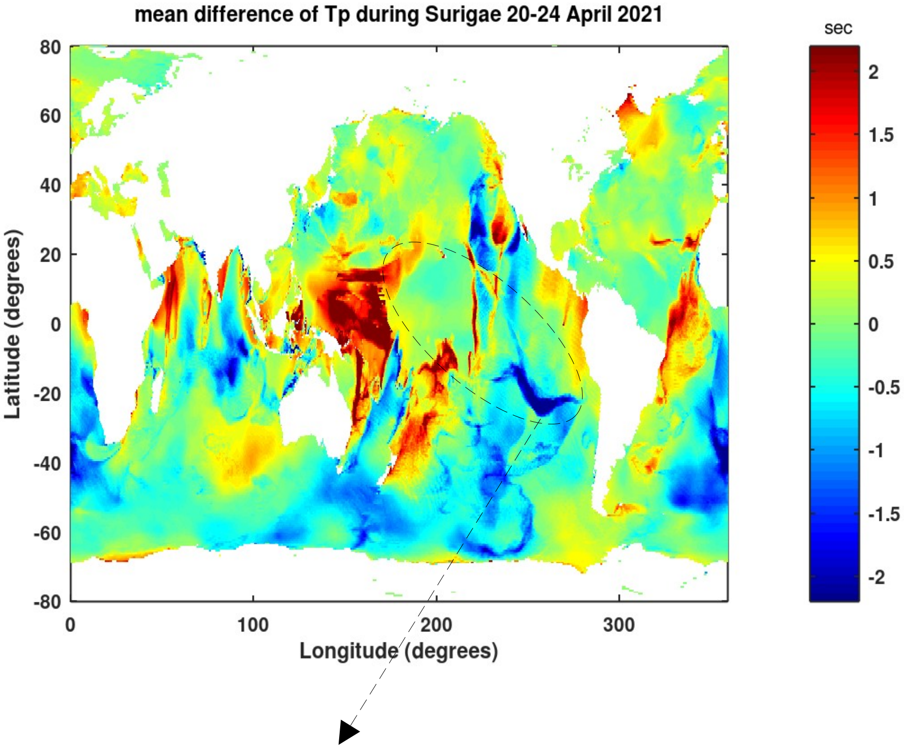
the impact of wide swath SWH and directional wave spectra in typhoon Surigae : 20-24 April 2021

Average of difference of parameters w/wo DA

Sig. Wave Height

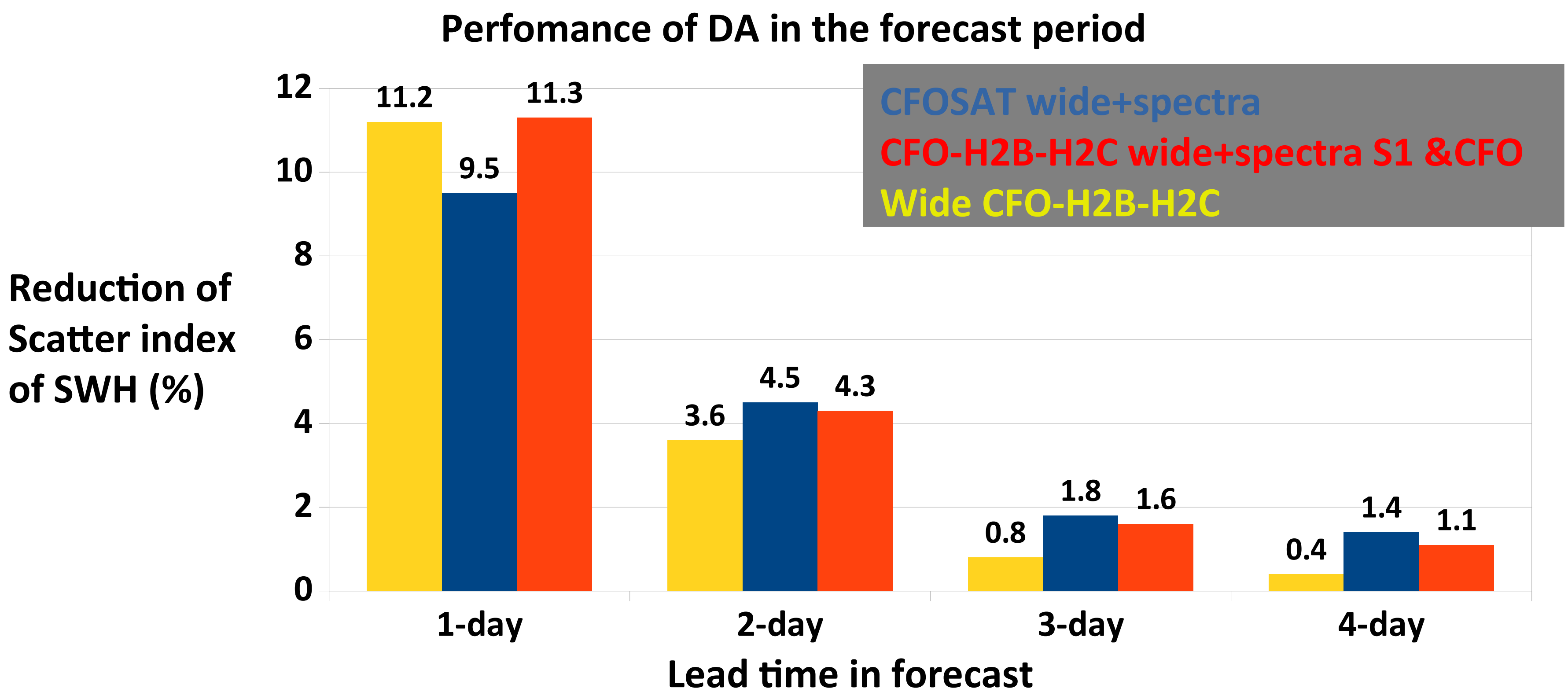


Peak period



Better swell tracking : thanks to Directional wave spectra from SWIM and SAR

Benefit of directional wave spectra in the forecast : May 2021



The use of wide swath SWH multi-missions enhances the impact positively during the 1-day Of forecast. Directional spectra from S1 and CFOSAT keep the impact efficient until 3-day forecast

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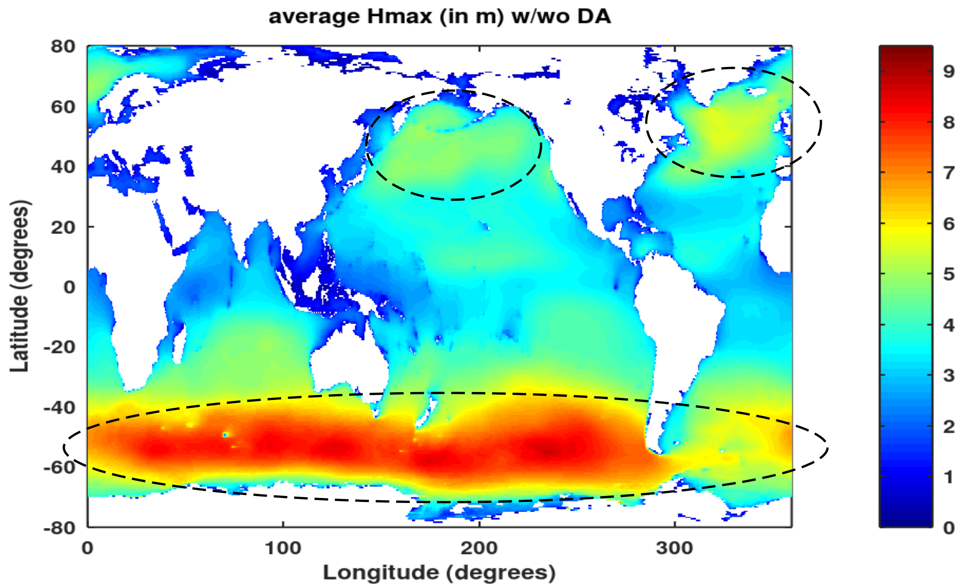
Validation with independent altimeters (Jason-3, Saral and S3)

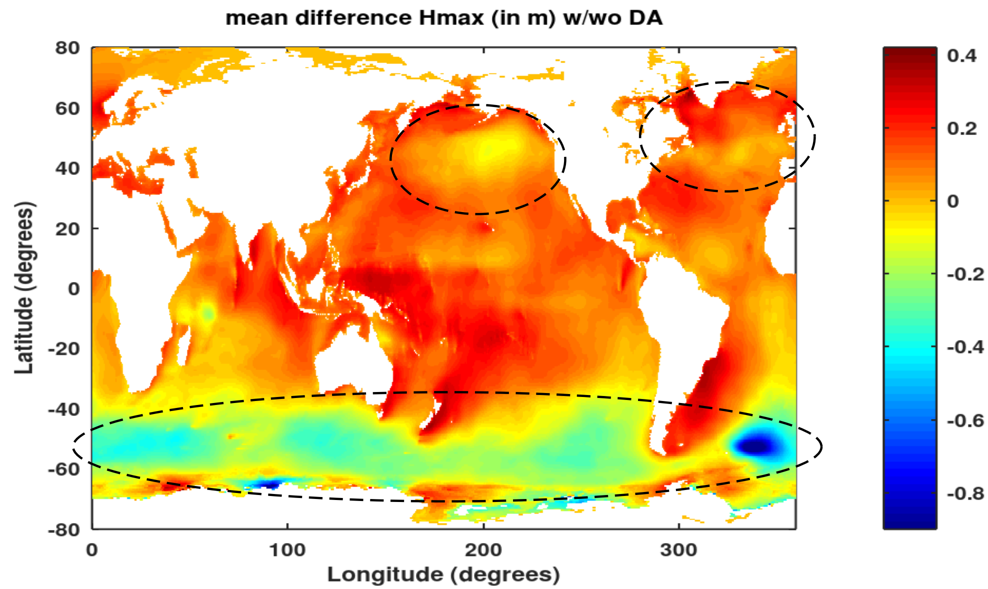
Impact of DA (multi+spectral) on Hmax : Jan-Jun 2021

