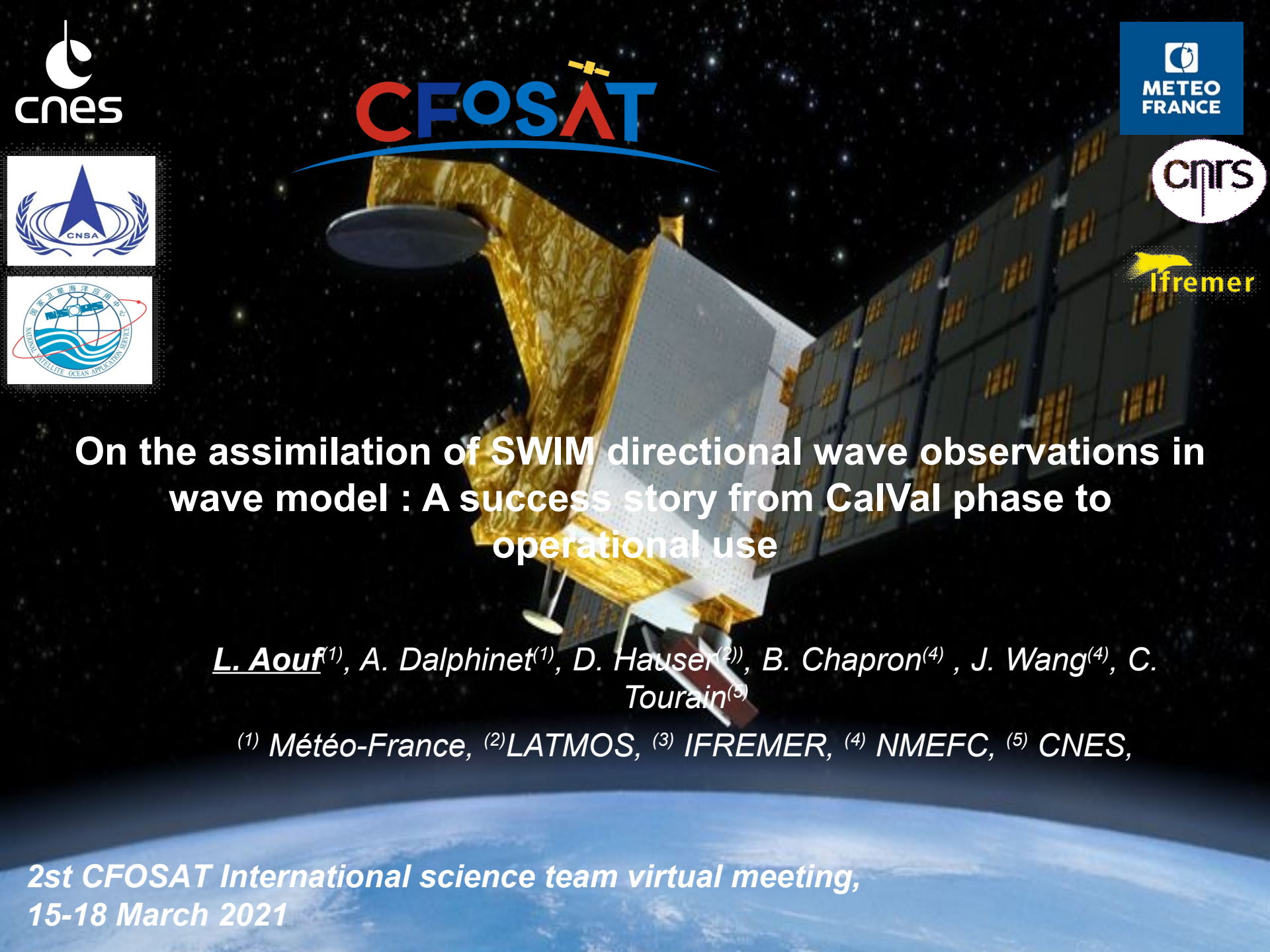


On the assimilation of SWIM directional wave observations in wave model : A success story from CalVal phase to operational use

L. Aouf[(1)], *A. Dalphinet*[(1)], *D. Hauser*[(2))], *B. Chapron*[(4)] , *J. Wang*[(4)], *C. Tourain*[(5)]

[(1)] *Météo-France,* [(2)]*LATMOS,* [(3)] *IFREMER,* [(4)] *NMEFC,* [(5)] *CNES,*

2st CFOSAT International science team virtual meeting, 15-18 March 2021

OUTLINE

1- Motivation

2- Data (IPF.5.0) and DA experiments

3- Results and discussions

4- impact cases

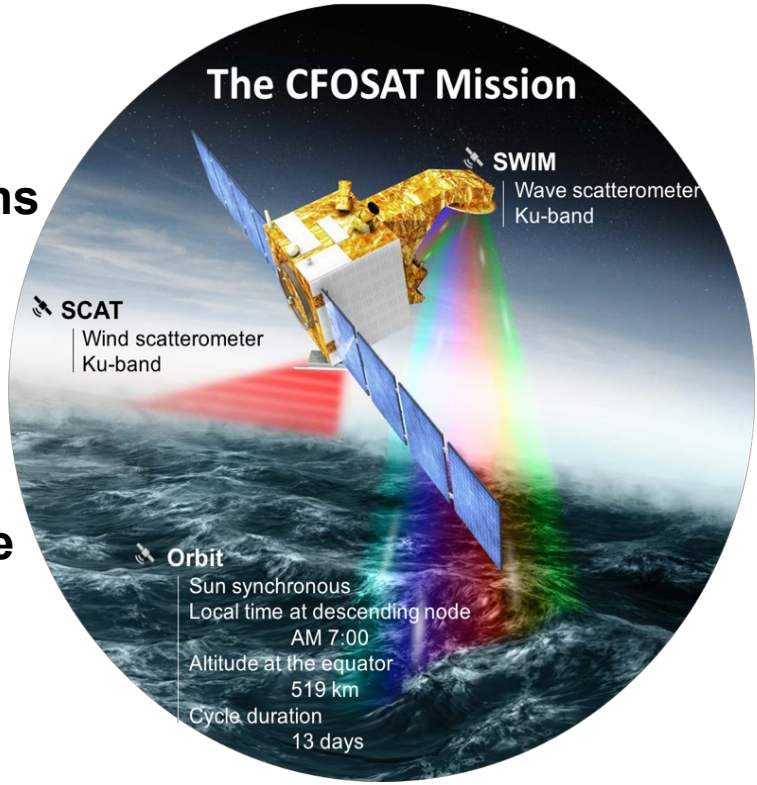
5- conclusions

Motivation

- The directional wave observations from SWIM have revealed the capacity to improve energy transfer in wind-wave growth phase. This opens a promising perspectives for operational wave forecasting : reliable wave submersion warning

- Assessement of long period assimilation of reprocessed (IPF.5.0) SWIM L2 data. Prepare the assimilation of wavenumber components. Choice of MTF, off-nadir SWH impact,...

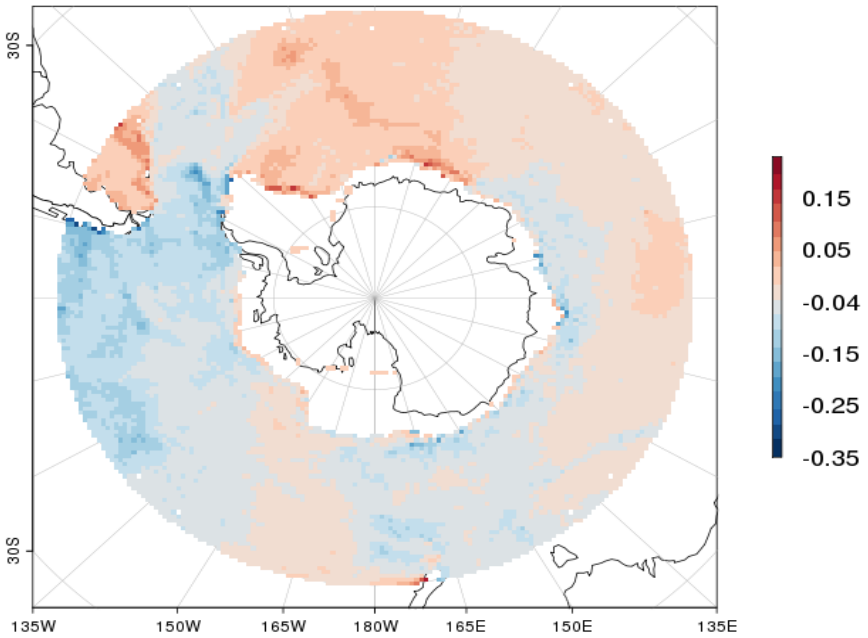
- Analysis of the assimilation impact in critical wave events (storms, cyclonic season, coupling...)



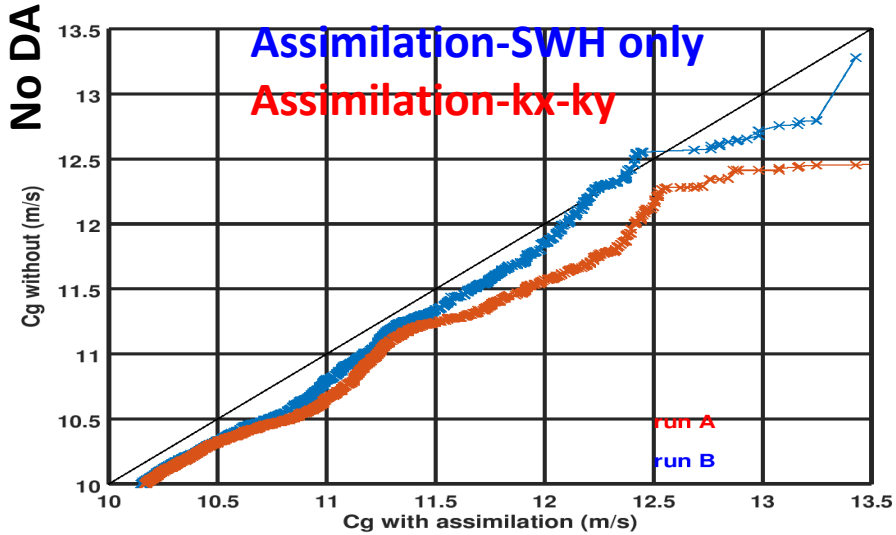
The uniqueness of using directional wave observations from SWIM in Southern Ocean

For fast severe storms under unlimited fetch conditions the assimilation of Wavenumbers components keeps the waves under wind-wave growth regime and correct the energy transfer. This removes completely the bias of SWH linked to misfit of model Parametrization (Aouf et al.2021)

Difference of wave age at the peak with and Without DA



QQplot of wave group velocity



With DA

Only the use of directional wavenumbers can correct group wave velocity under fast Storms with unlimited fetch conditions

