On the assimilation of wide swath SWH and directional wave observations : A synergy between HY2B & 2C, CFOSAT and Sentinel-1 missions

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OUTLINE

1- Motivation

2- Methodology and data description

3- Results and discussions

4- Deep learning for Maximum wave height

6- key messages

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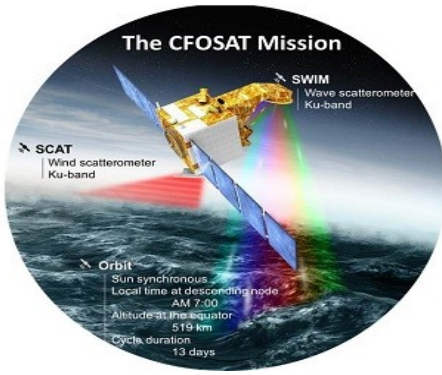
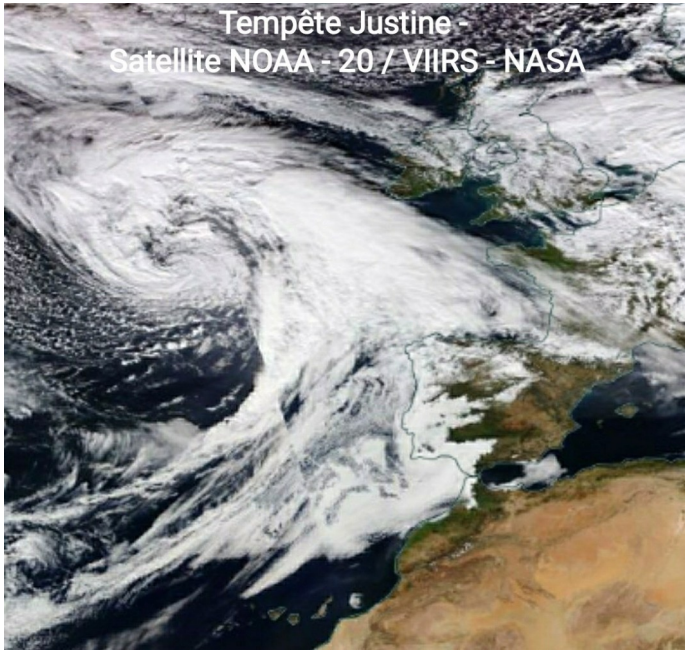
Motivation

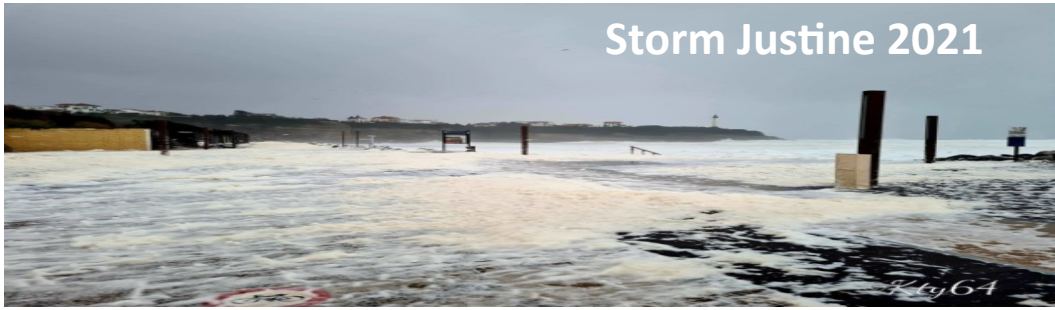


- **Development of wide swath SWH on Scatterometer/Altimeter joined mission HY2B-2C or CFOSAT. Retrieval model based on Deep Learning (Wang et al. GRL 2021).**

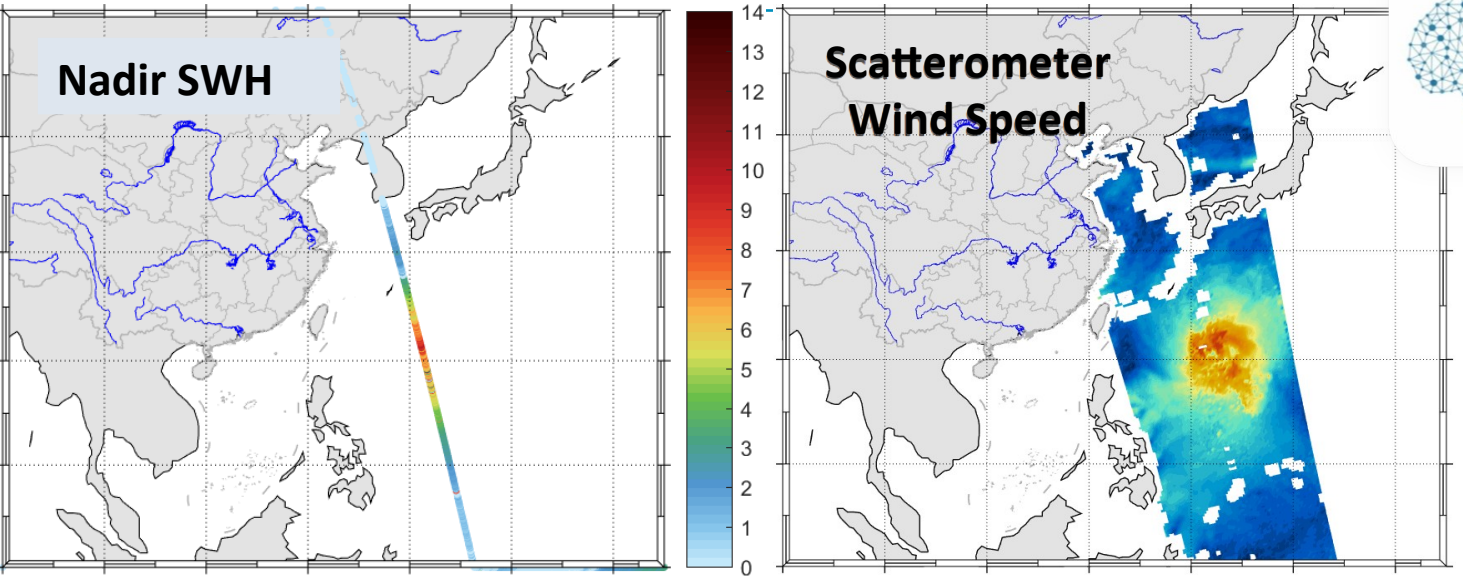
- **Synergy between directional wave observations from CFOSAT and Sentinel-1 :**
  → Better scaling of swell propagation under severe severe storm conditions (such as in Southern Ocean).

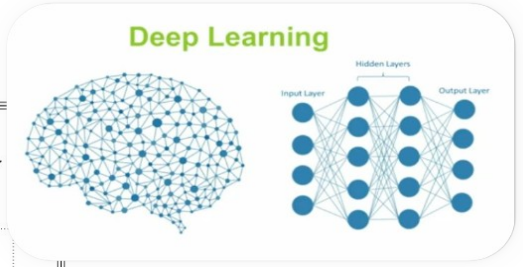
- **Evaluation of the impact of assimilating both wide swath SWH and directional spectra in order to improve Wave reanalysis and investigating consequences on atmosphere/ocean coupling**



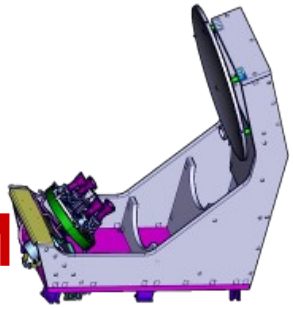


Synergy between wind and wave (nadir+ directional) observations





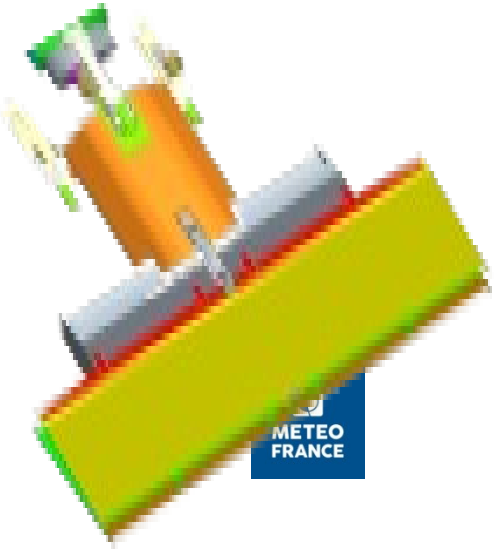
- **SWIM**



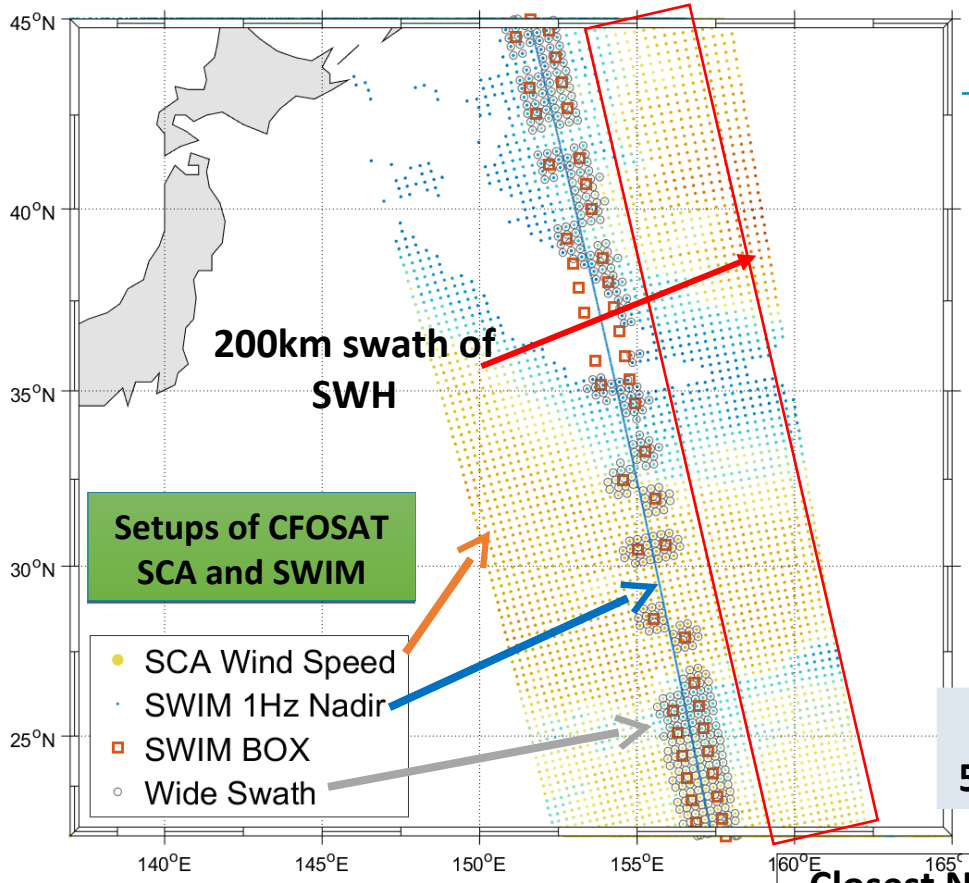
Nadir SWH and wave spectra from beam measured by SWIM

