On the upgrade of the wave forecasting system of CMEMS : Assimilation and coupling processes

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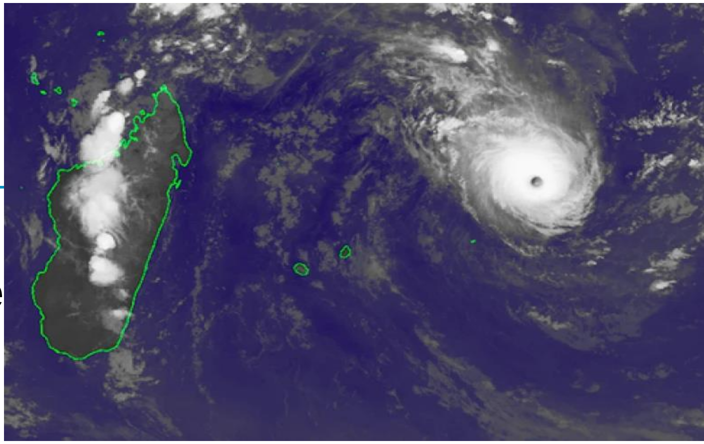
3rd International workshop of Waves, Storm surge and Coastal Hazards, Notre Dame, 4 October 2023

Motivation



■ **Improvement of the assimilation with new satellite wave observations : adaptation of the assimilation scheme**

■ **Upgrade of the model MFWAM with wave-ice interactions term : relevant for ocean/wave coupling in polar oceans**

■ **Improvement of model spectral resolution in wave direction and consequences on extreme wave prediction**

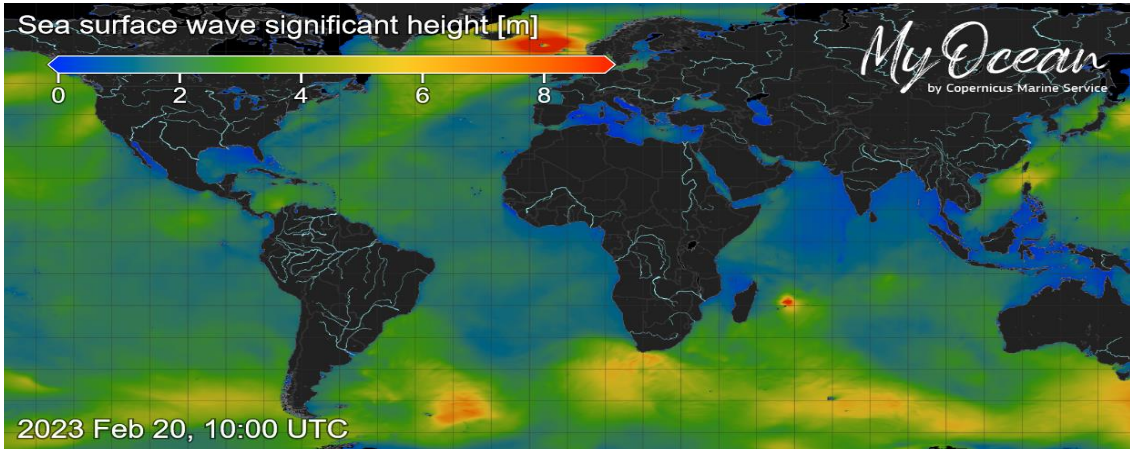
■ **Better estimate of extreme wave parameters (Hmax, BFI, CTCOR) and establishing dangerous seas indicators**

Operational wave systems MFWAM

Two global operational suite of MFWAM model

Global MFWAM-CMEMS
Grid resolution 10 km
IFS-atmospheric forcing
Surface Currents forcing
CMEMS-PHYS
DA altimeters and spectral (CFOSAT and S1)

Global MFWAM-Arpege
Grid resolution 20 km
ARPEGE atmospheric forcing
No surface currents forcing
DA altimeters and spectral (CFOSAT and S1)



Snapshot of SWH : global wave products from marine.copernicus.eu

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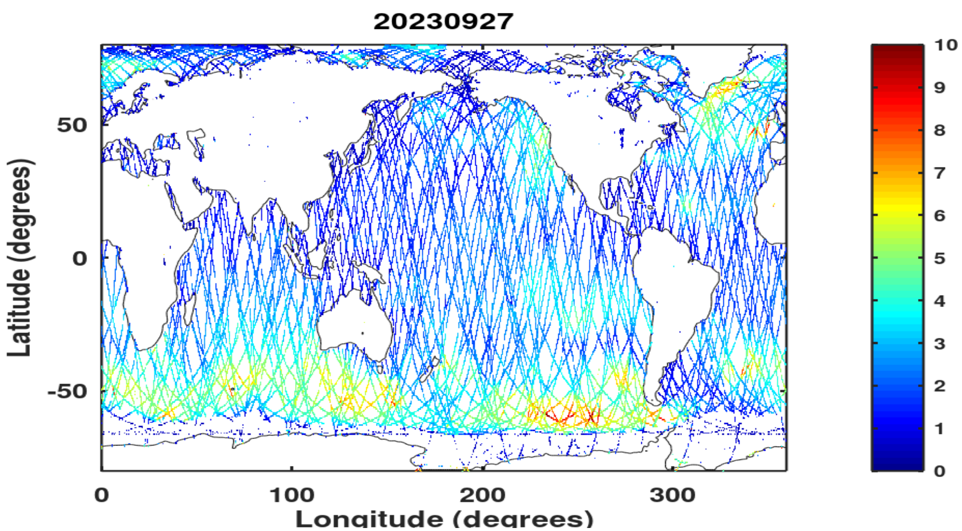
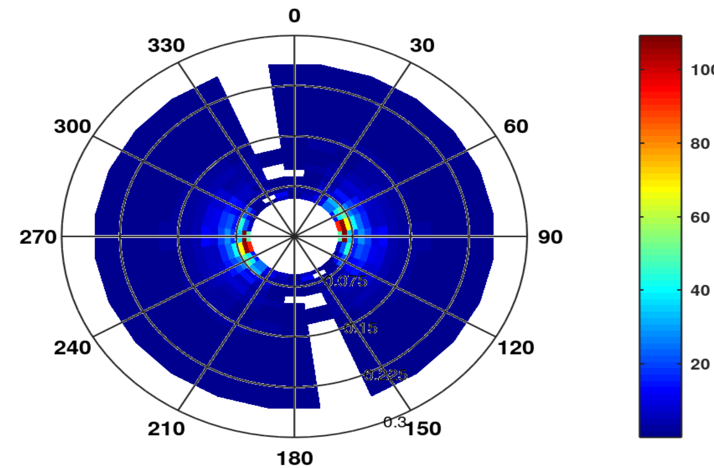
Operational combined assimilation of satellite wave data in model MFWAM

Daily coverage on 27 September 2023

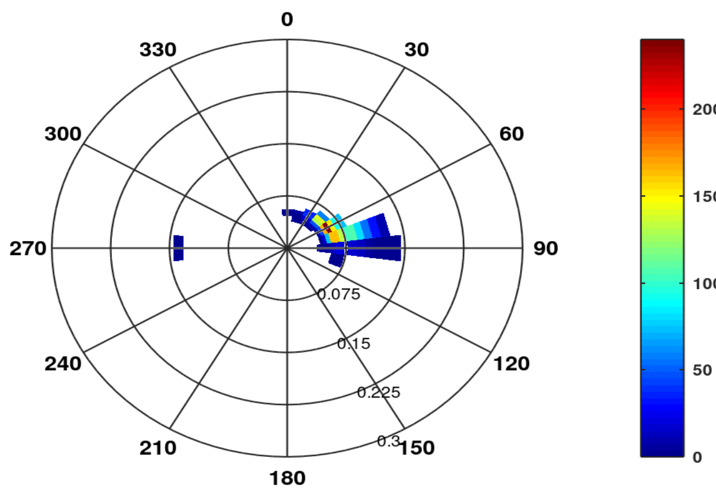
SWH from 7 altimeters missions



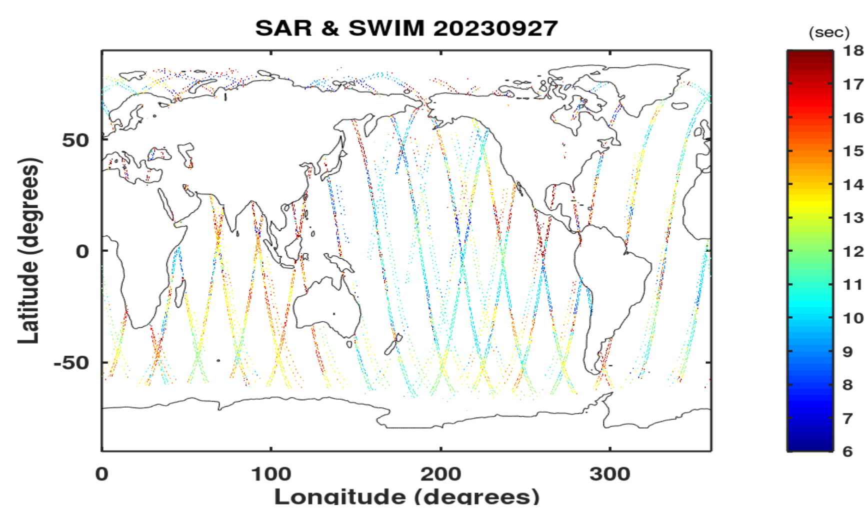
CFOSAT/SWIM : wavelength range 60-500 m)



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



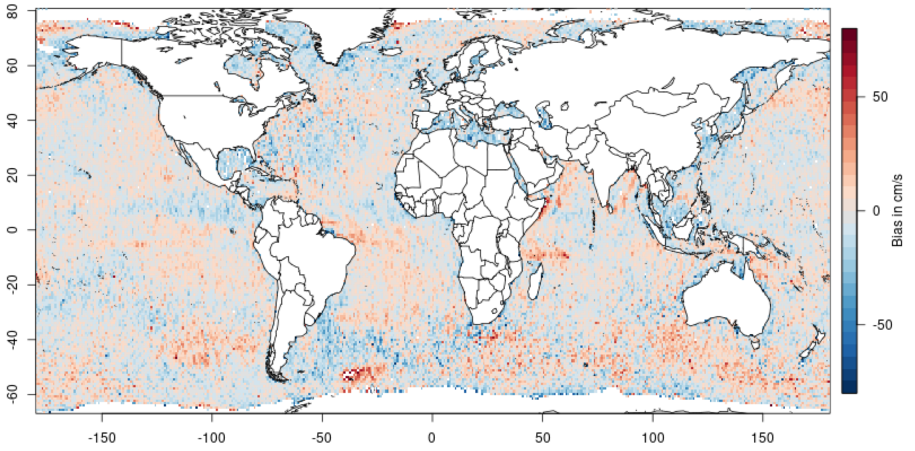
SAR and SWIM wave spectra Peak period on tracks



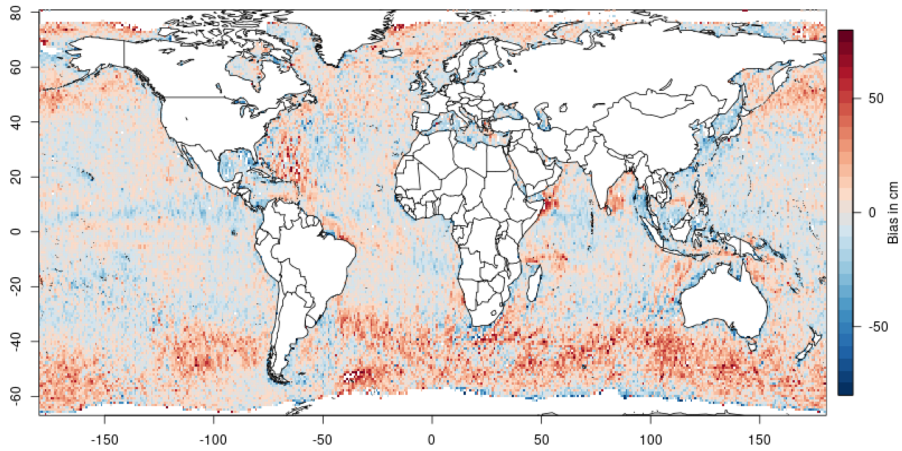
Performance of global operational MFWAM models : 1-day forecast

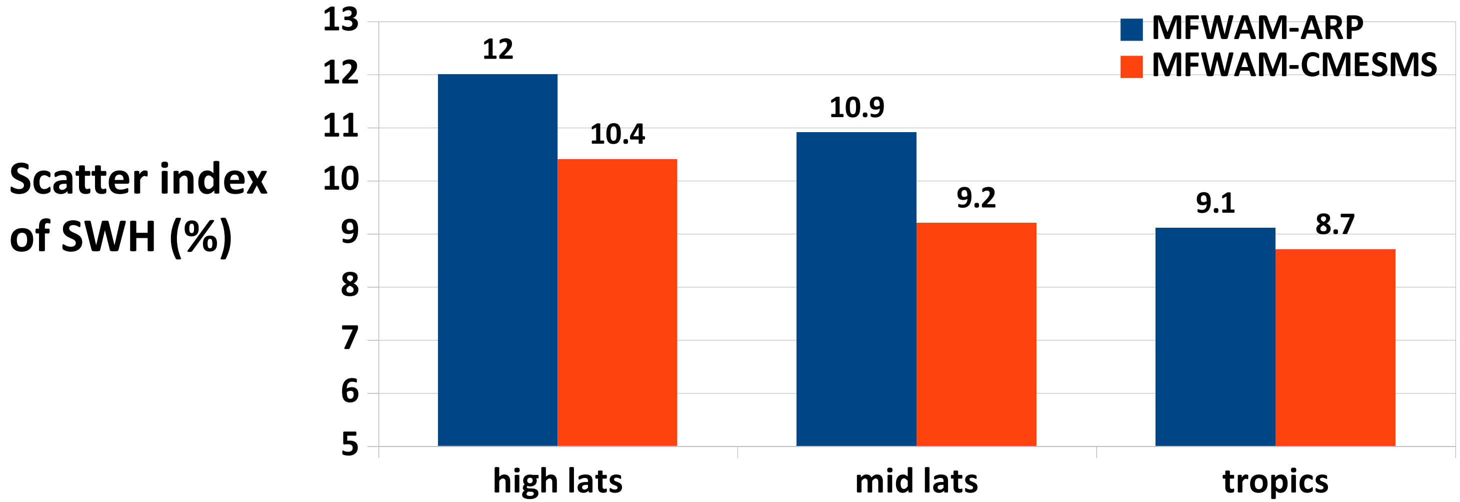
Bias of SWH maps in cm (maximim range 80 cm)

MFWAM-CMEMS (10 km)



MFWAM-ARPEGE (20 km)





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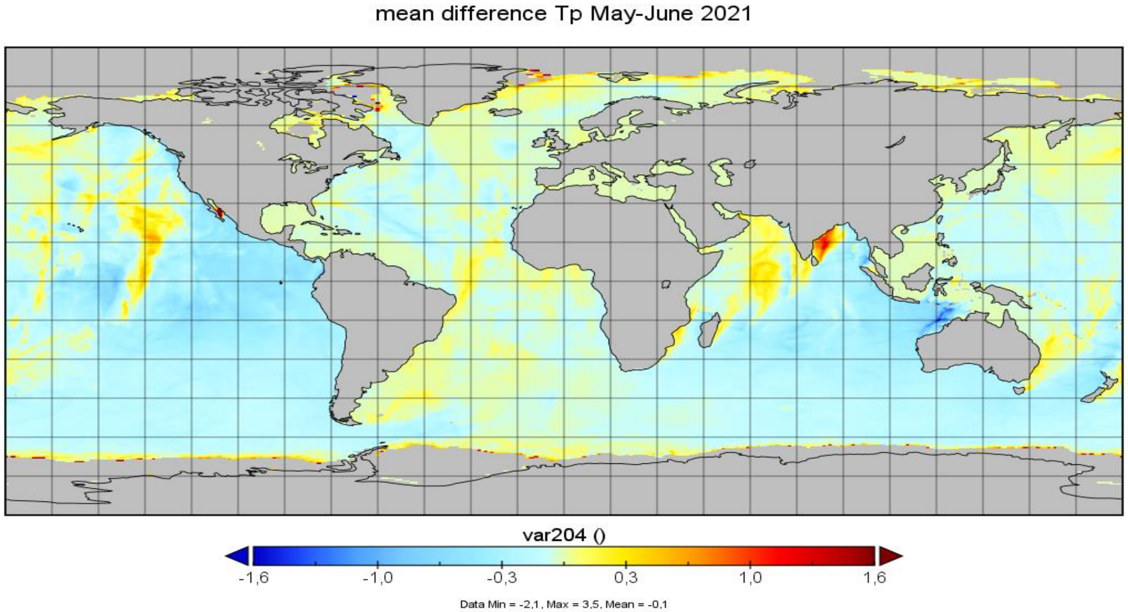
Comparison with SWH from altimeters : 1-18 September 2023