Average Hmax



High Hmax are located in SO, North-Atlantic and North-Pacific

Mean difference of Hmax w/wo DA

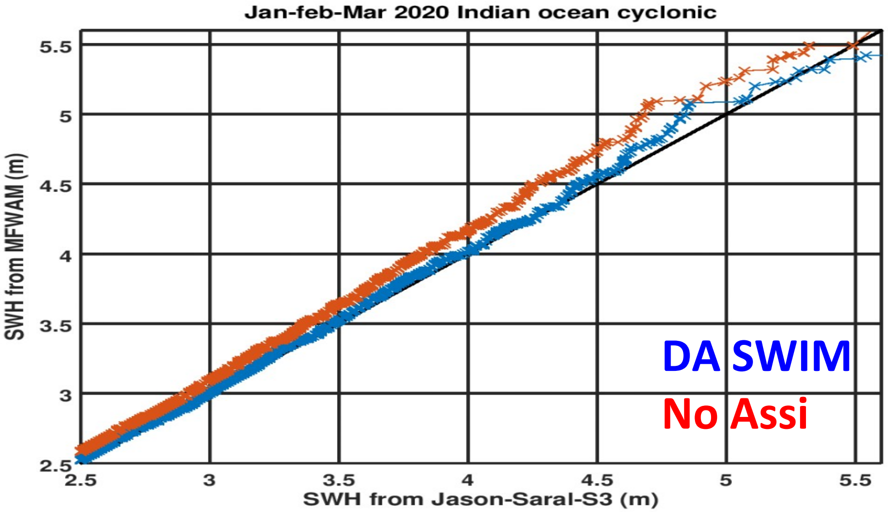


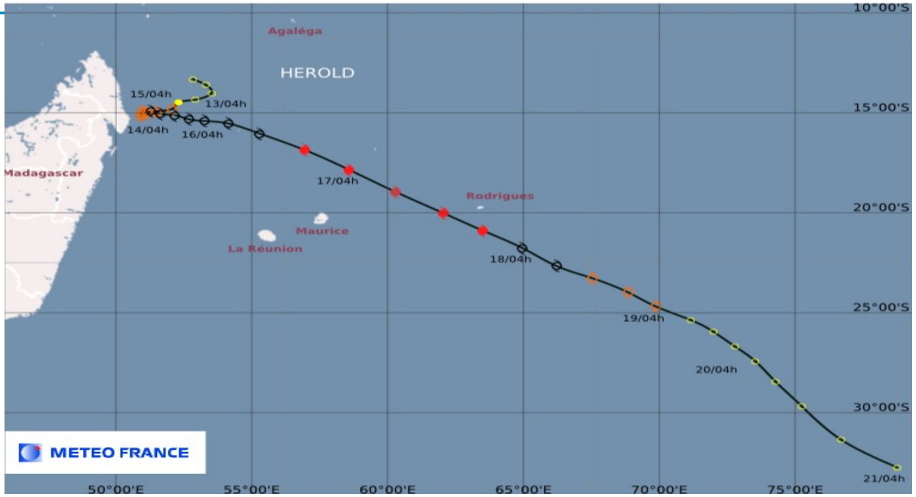
The assimilation of wide swath SWH And spectra impacts significantly the Estimate of Hmax

Difference values : red color indicates Underestimation, while blue color Indicates overestimation

Assimilation of SWH and wave spectra from SWIM during cyclone HEROLD in indian ocean 2020

Qqplot SWH Model and Independent altimeters



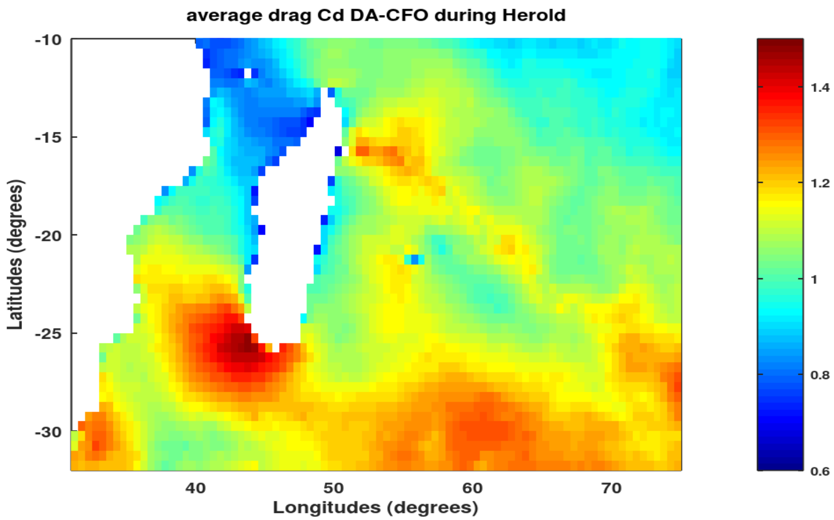


Good improvement of SI by ~14%
Reduction of bias in average from -12 cm to -4 cm.

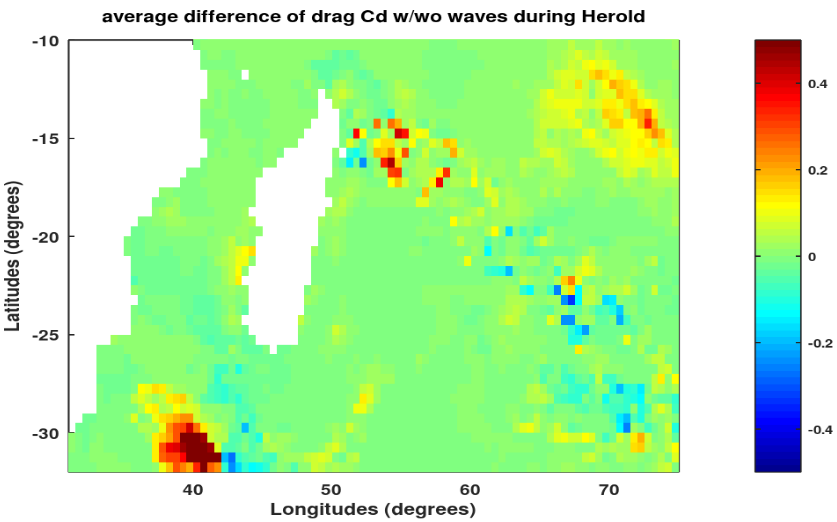
Improved sea state integrated parameters and Forcing to ocean model : Stokes drift, stress Modified by the waves and turbulence of wave Breaking in the ocean mixed layer

Coupling experiments MFWAM and NEMO during cyclone Herold
Impact of DA CFOSAT on drag-stress forcing

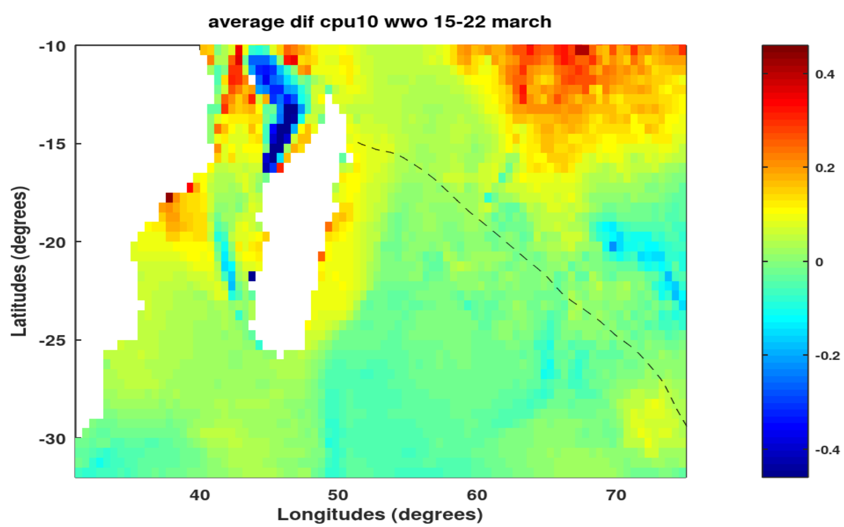
Average of Cd 15-22 March : strong value on cyclone trajectory and southern swell



Average difference Cd w/wo assimilation of CFOSAT : correction on dominant waves



Average difference Cp/U10 w/wo assimilation of CFOSAT : Correction of underestimation wave age in swell dominant seas (red). Blueish stand for Correction of overestimation Of wave age in youger seas.



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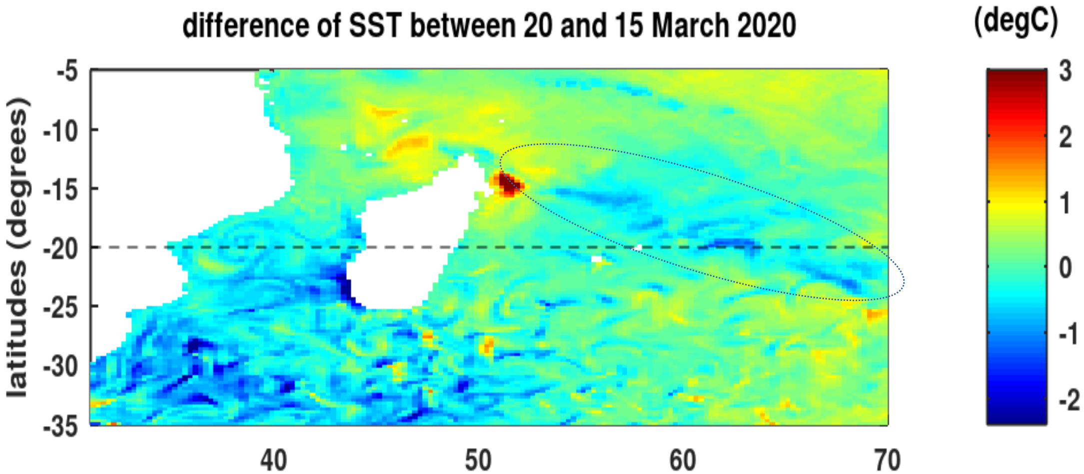
Impact of the waves coupling on ocean temperature during cyclone Herold



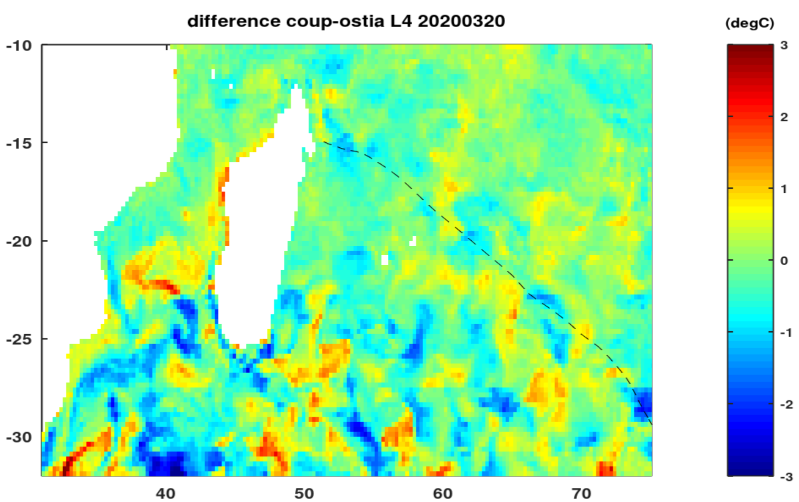
Top figure indicates the difference of SST on 15 and 20 March. The surface Cooling shows the cyclone trajectory Moving southeastward