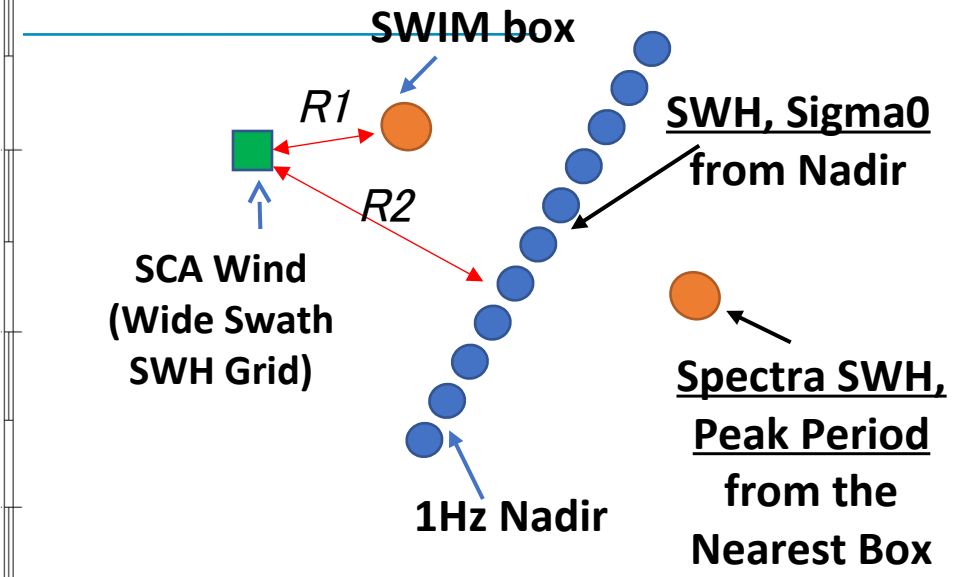
- **SCAT**

Wind vector on Swath from scatterometer



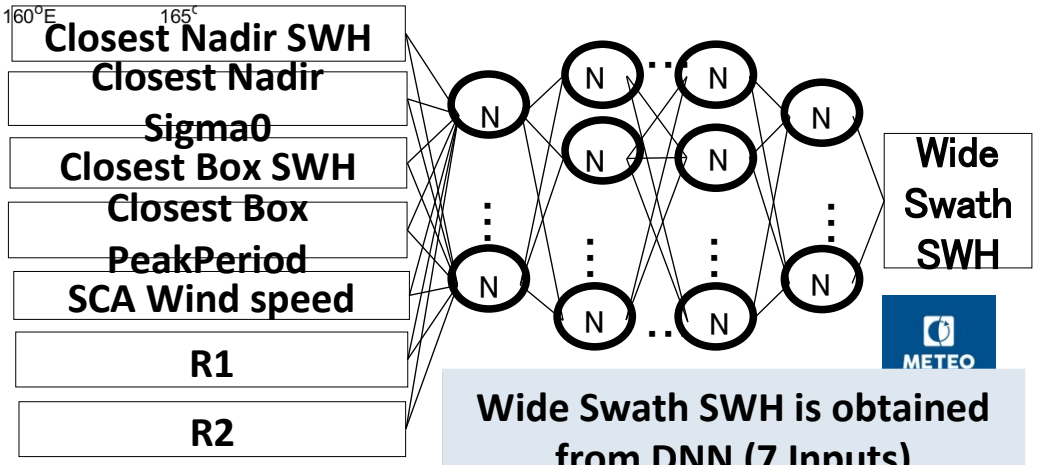
Deep neural network based retrieval of wide swath SWH (Wang et al. 2021)





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

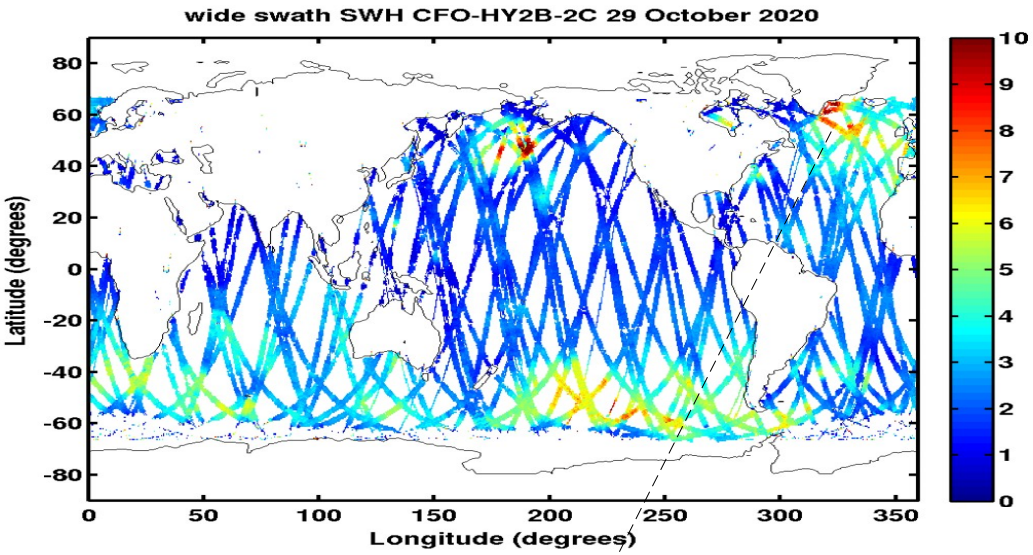


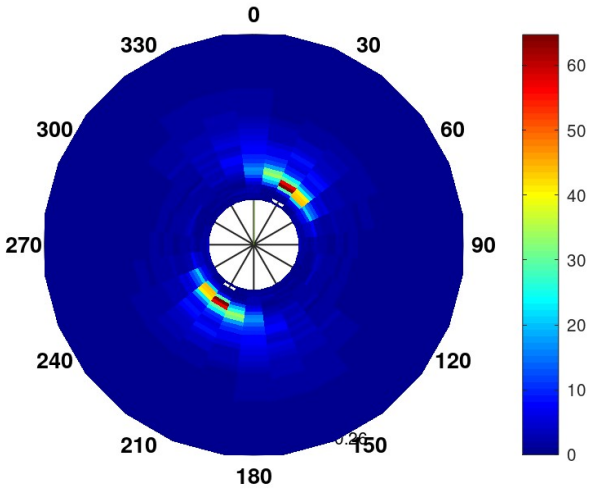
Wide Swath SWH is obtained from DNN (7 Inputs)

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

CFOSAT/SWIM : wavelength range 60-500 m)

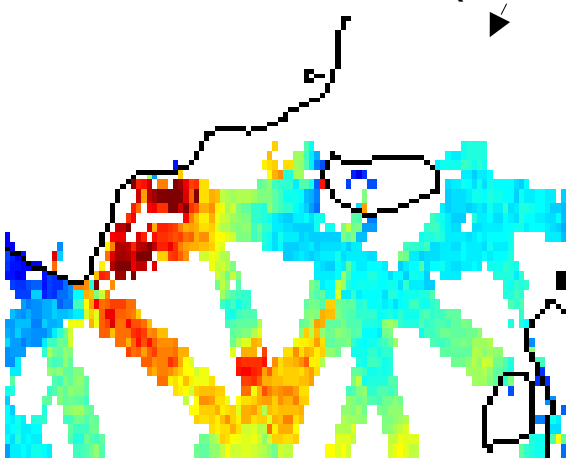
1-day coverage of wide swath SWH CFO-HY2B-2C 28 October 2020

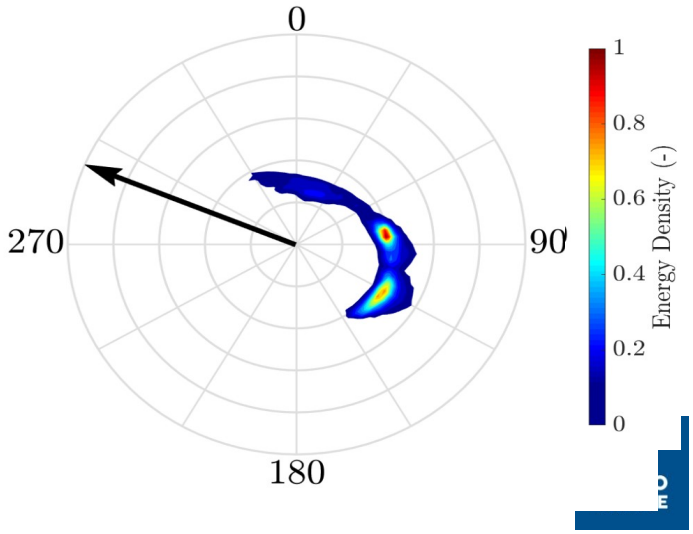




S1/SAR : wavelength range 200-800 m)

Interest for coastal zones (zoom on Iceland)





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 october 2019-December 2020 :

-Run A : DA with Wide swath SWH (multi-missions) and wave spectra from CFO and S-1
-Run B : DA of Wide swath SWH (1 mission)
-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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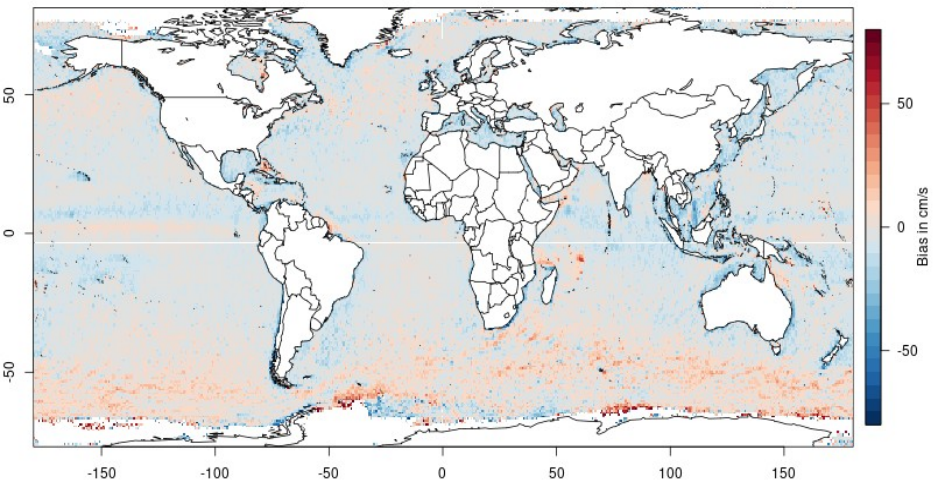
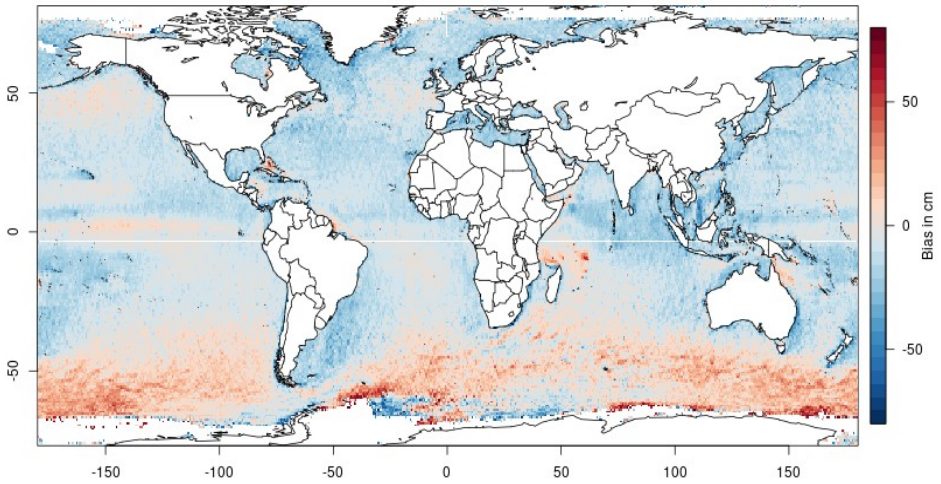
Impact of the assimilation of wide swath and directional wave spectra
Austral winter (May-Aug 2020)