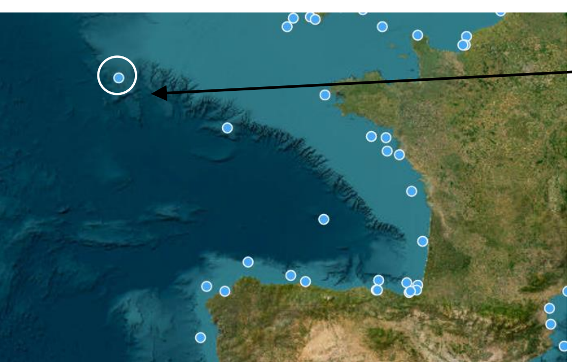
Scaling wave period after DA of SWH altimeters : improved Correction on wave spectrum

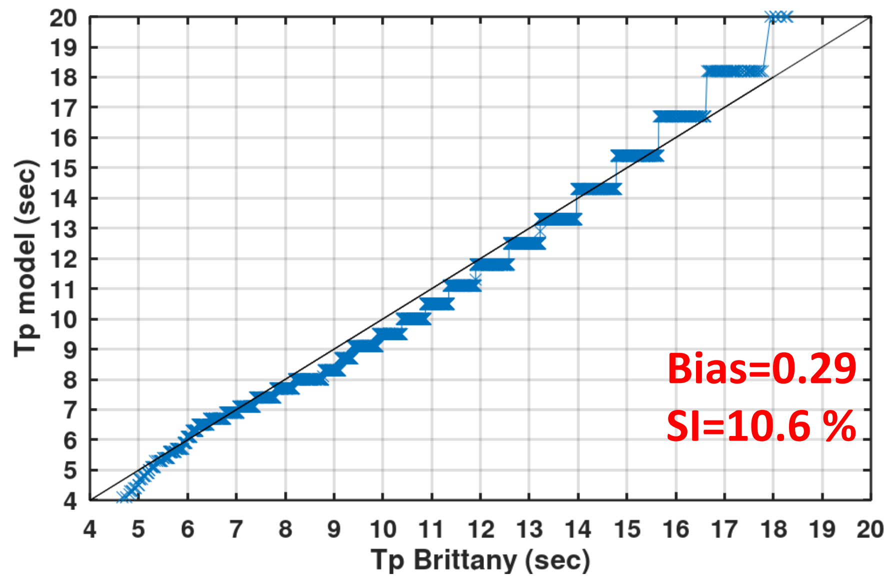
Average difference of Tp before and after correction (may-jun 2021)



Blue color indicates overestimation of Tp, while red shows an underestimation

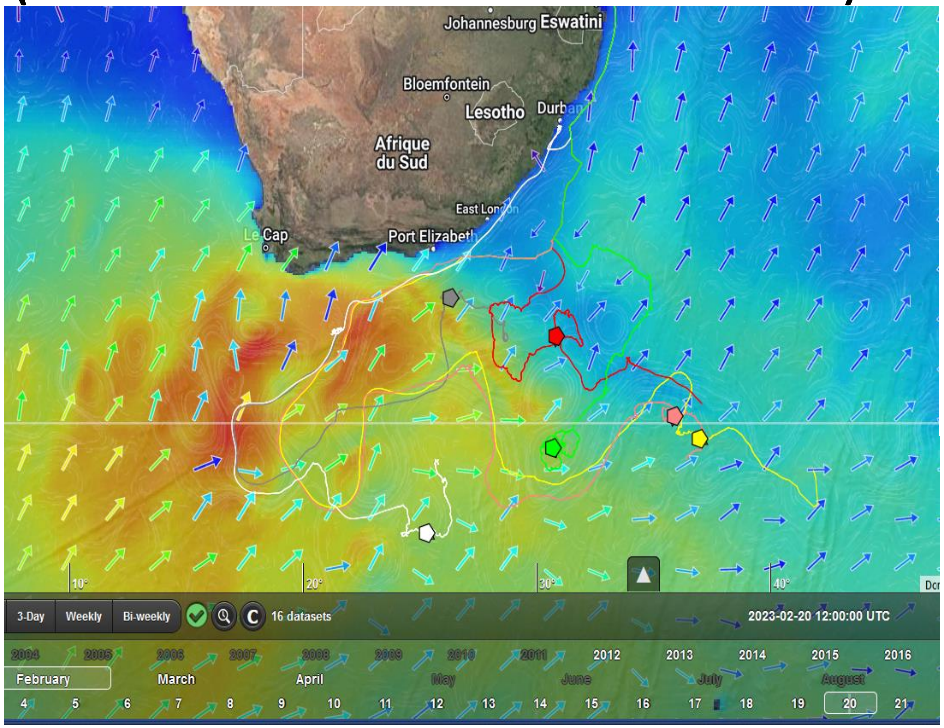
Qqplot of peak period shows good consistency With brittany buoy





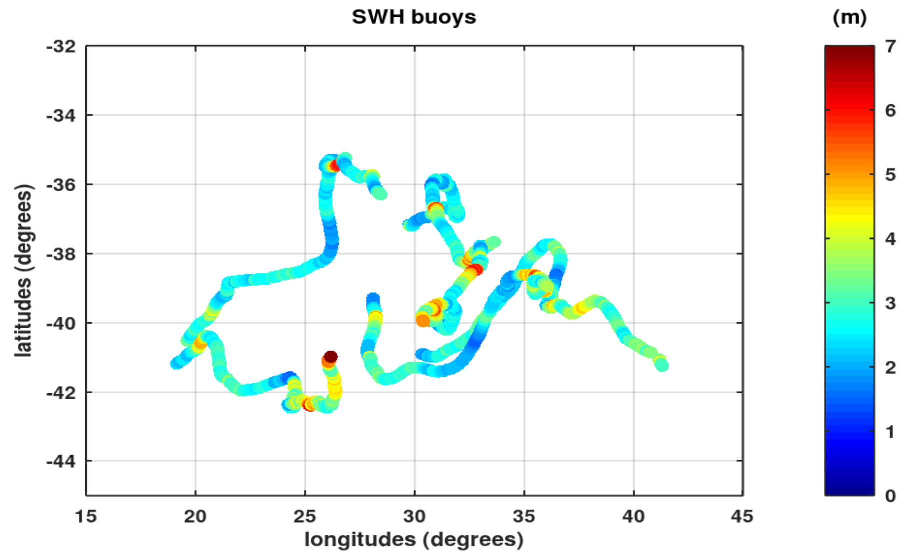
Verification with OMB drifting buoys : Jan & Feb 2023

6 OMB buoys trajectories in the Agulhas region and positions (hexagones) on 20 February 2023 (arrows indicate dominant wave direction)

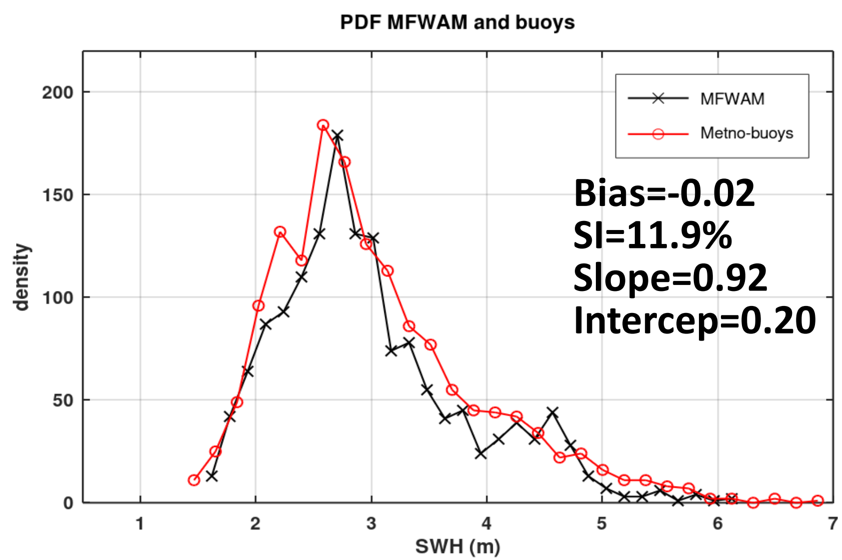


Good consistency of SWH PDF from MFWAM and OMB buoys

SWH from OMB buoys following trajectories

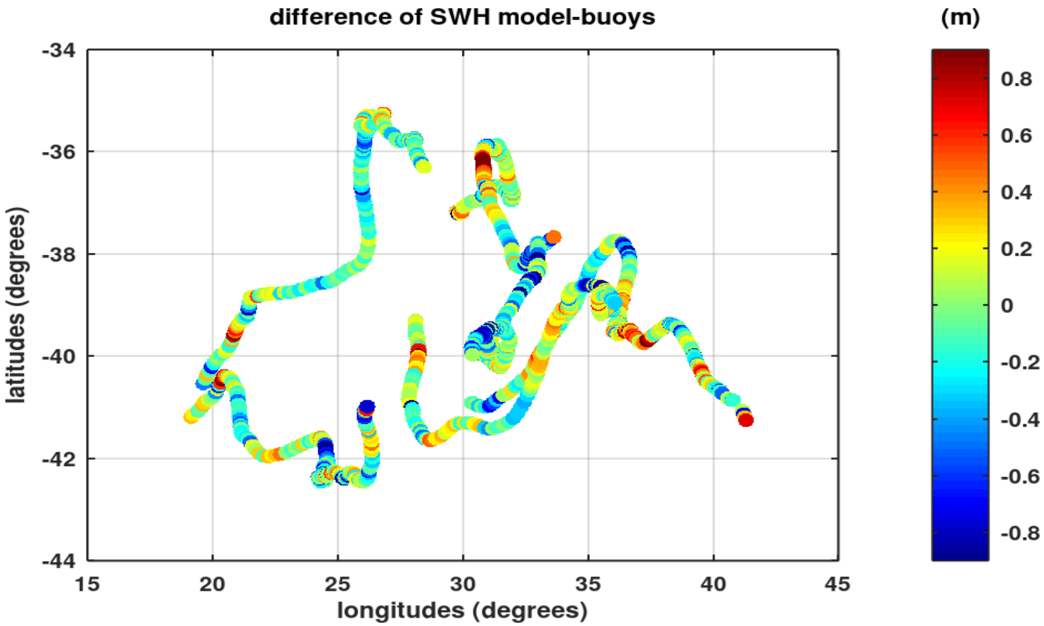


PDF of SWH

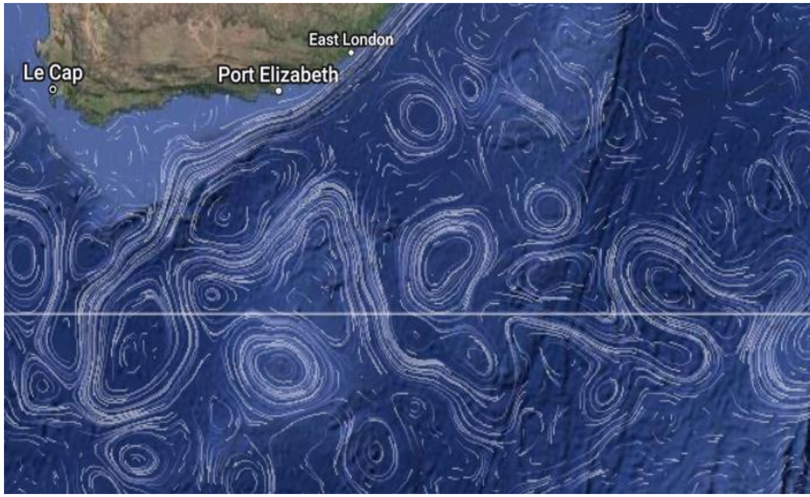


Verification with OMB drifting buoys : Jan & Feb 2023

Bias SWH following buoys trajectories

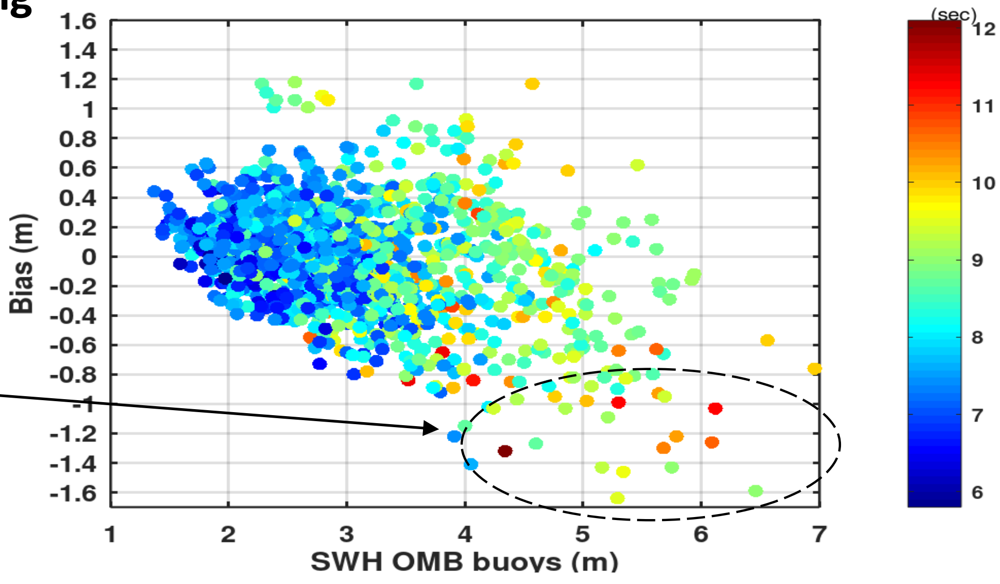


Agulhas current and submesoscale Cells shown in white filament



Strong wave-current interactions inducing Difference of SWH between model and buoys

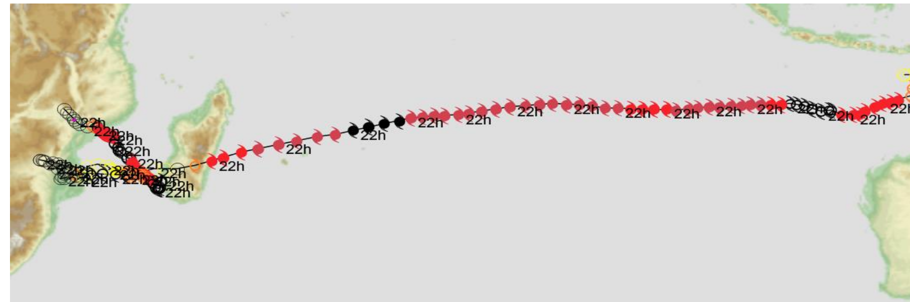
SWH bias variation with SWH and Tm2 (in sec)



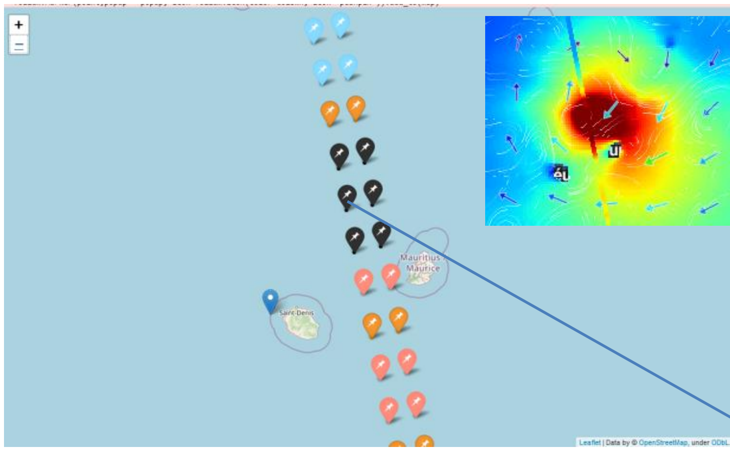
Limited bias at different range of SWH and mean period : larger Bias for longer waves probably Induced by position misfit of current cells from ocean model