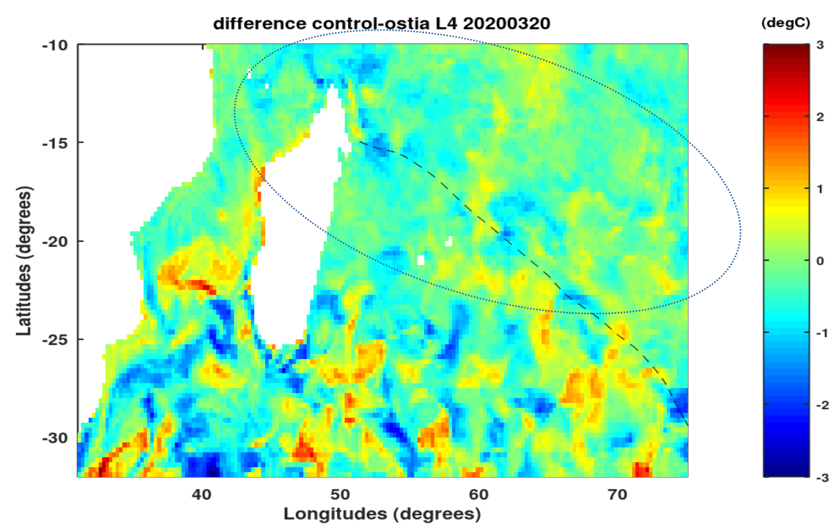
Validation of SST with CMEMS-L4

With waves coupling

Smaller bias on the cyclone track When using waves coupling

Without coupling



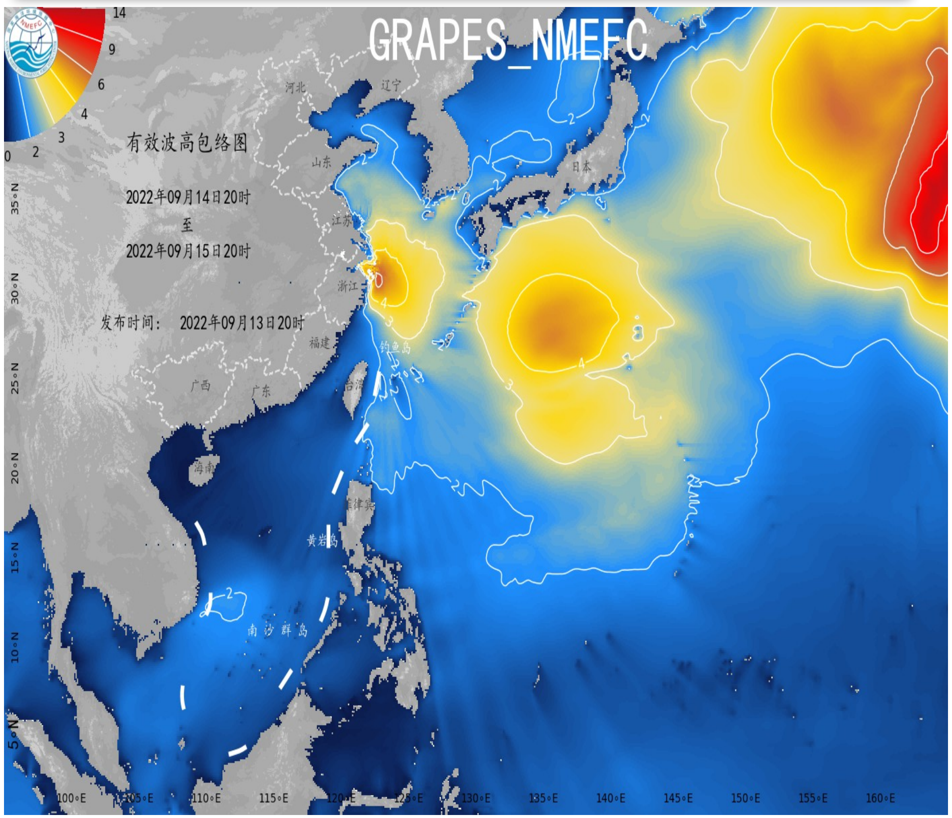


Dashed line shows the cyclone trajectory

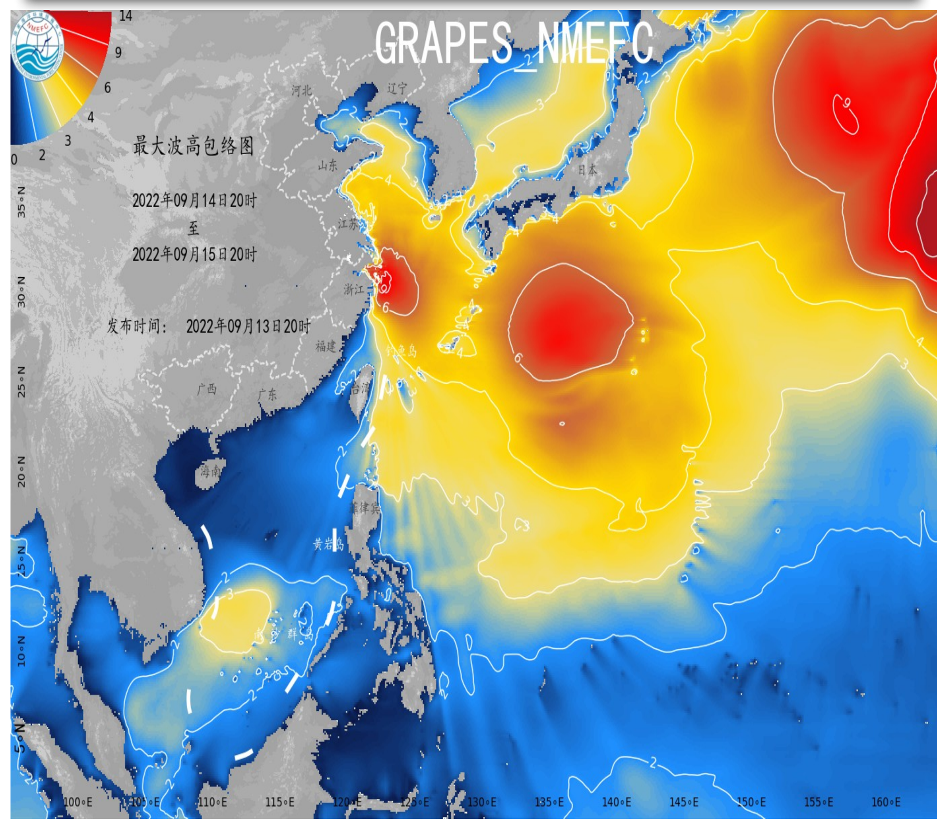
Motivation: Urgent demand for operational marine forecasting

- Hmax wave height (MaxH) is dangerous for ships navigation and marine structures
- Hmax is used to estimate the freak waves occurrence : Hmax/Hs >2
- lack of observation for Hmax (particularly open ocean).
- Hmax is computed by wave model : empirical methods.

Significant Wave Height

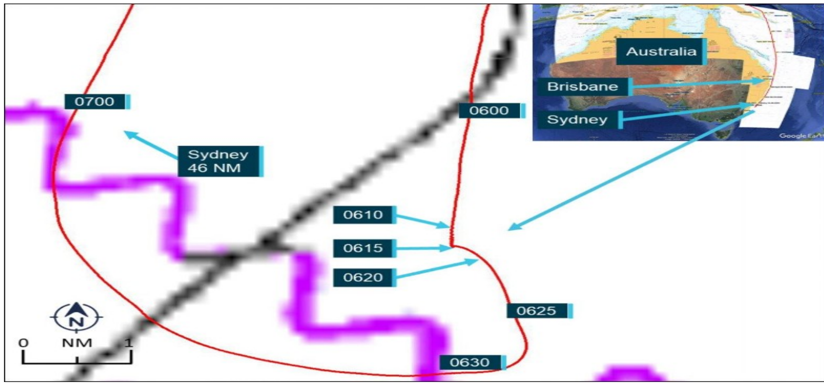


Maximum Wave Height

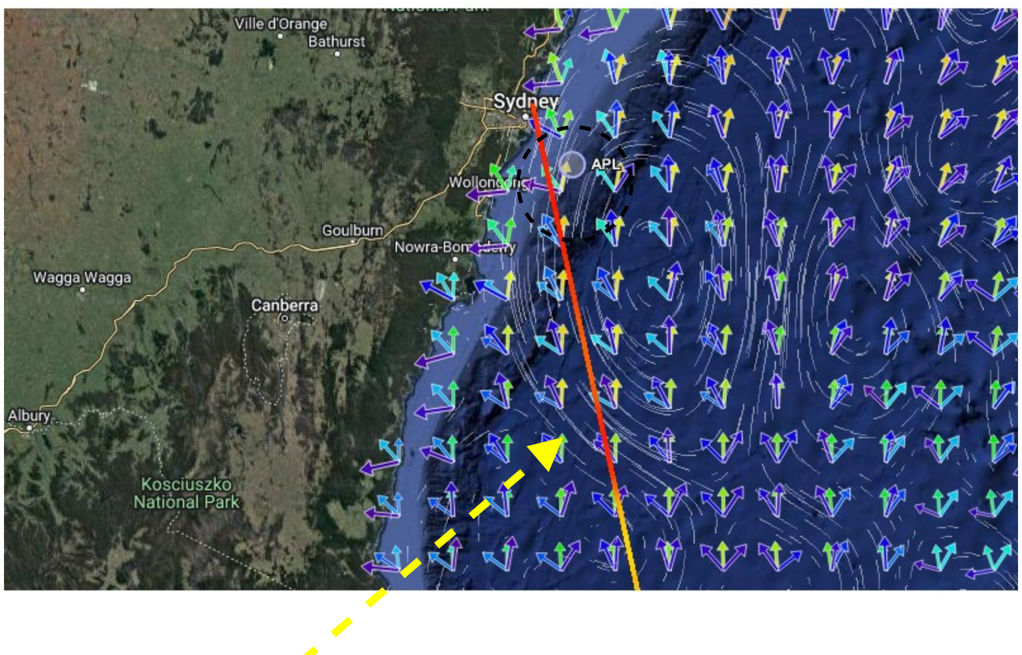


The case of APL England (24 May 2020 at 6-9h (UTC) : occurrence induced By strong current cell (white stream line)