With DA

Bias map (max. 60 cm)

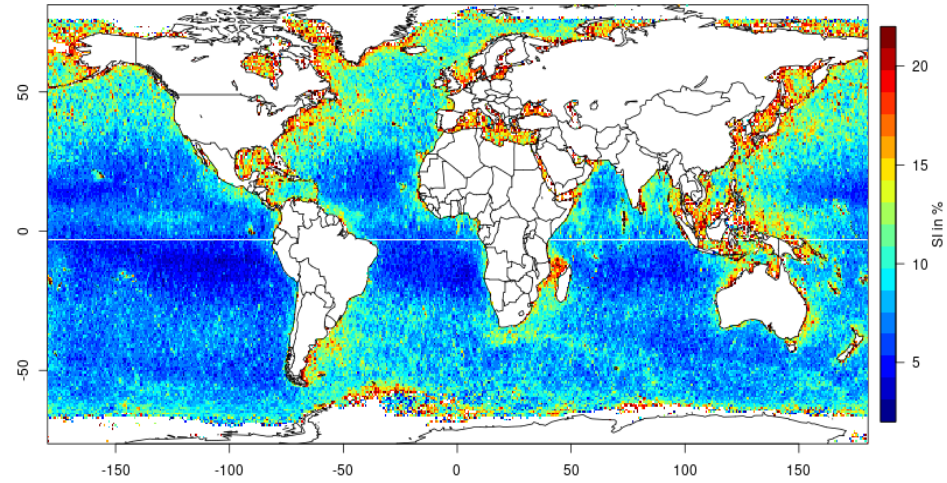
Without DA

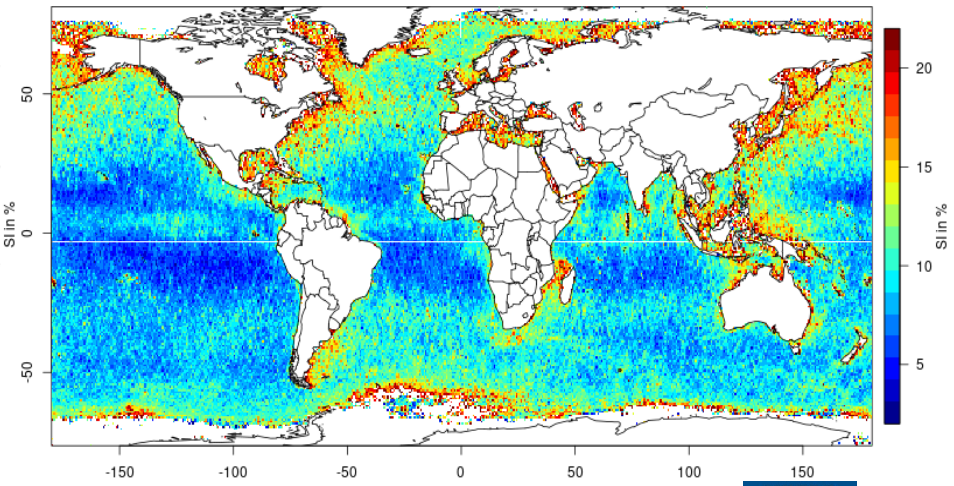




Remarkable bias reduction
Induced by DA (SO and mid lats)

Scatter index map (%)





The smaller scatter index is, the better

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

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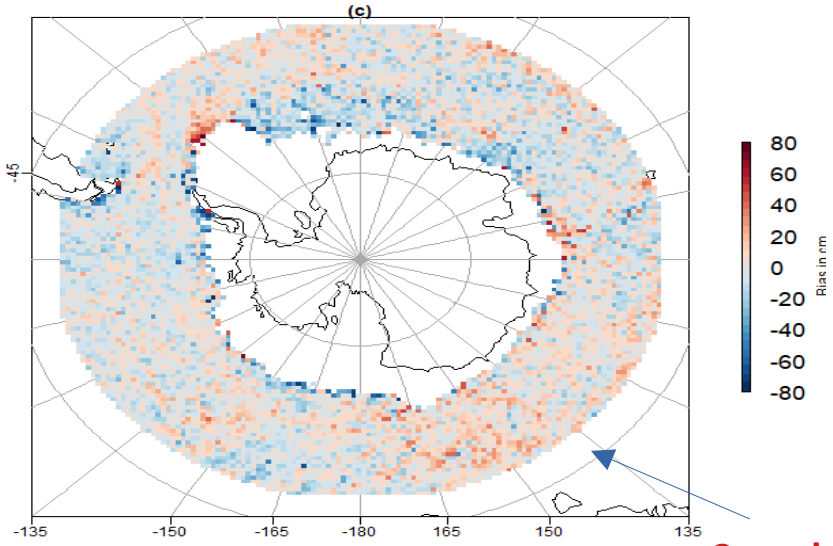
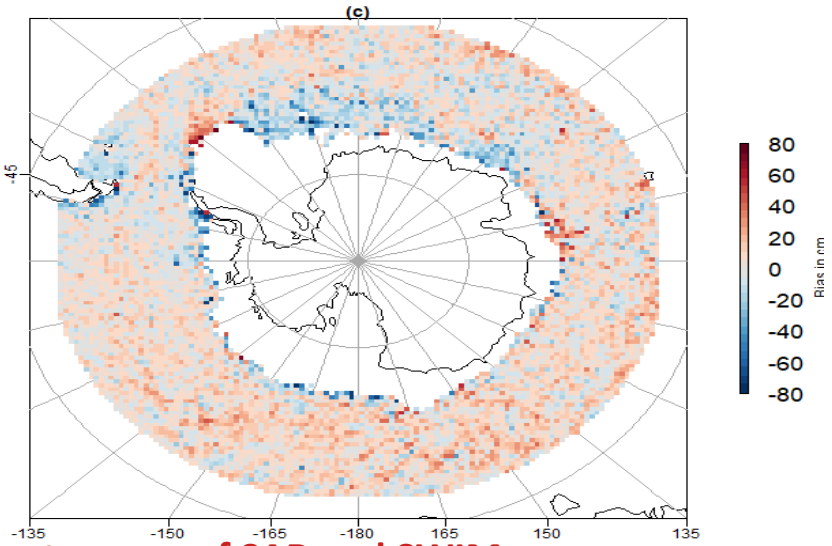
Performance in Southern Ocean and complementary use of SWIM and SAR directional wave spectra : May-Aug 2020

Bias maps (max. 80 cm)