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

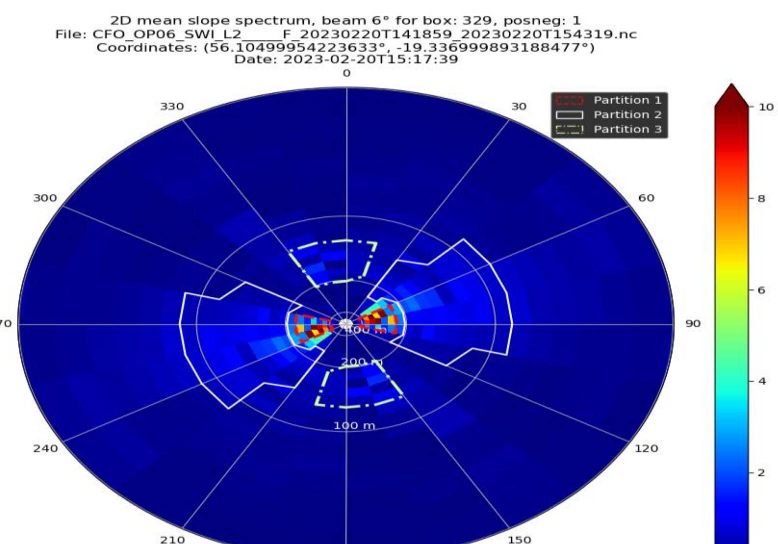
Trajectory of cyclone Freddy



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

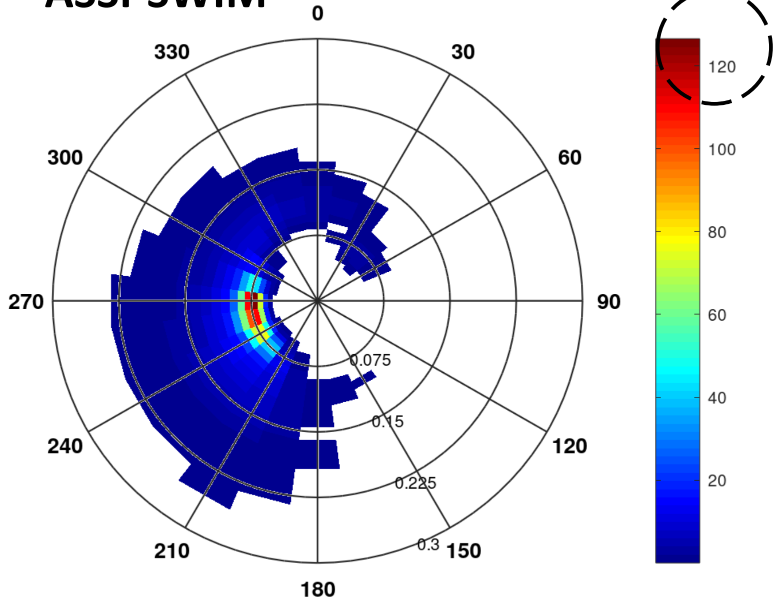


partition	SWH(m)	wavelenth(m)	direction (°)
1	7.286	314.087	74.515
2	4.332	171.303	69.401
3	–	–	–

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

Impact of the spectral assimilation near the eye of the cyclone (left side) trajectory of cyclone Freddy : long=56.1° E & Lat=19.5° S

ASSI-SWIM



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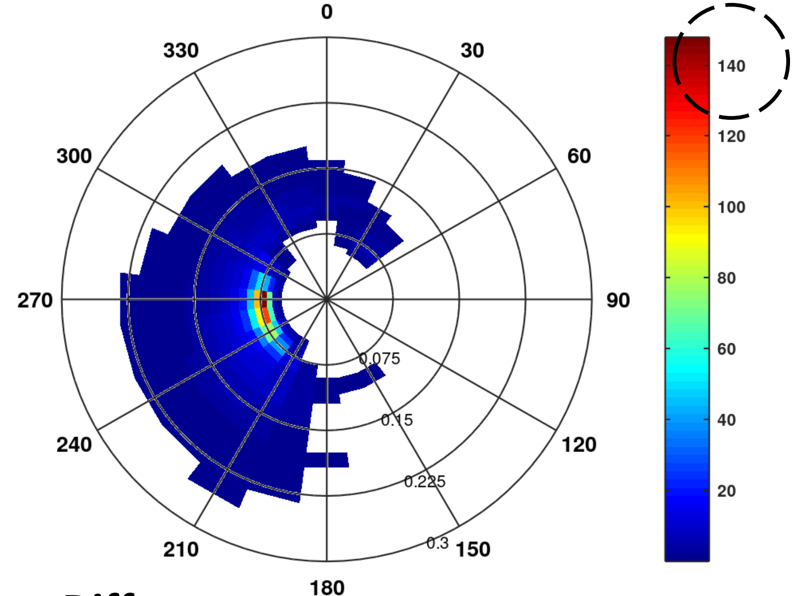
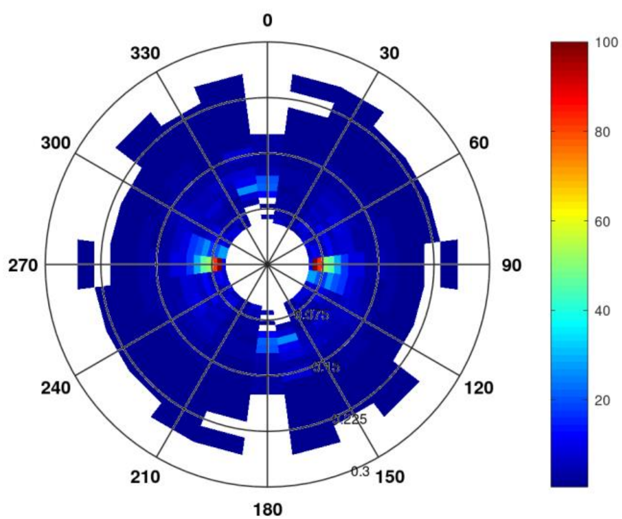
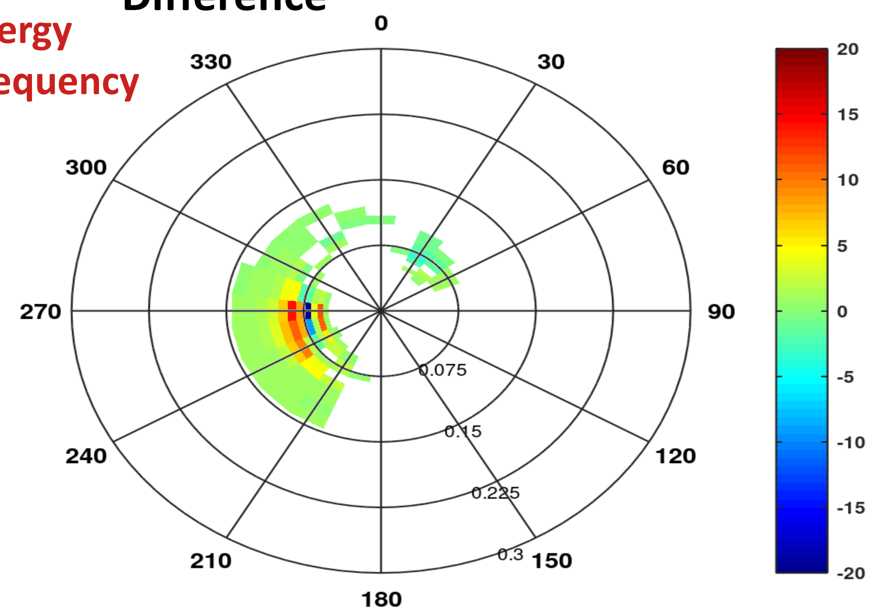


SWIM spectrum



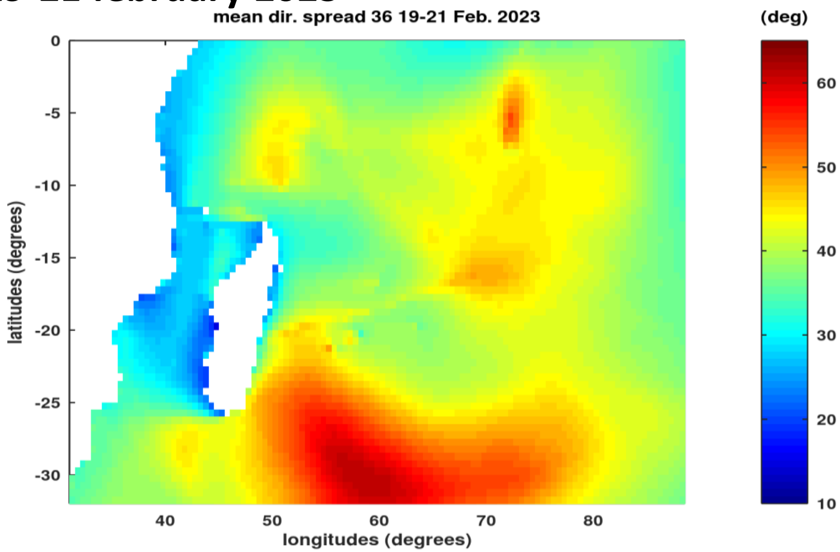
Correction of energy and scaling of frequency spreading

Difference

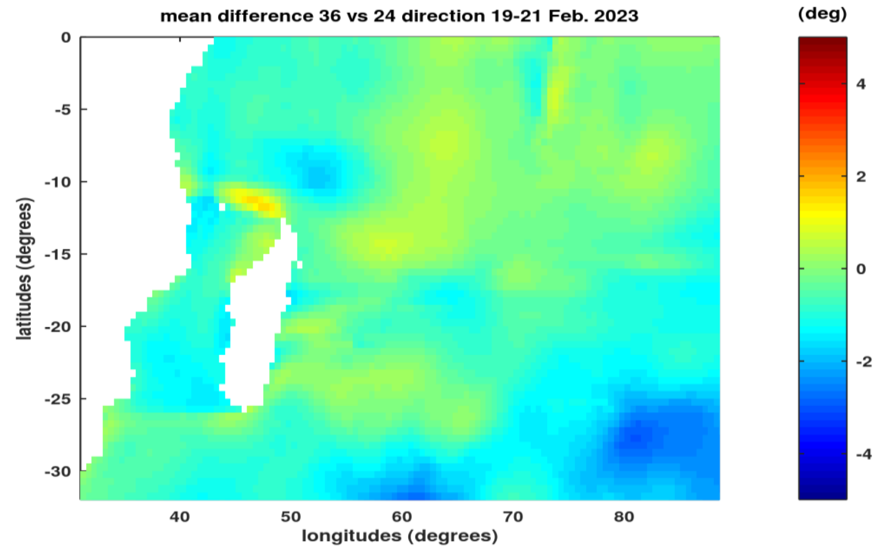


Impact of spectral resolution 36 vs 24 directions in the assimilation
Cyclone Freddy

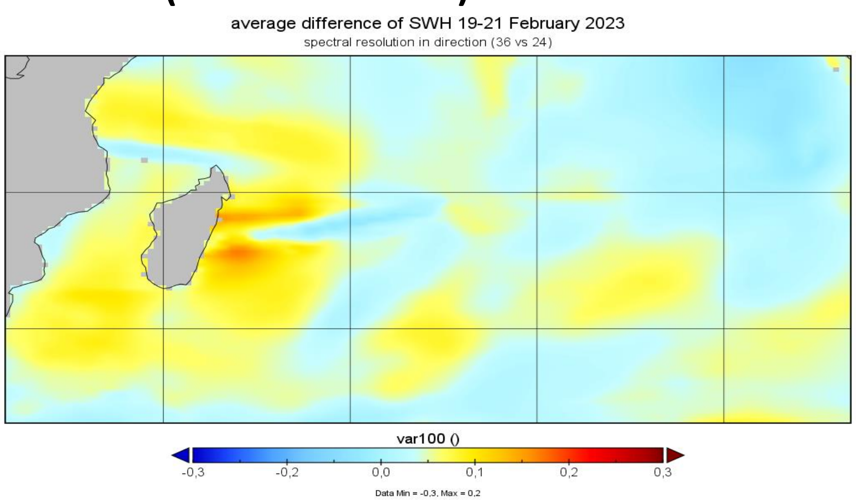
Average directional spreading with 36 directions 19-21 february 2023



Average difference of directional spreading between 36 and 24 directions



Average difference of SWH between 36 and 24 Directions (19-21 Feb. 2023)



Improved spectral resolution during the cyclone Impacts SWH (max range in average of 0.3 m) and also direction spreading on the cyclone trajectory

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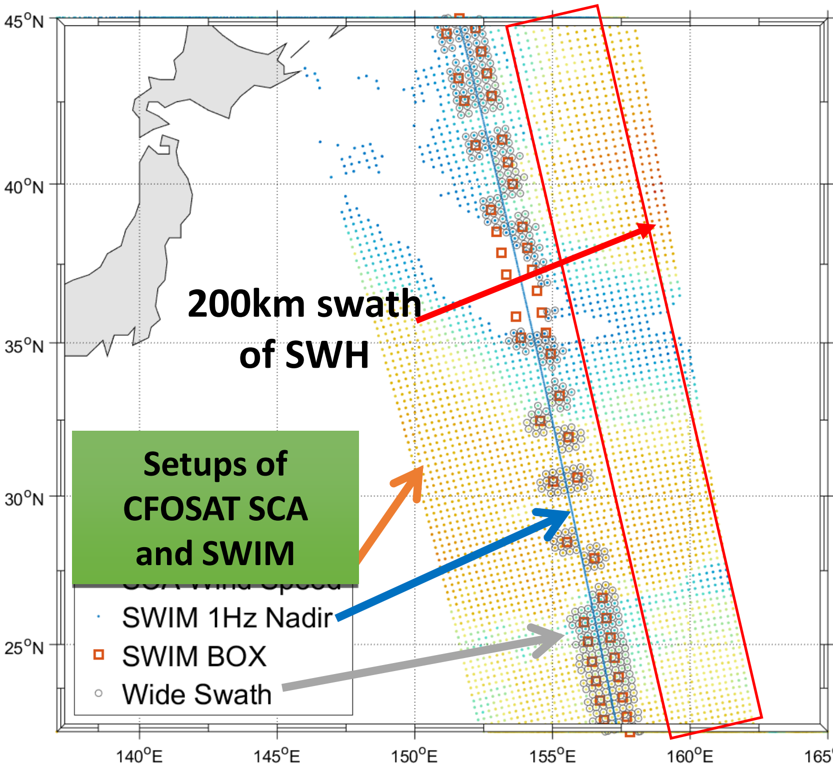
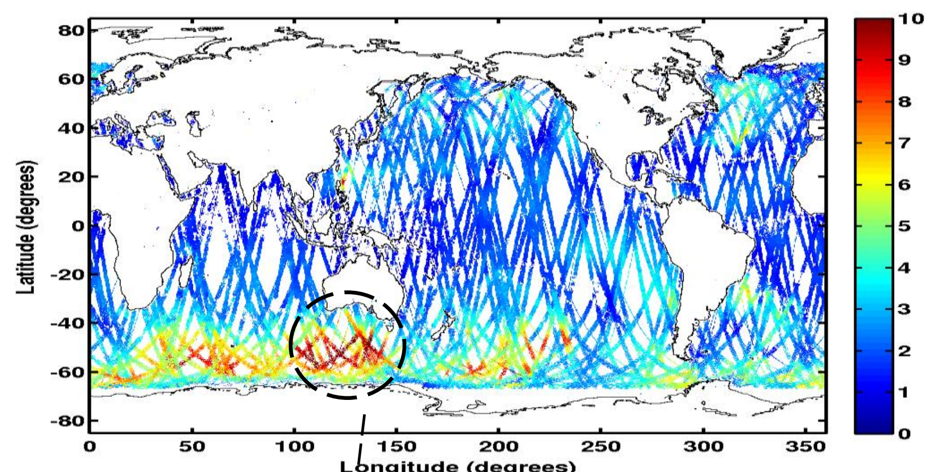
Deep neural network based retrieval of wide swath SWH (Wang et al. 2021)