Pitching and rolling of the container ship

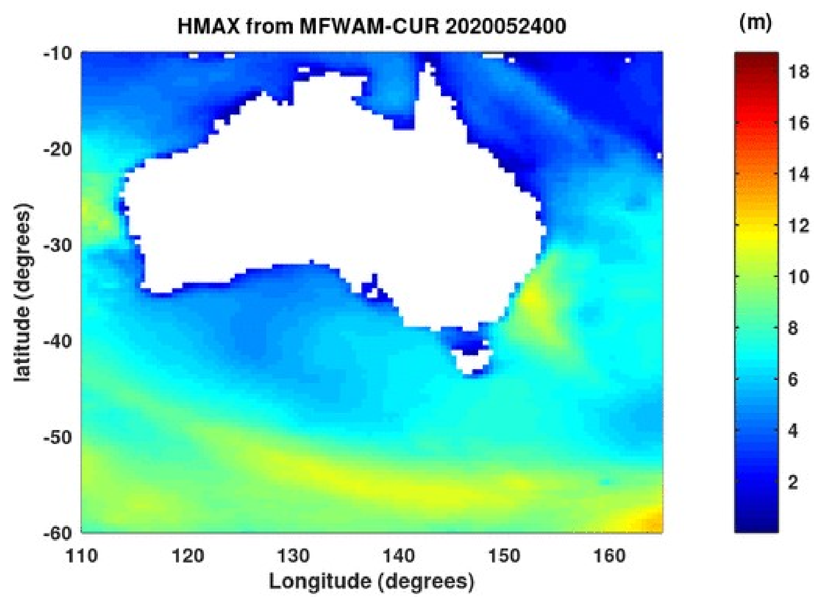


Wind-wave 8.6 sec, 1st swell:9.5sec 2nd swell 12.6 sec



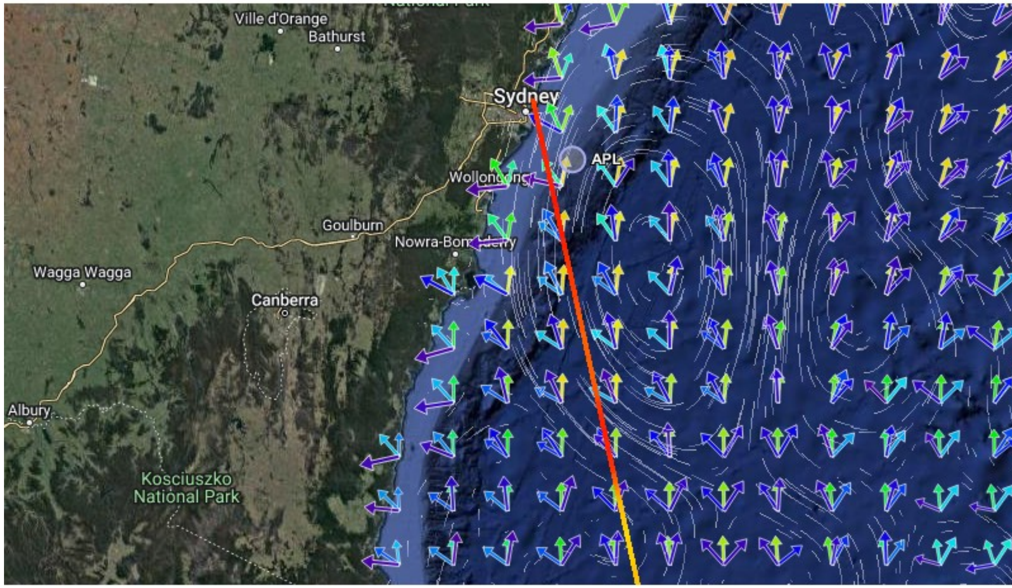
CFOSAT track at 9:25 UTC

Animation of hmax snapshots during the event (3-hourly from 0:00-21:00)

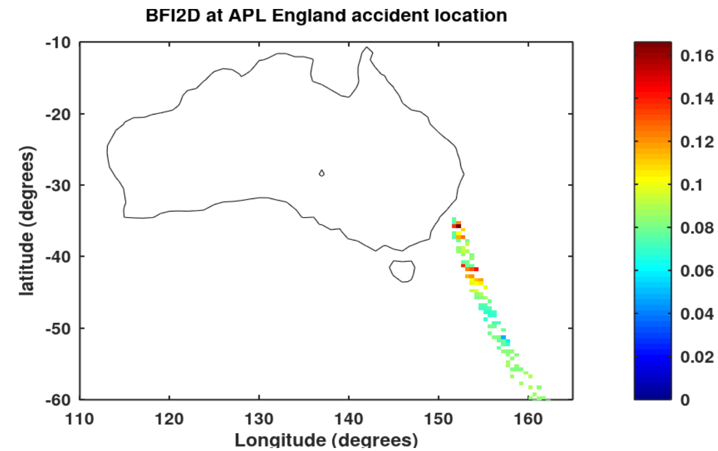


Strong increase of Hmax more than 16 m at the accident location

Wind-wave 8.6 sec, 1st swell:9.5sec 2nd swell 12.6 sec



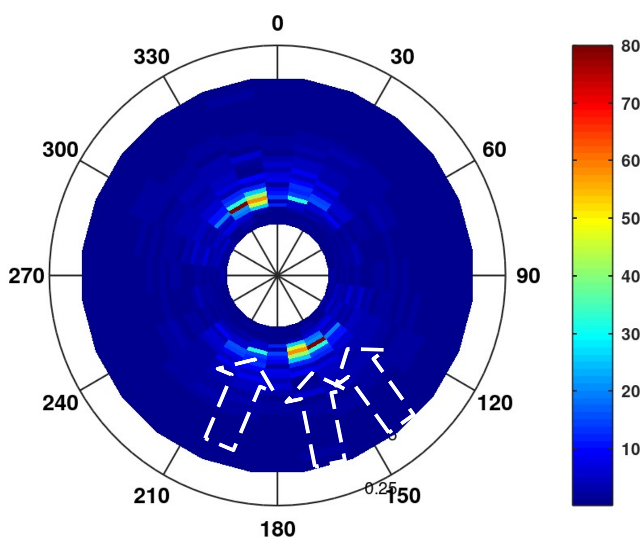
BFI2D from model at CFOSAT tracks



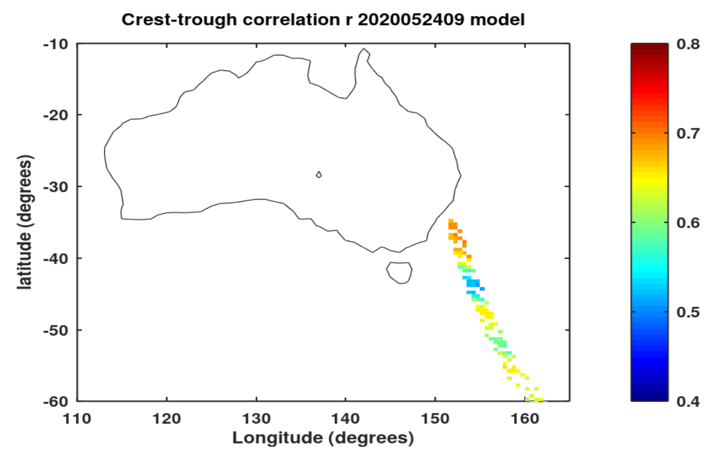
SWIM wave spectrum nearby

40 km from the location

R=0.6 & BFI2D=0.13



Crest/trough correlation



Higher values for BFI2D and Crest Correlation and consistent with those computed SWIM wave spectra

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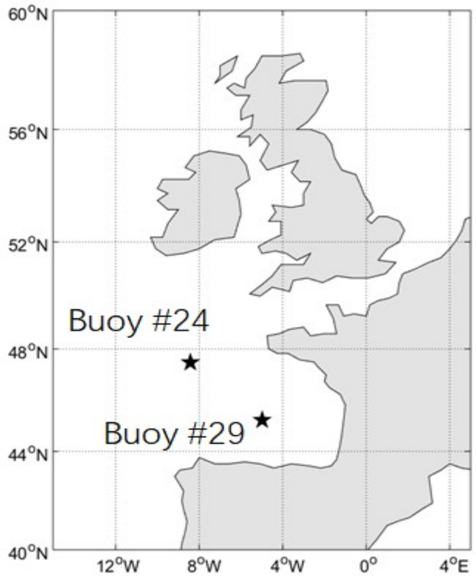
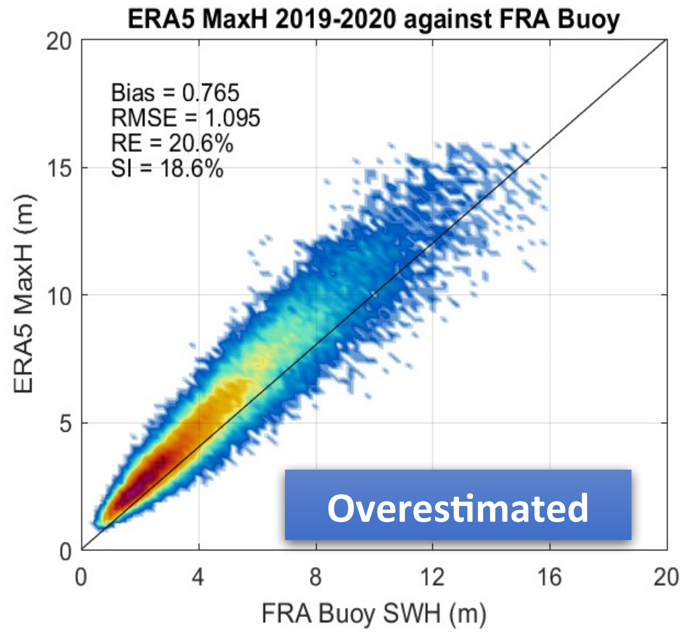
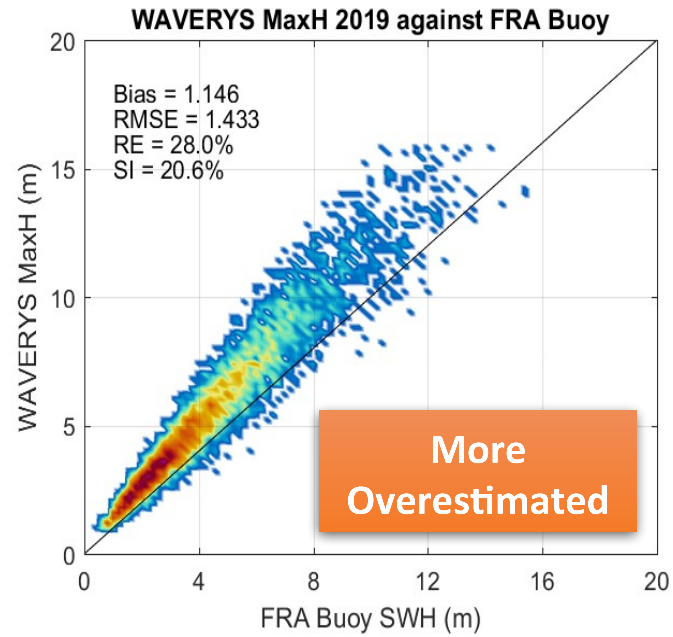
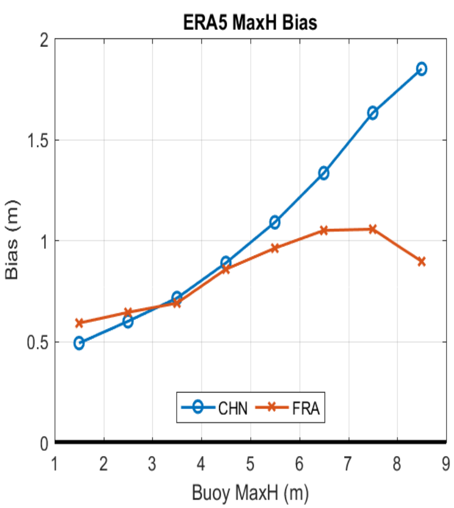
Forte croissance du BFI2D et la corrélation crête/creux