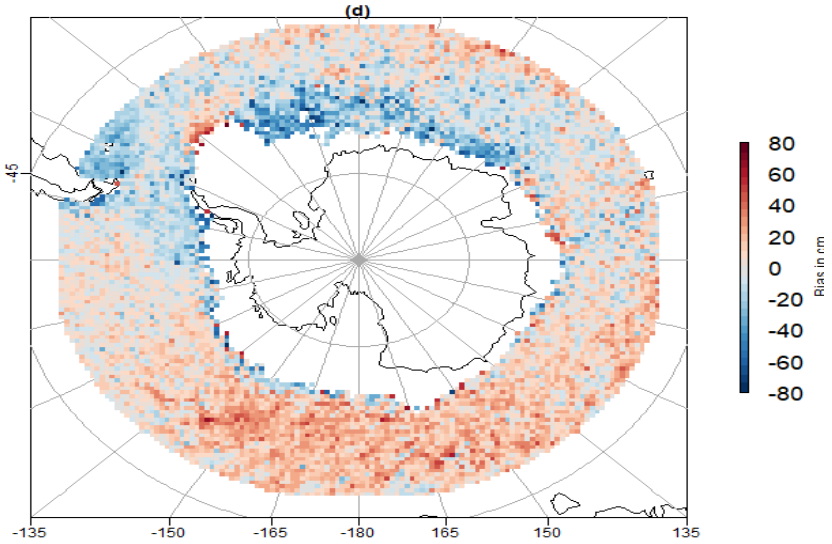
With DA wide+SWIM+SAR



With DA wide+SWIM

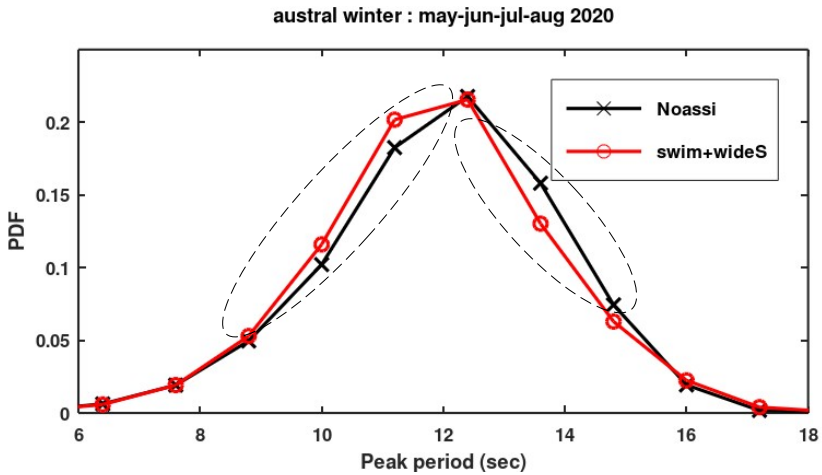


Without DA

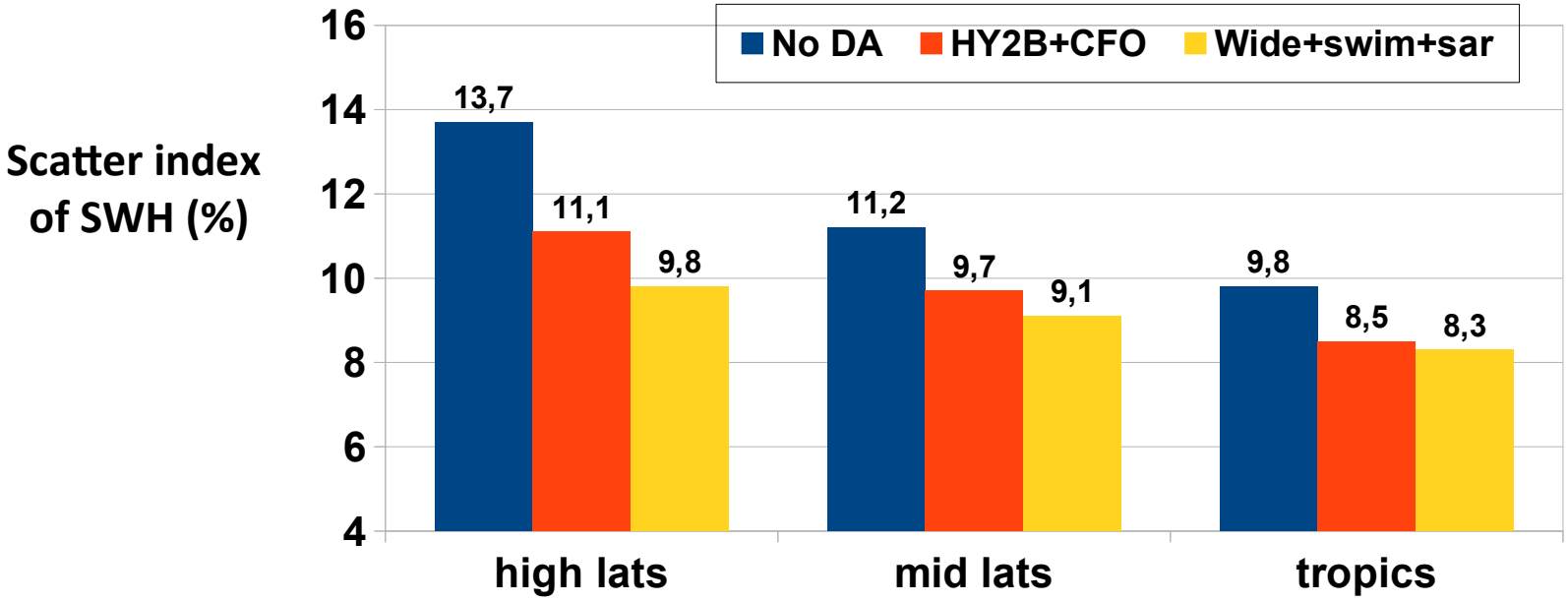


Complementary use of SAR and SWIM wave Spectra enhances SWH bias reduction in SO

Improvement of peak period Tp PDF with DA



Performance of DA in different ocean basins from May-Aug 2020
Comparison with SWH from altimeters (Jason-3,Saral,S3)



The scatter index of SWH is significantly improved when using wide swath SWH and Wave spectra (yellow bars) in all ocean basins compared to using only SWH (red bars) the strongest impact is obtained in high and mid latitudes

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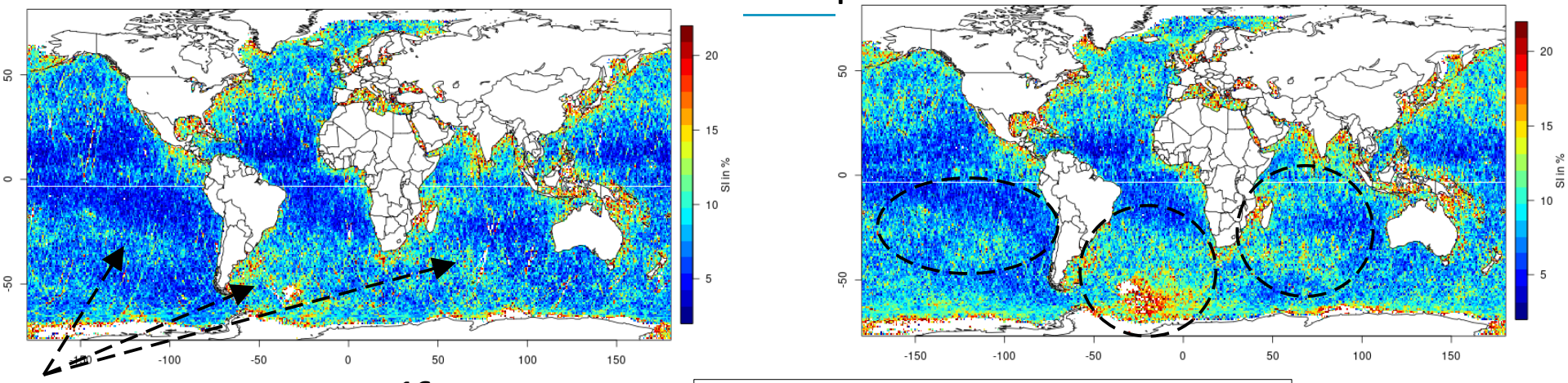
Performance of synergy between satellite missions (Jan. & Feb. 2021)

Mult-missions (wide swath CFO-HY2B-2C)

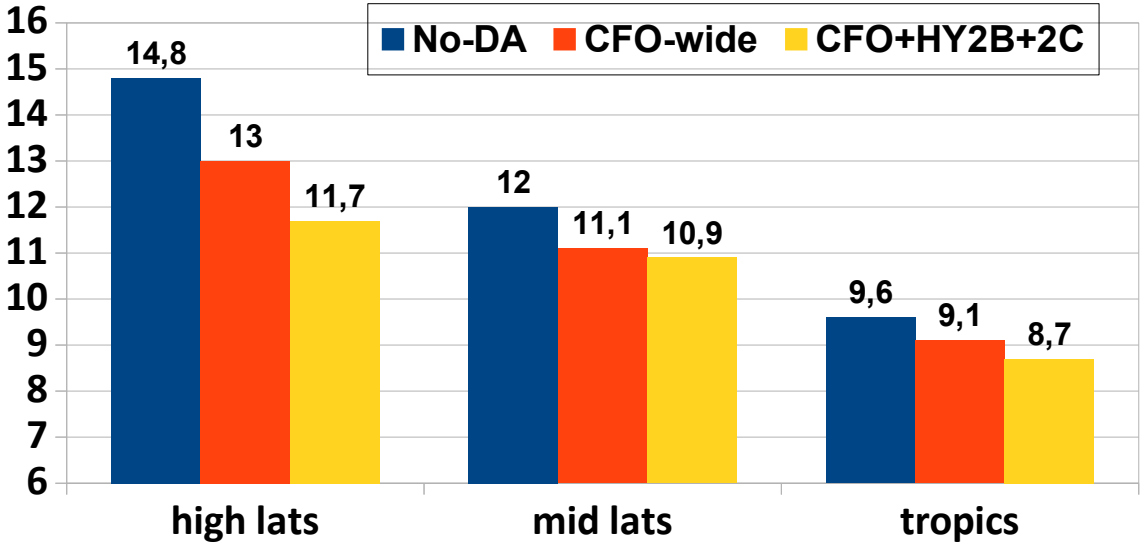
Scatter index (%) maps

CFO mission (wide swath)



Enhanced impact in mid and high lats

Scatter index of SWH (%)



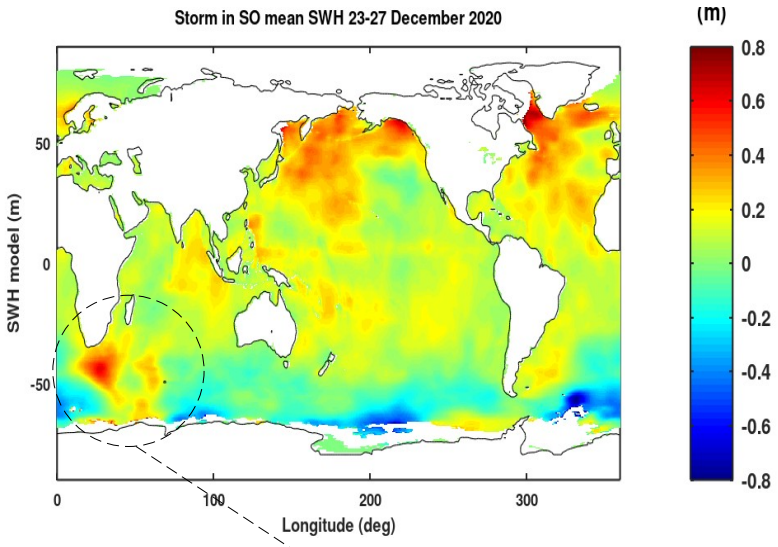
Significant reduction of scatter index of SWH when using CFOSAT spectra and wide swath. The reduction is enhanced by adding wide swath of HY2B and 2C.

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

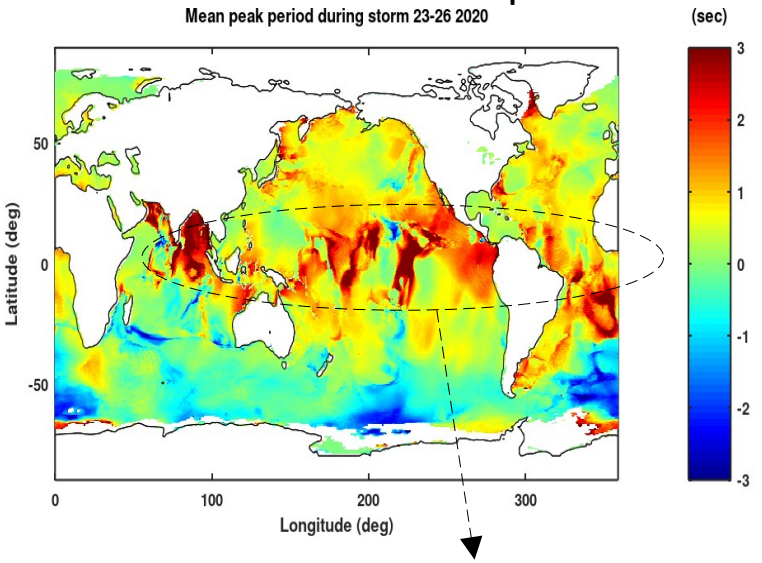
The impact of wide swath SWH and directional wave spectra in storm Conditions : 23-26 December 2020