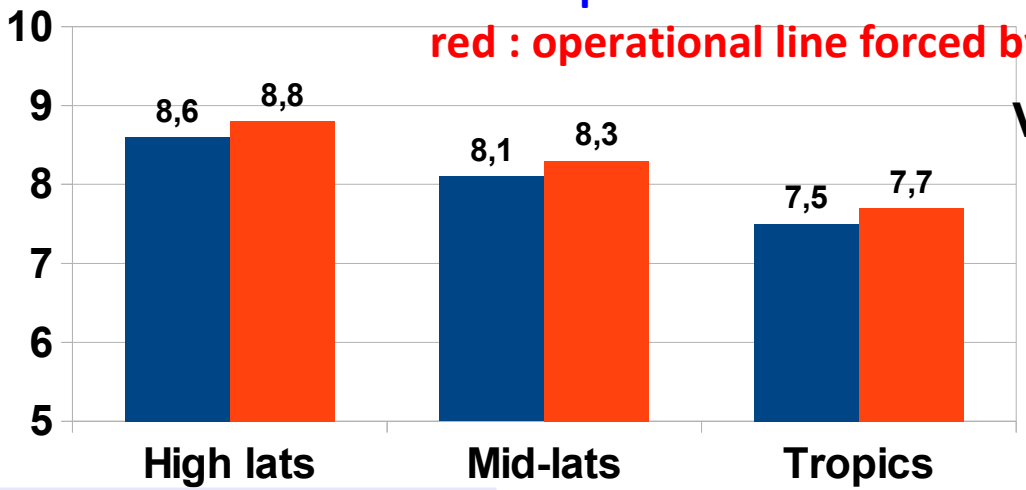
METEO FRANCE

Performance of operational global systems MFWAM after the assimilation of SWIM directional wavenubers : 2-28 February 2021

Blue : operational line forced by ECMWFwinds (CMEMS)

red : operational line forced by ARPEGE winds

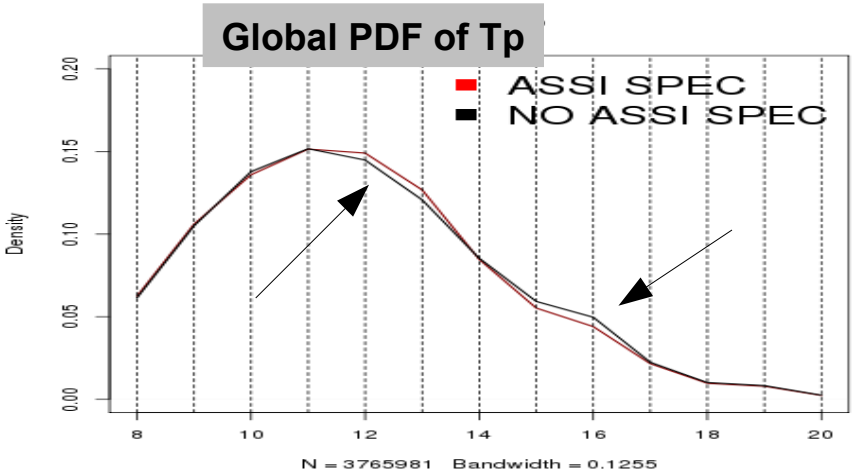
Scatter Index of SWH (%)

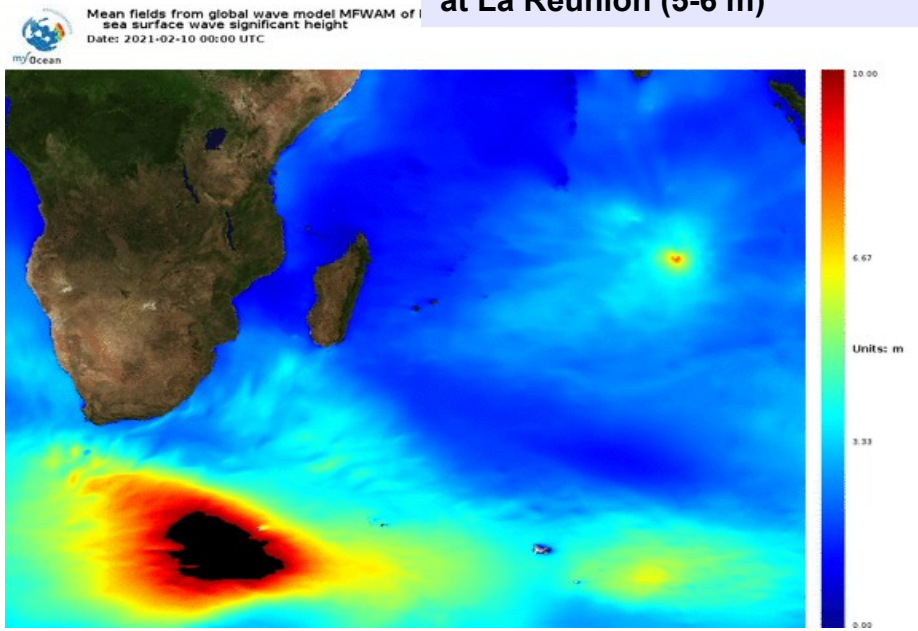


Validation with HY2B SWH

Remarkable scatter index of SWH in average about ~8%, and bias smaller than 4 cm

6-hourly SWH from CMEMS-Global
10-12 february 2021
Skillfulness of the assimilation in storm event swell warning at La Réunion (5-6 m)





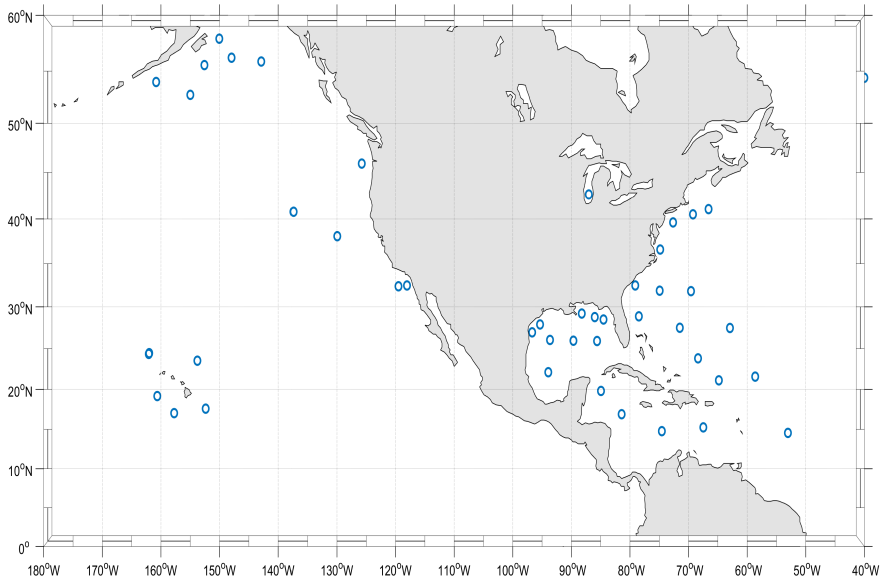
Two Tp ranges affected by the assimilation of Kx-ky : increase in 11-13 sec and decrease in 15-17 sec

Data analysis

SWIM L2 data have reprocessedwith IPF.5.0

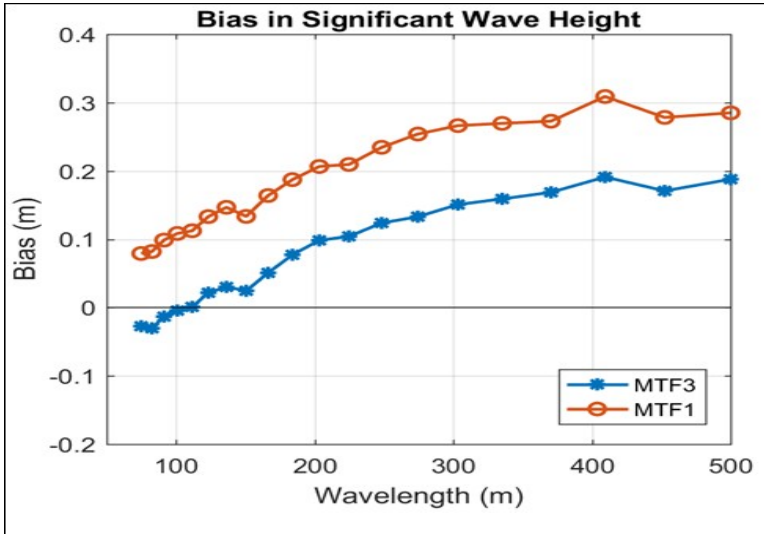
- **Colocation of SWIM spectra with NDBC Buoys (May-Aug 2019)**
- **Computation of wave heights for Different frequency ranges**
- **Computation of SWH for wavelength 70-500 m**
- **Statistical analysis**

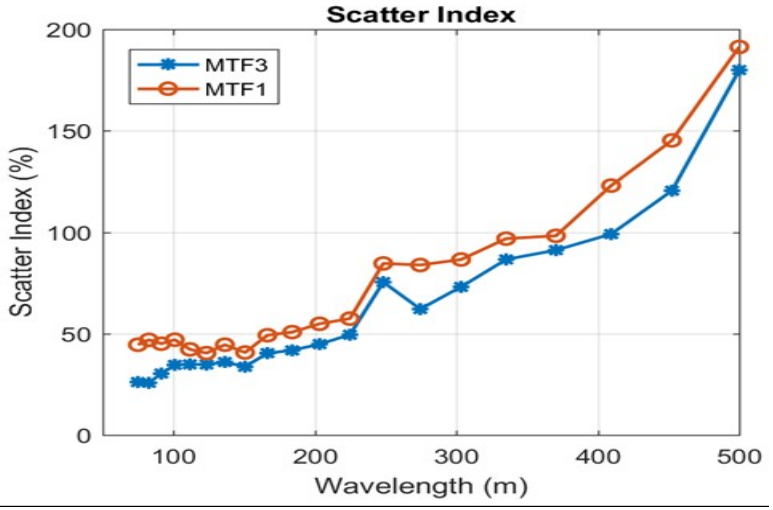
NDBC buoys locations



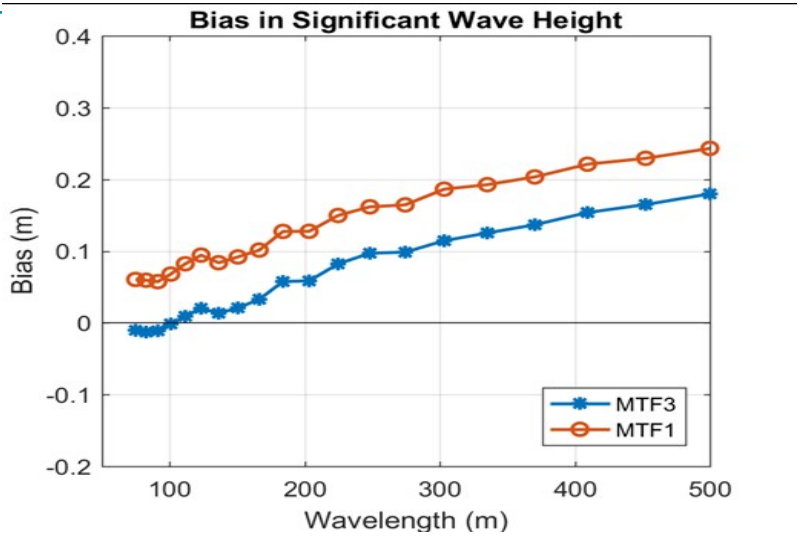
Assessement of SWIM spectra (IPF.5) : comparison with buoys