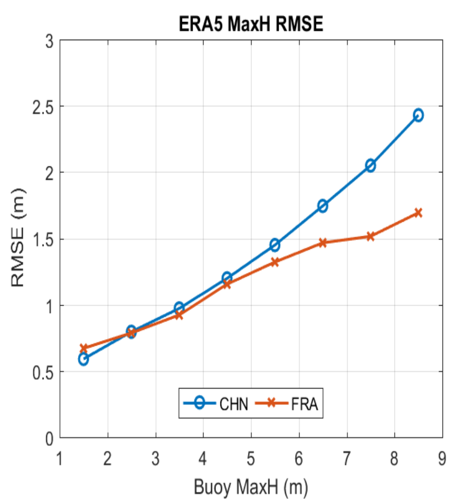
MaxH from ERA5 and WAVERYSreanalysis : Assessment against French Buoys

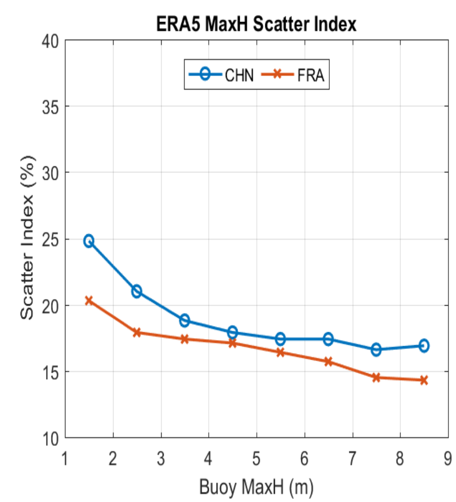


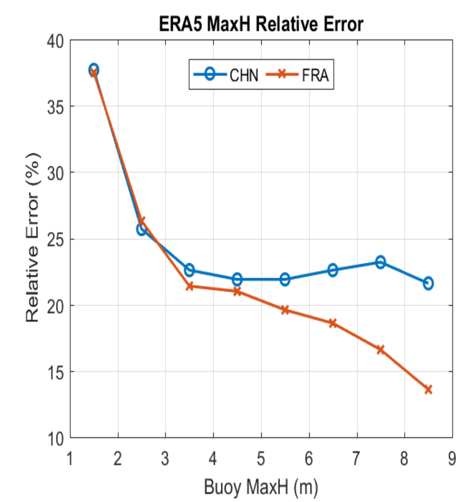












Objectives and Method (see Jiuke Wang, poster)

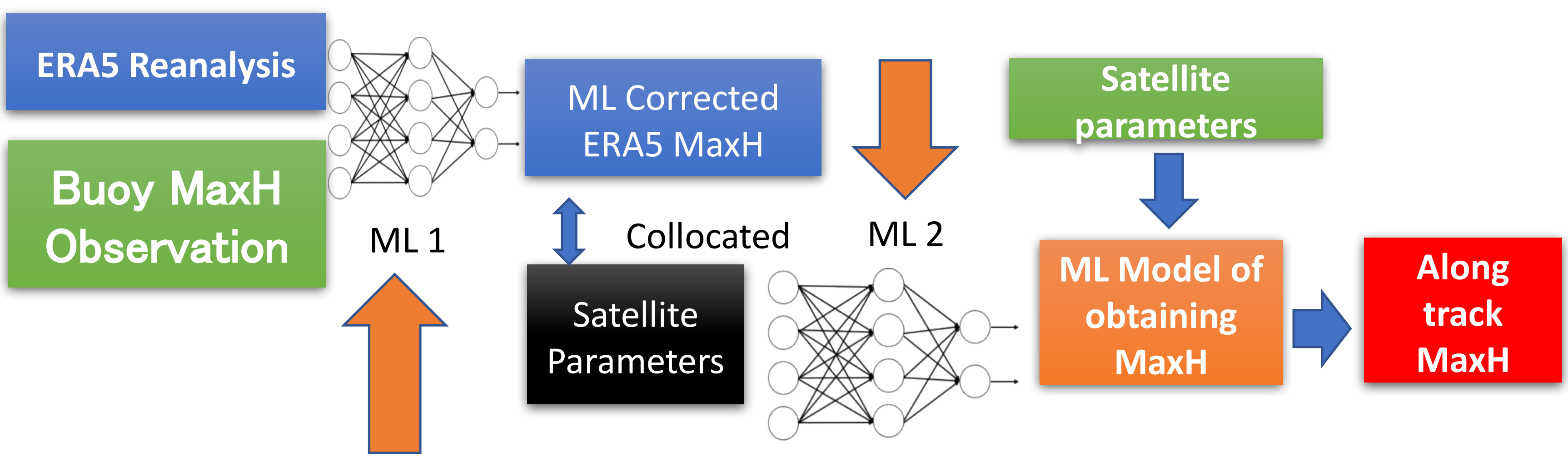
The objective: obtain the MaxH based on Along Track observation through ML

Accurately Capture the Individual Freak Wave

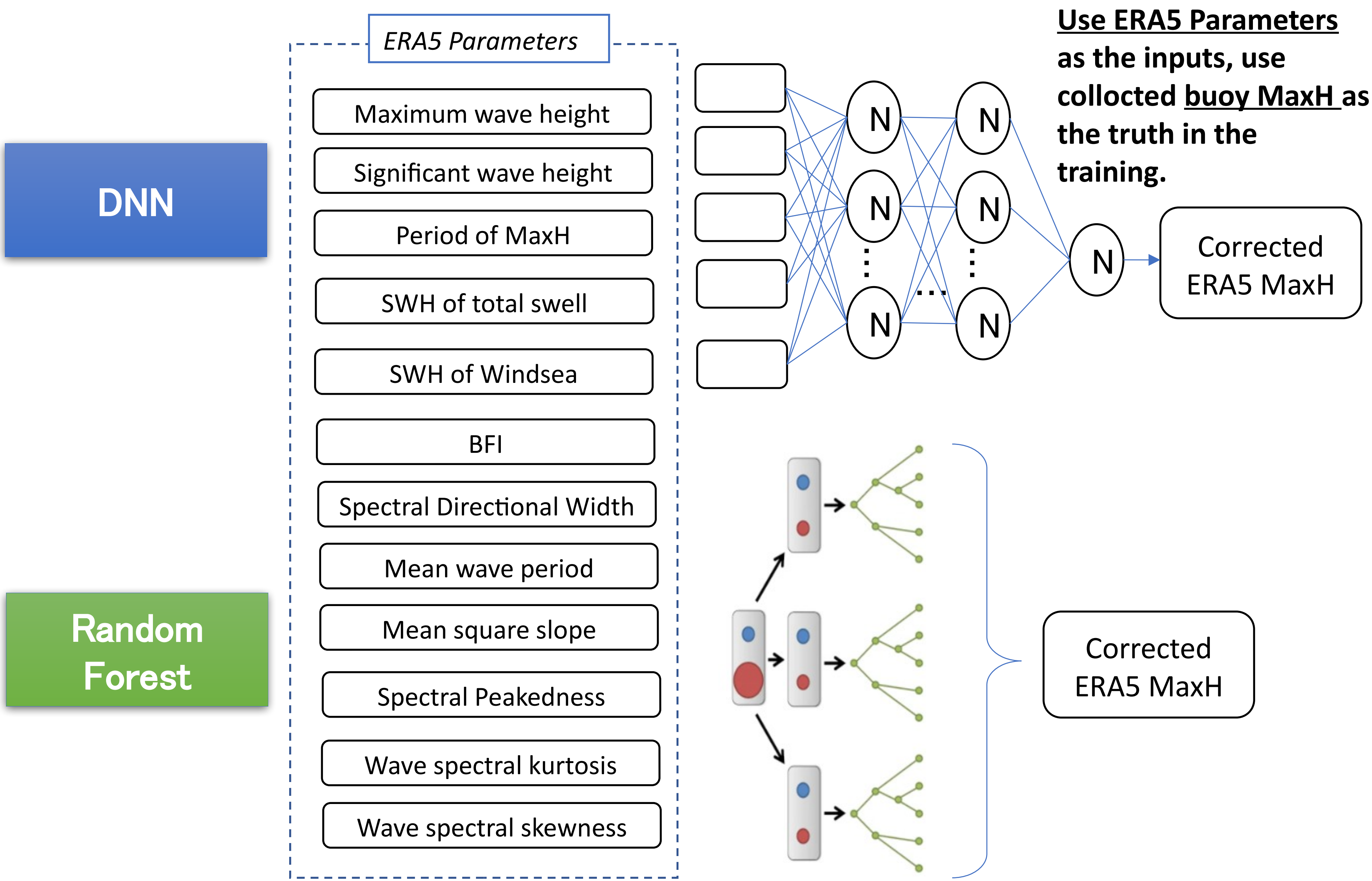
Obtain the Similar Distribution of MaxH/SWH