Average of difference of parameters w/wo DA from 23 to 26 december 2020

Sig. Wave Height

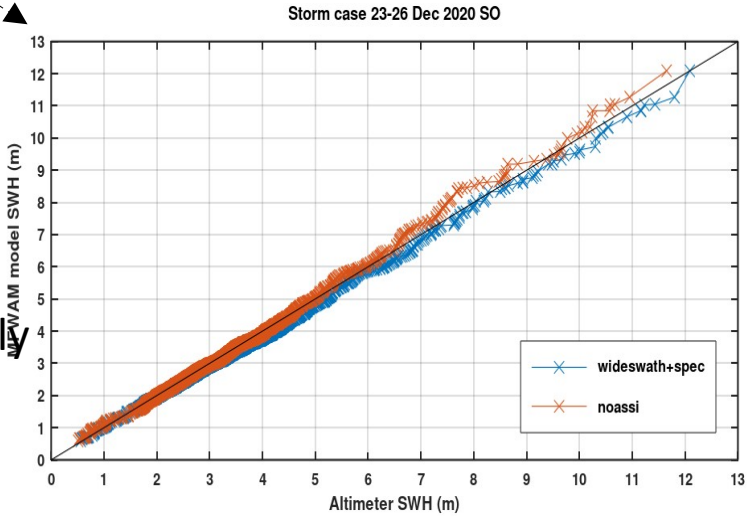


Peak period



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

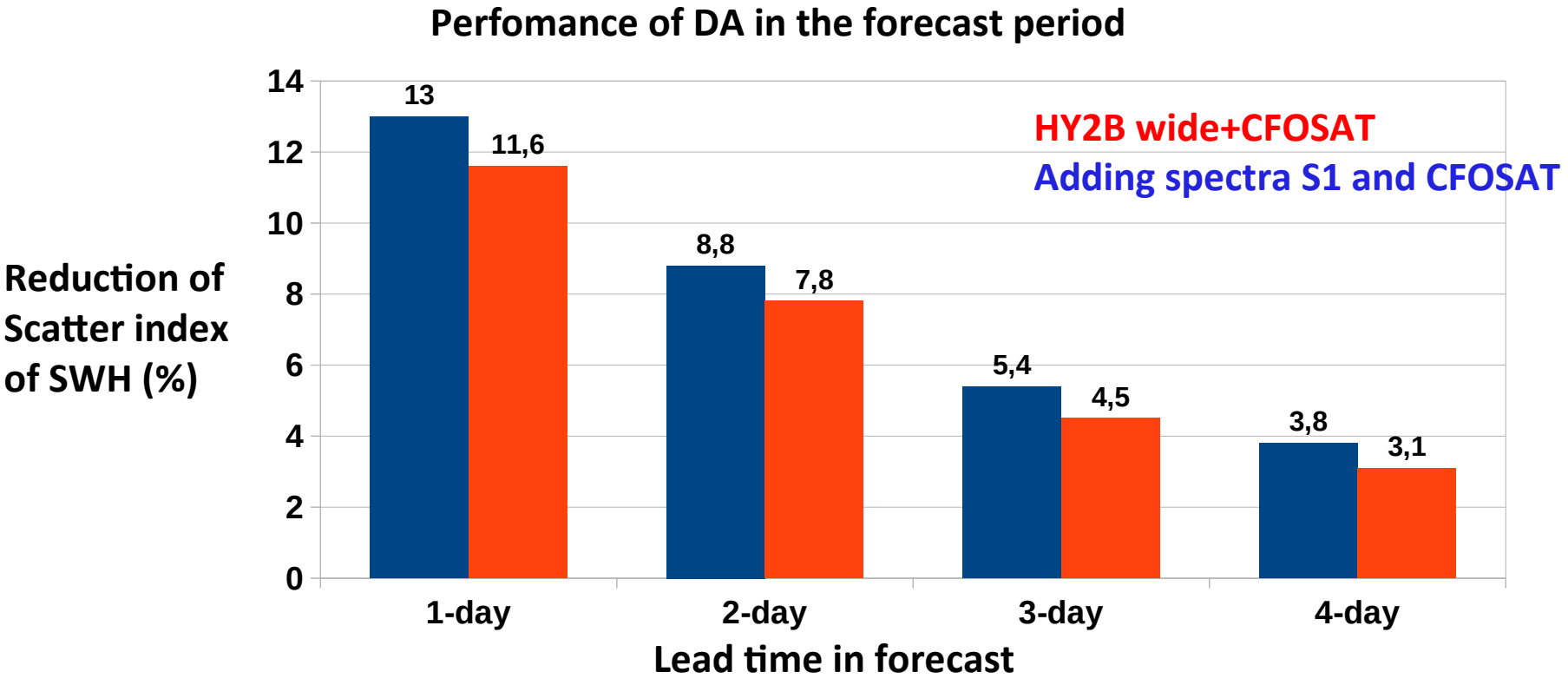
Q-Q plot of SWH
Indicates better PDF of SWH from DA (wide+spec) in Blue line particularly For high waves.



Roughly during the agulhas storm Moving to La Réunion island SWH is improved by ~16 %

Validation with altimeters (ja3,Saral, S3)

Benefit of directional wave spectra in the forecast : October 2019



Only two satellite missions with wide swath SWH keep the impact significant after 3 days forecast. The use of directional spectra from S1 and CFOSAT enhances the impact, which remains efficient after 3-day forecast

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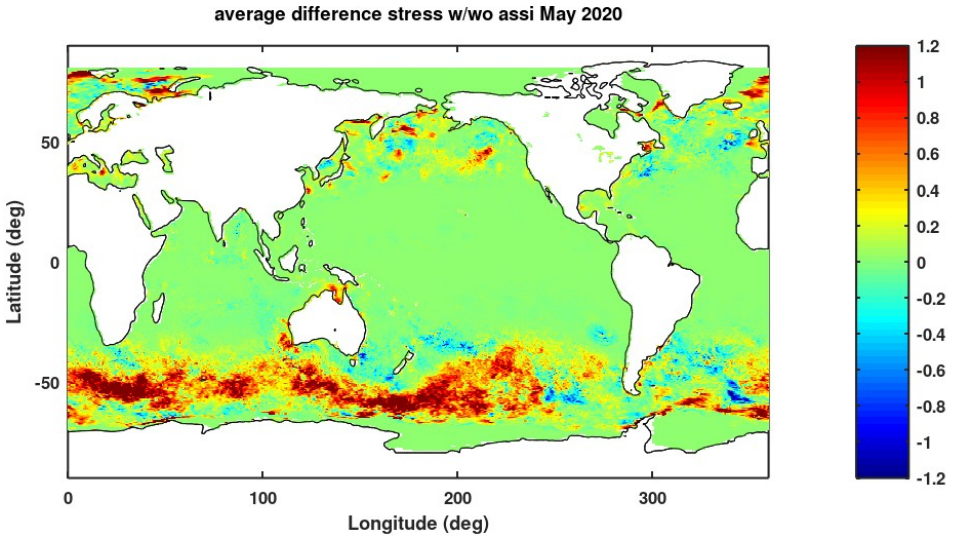
Validation with independent altimeters (Jason-3, Saral and S3)

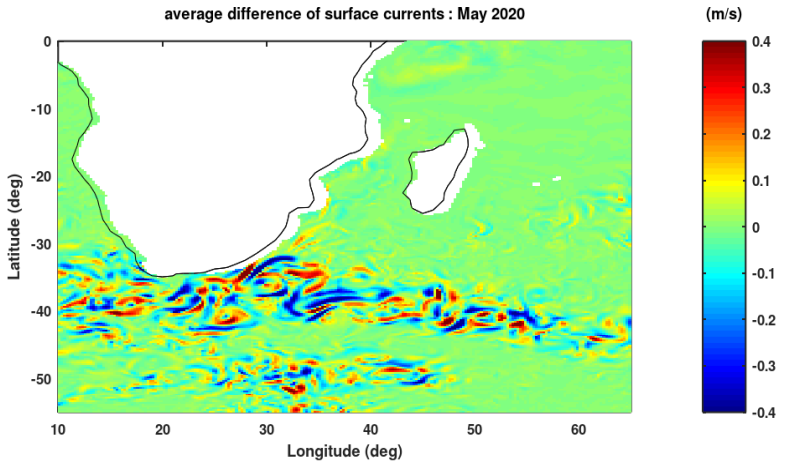
Impact of the assimilation on surface stress released to ocean

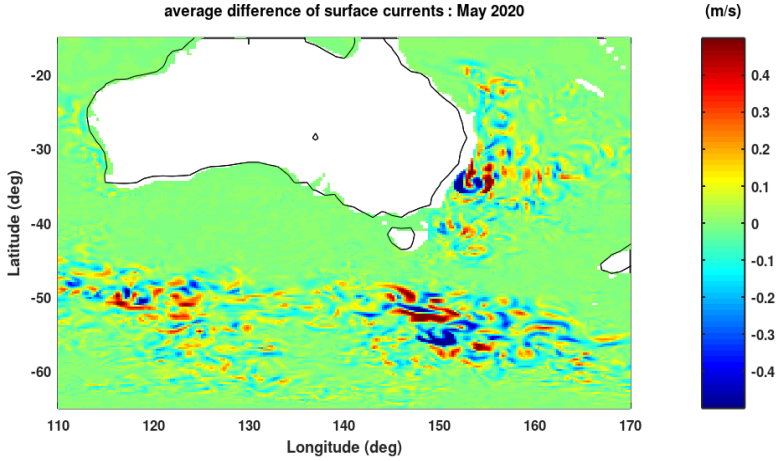
Average difference of stress w/wo DA on May 2020

Coupled ocean/wave experiments with improved wave forcing induced by the assimilation of SWH and directional wave spectra from CFOSAT :
Three coupling processes have been Included in the ocean system NEMO:
1-surface stress modified by the waves, 2-Stokes drift, 3- ocean mixing induced by turbulence from wave breaking



Impact of improved wave forcing on strong currents areas (Agulhas and ACC)
Average difference of current intensity w/wo wave forcing on May 2020

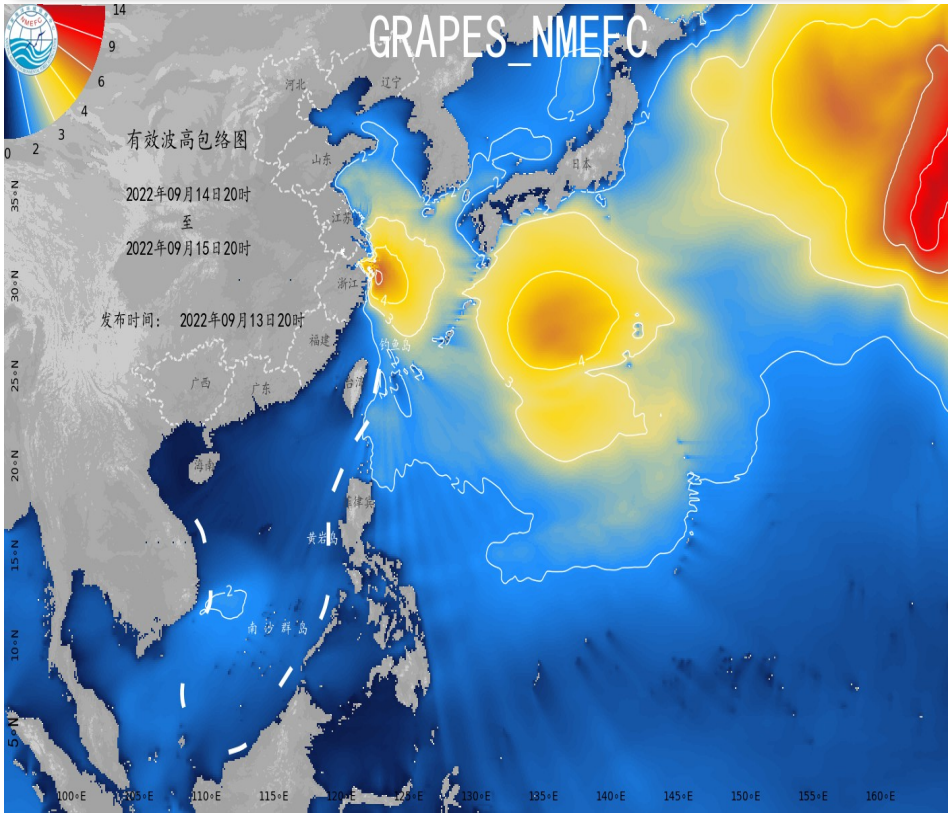




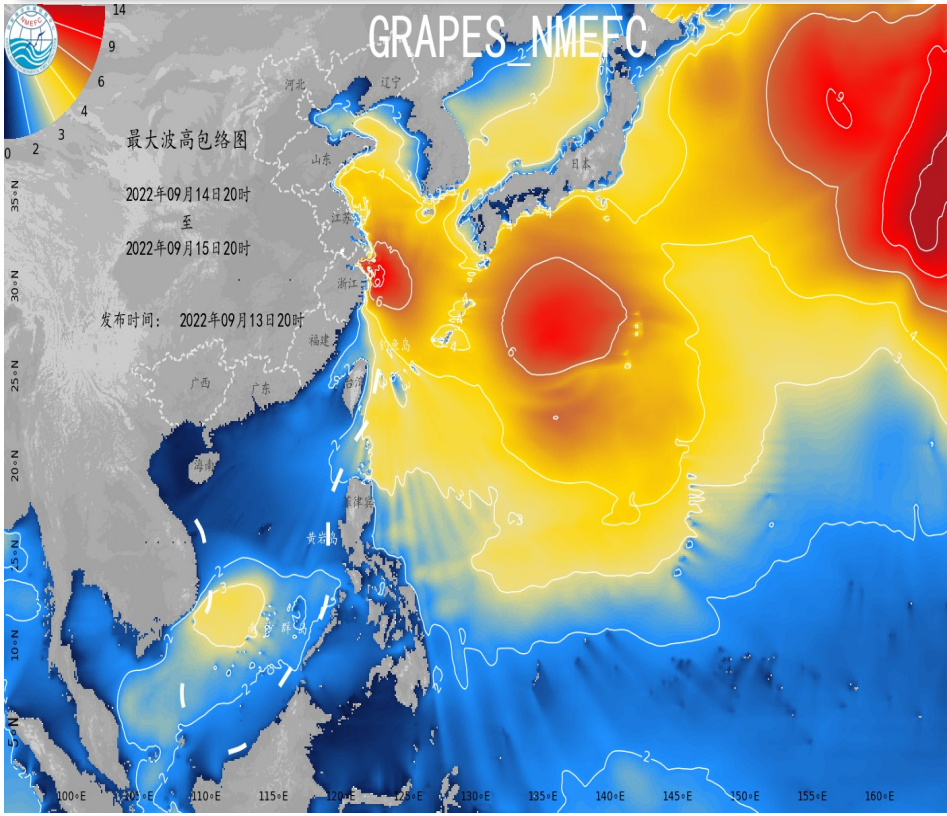
Motivation: Urgent demand for operational marine forecasting