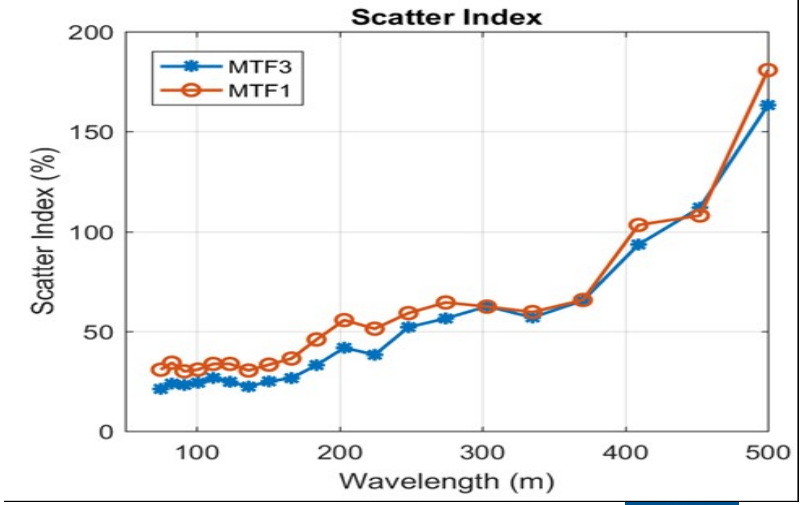
Beam 6°





Beam 10°

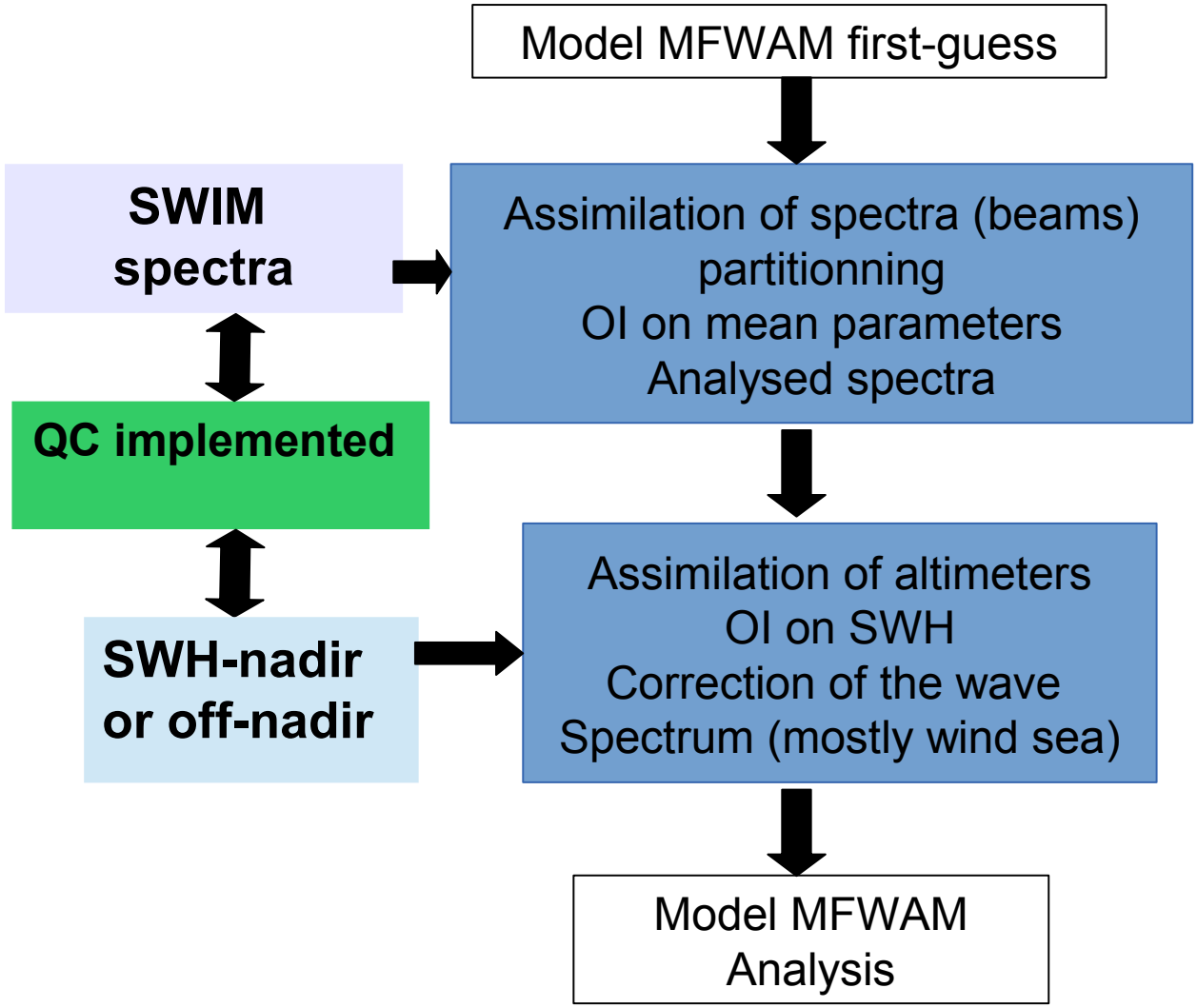




Beam 10° with MTF3 shows reduced bias and scatter index for SWH of different wavelengths ranges

METEO FRANCE

Description of combined assimilation system



Assimilation experiments : May-Dec 2019 and Jan-March 2020

- Reprocessed SWIM data with IPF.5.0 : MTF3 and beam 10° has been prepared for the assimilation in the model MFWAM.

- Model MFWAM : global configuration with grid resolution of 0.5° and atmospheric forcing from IFS-ECMWF (ice-fraction and winds)

- Long period model runs have been performed :

- Assimilation of wavenumber kx-ky of partitions
- Assimilation of SWIM nadir SWH 1 Hz
- Assimilation of SWIM nadir 1Hz and wavenumbers kx-ky
- Assimilation of wavenumbers kx-ky and off-nadir SWH (1,2)

- Azimuthal cut-off set to 0.151 Hz on SWIM spectra (sensitivity tests in previous study)

- Validation with independent altimeters and buoys data

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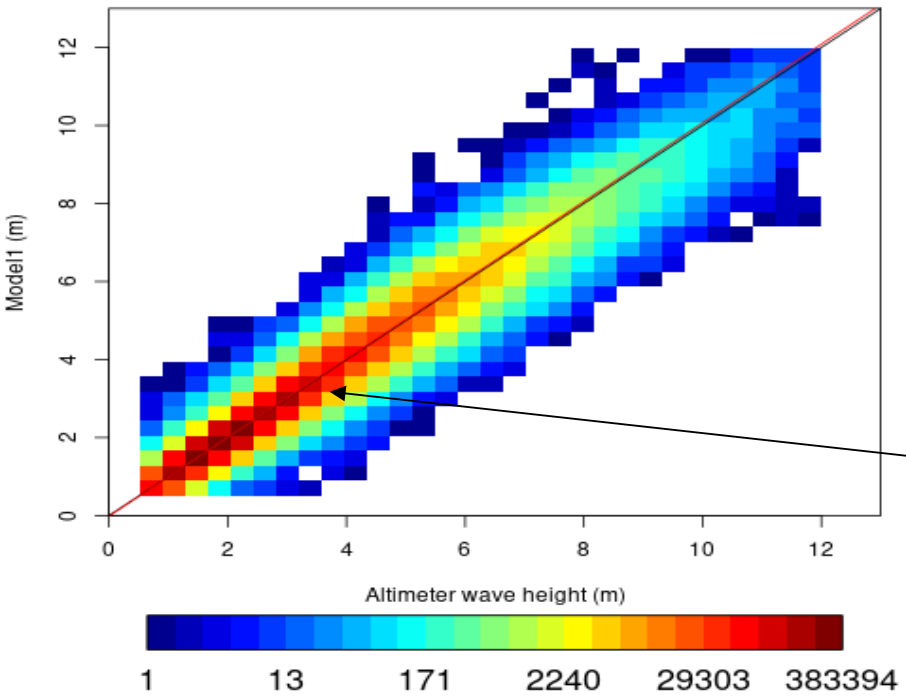
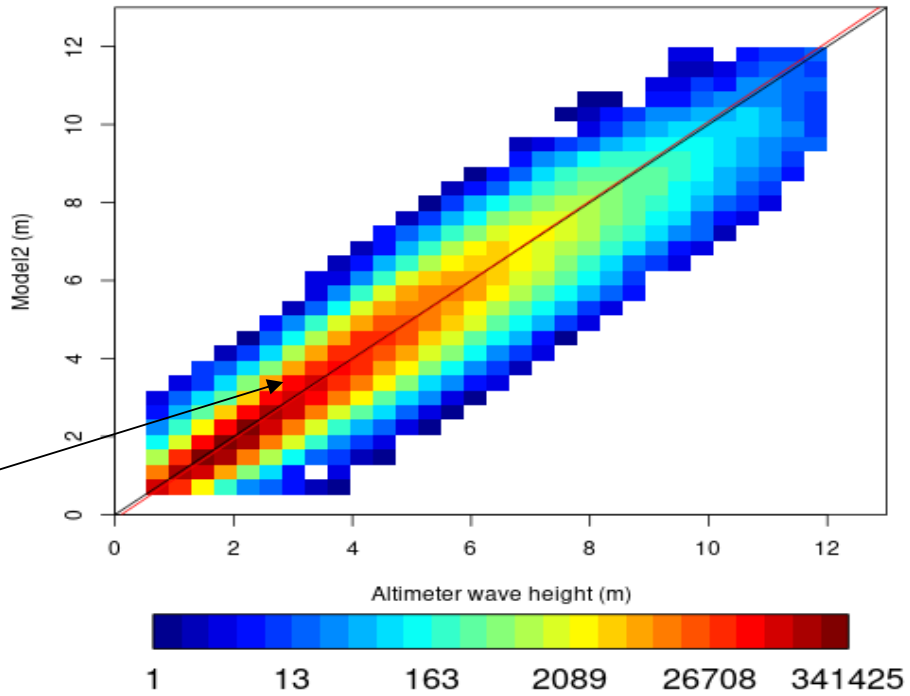
Impact of the combined assimilation (nadir+Kx-Ky)
Scatter plots of SWH period Jul-Dec 2019

Assimilation of SWIM-L2 (Nadir+ Kx-Ky beam 10)



Without assimilation



Bias=0.01
SI=10.1 %
RMSE=10.1%
Slope=1.01
Intercep=-0.01

significant improvement of Scatter index (in average by 16%) and reduced bias

Bias=-0.06
SI=11.9 %
RMSE=12.1%
Slope=1.02
Intercep=-0.11

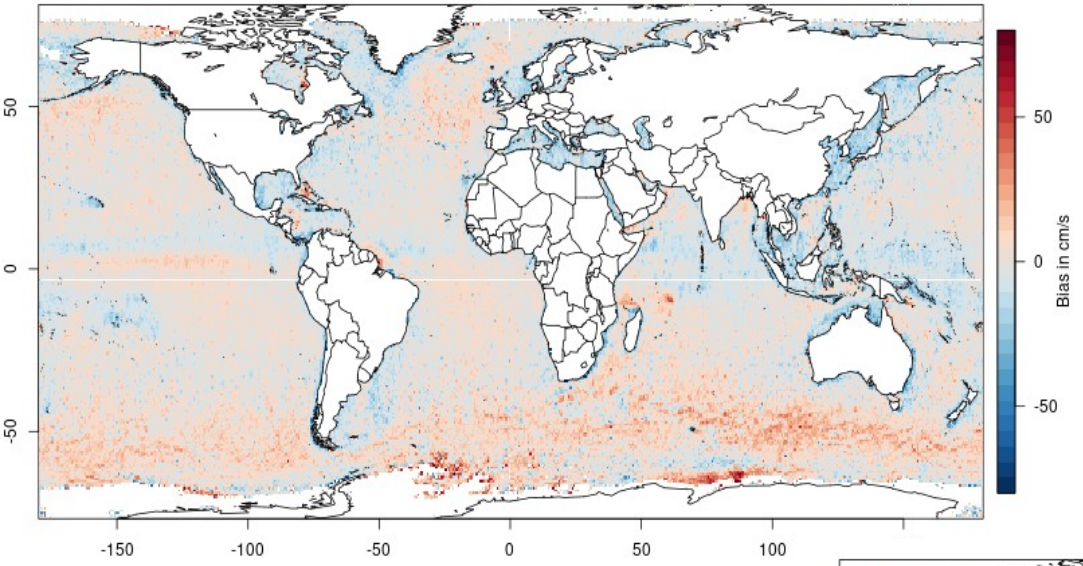
METEO FRANCE

Comparison with SWH from Ja-3, Saral and S3A

Bias maps of SWH : July–December 2019
Impact of the assimilation of SWIM- L2 (nadir+Kx-Ky)