The Method:

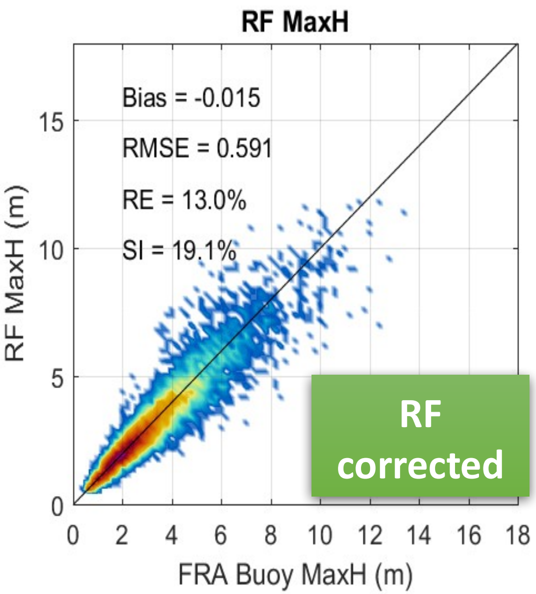
1) Build ML model to correct ERA5 MaxH against buoy observation (use buoy MaxH as truth);
2) Correct ERA5 MaxH using ML, and collocate HY2/CFOSAT with ERA5
3) Build ML model 2 to obtain MaxH from satellite parameters (use corrected ERA5 as truth)
4) So ML 2 is the model to obtain MaxH from satellite.

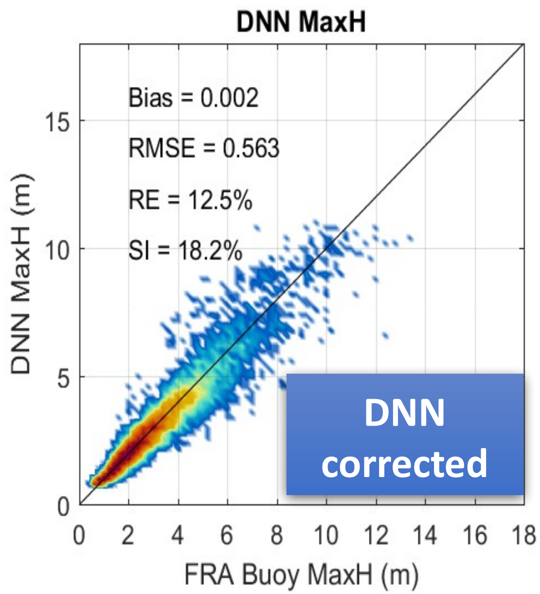


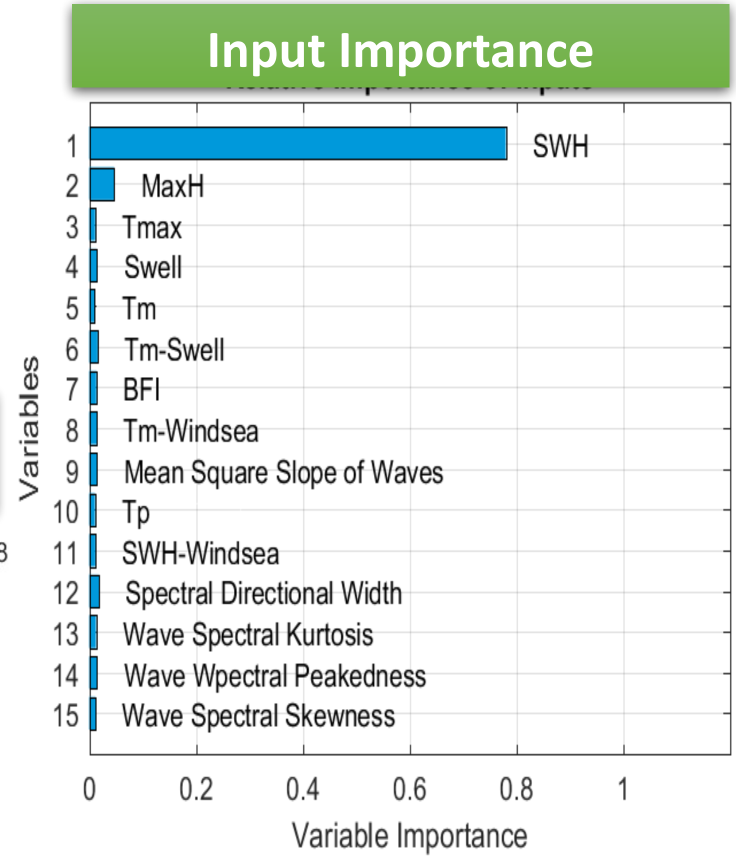
ERA5 MaxH Correction from DNN and Random Forest

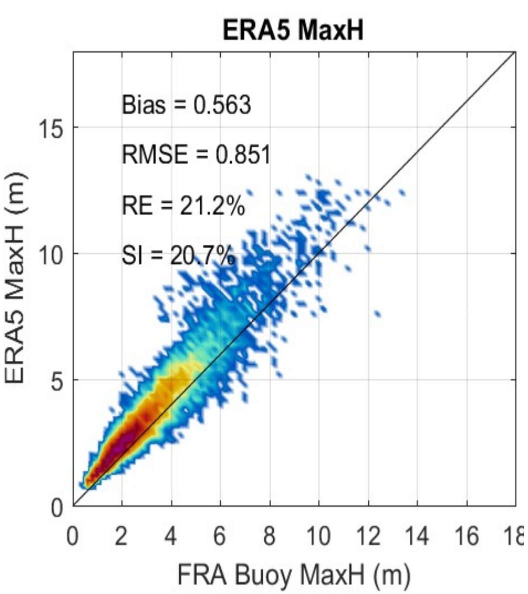


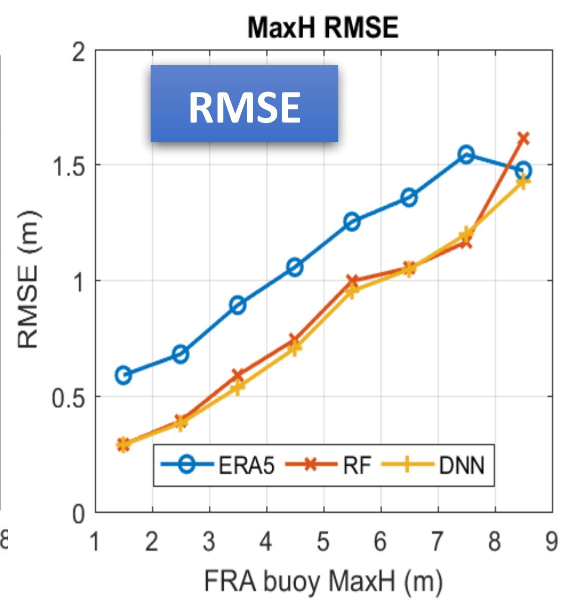
DNN and RF MaxH Correction Comparisons on Test Datasets





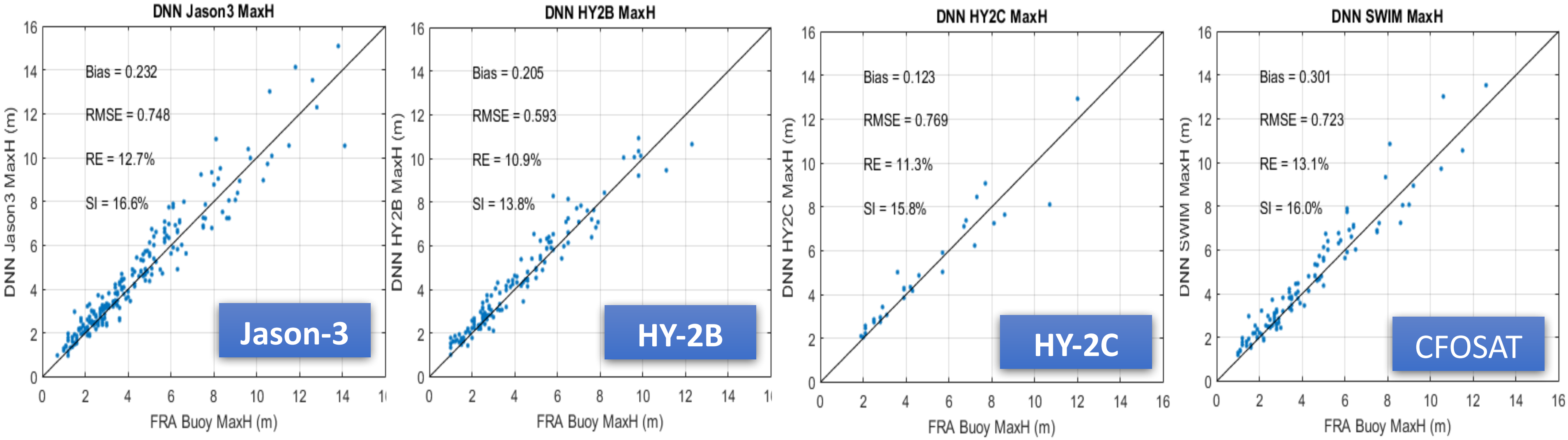






	Bias	RMSE	RE	SI
ERA5	0.56	0.85	21.2%	20.7%
RF	-0.02	0.59	13.0%	19.1%
DNN	0.0	0.563	12.5%	18.2%

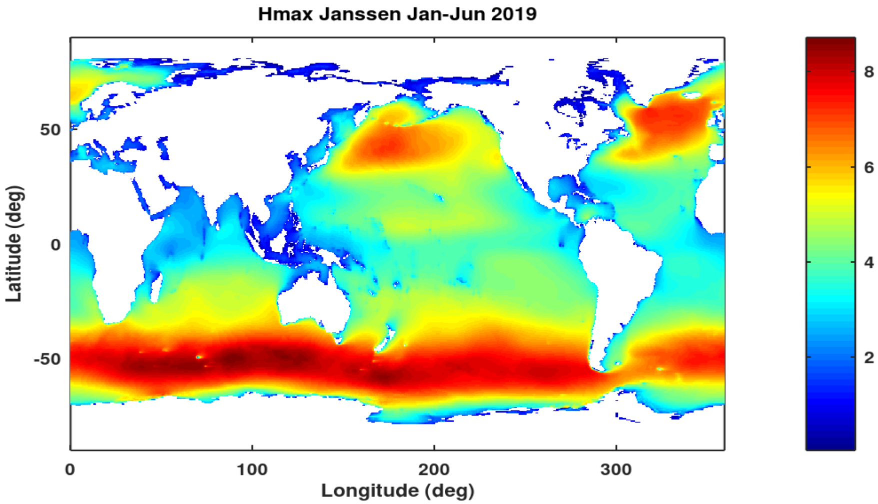
Satellite MaxH Assessment Against French Buoys