- Max wave height (MaxH) is dangerous for ships or marine structure, NMEFC now starts to concern.
- MaxH is also a crucial symbol of “Freak Wave”.
- However, MaxH is seriously lack of observation, especially globally.
- MaxH can be obtained from wave model but from empirical methods.

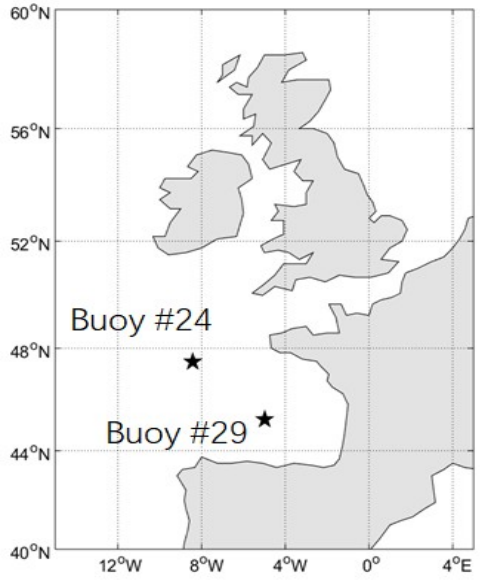
Significant Wave Height

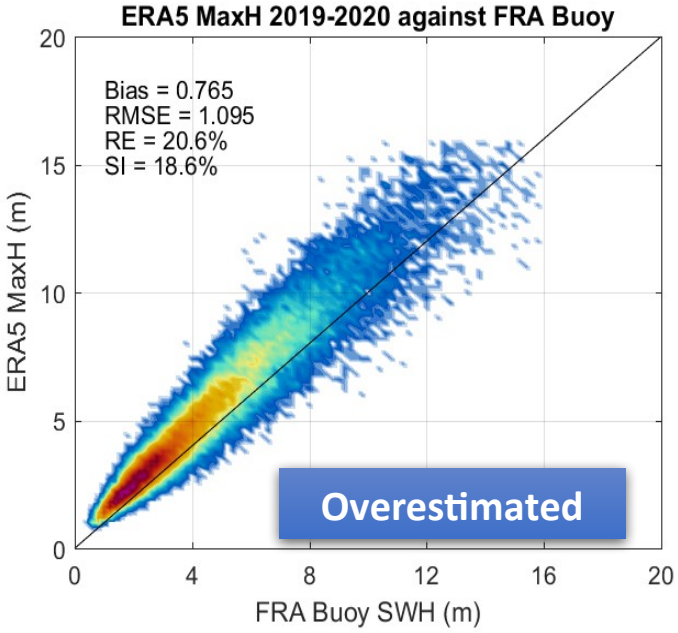


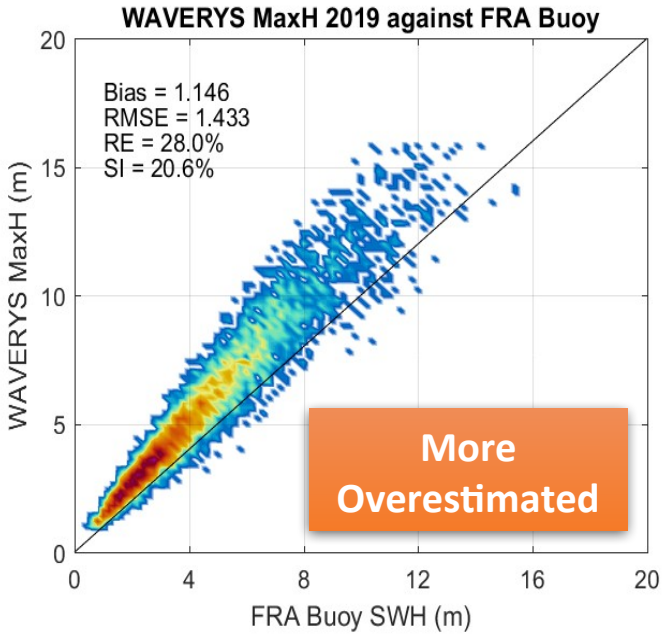
Maximum Wave Height

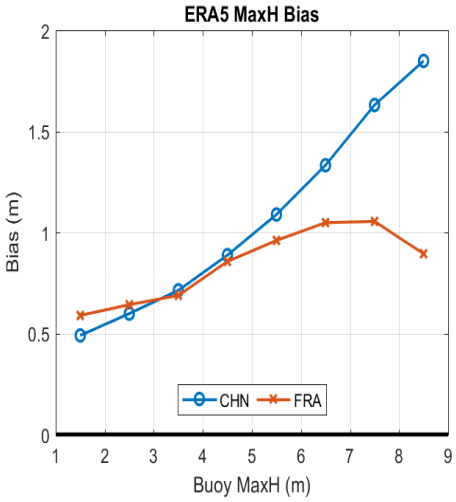


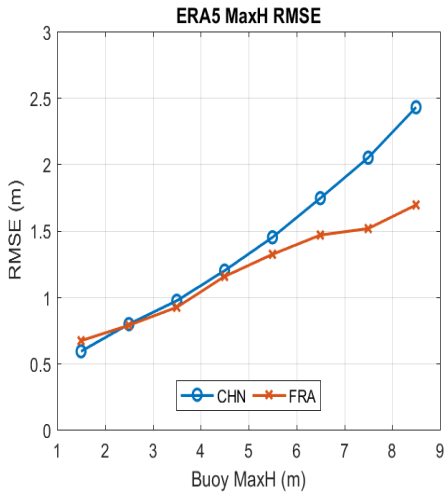
MaxH from ERA5 and WAVERYS Assessment against French Buoys

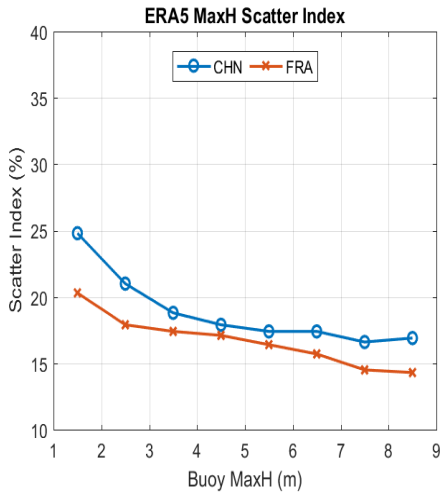


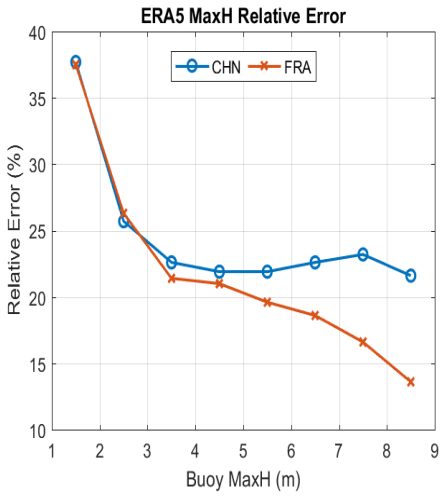












Objectives and Method

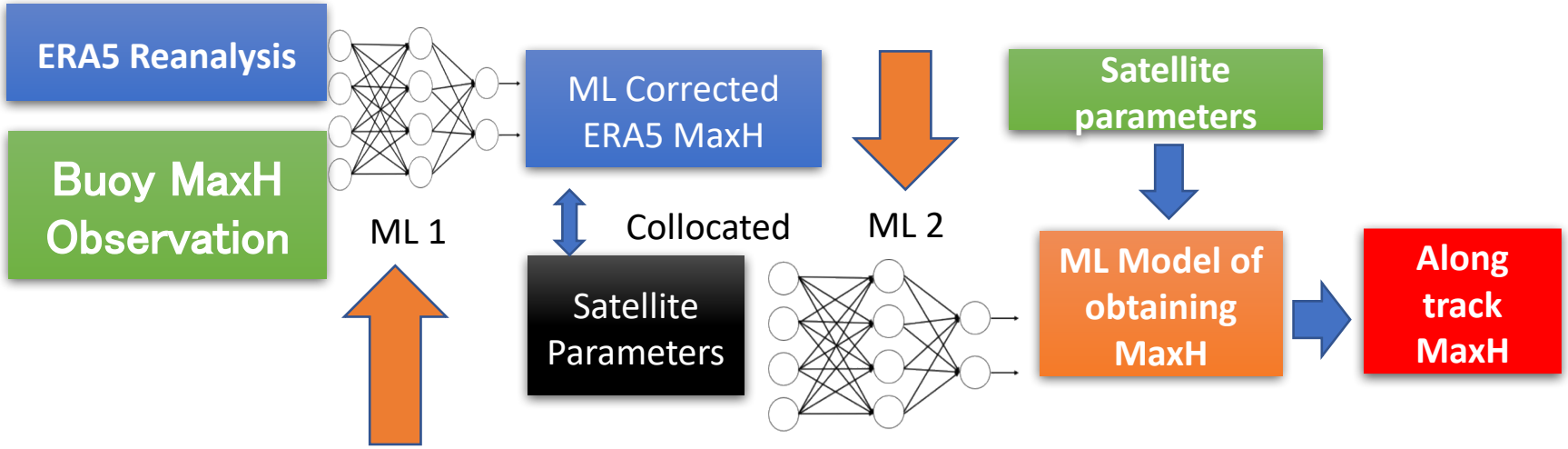
The objective: obtain the MaxH based on Along Track observation through ML

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.