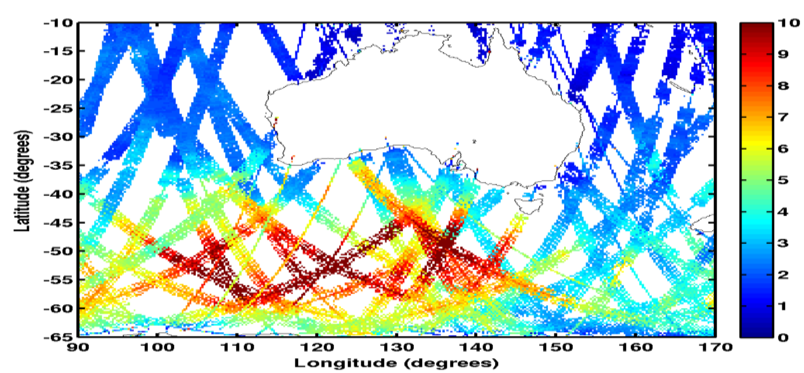


Synergy between wind scatterometers and SWIM or altimeters for satellite Missions : CFOSAT, HY2B, HY2C

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



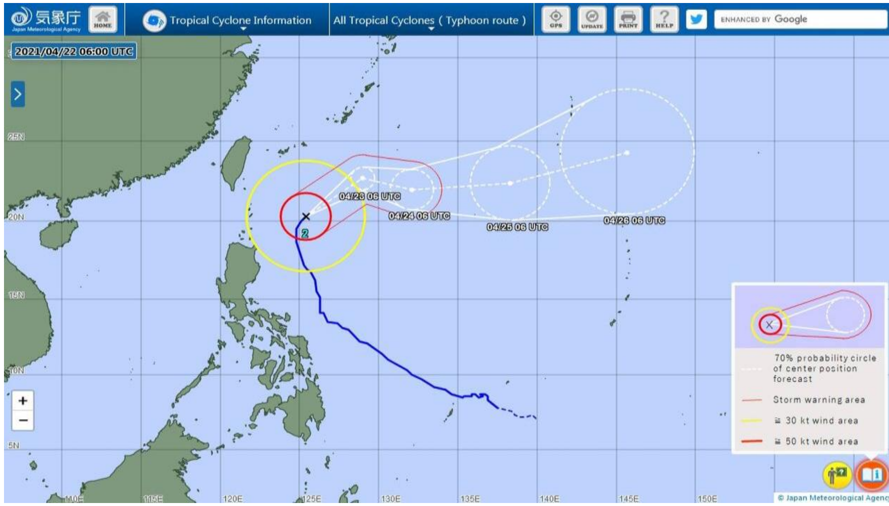
Both wind-wave and swell regimes are captured from SCAT and SWIM



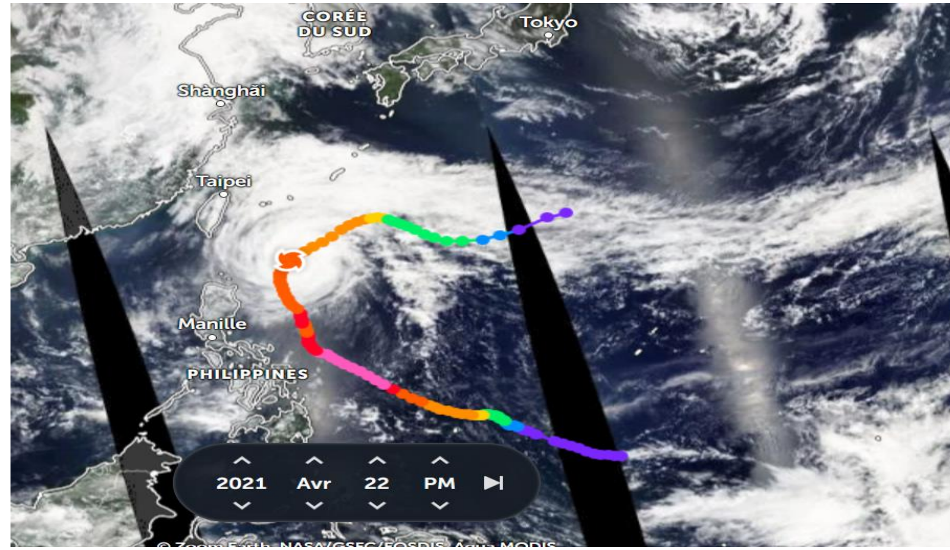
Tracking storms and propagatin[g]
the best initial conditions

Mult-imissions wide swath SWH in typhoon Surigae April 2021

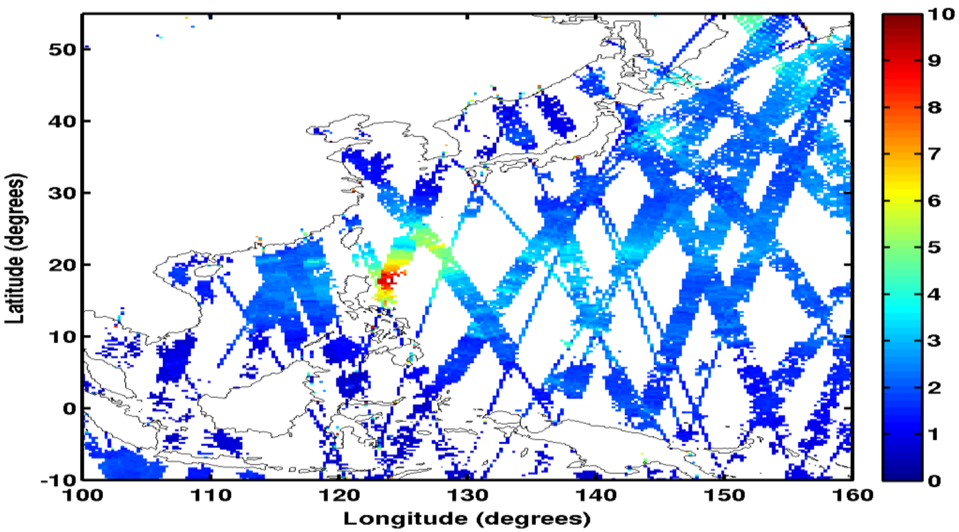
Trajectory of typhoon Surigae



Super typhoon Surigae generating long swells



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



Damages at Philippines

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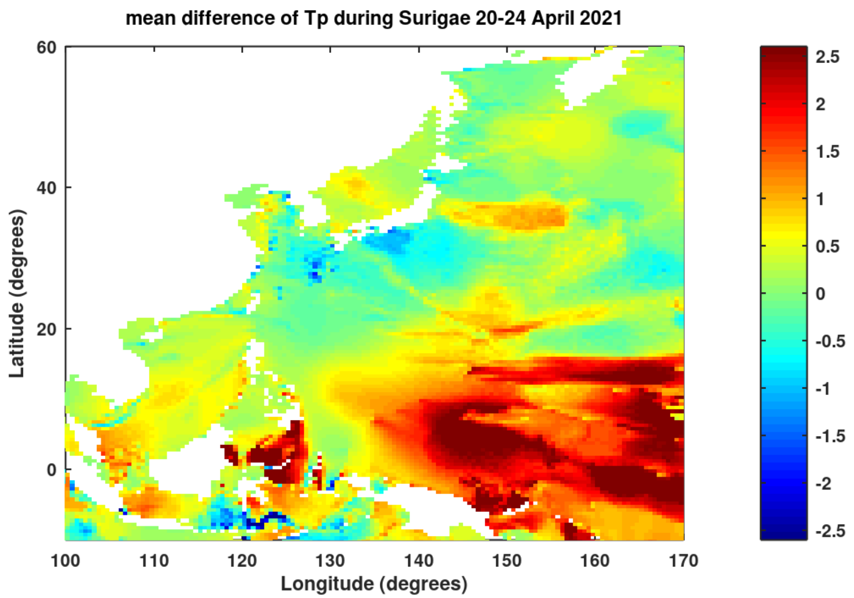
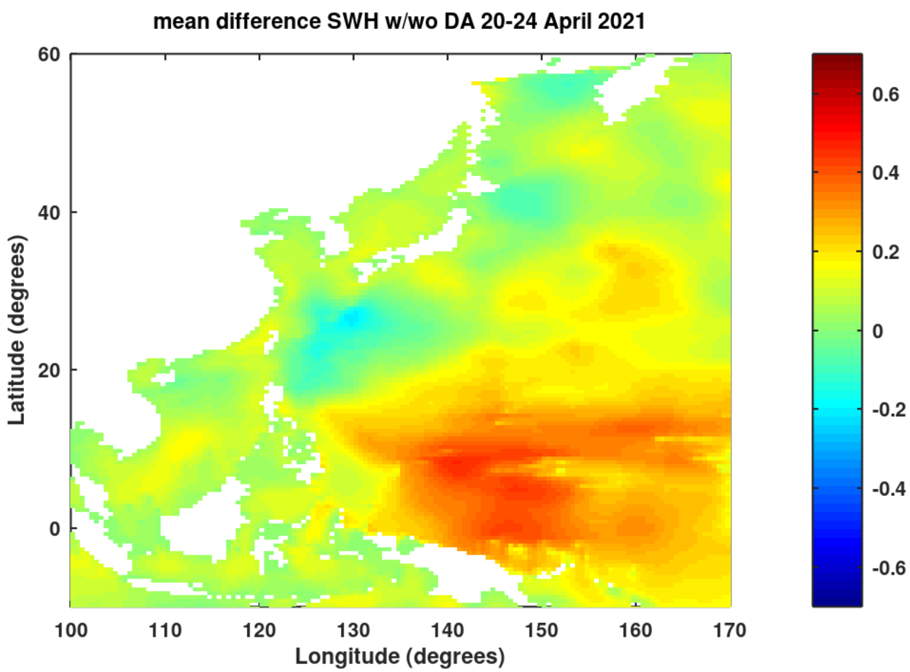
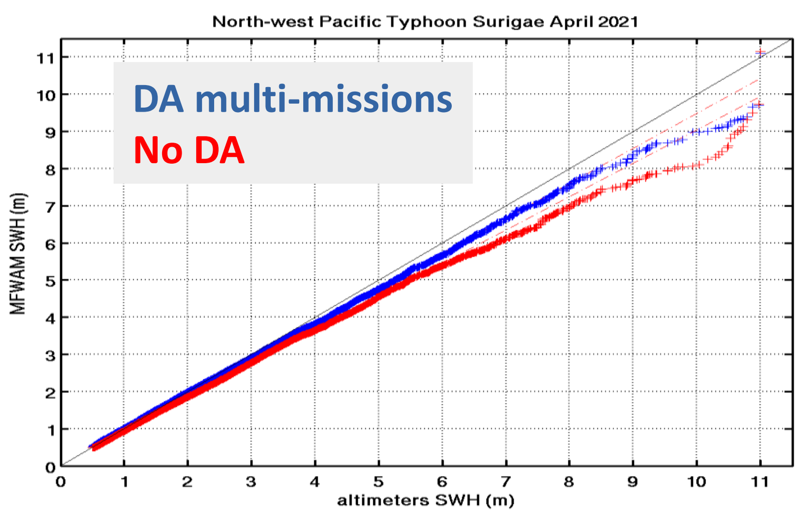
the impact of wide swath SWH (CFOSAT & HY2B & HY2C and directional wave spectra in typhoon Surigae : 20-24 April 2021

Difference of Peak period w/wo DA



Difference of Sig. Wave Height w/wo DA



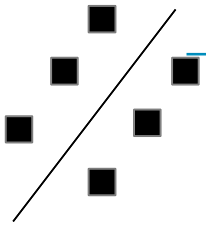


Q-Q plot of SWH indicates better PDF of SWH from DA (wide+spec) in Blue line particularly for high waves.

Validation with altimeters (ja3,Saral, S3)

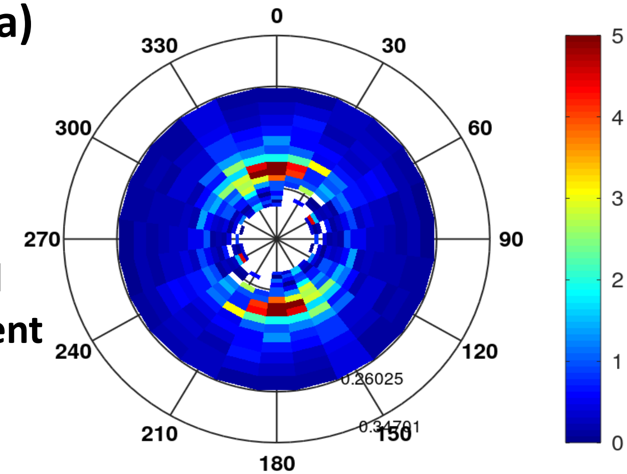
During typhoon SURIGAE SWH is improved by roughly ~13 %

Tracking waves in complex seas (SO-Weddell sea)

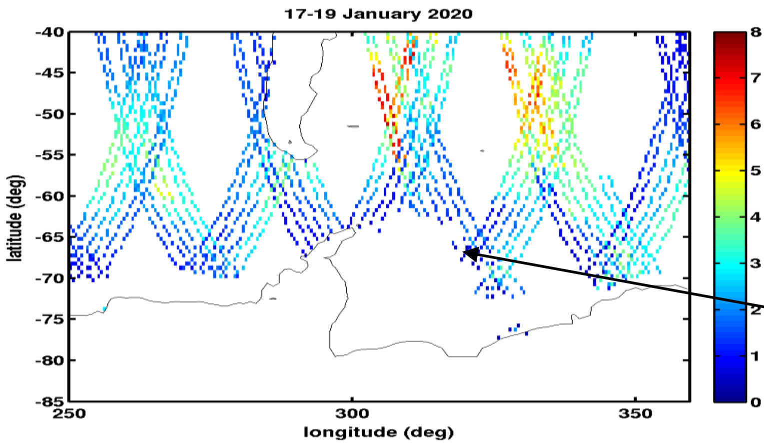


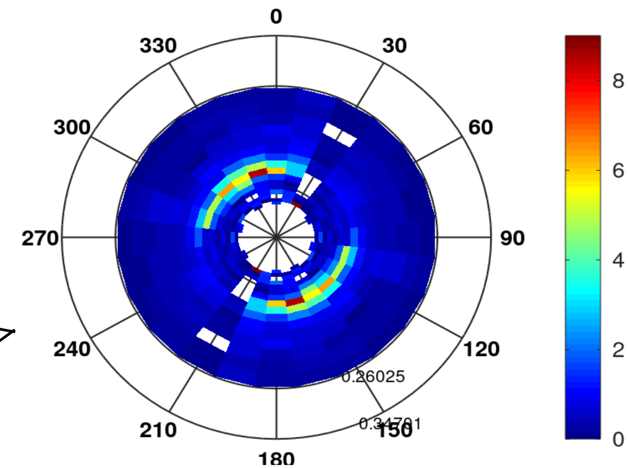
Every passage wave spectra and SWH are provided off-nadir