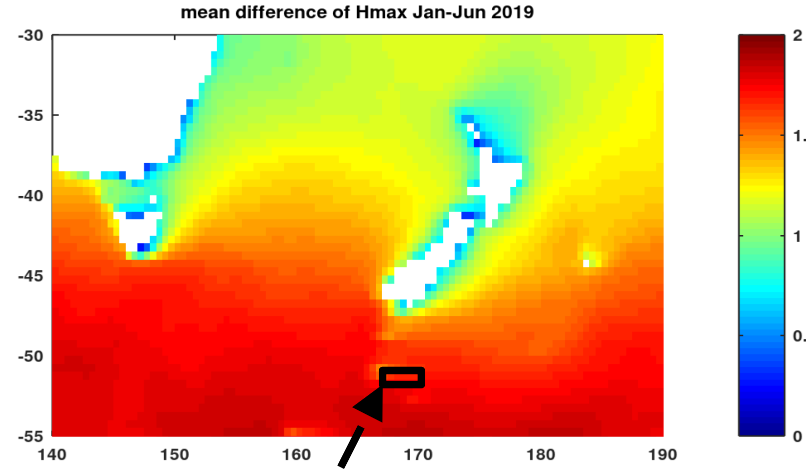
	ERA5	Jason-3	CFOSAT	HY-2A	HY-2B	HY-2C
Bias (m)	0.765	0.232	0.301	-0.035	0.205	0.123
RMSE (m)	1.095	0.748	0.723	0.764	0.593	0.769
Relative Error (%)	20.6	12.7	13.1	12.4	10.9	11.3
Scatter Index (%)	18.6	16.6	16.0	16.6	13.8	15.8

Validation at Campbell Island Southern Ocean : Jan-Jun 2019

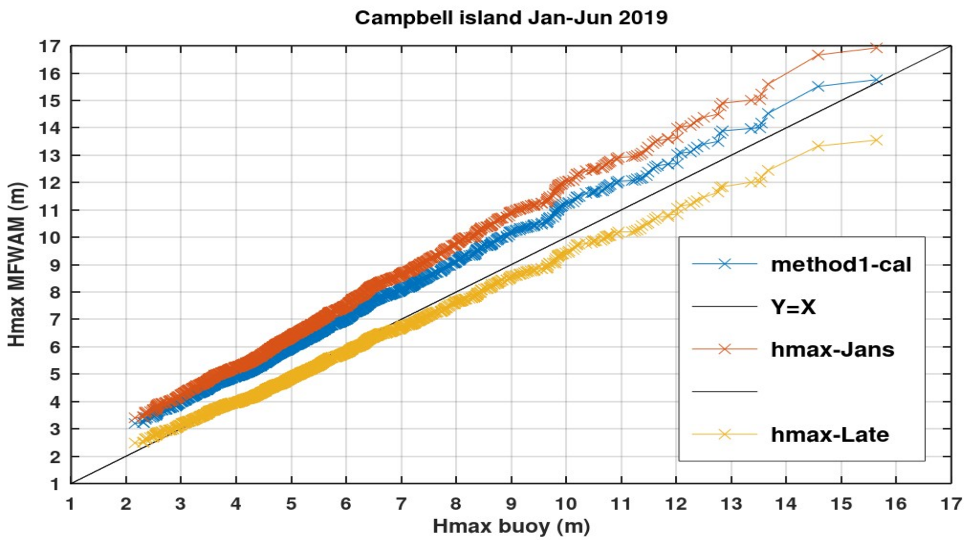
Mean Hmax from CMEMS-MFWAM



Mean difference Hmax (Janssen-Latemar)



Campbell Island buoy location (52.7°S-169°E)



Hmax Q-Q plot from model and buoy

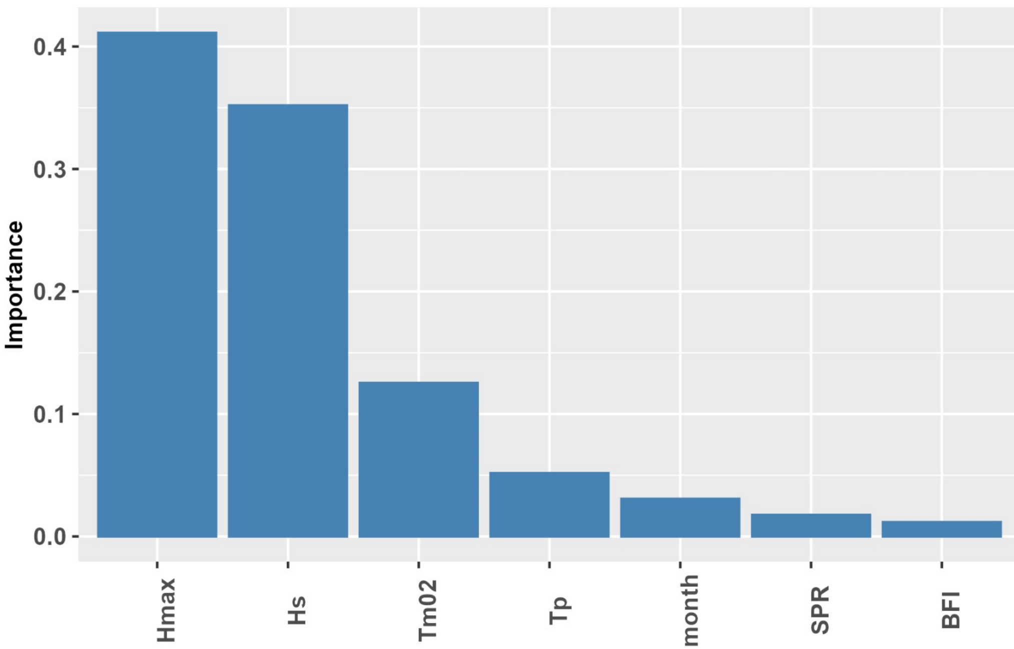
	janssen	Latmar	Janssen-Cal
Bias (m)	1.48	-0.19	1.01
SI (%)	16.8	15.3	15.9

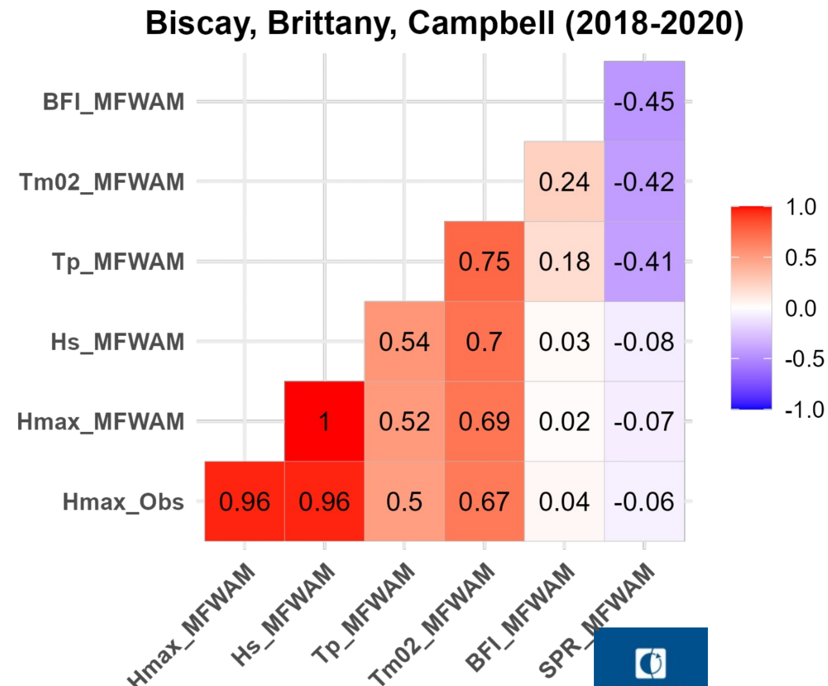
In the SO, Hmax > 10 m is oftenly occurred and
The Latemar method is misfiting strongly the estimate.
Janssen method can be improved.

Calibration of Hmax from NRT by using Deep Learning scheme : Brittany, Biscay and Campbell island

- Input for the DNN training : Hmax, SWH, Tm02, Tp, month, Directional Spreading, BFI
- Learning methods : ANN, Random Forest, Gradient Boosting