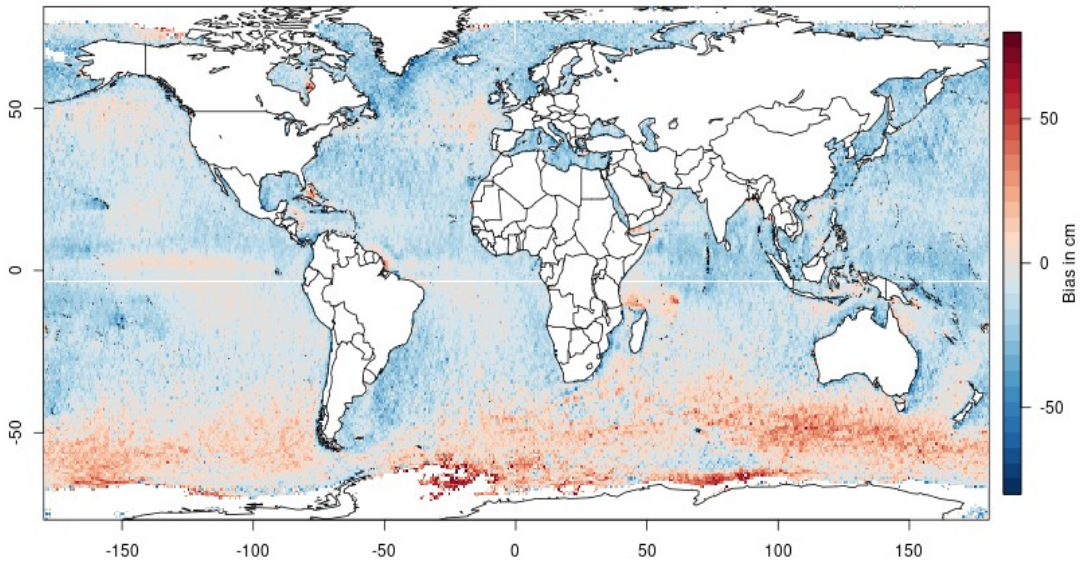
Assimilation of SWIM (nadir+kx and ky)

Maximum range 60 cm



Good reduction of SWH bias in high and mid latitudes.

Comparison with SWH from Jason-3, Saral and S3A

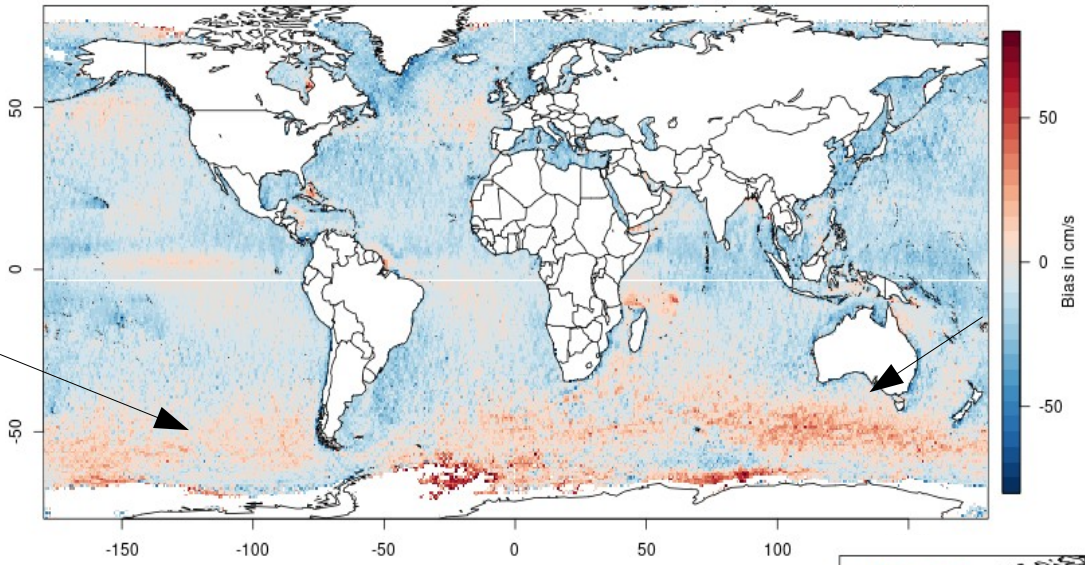


Without assimilation

Bias maps of SWH : July–December 2019
Impact of the assimilation of SWIM-NRT (Kx-Ky)

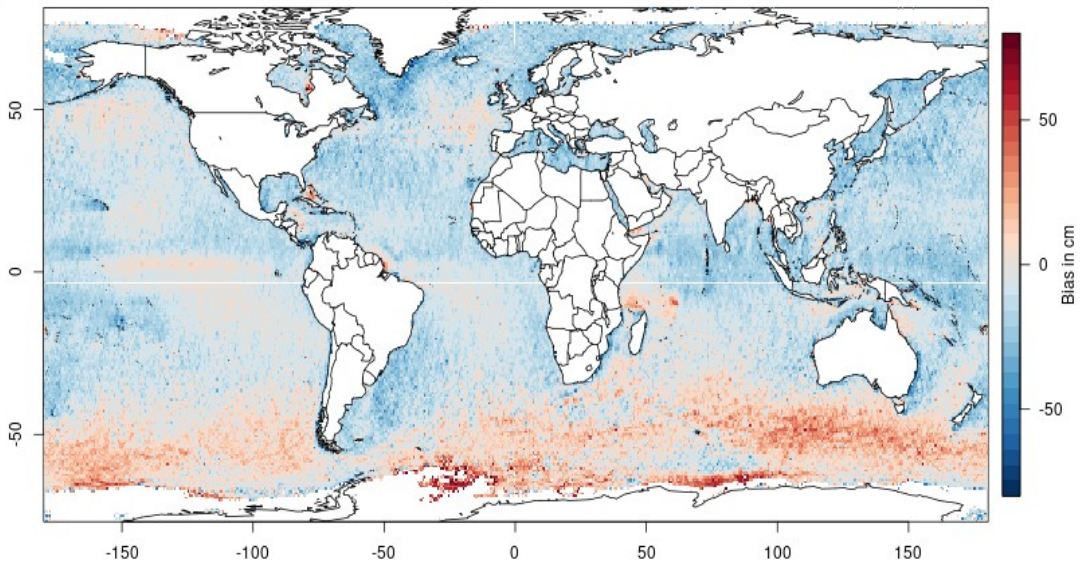
Assimilation of SWIM (kx-ky)

Maximum range 60 cm



Mostly significant reduction in SO and slightly in the tropics and Mid

Comparison with SWH from Jason-3, Saral and S3A

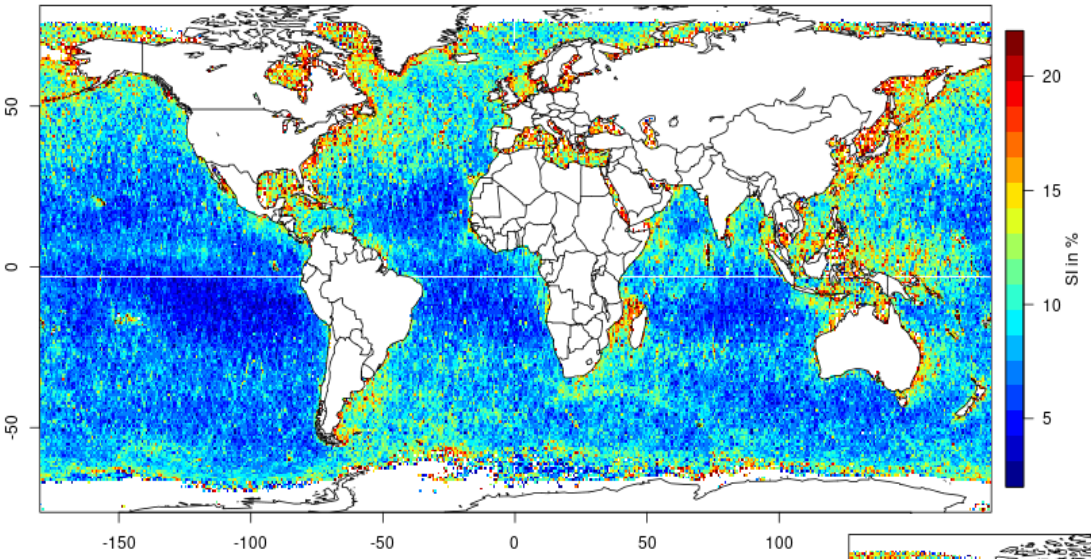


Without assimilation

Scatter index maps (in %) of SWH
July-Dec 2019

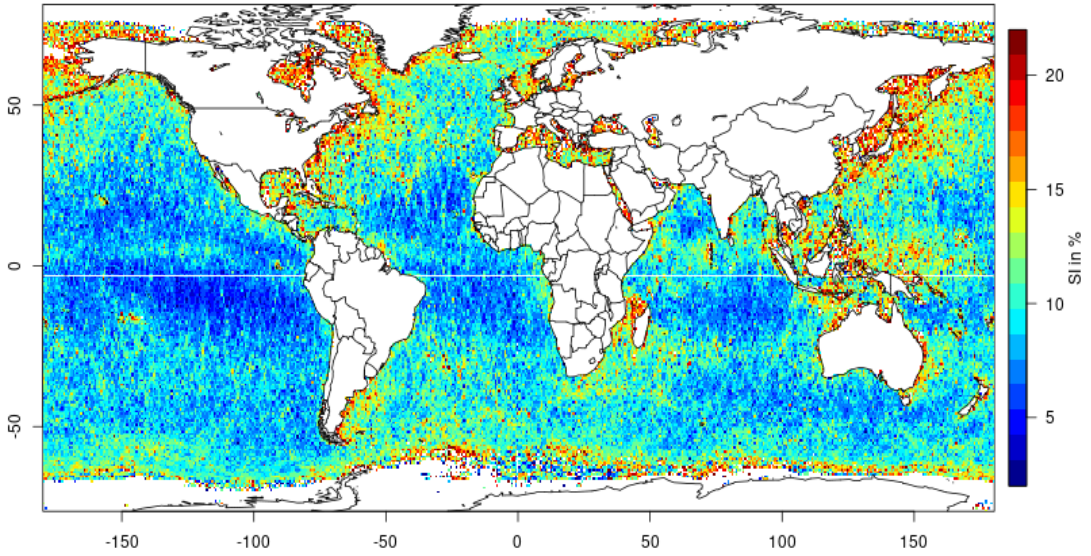
Assimilation of Nadir+kx-kv (10°)

(Maximum range 22%)



Clearly better SI globally when Using Nadir and Kx-Ky from SWIM (IPF.5). Particularly In high and mid lats in all Ocean basins.