Ambiguity removal by cross-assignement with model

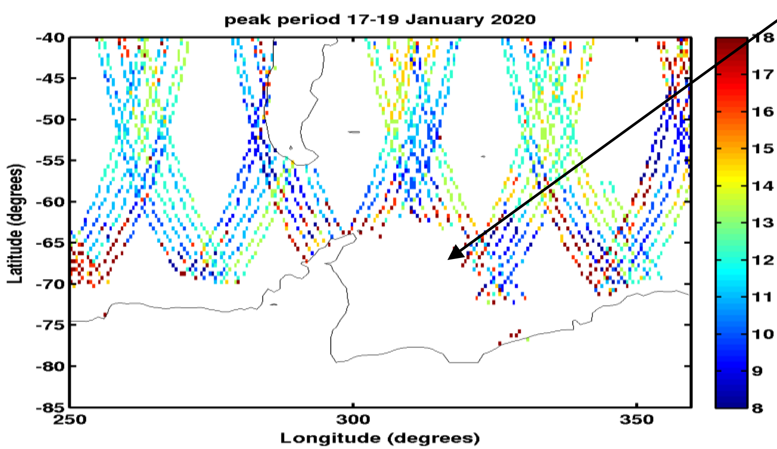


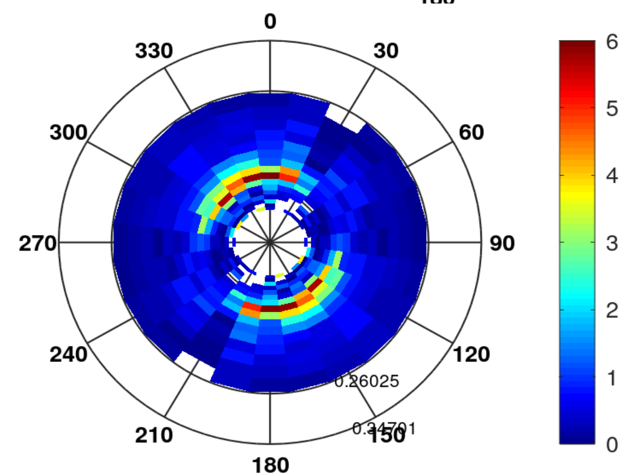
wave height 17-19 Jan. 2020





Dominant wave period





Spectral variability From SWIM in Storm conditions

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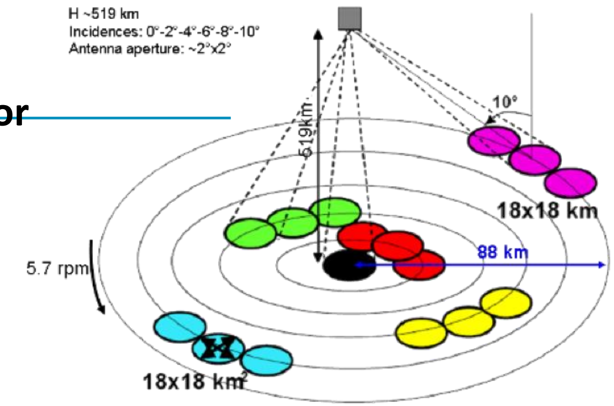
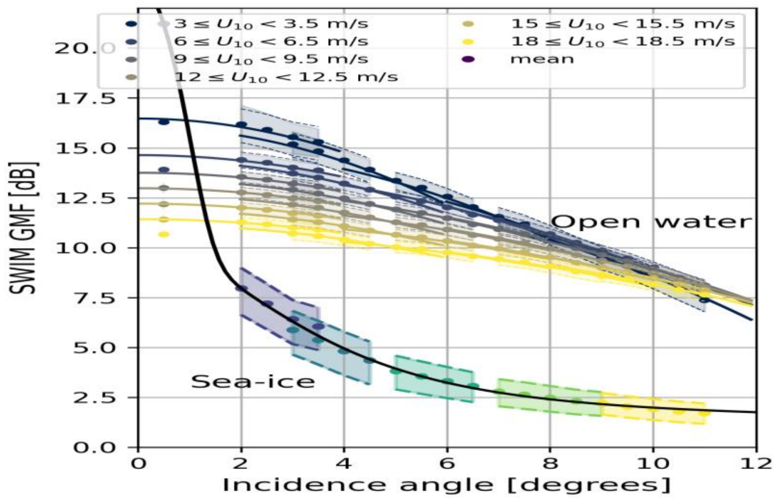
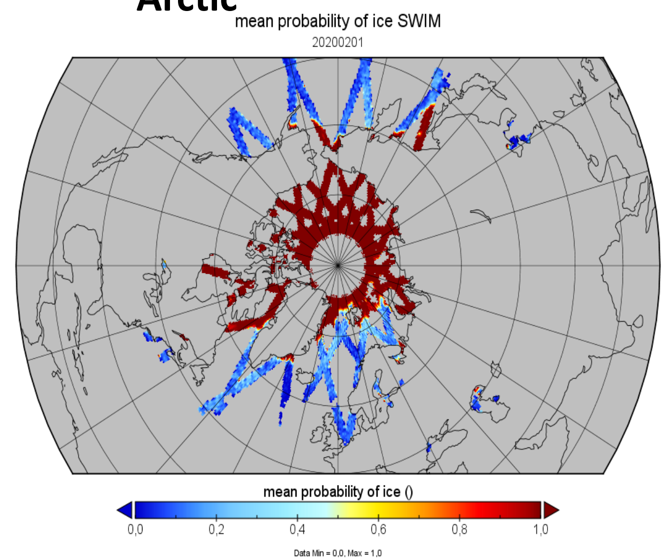
Sea ice retrieval from off-nadir SWIM

The 5 SWIM off-nadir beams Normalized Radar Cross Section(NRCS) Is lower on sea ice than on open water. A maximum likelihood estimator Is derived from Geophysical Model Functions.This flag is estimated Down to ~10 m resolution (C. Peureux et al., 2022)

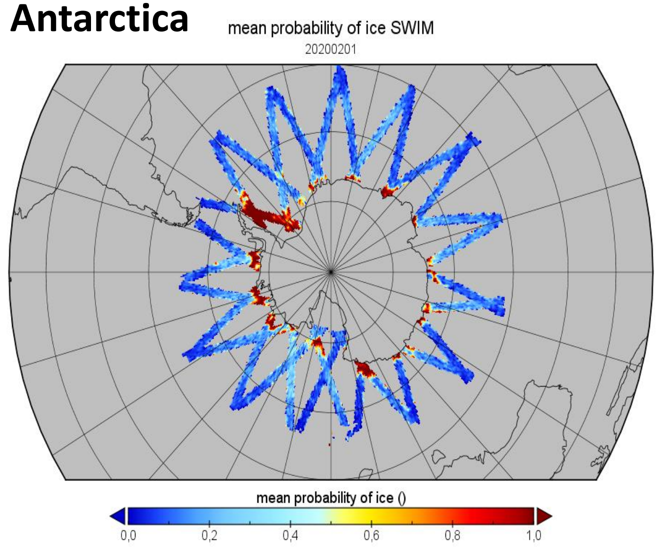




Arctic



Antarctica



Daily products :Sea-ice fraction 1 february 2020

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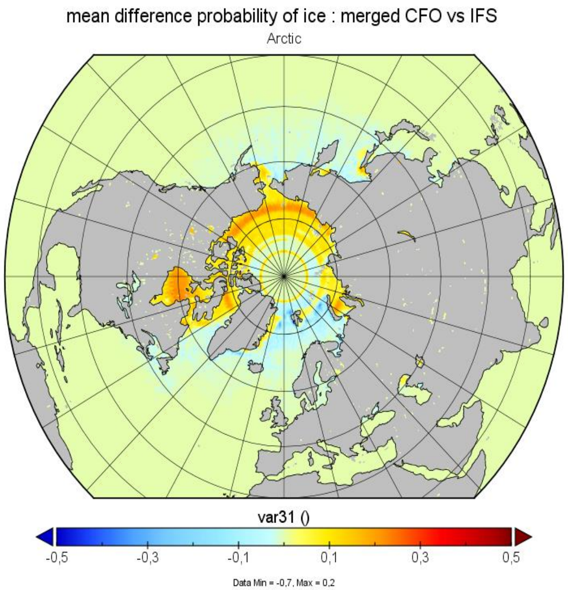
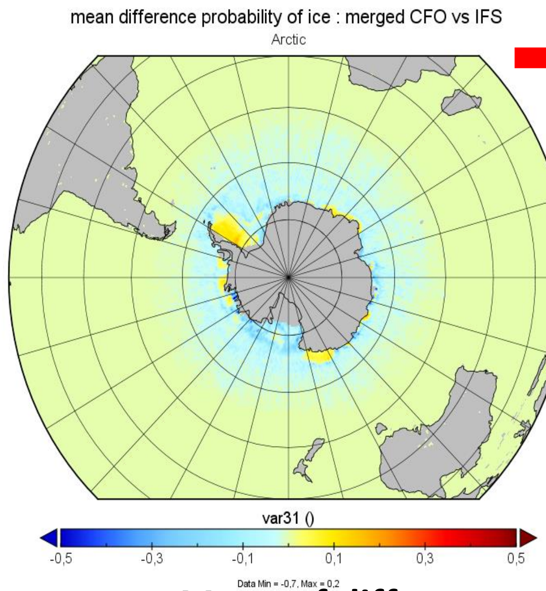
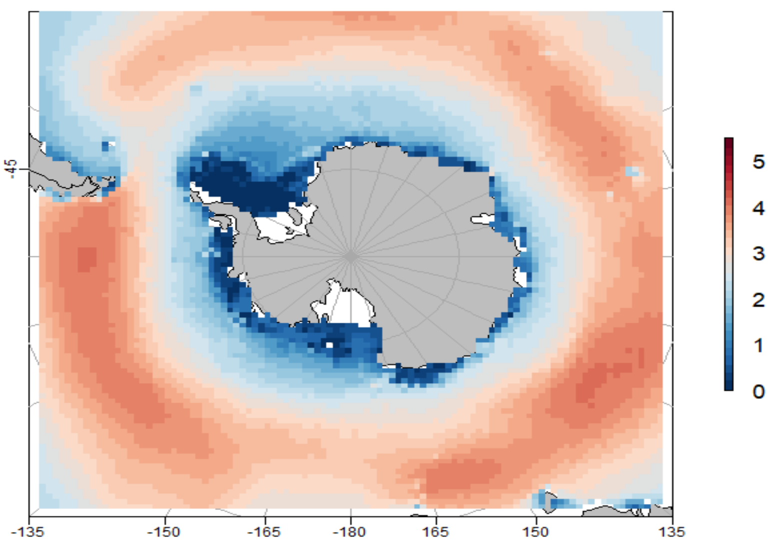
Average difference of probability of ice
Merged IFS-CFOSAT vs IFS :January 2020



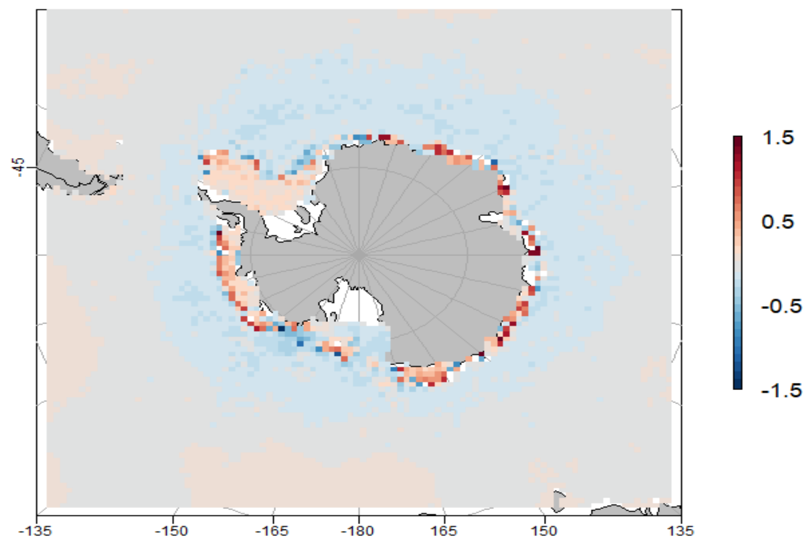


Red color indicates an overestimation of ice fraction, while blue color Indicates an underestimation

Mean SWH in January 2020
MFWAM with SWIM ice

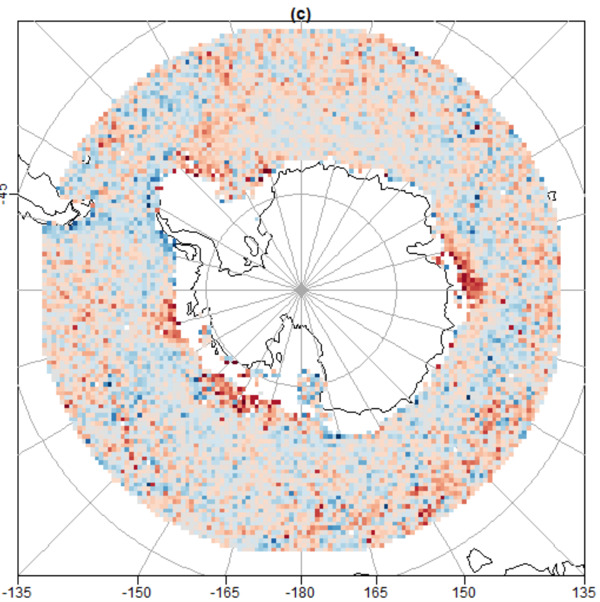


Mean of difference of SWH January 2020
MFWAM with Merged CFOSAT+IFS ice and

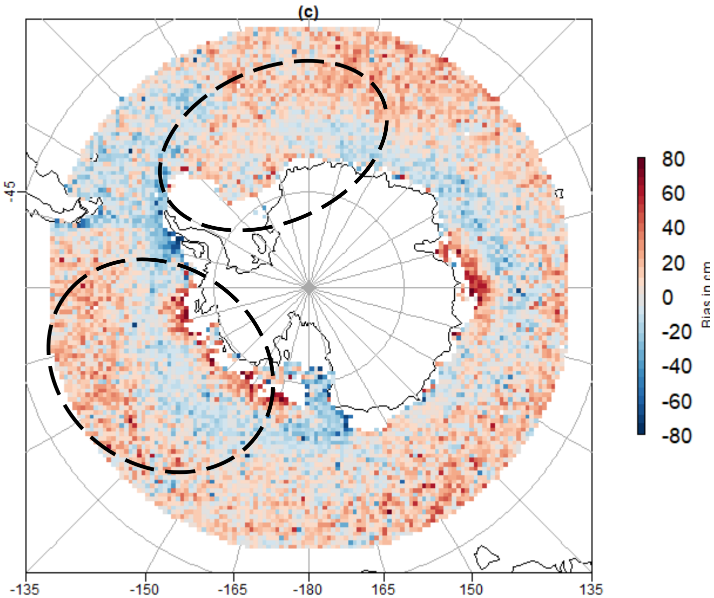


Sensitivity to sea ice forcing : enhanced impact of SWIM spectral DA
With improved CFOSAT+IFS sea ice forcing

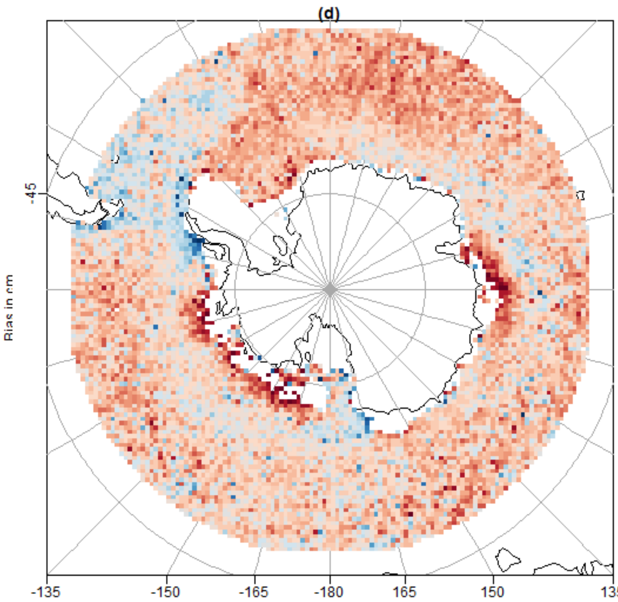
ASSI-Merged CFO-IFS



Merged CFO-IFS



IFS sea ice



➡ **Remarkable reduction of SWH bias particularly in Weddel, Amundsen and Ross seas**
For latitudes below 45° S the SWH bias decreases from 12 to 3 cm in average.

Validation of SWH with altimeters : Jan-Feb 2020

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Using ice thickness in the wave model MFWAM

Source term used for the wave attenuation by ice bottom friction from Yue et al. (2022)

$S_{ice} = -2 * C_g * \gamma * F(f,\theta)$

where

$F(f,\theta)$ is the wave spectrum,

$\gamma = A * I_t^{1.25} * f^{4.5}$ and $A=2.923$

I_t : the sea ice thickness,

f : wave frequency

C_g : the group velocity in open ocean.