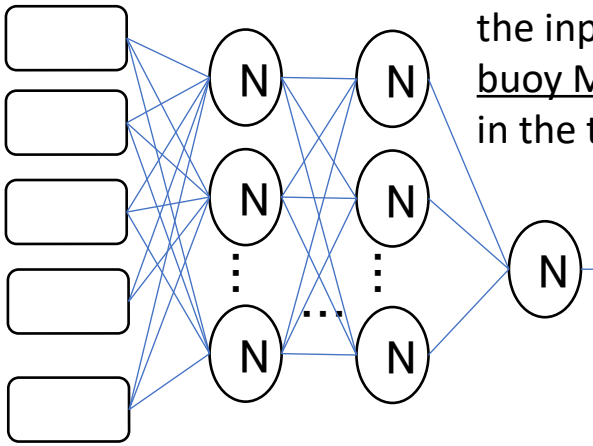
ERA5 MaxH Correction from DNN and Random Forest

DNN

Random Forest

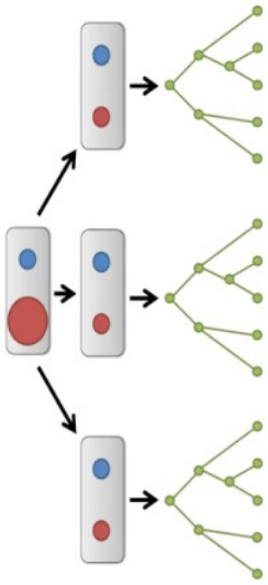
ERA5 Parameters

- Maximum wave height
- Significant wave height
- Period of MaxH
- SWH of total swell
- SWH of Windsea
- BFI
- Spectral Directional Width
- Mean wave period
- Mean square slope
- Spectral Peakedness
- Wave spectral kurtosis
- Wave spectral skewness



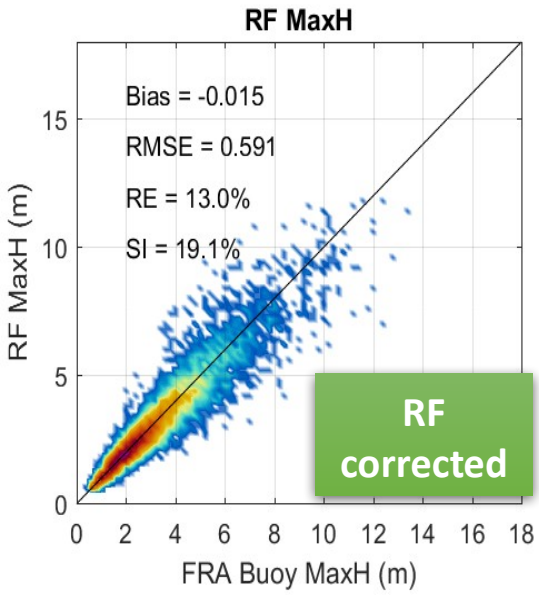
Use ERA5 Parameters as the inputs, use collocted buoy MaxH as the truth in the training.

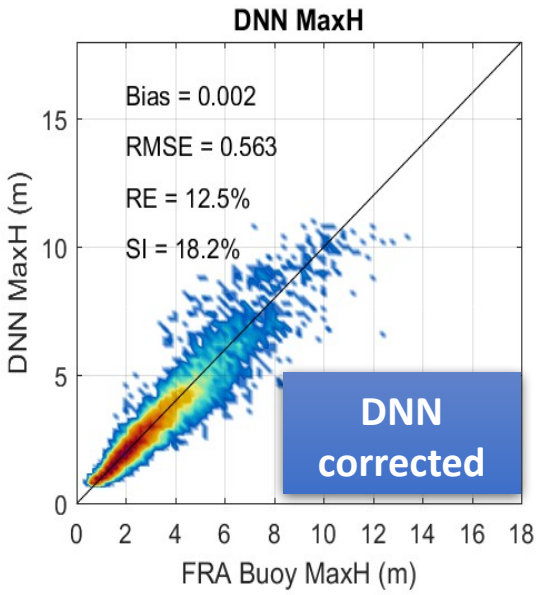
Corrected ERA5 MaxH

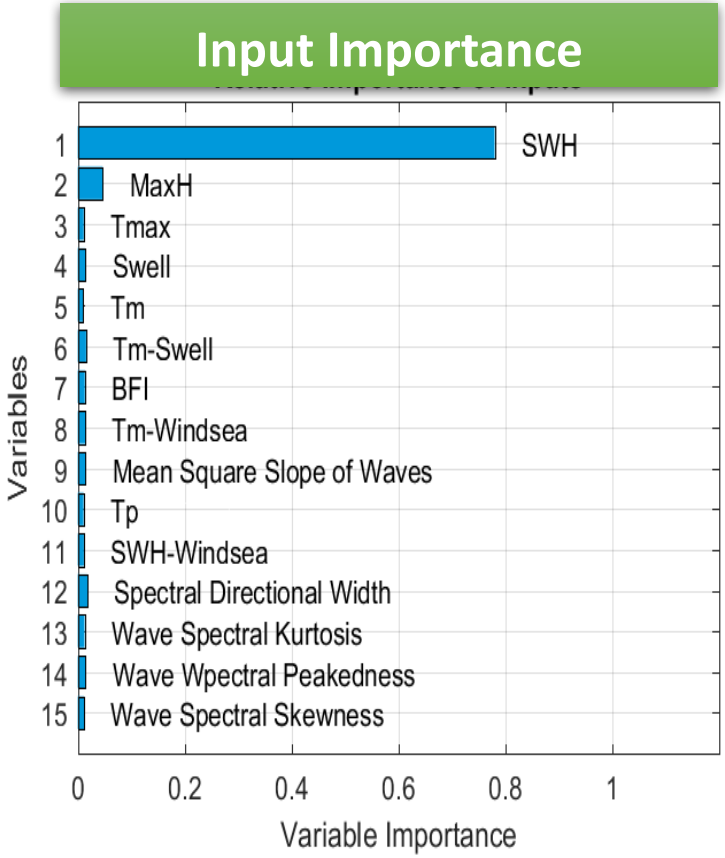


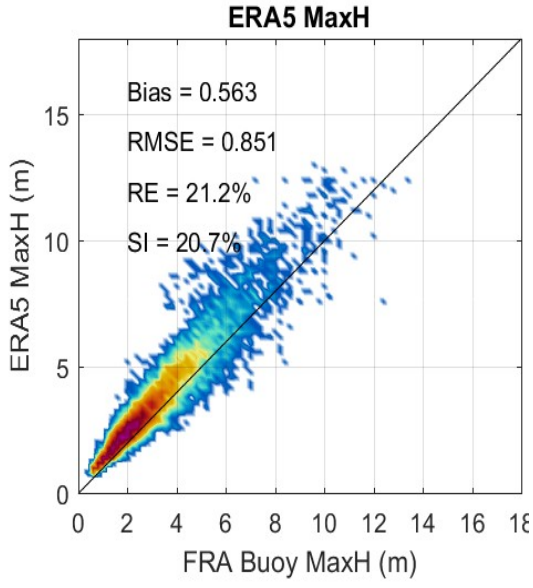
Corrected ERA5 MaxH

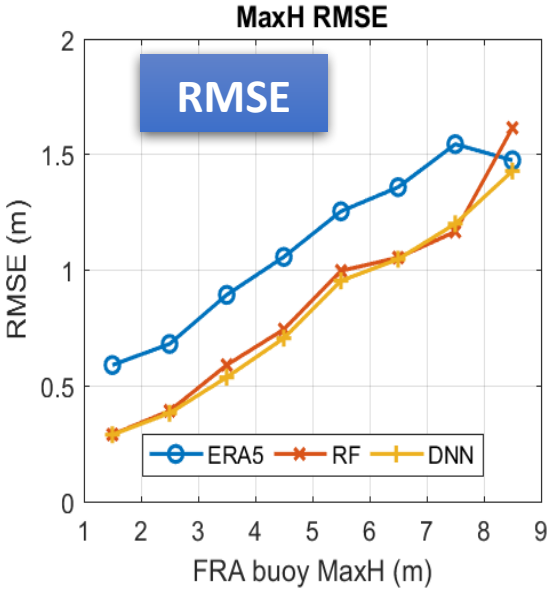
DNN and RF MaxH Correction Comparisons on Test Datasets





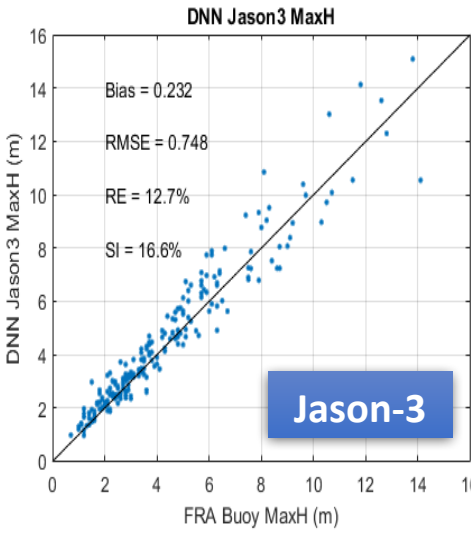


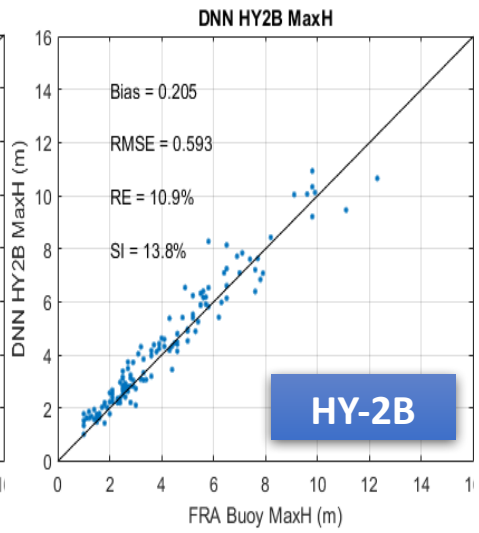


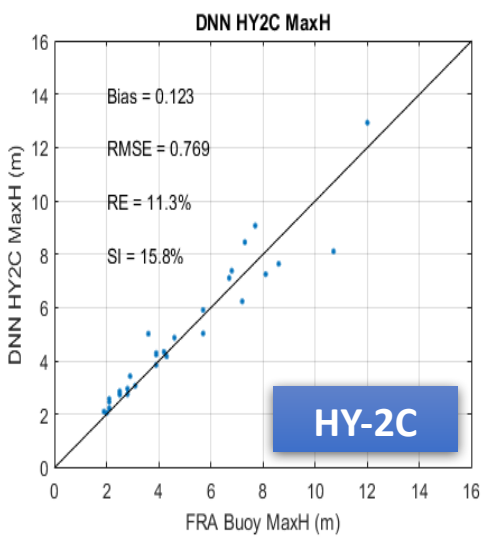


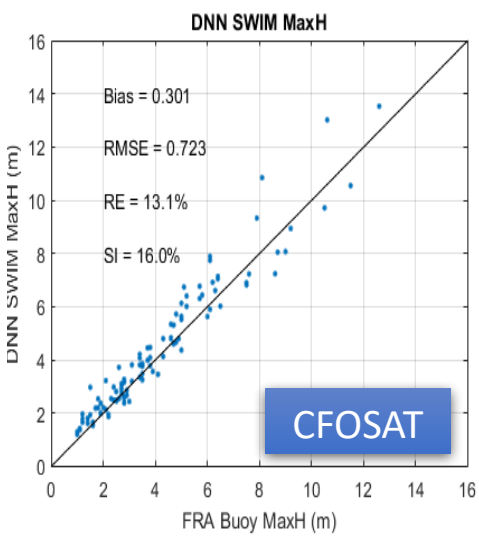
	Bias	RMSE	RE	SI
ERA5	0.56	0.85	21.2%	20.7%
RF	-0.02	0.59	13.0%	19.1%
DNN	0.0	0.563	12.5%	18.2%