Without assimilation



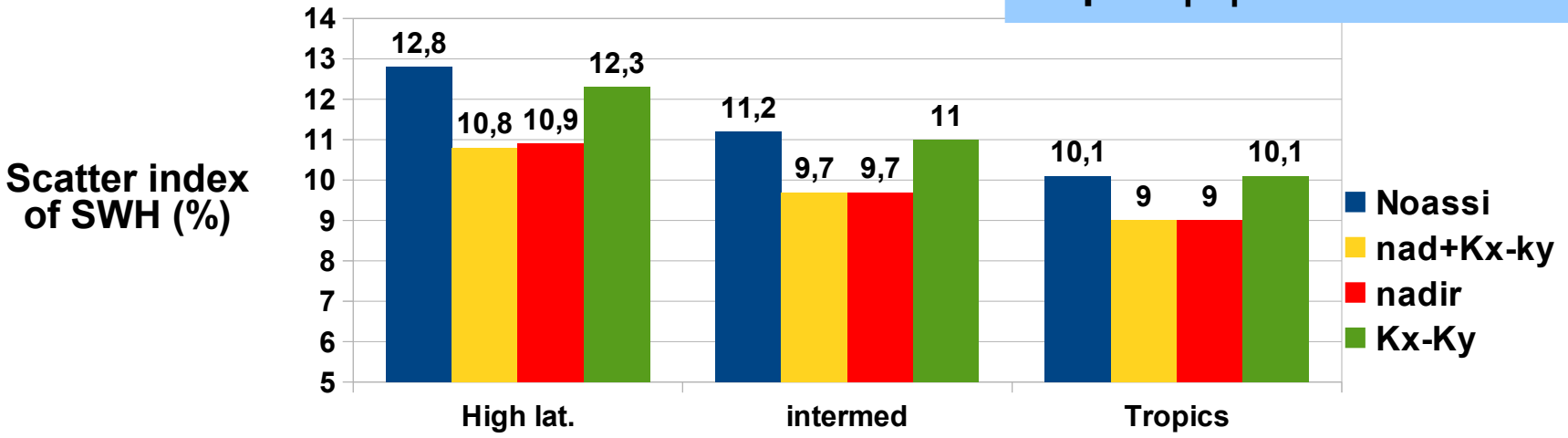
Blue is good

Red is bad

Comparison with SWH from Jason-3, Saral and S3A

Performance of the assimilation in different ocean basins July- Dec 2019

High Lat |Φ|> 50°
Intermediate lat 20°<|Φ|<50°
Tropics |Φ|<20°



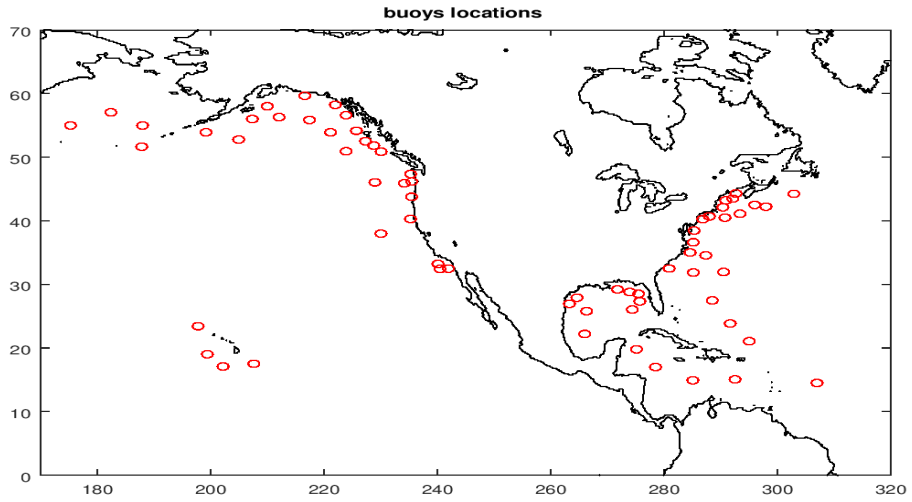
Combined assimilation of Nadir SWH and wavenumbers (beam 10°) ensures the best performance : Scatter index is significantly improved in high and mid latitudes (by ~15%) and the tropics (by ~22%).

The assimilation of kx-ky mostly improves in high and mid latitudes

Comparison with SWH from Jason-3, Saral and S3A

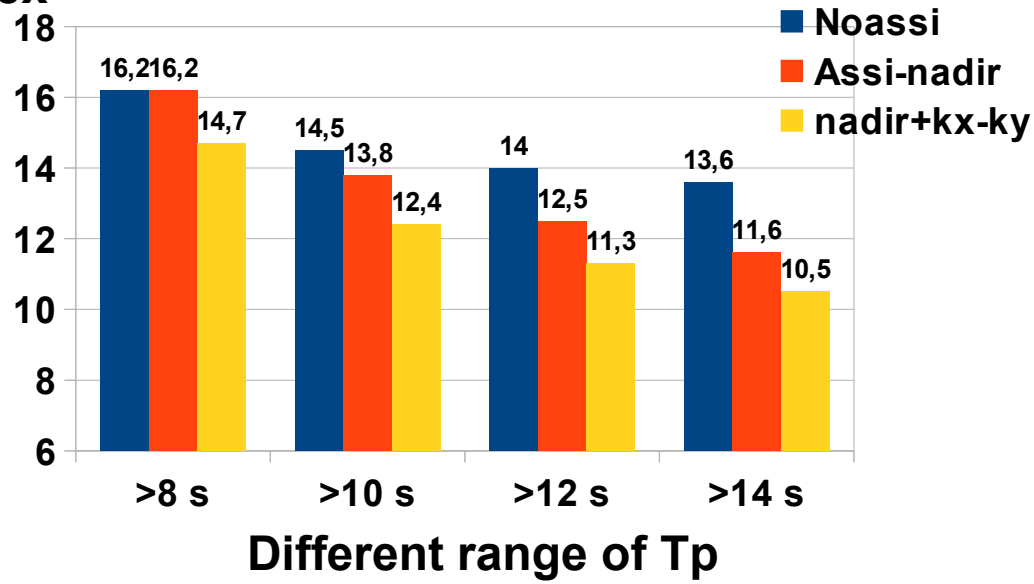
Validation with NDBC buoys data : Peak period Jul-Dec 2019

Buoys locations (data from LC-WFV, thanks to J. Bidlot)



Using directional wavenumber removes the bias on Tp (0.01 sec) in Comparison with runs of assimilation of SWH only (0.26s) and without assimilation (-0.28s)

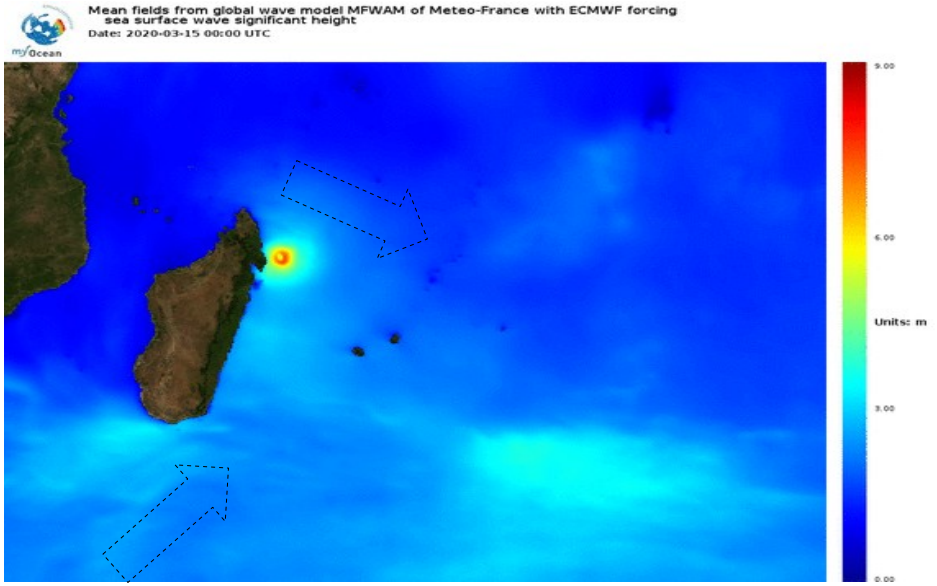
Scatter index of Tp

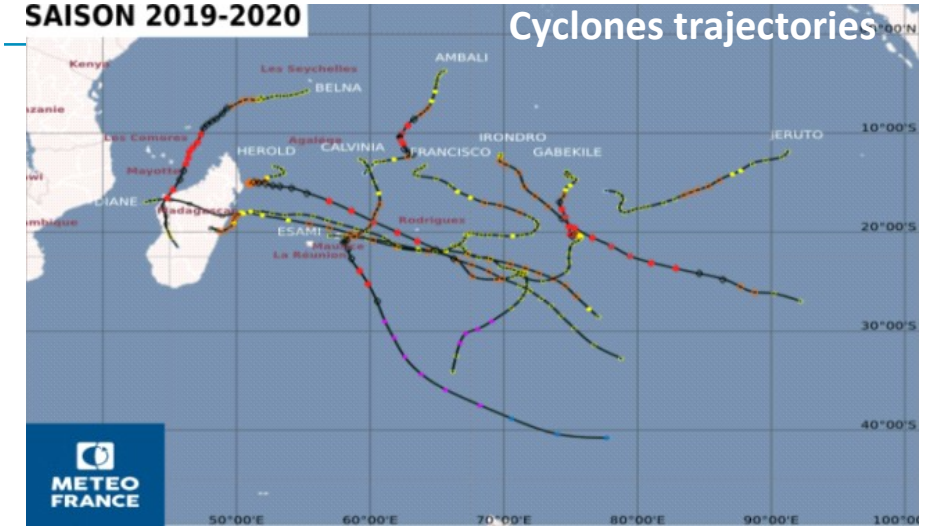


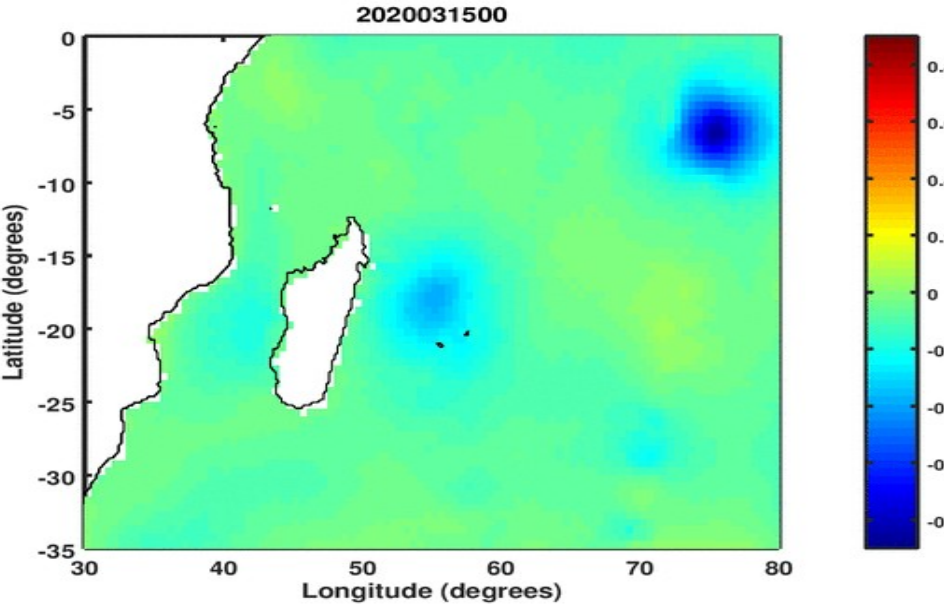
Assimilation of kx-ky induces a Significant impact on Tp. For waves With Tp greater than 10 sec, the impact is ~3 times larger than using SWH-only