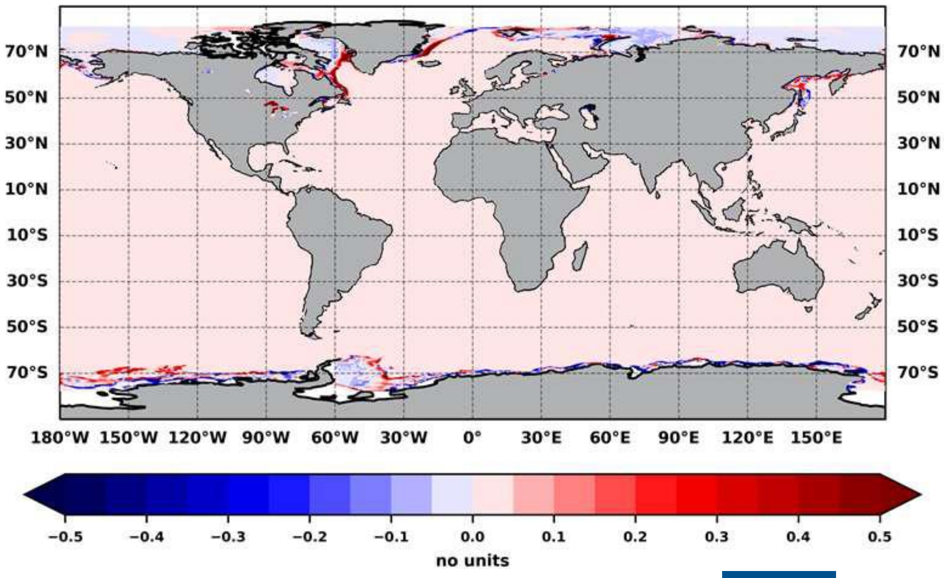
Implemented in the wave model MFWAM

Testing experiments using Ice thickness and Sea ice concentration from GLORYS (Copernicus global ocean Reanalysis) and wind from ERA5 : January 2020

CMEMS-GLO12

Jan.-Feb. 2021 : sea-ice from CMEMS-GLO12 and wind from IFS-ECMWF

Difference of Sea ice conc between ERA5 and GLORYS 15 jan. 2020



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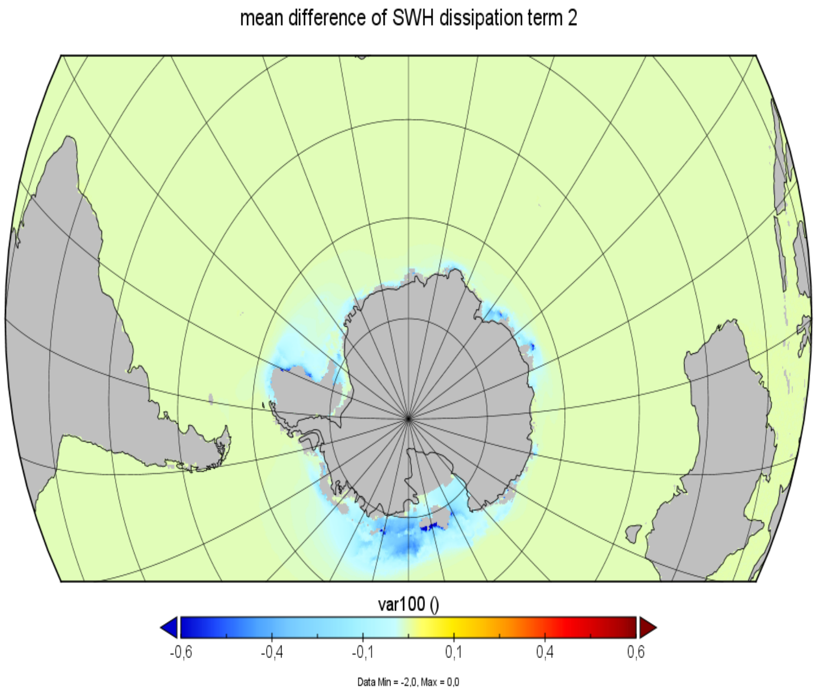
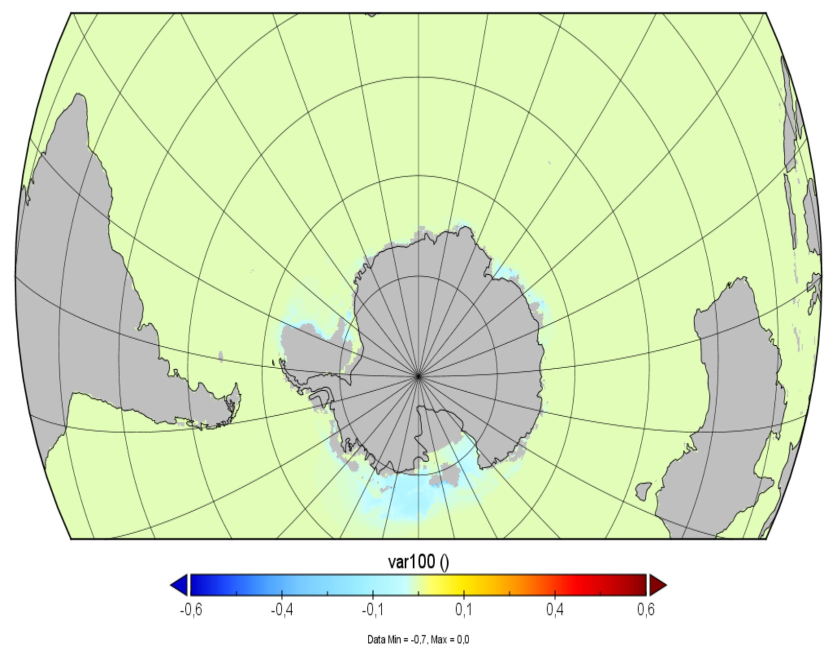
Impact of using wave-ice interactions source terms in the model
January 2020

Average difference of SWH w/wo wave attenuation

Parametrization based on Yue et al. (2022)



Parametrization based on Kohout et al. (2011)

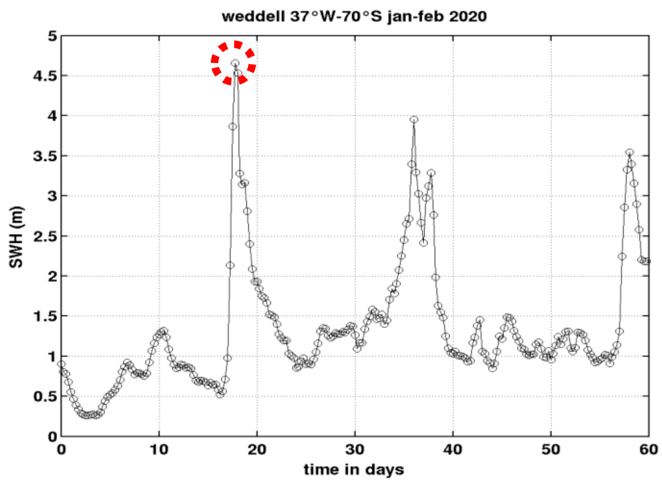


Yu et al. Gives an enhanced impact on SWH Weddell and Amundsen seas

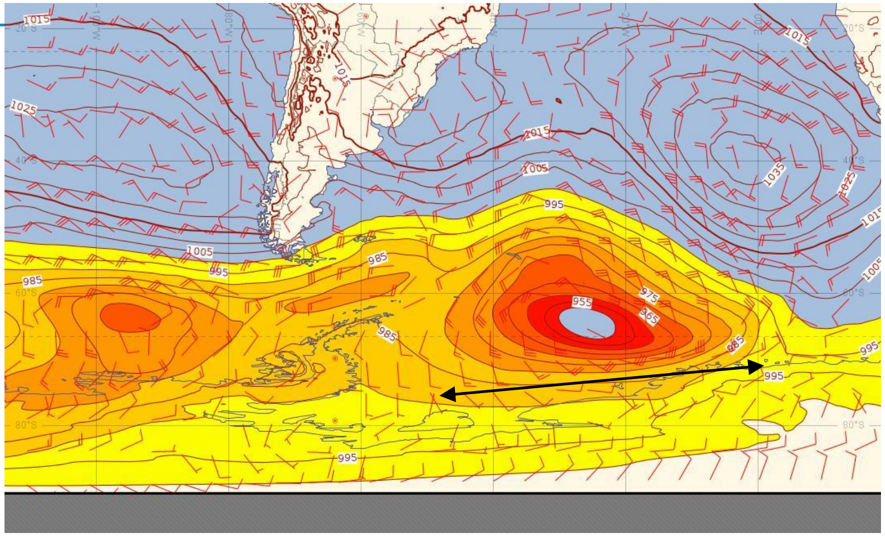
METEO FRANCE

Complex wave systems in Weddell Sea (37° W-70° S)

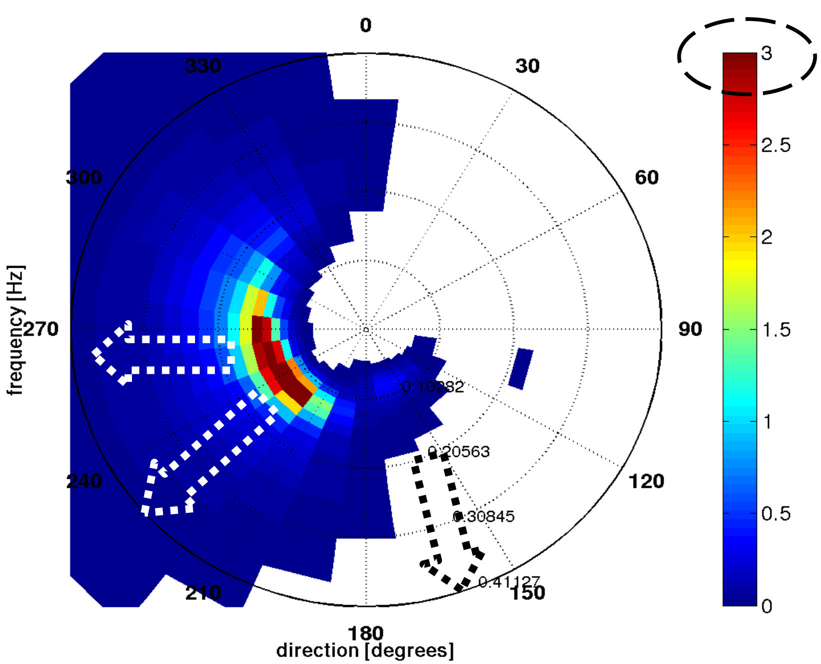
Storm event in 18 January 2020

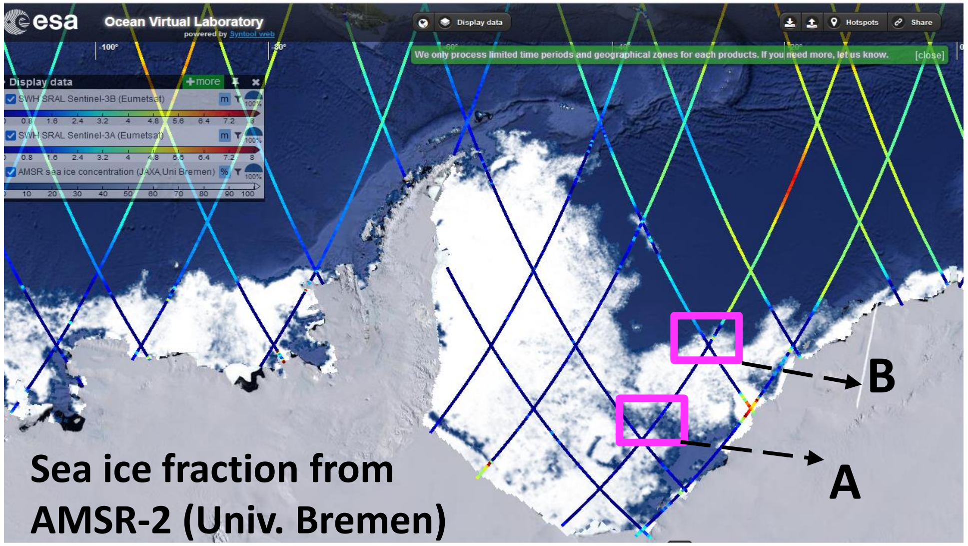


weather chart 20200118 at 0:00 UTC



wave spectrum 2020011803 (before « B »)

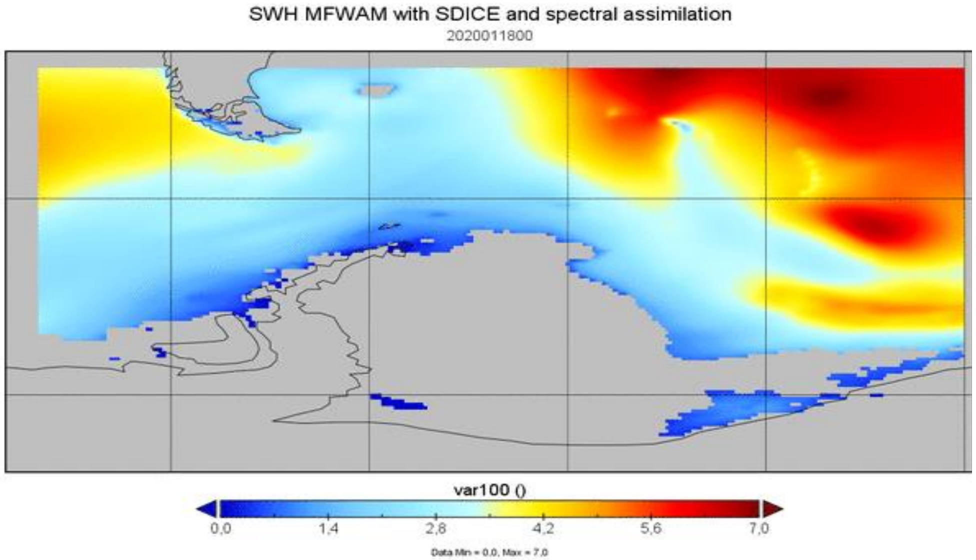




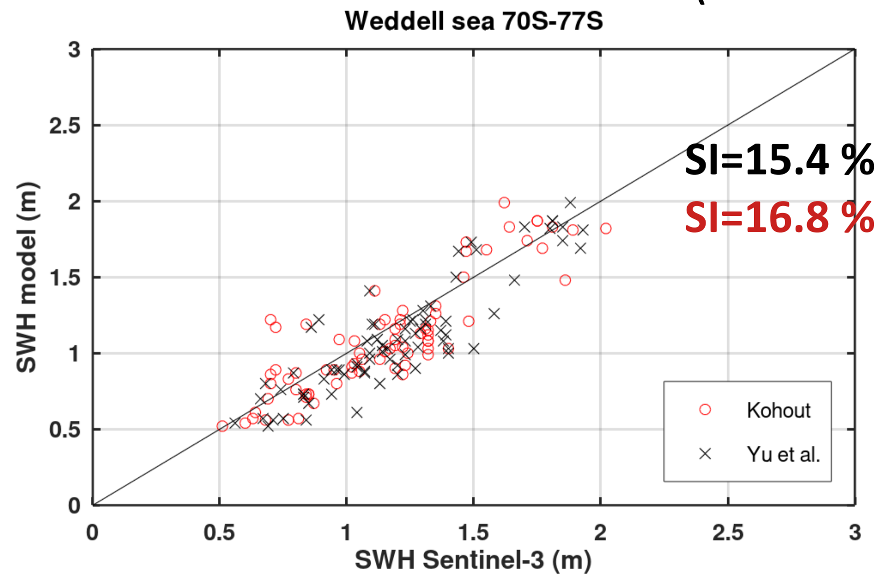
Impact of using wave-ice interactions during Storm in 18 January 2020

Weddell sea : Jan. 2020 & 2021
70° S - 77° S

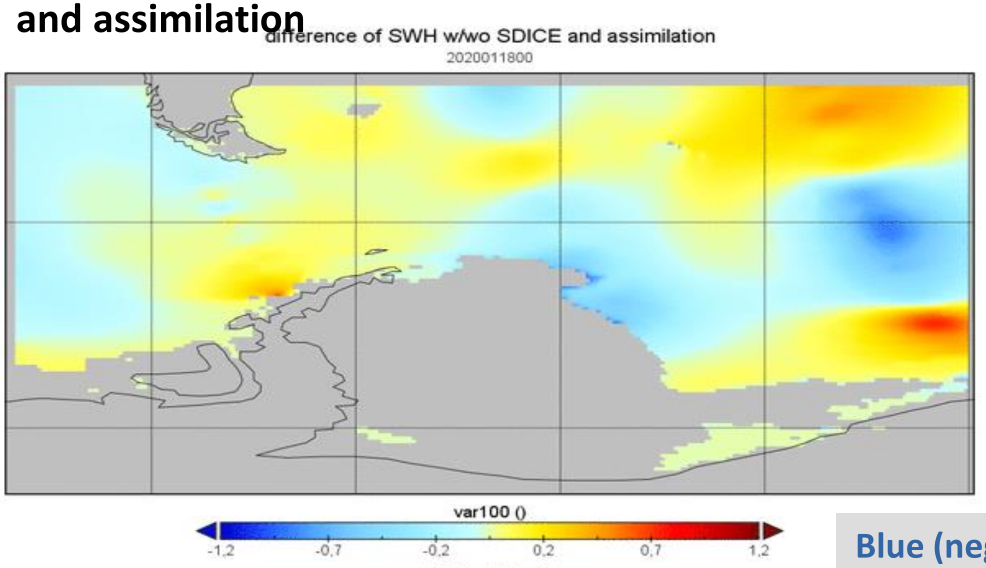
3-hourly SWH from MFWAM with SDICE and assimilation of SWIM wave spectra 18 January 2020 0:0 to 21:00 UTC