Satellite MaxH Assessment Against French Buoys





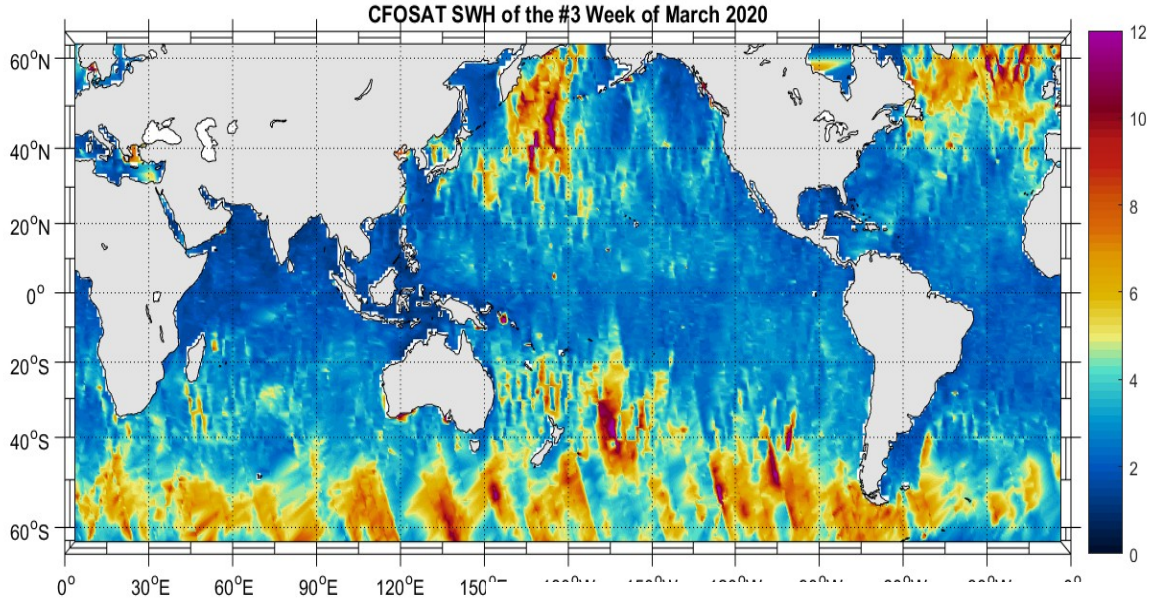




	ERA5	Jason-3	CFOSAT	HY-2A	HY-2B	HY-2C
Bias (m)	0.765	0.232	0.301	-0.035	0.205	0.123
RMSE (m)	1.095	0.748	0.723	0.764	0.593	0.769
Relative Error (%)	20.6	12.7	13.1	12.4	10.9	11.3
Scatter Index (%)	18.6	16.6	16.0	16.6	13.8	15.8

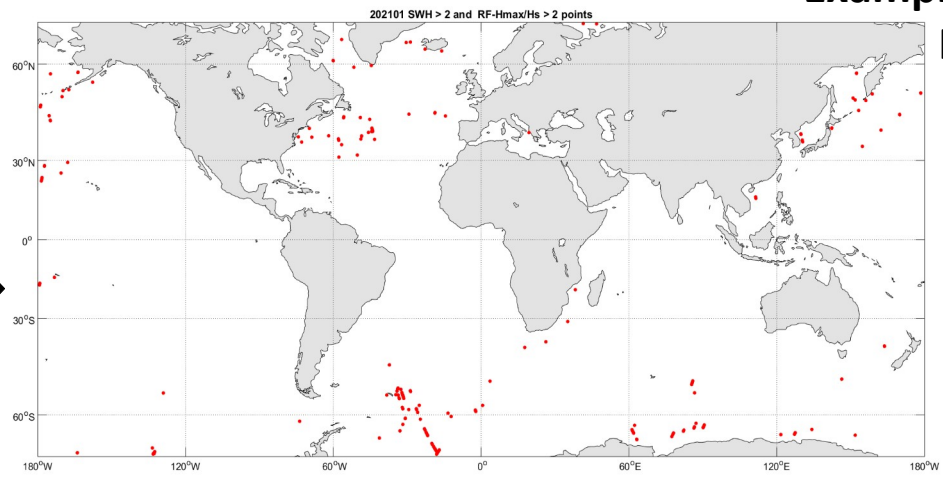
The first time predicting max. wave height from satellites

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



Preventing damages of rogues waves

Example from CFOSAT For 2021



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

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Key messages

➔ **Joint DA of wide swath SWH and directional wave spectra has showed a very promising and significant impact for operational wave forecasting : good perspective with HY2 series B, C and D, CFOSAT and S1 missions**

➔ **Longer wide swath SWH will be processed in order to be used in wave reanalysis**

➔ **Using 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.**

➔ **Deep learning will be used to improve the quality of S1 and CFOSAT wave spectra.**

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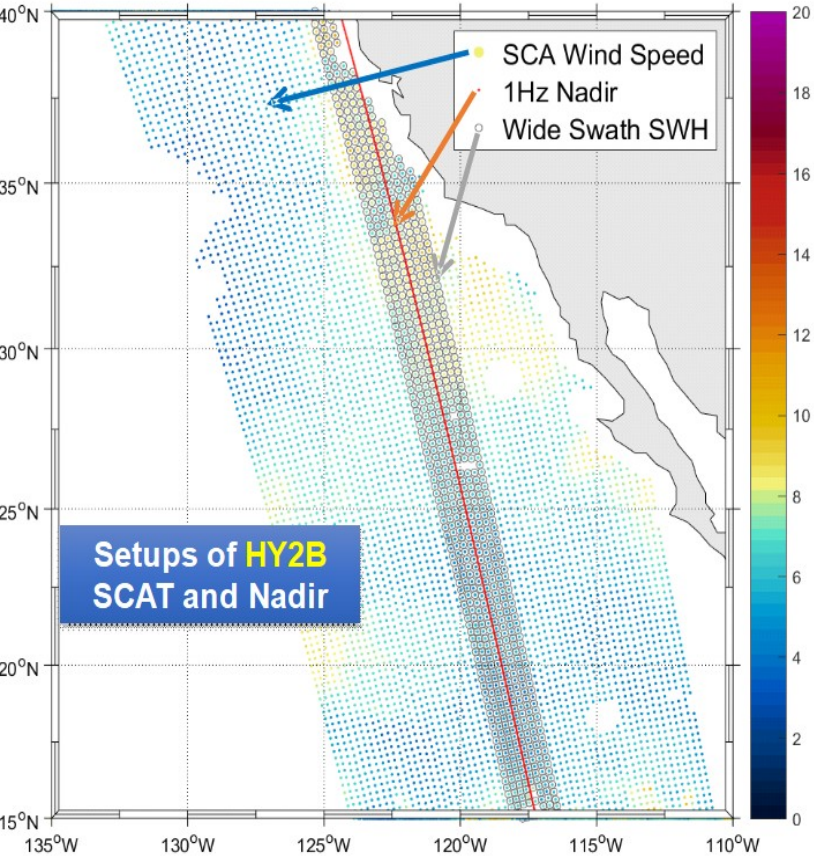
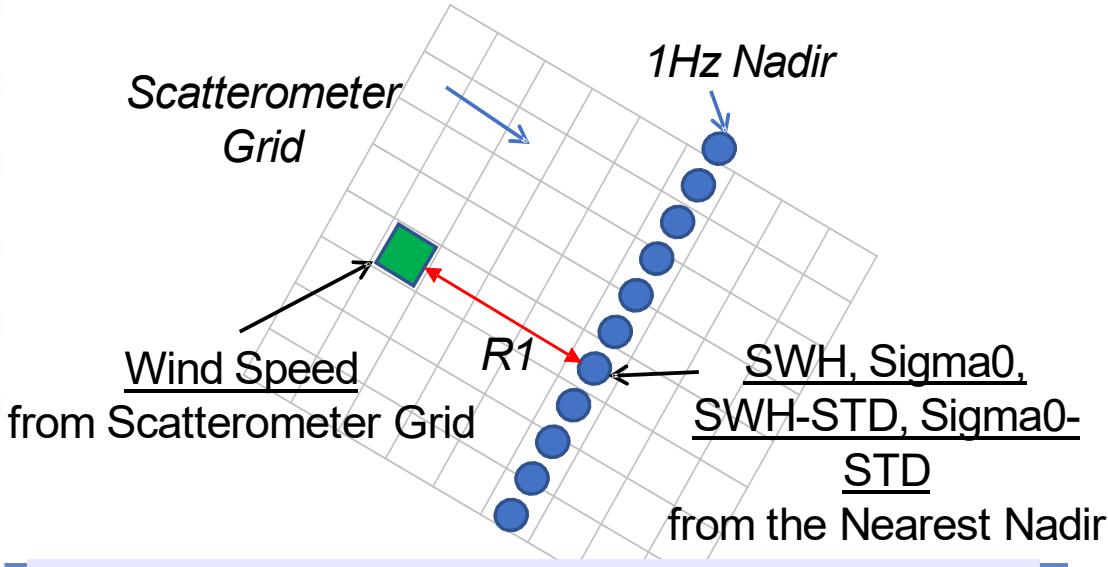
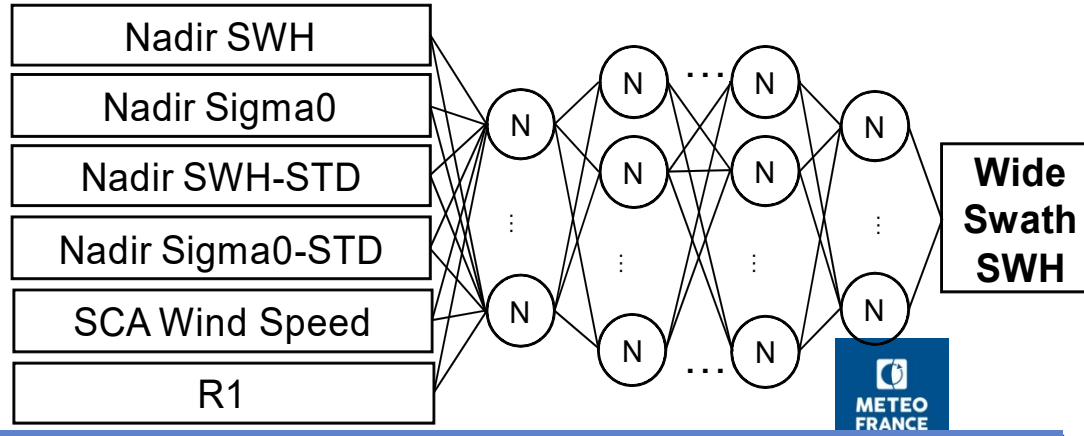
Deep neural network based retrieval of wide swath SWH (Wang et al. 2021)

Deep Learning model for retrieval SWH on scatterometer swath





The distance of Wide Swath grid is of 200 km from the nearest Nadir point (R1)



Wide Swath SWH is obtained from DNN (6 Inputs)

Complementary use of wind and wave Observations from satellite missions