Performance of SWIM DA during cyclonic season in indian ocean 2020

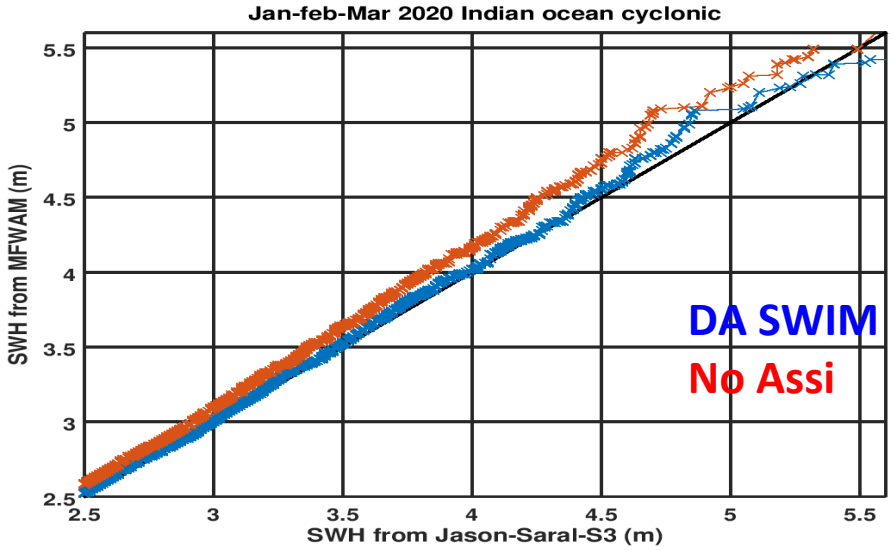
Snapshots of SWH during cyclone HEROLD 15-17 March 2019 (6-hourly)





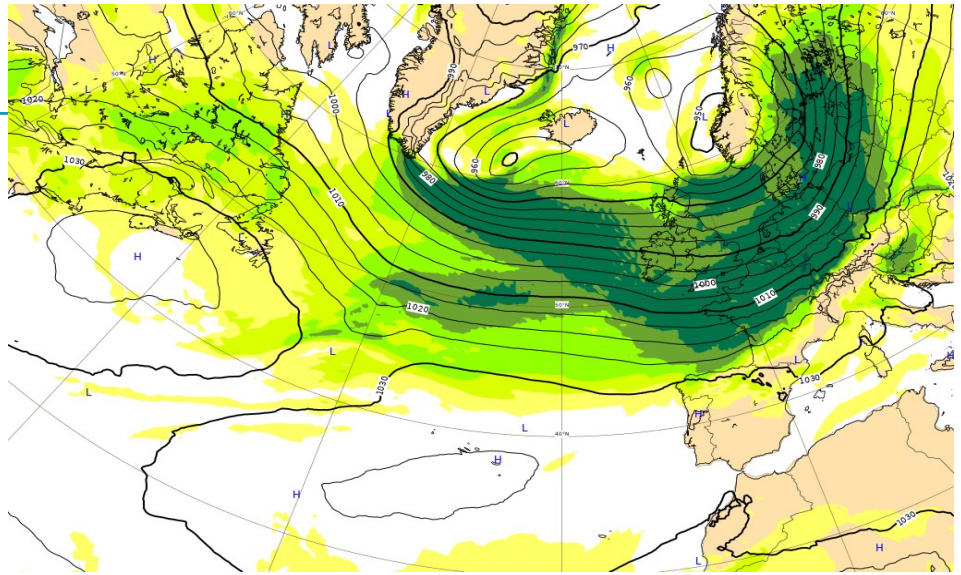


Good improvement of SI by ~14%
Reduction of bias in average from -12 cm to -4 cm.

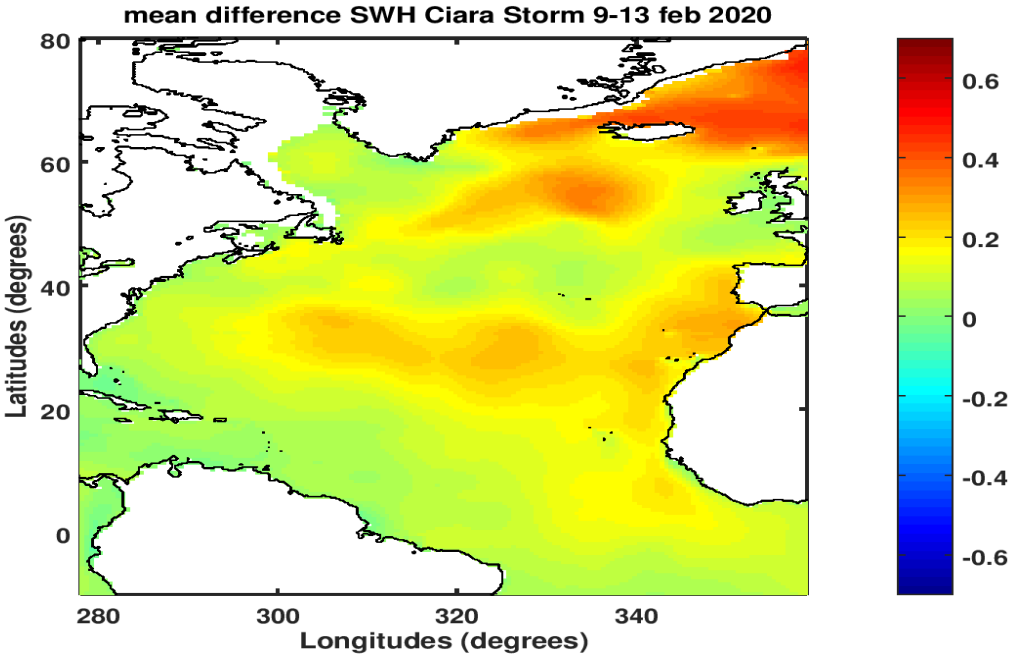


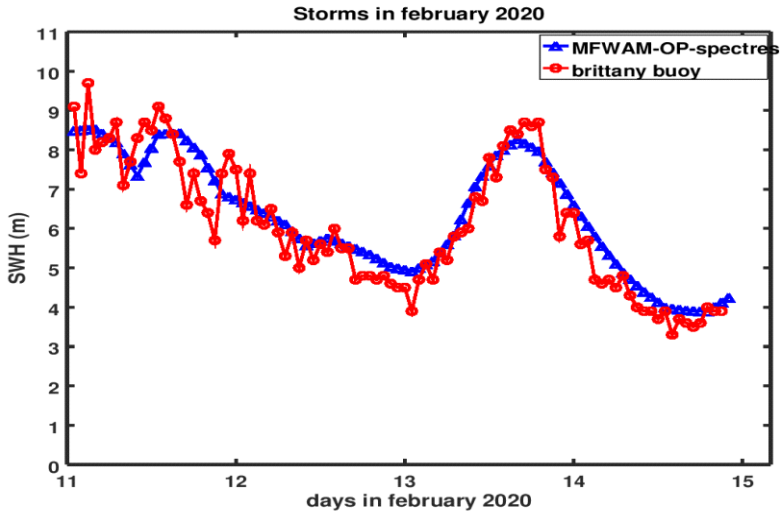
Storm CIARA 2020
Wave submersion warning

Strong winds near the french coasts (120-150km/h)



Snapshot of mean difference with and without DA
From 9-13 February 2020

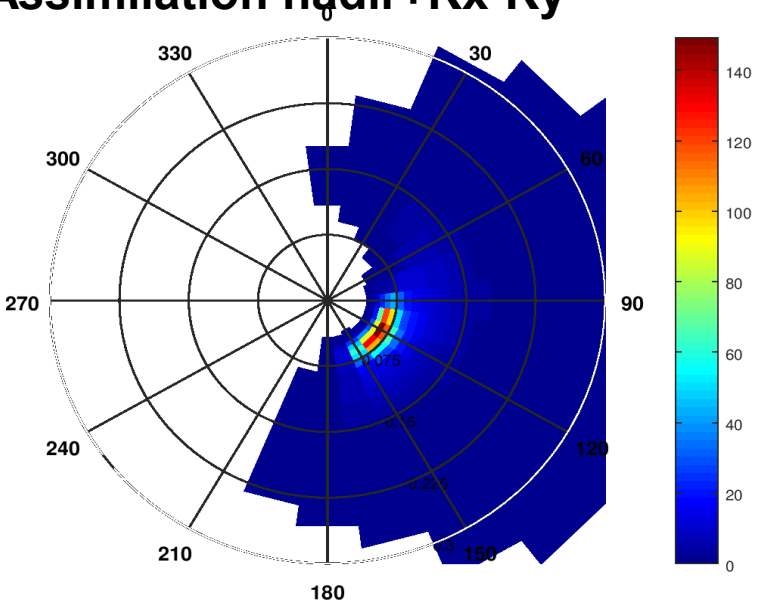




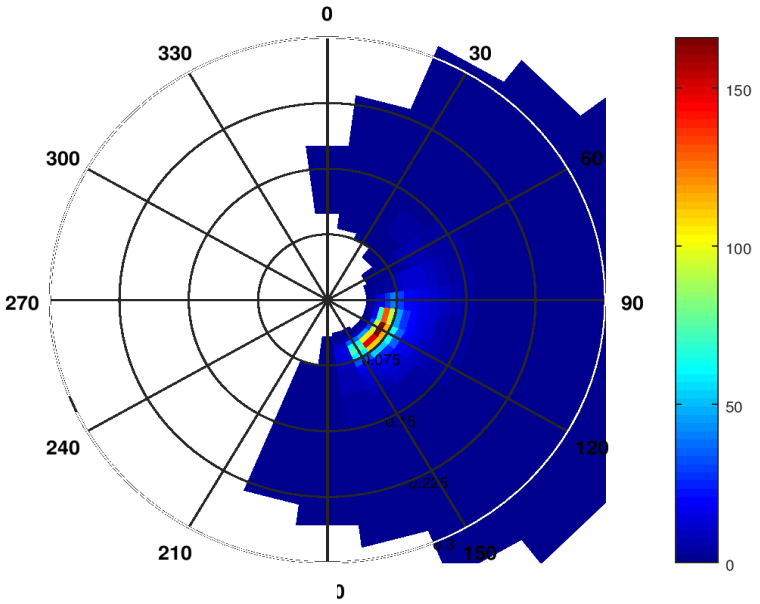
SWH time series at brittany buoys

Validation with biscay buoy during the storm CIARA (9-13 Feb. 2020)