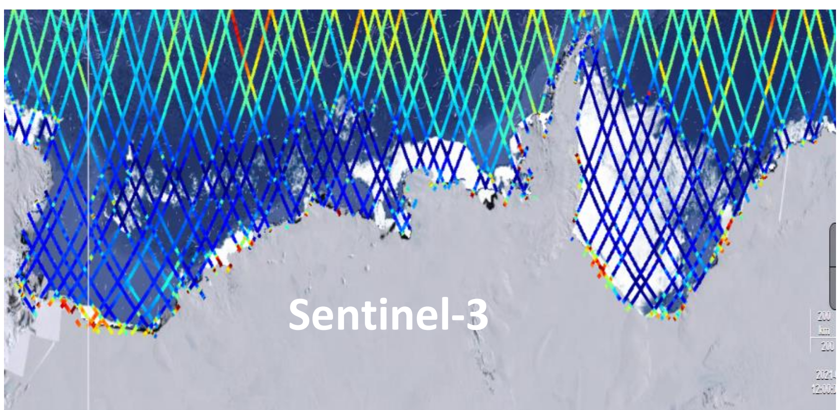


(m



3-hourly corresponding difference of SWH w/wo SDICE and assimilation

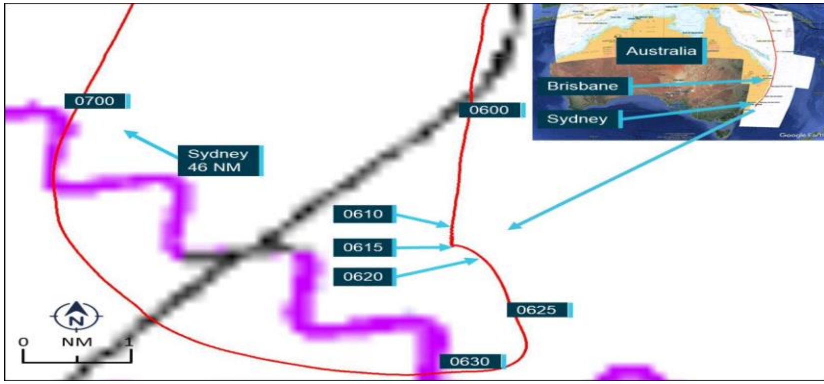




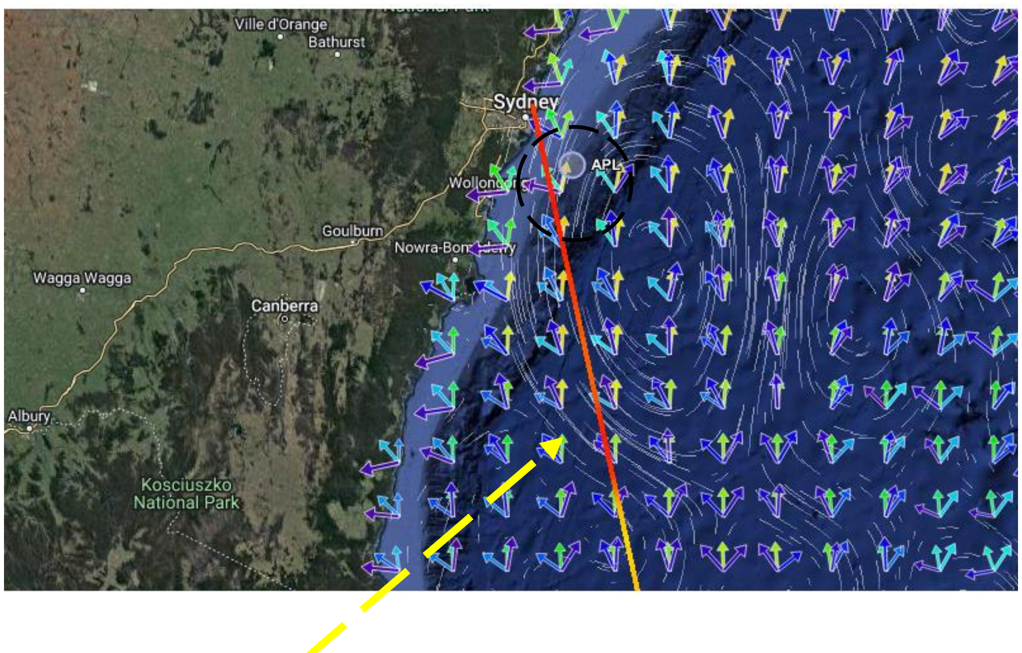
Blue (negative= overestimation
Red (positive) underestimation

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

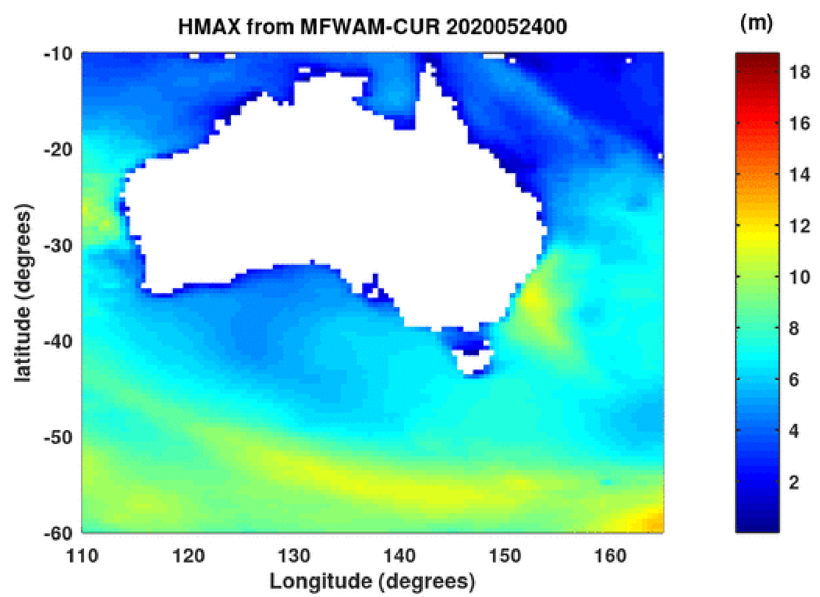


Wind-wave 8.6 sec, 1st swell:9.5sec 2nd swell 12.6 sec



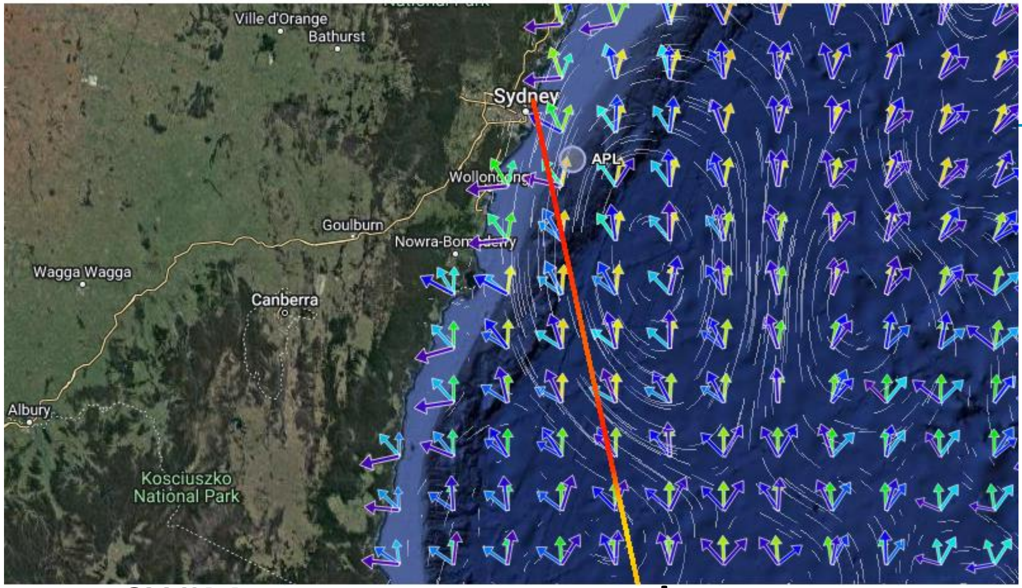
CFOSAT track at 9:25 UTC

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

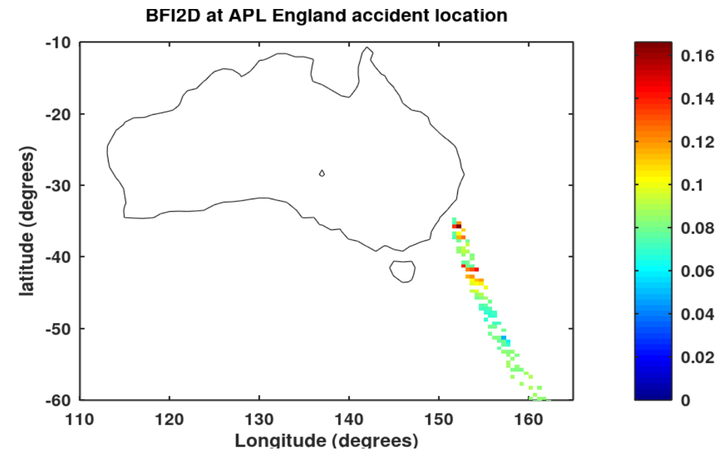


Strong increase of Hmax more than 16 m at the accident location

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



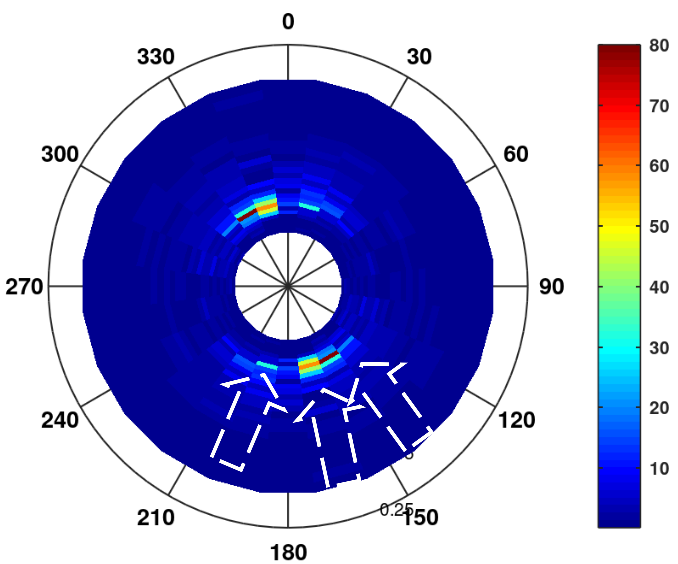
BFI2D from model at CFOSAT tracks



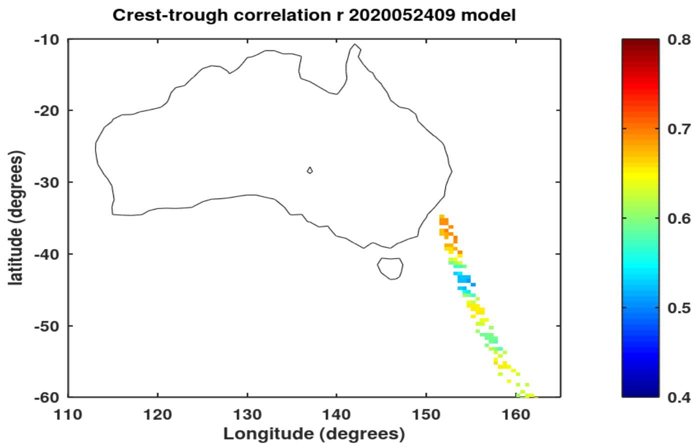
SWIM wave spectrum nearby

40 km from the location

R=0.6 & BFI2D=0.12



Crest/trough correlation



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

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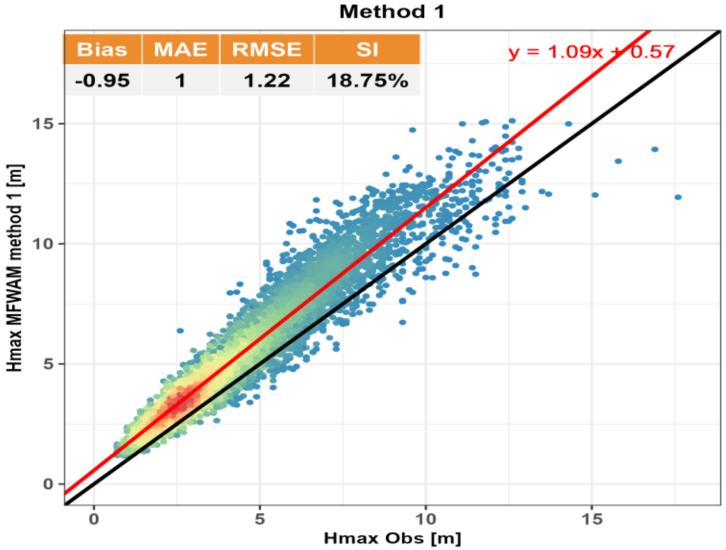
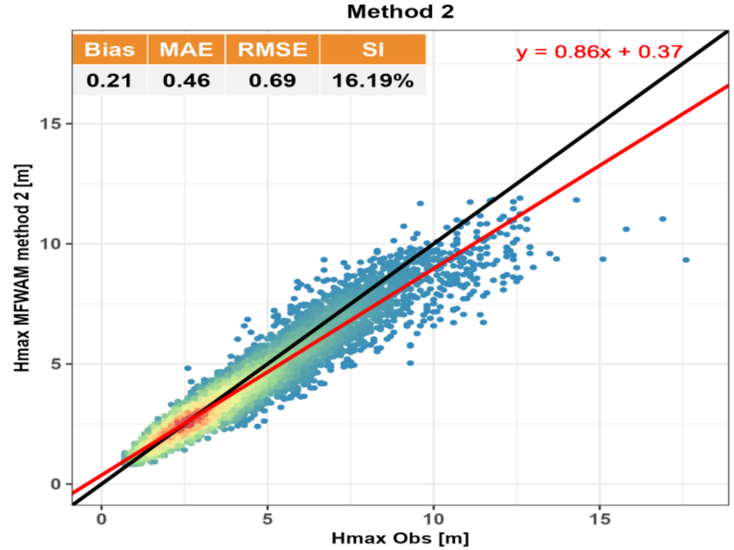
Increase of BFI2D and Crest/trough correlation

Uncertainties on computation of Hmax :Hmax from GLO-waves at Brittany and Bisca in North-East Atlantic : Jan-Jun 2019

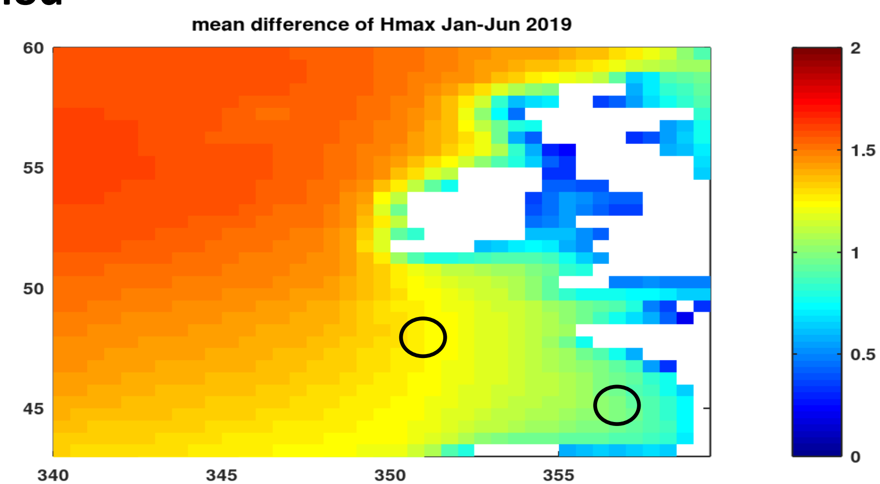
Two computations : method-1 (Janssen) and method-2 (Latemar : Benetazzo et al.)