Sensitivity to inputs : the most important SWH, Hmax and TM02





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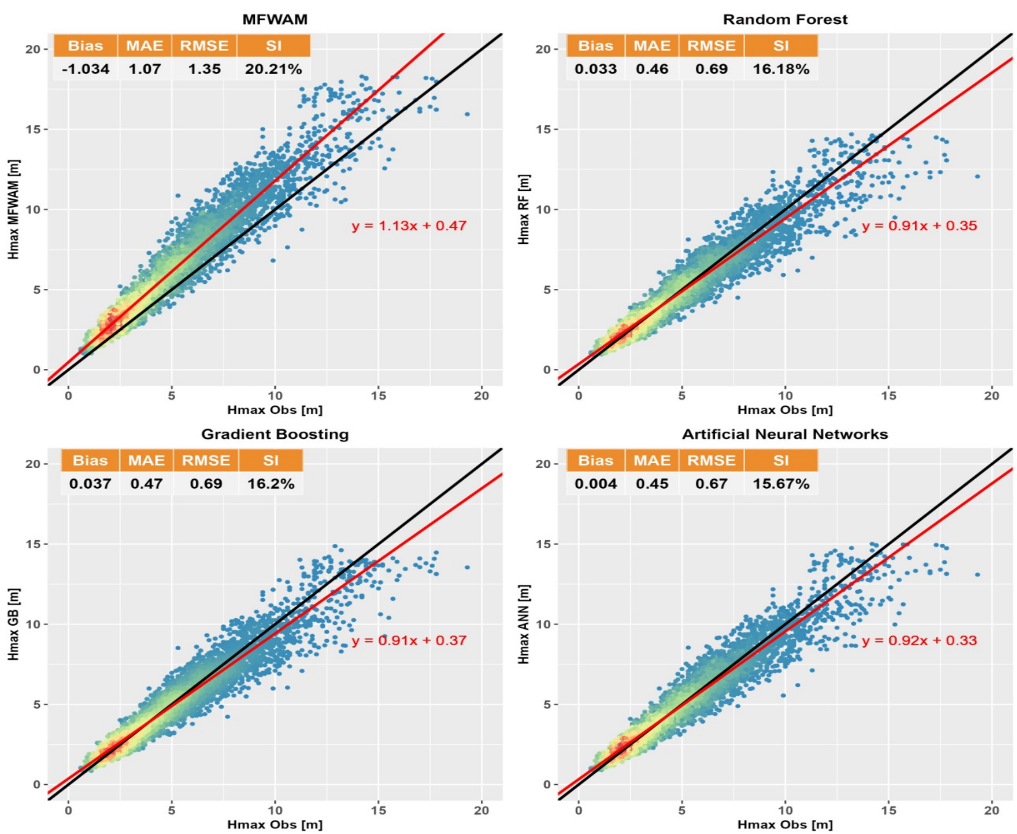
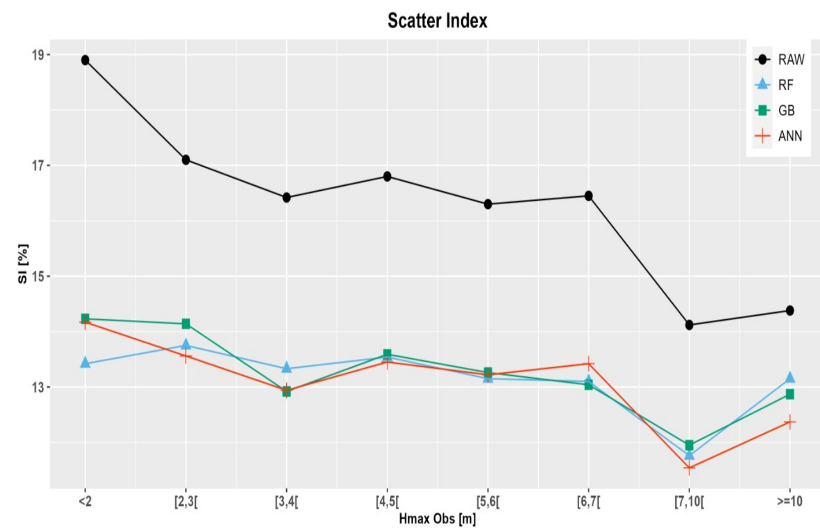
Deep Learning correction with several technique : ANN, Ranom forest Gradient boosting

Scatter plots show the significant reduction of bias after deep learning correction



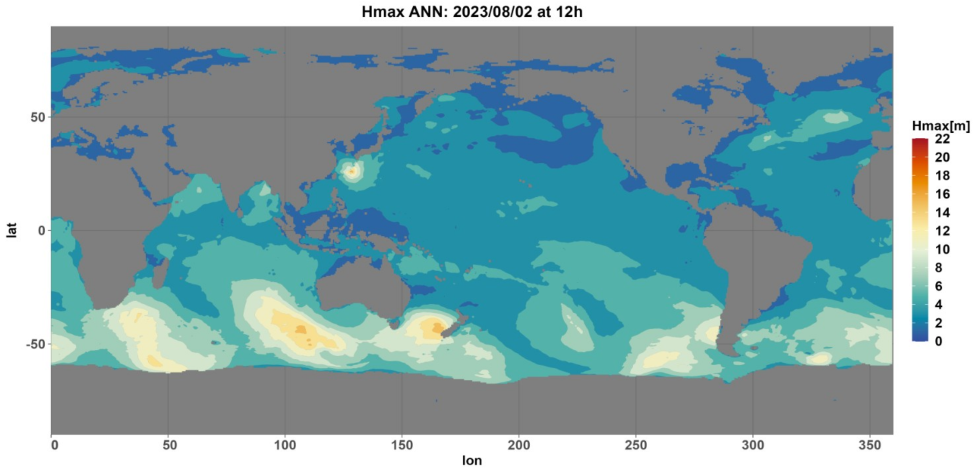
Significant improvement of SI for different range of Hmax and the best estimate is for ANN (Neural Network)



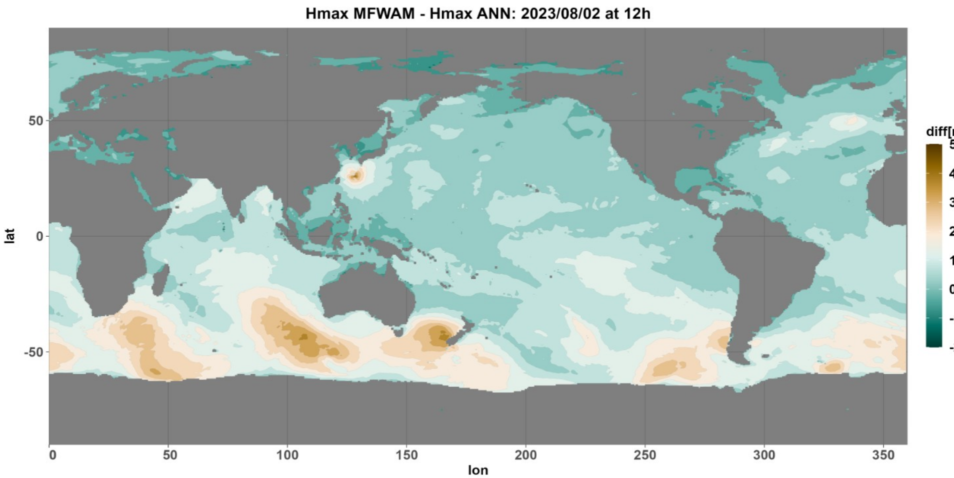
SI variation with Hmax range

Example of Hmax (CMEMS-global) with ANN : 2 August 2023 à 12h UTC

Hmax ANN



Difference of Hmax (wo/w ANN)

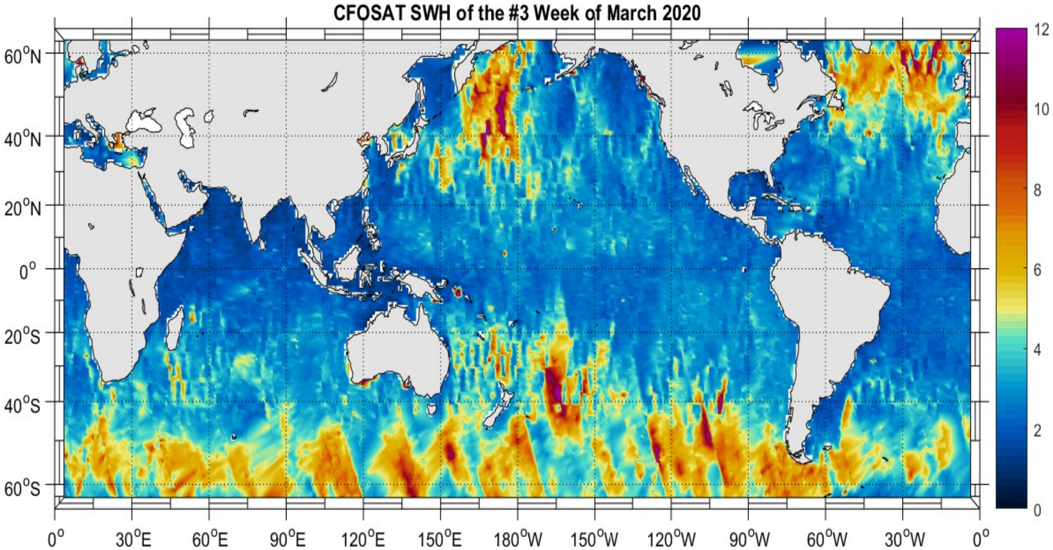


Moins de points d'occurence Avec ANN : éviter les fausses alertes

Strong difference in Southern ocean and North-East Atlantic during storm

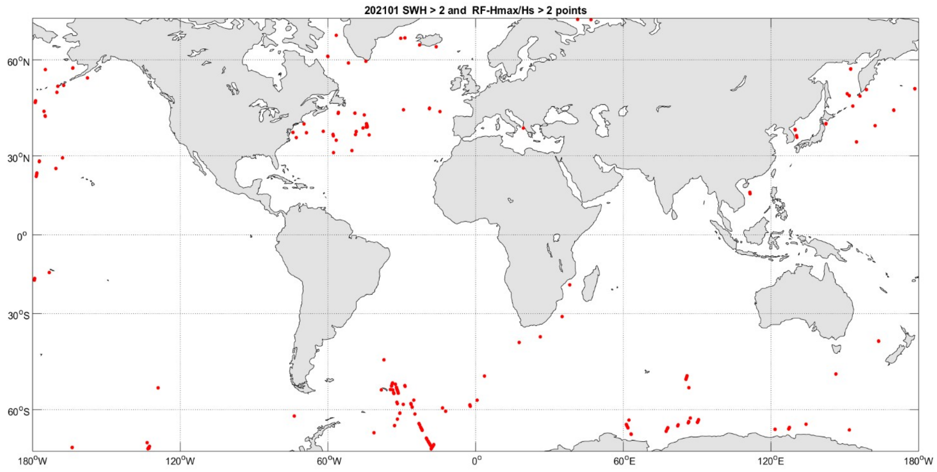
The first time predicting max. wave height from satellites

Maximum wave height from CFOSAT
During 3rd week of March 2020



Example from CFOSAT
For 2021

Estimate of Hmax/SWH>2
Rogue waves detection
Relevant for ship navigation



Key messages

➔ Remarkble impact induced by the assimilation of wide swath SWH and wave spectra on integrated wave parameters : improvement of wave tracking in extreme conditions

➔ Using both SWH and directional wave spectra improves ocean/waves coupling and ocean circulation in upper layers

➔ Preparation for a longer period wide swath data with HY2B, HY2C and HY2D, CFOSAT, and wave spectra from CFOSAT (SWIM) and S1 (SAR) missions

➔ Directional wave observations enhances the persistency of the assimilation in the forecast (3 to 4 day of efficiency).

➔ Deep learning technique has been used successfully to retrieve Maximum wave height : Promising perspective of detecting rogue waves from HY2 and altimetry missions.

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Perspectives

- Exploit wide swath SWH in operational use : production as a level-3, which needs support from Dragon-5 (ESA/MOST).

- Retrieval of Hmax from altimetry will be assessed and used to set a rogue waves Indicator.

- Enhance the analysis on the impact of combined assimilation on ocean/wave coupling