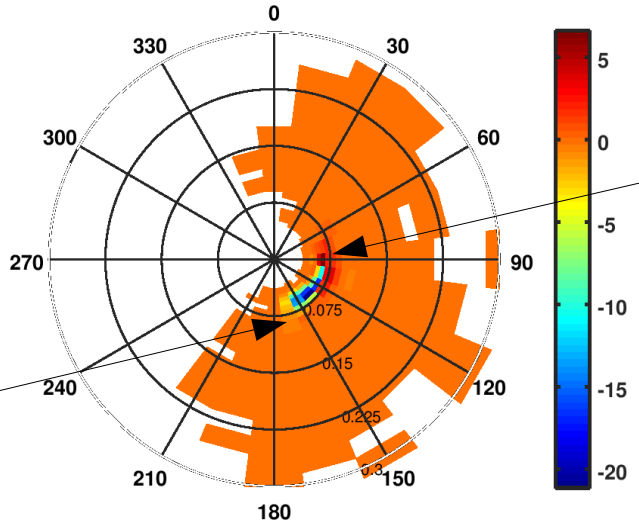
Assimilation nadir+Kx-Ky



Without assimilation

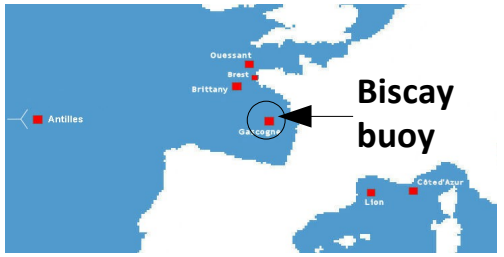


Difference of directional Energy between With and without DA :



DA corrects the missing energy On the waves propagating to The east

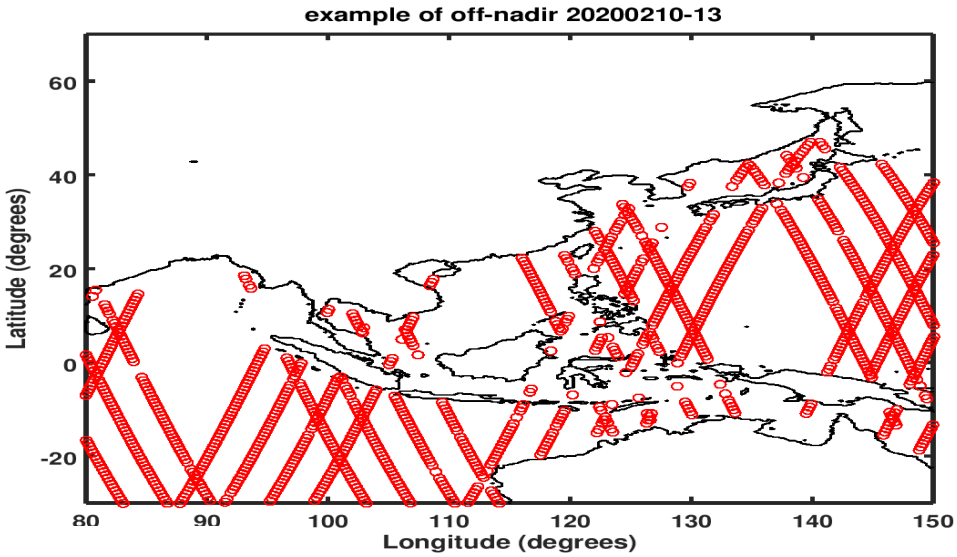
DA corrects the over-estimation of energy at Dominant partition

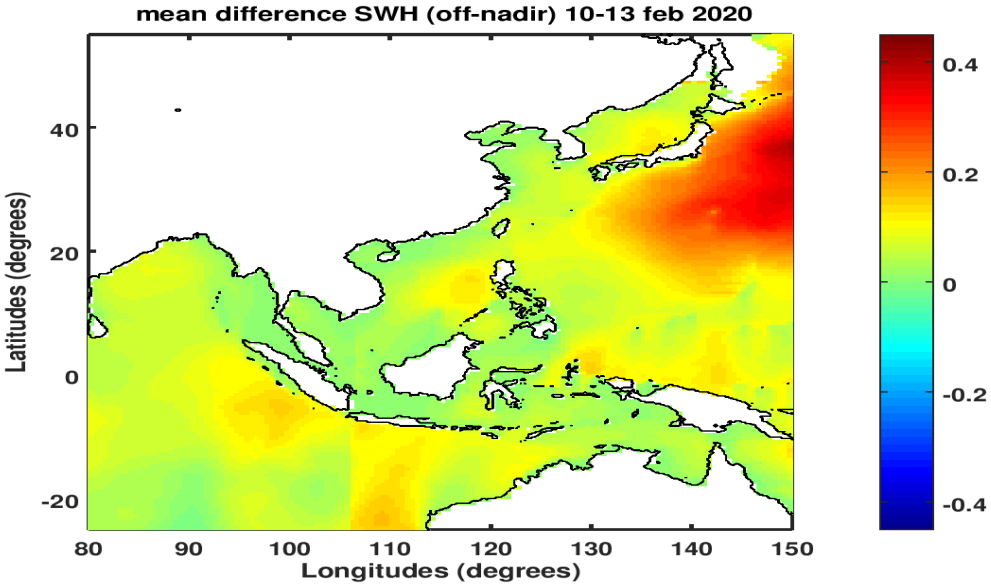


Assimilatio of kx-ky partition wavenumbers and off-nadir SWH

box SWH ensures accounting the wave Energy correction with assimilation of Wavenumbers.
Each passage of CFOSAT two tracks of SWH on each side (70 km away) of the nadir one. This can be helpful to improve impact to coastal areas.

Good coverage of off-nadir tracks



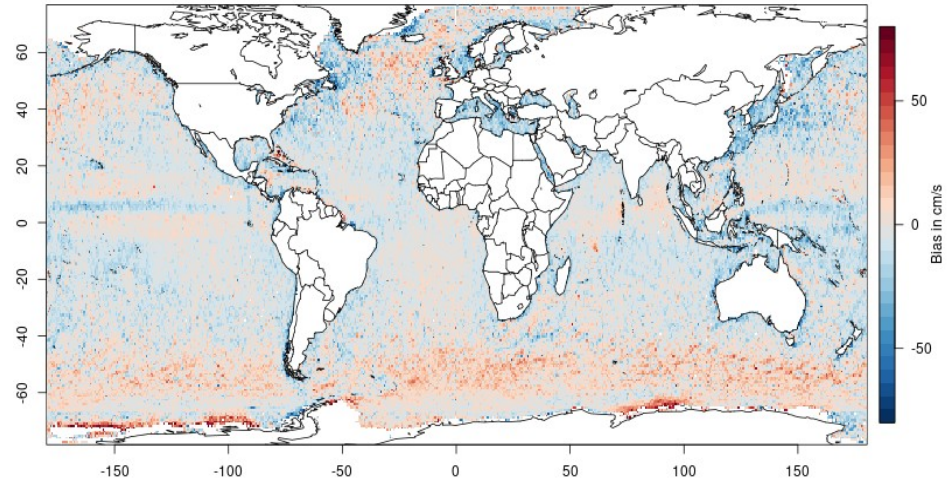


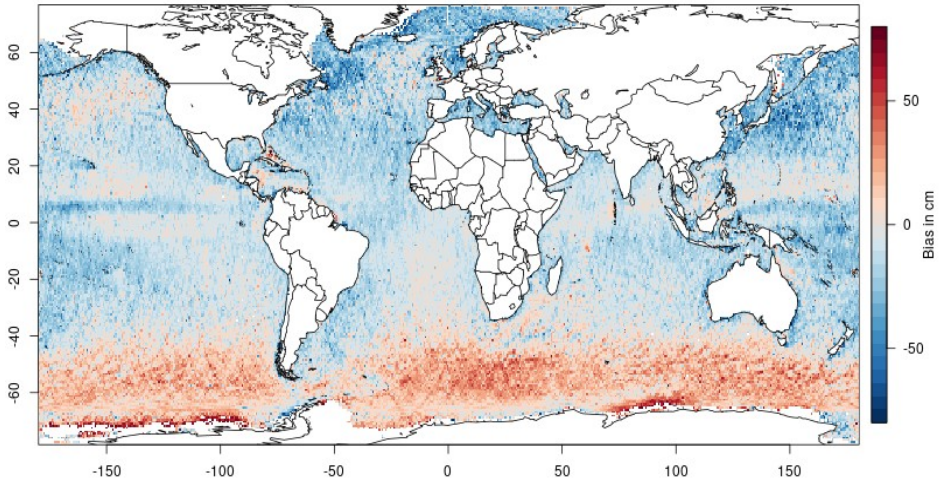
Snapshot of mean difference with and And without assimilation of off-nadir and wavenumbers 10-13 Febraury 2020

Performance of the assimilation of wavenumbers kx-ky and off-nadir SWH : Jan-Feb-March 2020

Significant bias reduction of SWH
In all regions, particularly in SO

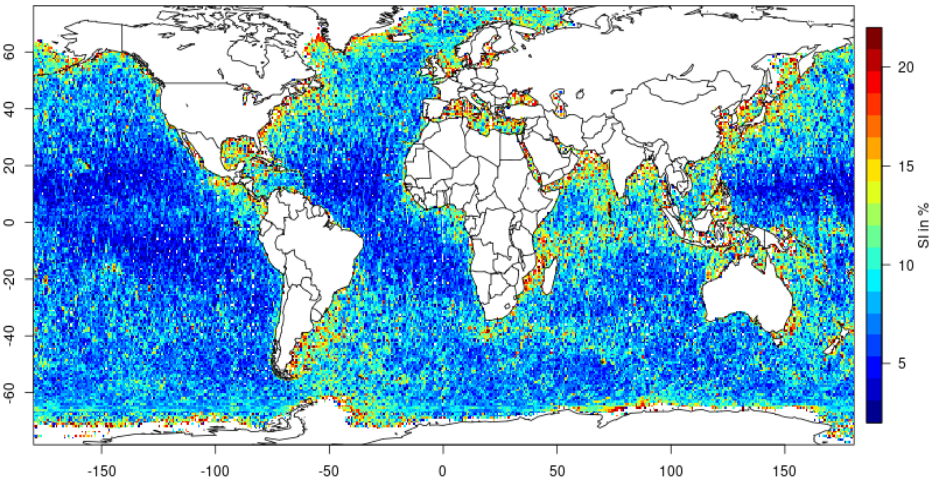
Bias maps (maximum 50 cm)

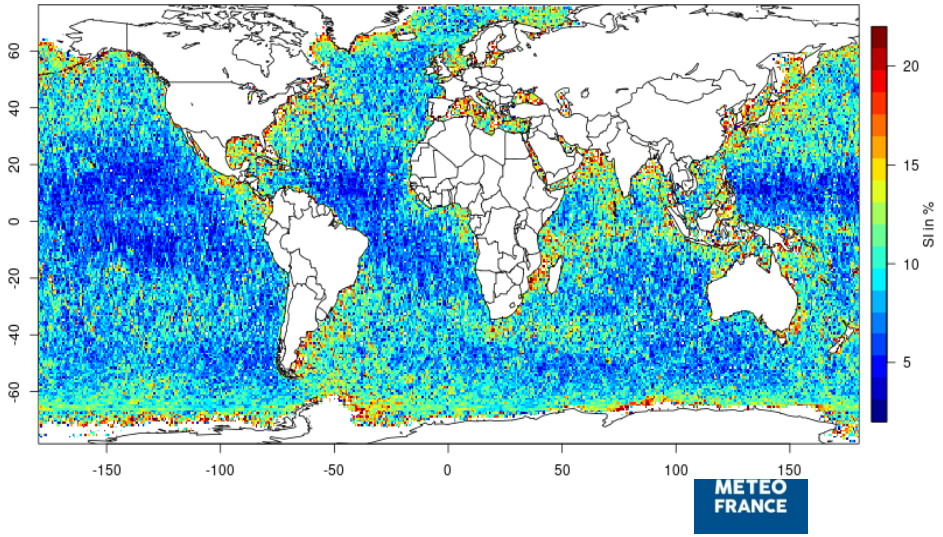




SI maps (%)