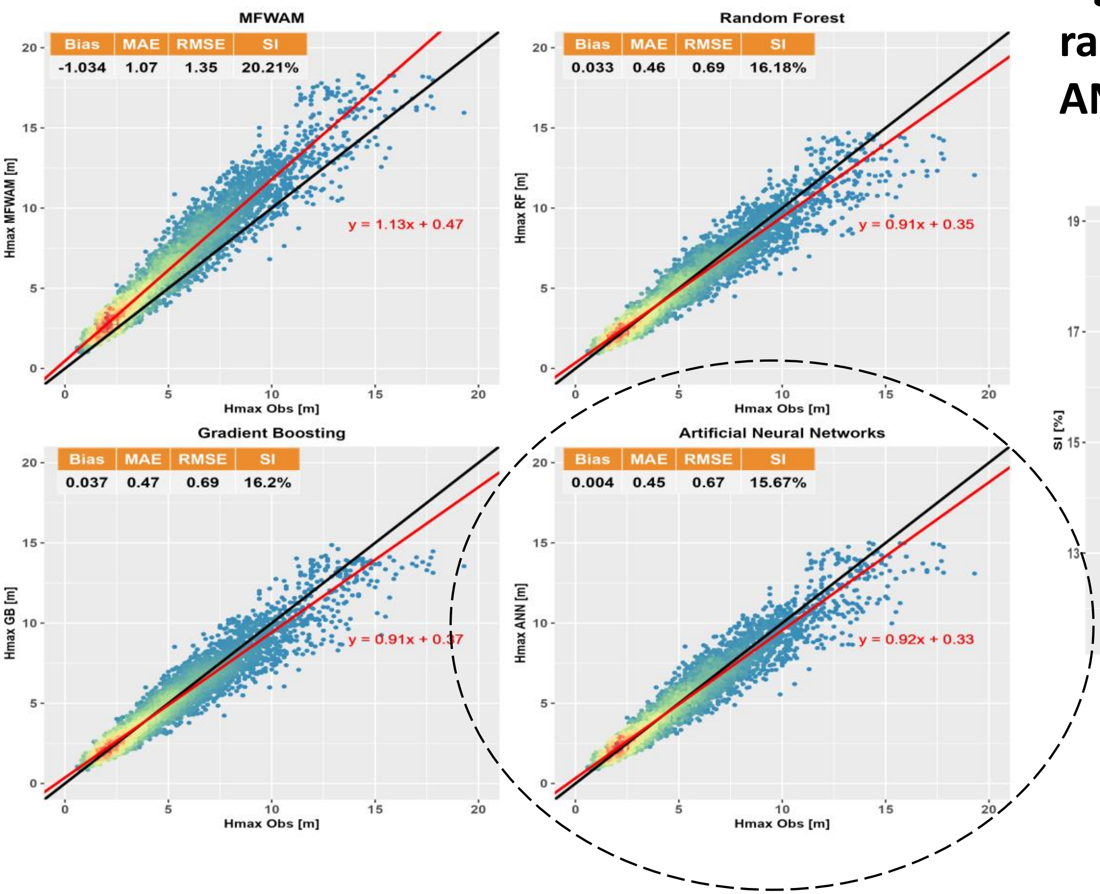
For hmax <8 m Latemar method has a better Estimate, while for Hmax > 8 m Latemar method Is strongly underestimating the observations

Mean difference Hmax (Janssen-Latemar)

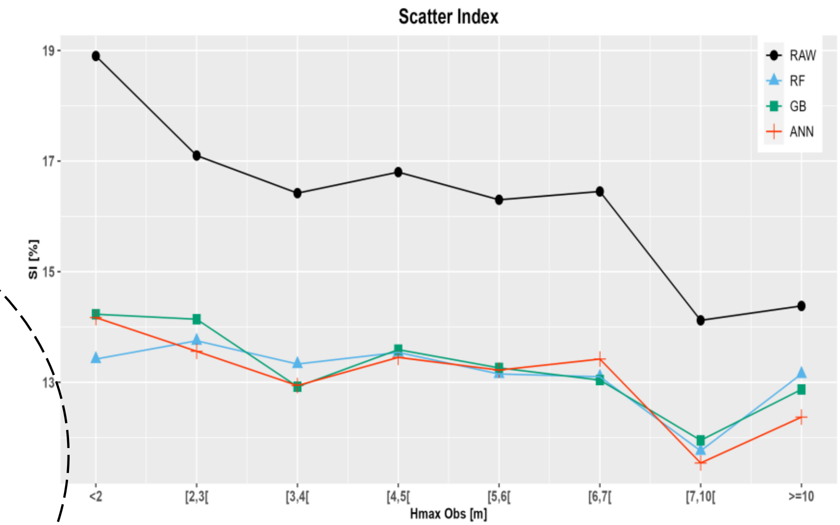


Deep Learning correction with several technique : ANN, Ranom forest Gradient boosting

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

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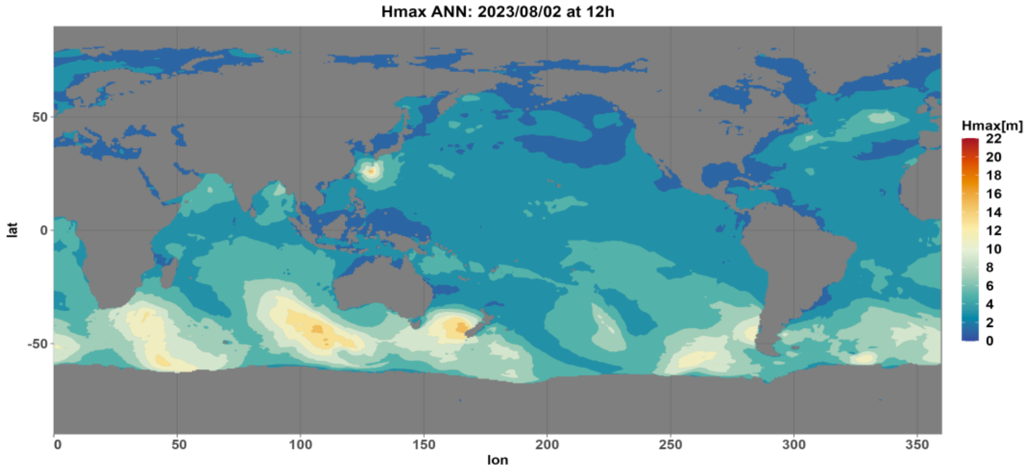
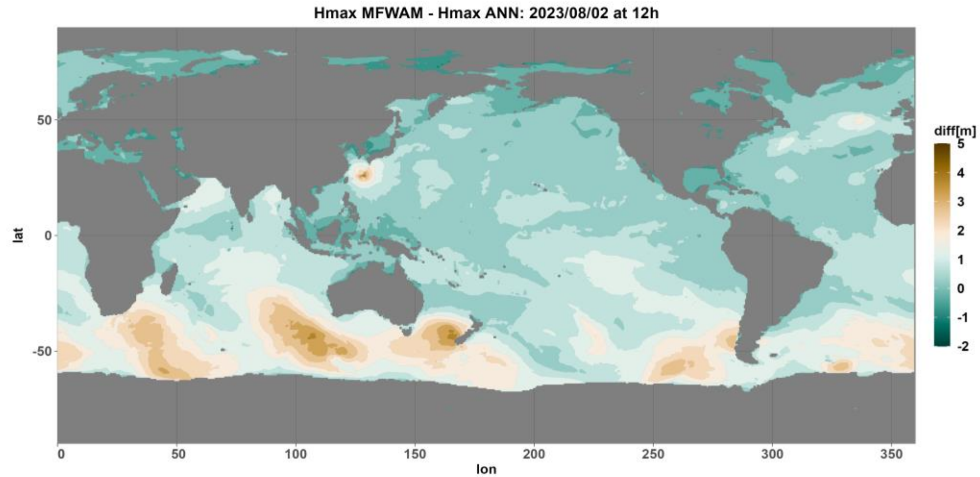
Example of Hmax (CMEMS-global) with ANN : 2 August 2023 à 12h UTC

Hmax ANN



Difference of Hmax (wo/w ANN)



Reduction of occurrence of Hmax/SWH >2

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

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Key messages

➔ New wave data (wide swath SWH) can be used : positive impact and skilfullness to track rapid storms. Preparation of using data from SWOT (CNES/NASA) mission

➔ Successful use of wave-ice interaction source term : positive impact in Southern Ocean (Weddell and Ross seas). Dependency on the quality of ice-thickness forcing.

➔ Combined spectral and altimeters assimilation has a good performance of sea state forecasting in extreme wind conditions.

➔ Improved Hmax by using deep learning opens a better estimate the occurrence of rogue waves and analysis with spectral parameters.

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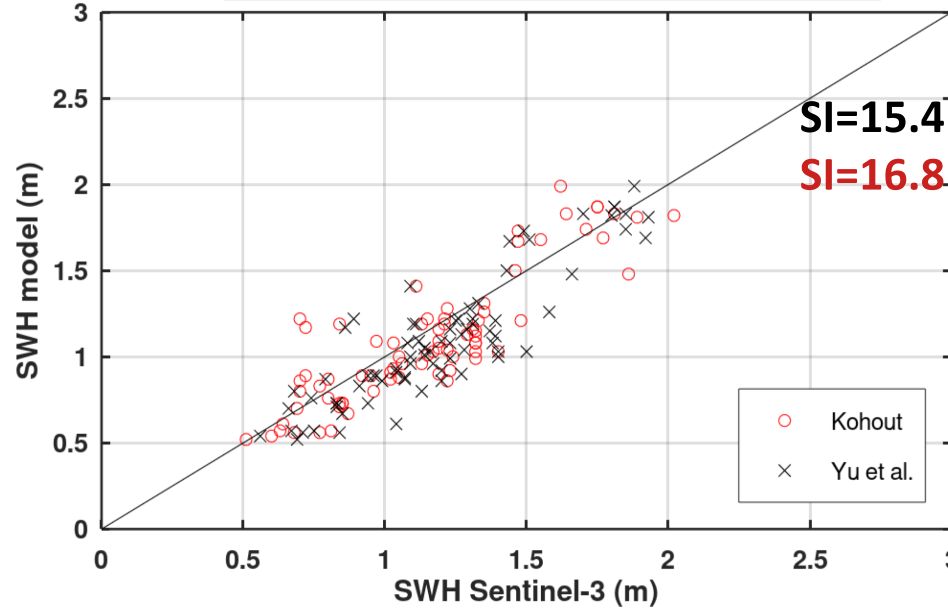
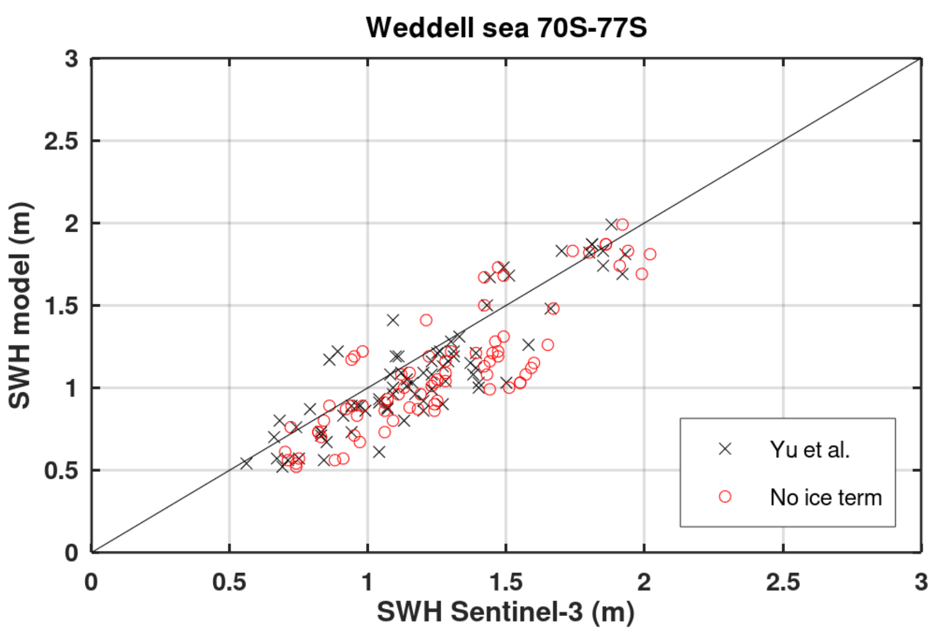
Weddell sea : Jan. 2020 & 2021
70° S - 77° S



Ross sea : Jan 2020 & 2021

SI=15.4 % SI=17.3 %

Bias=0.09 m Bias=0.16 m



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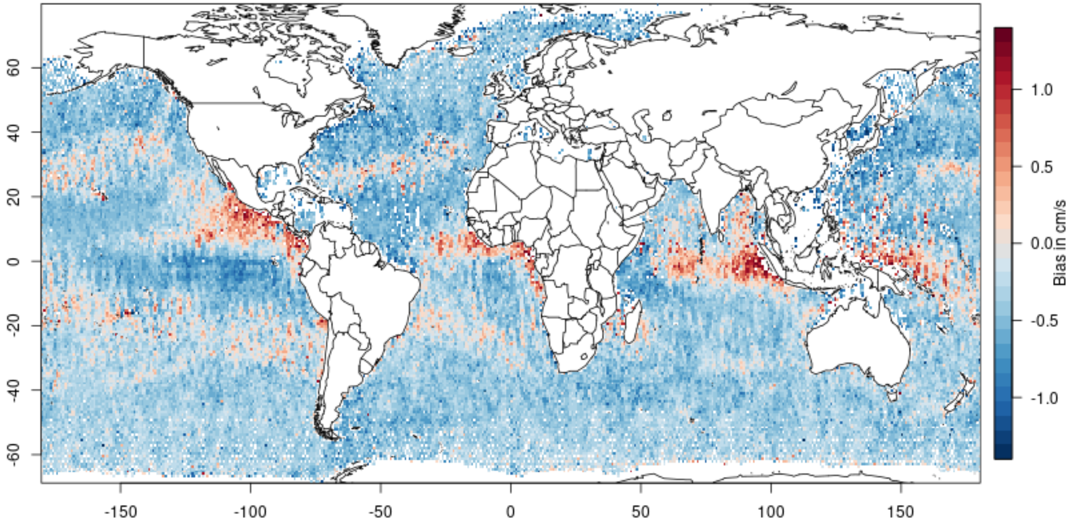
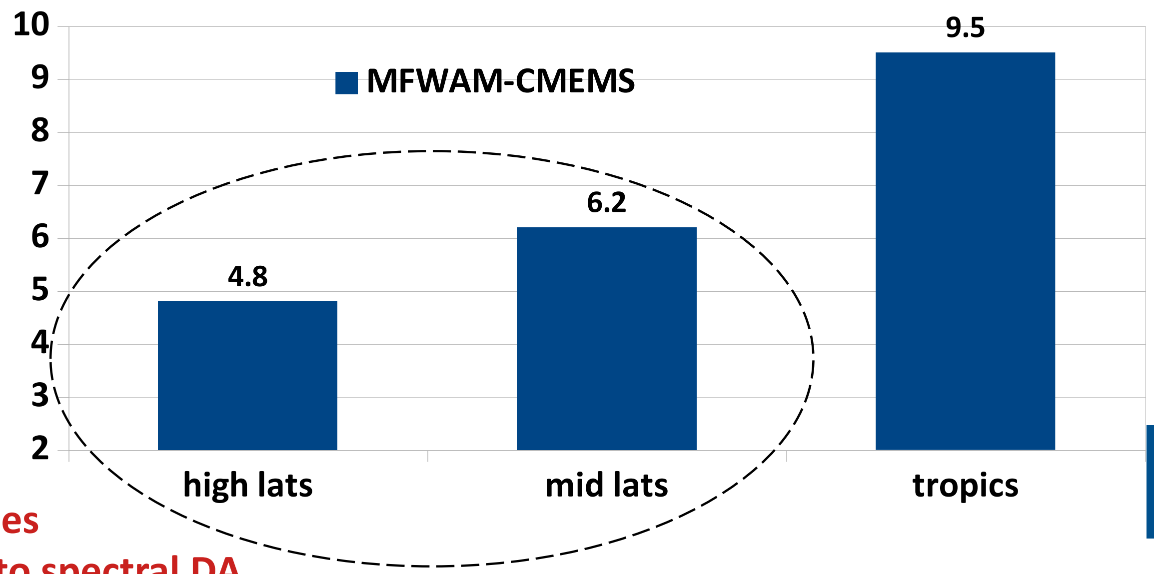
Validation of the spectral assimilation with mean wave period Tm02 (MFWAM-CMEMS): May-Jun 2021

Bias of Tm02 : negative bias of -0.31 in average



Mean period Tm02 are provided from CFOSAT by DNN algorithm (H. Jiang et al. RSE, 2021)

Scatter index of Tm02 (%)



Very good SI in high latitudes and mid latitudes : thanks to spectral DA

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