Remarkable SI after the assimilation (7-9%)

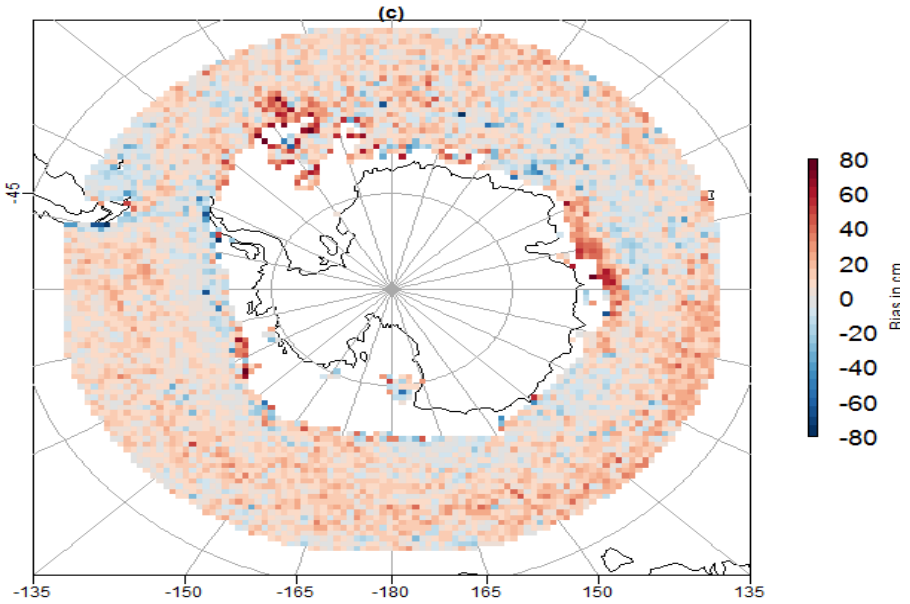


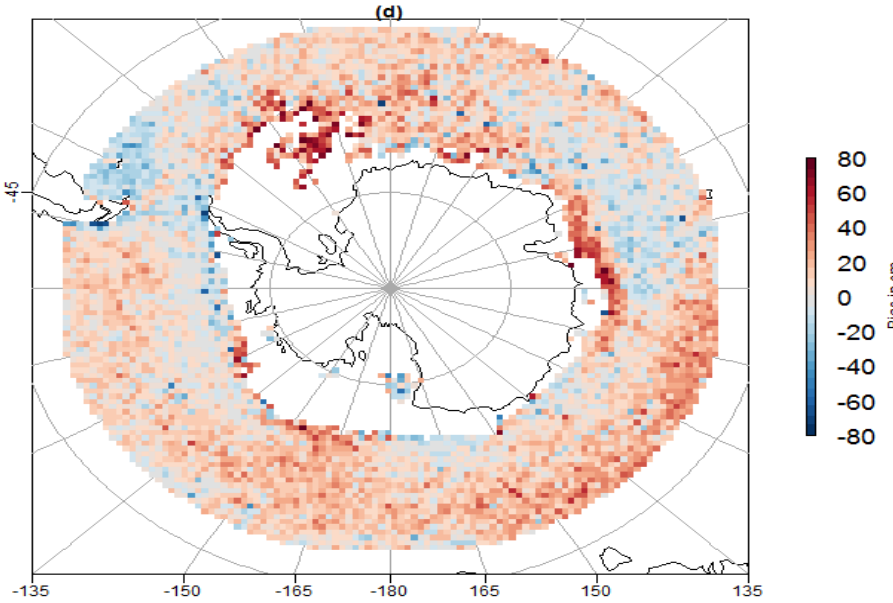


Validation with Jason-3, Sral and S3A-3B

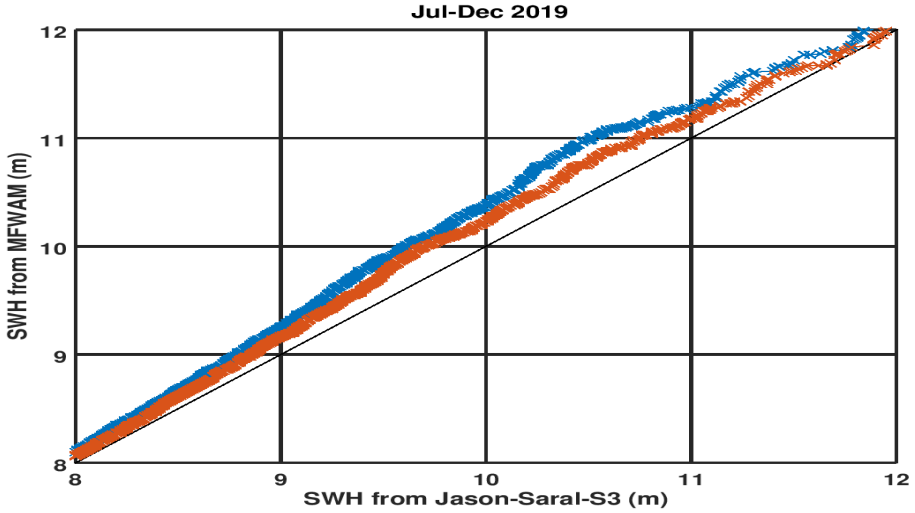
Performance of assimilation of wavenumbers (kx,ky) and nadir SWH In Southern Ocean : Jul-Dec 2019

Combined assimilation **Bias maps (in cm max 80)** **Without assimilation**





The assimilation of kx-ky and nadir SWH Shows good consistency (very close to slope 1) for high SWH



Assi-SWIM

No Assi

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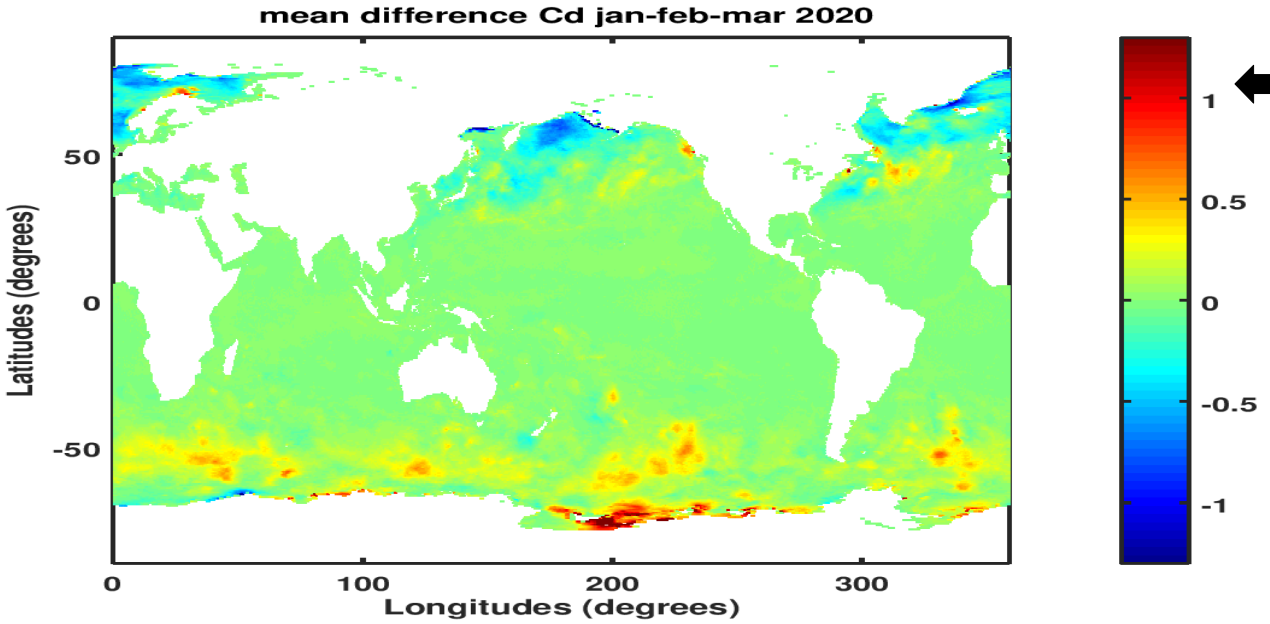
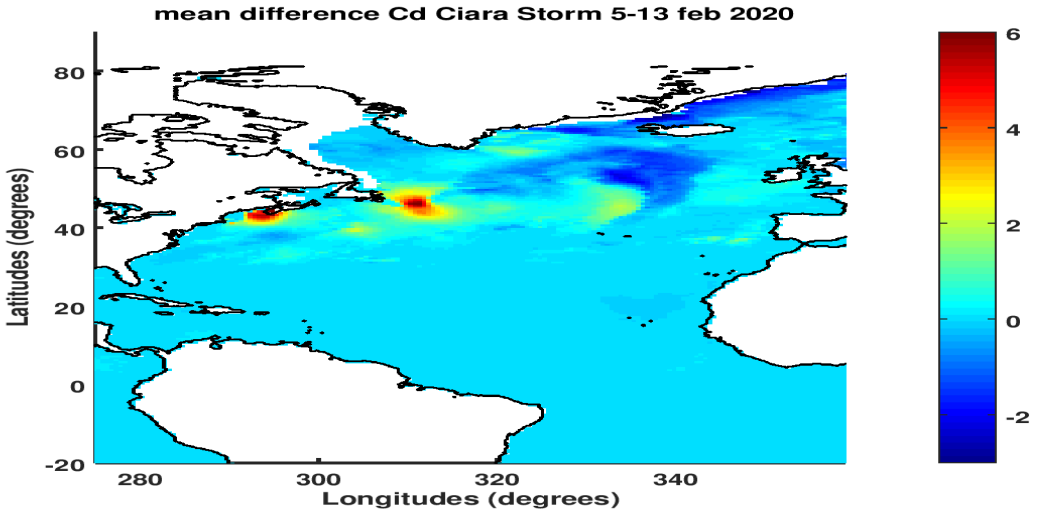
Impact of the assimilation of kx-ky and off-nadir SWH on surface stress (Drag coef) during winter season (Jan-Feb-Mar 2020)

Difference of mean Drag coefficient (Cd) with and without assimilation



Major impact (%) in SO and North Atlantic-Pacific Ocean regions affected By winter storms.

Focus on difference of mean Cd During storm CIARA in the North Atlantic ocean (9-13 February 2020)



Conclusions

- Since 2nd february 2021 the assimilation of partitions wavenumbers is activated in operational global model CMEMS and Meteo-France. wave product such SWH is significantly improved (SI of ~8% in average)

- The validation with buoys has indicated the uniqueness of directional wave observations to improve significantly peak period (by more ~20% for waves with wavelength greater 150m)

- Positive impact of off-nadir SWH with the assimilation of wavenumbers components : good reduction of bias and scatter index of SWH

- Benefit of using SWIM directional wave observations in cyclones conditions and storms with unlimited fetch such as in SO. Still work in progress in CalVal group to improve the estimate of energy partition

- DA of SWIM wavenumbers partitions lead to a better estimate of coupling parameters (stress, Stoke drift) : further analysis with coupled simulations will be conducted

METEO FRANCE

Aouf L., et al., « New directionalwave satellite observations : Towards improvedwaveforecasts and climate description in SouthernOcean », *Geophysical Research Letters,* 10.1029/2020GL091187