On the use of wind forcing for wave reanalysis

L. Aouf[1], S. Law-Chune[2], L. Louis[1], J. Wang[3]

[1] Météo France
[2] Mercator Ocean International
[2] Sun Yat Sen University

International Ocean Wind Vectors-Science team meeting, 1 December 2023, Nanjing

Motivation

- ➔ Providing accurate wave products for world wide users (wave climate studies, downstream applications, historical Extreme events,...etc).
- ➔ Investigationg the impact of better wind forcing with good description of small and large scale
- ➔ Update of wave reanalysis with best reprocessed wave data from past and current satellite missions. Better boundary conditions for regional MFCs.

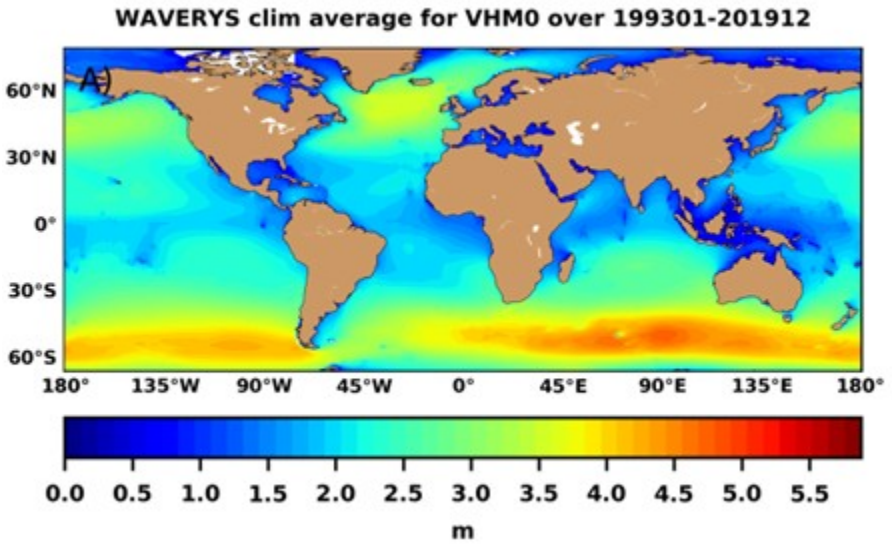
METEO FRANCE

CMEMS global wave reanalysis WAVERYS (1993-2022)
marine.copernicus.eu

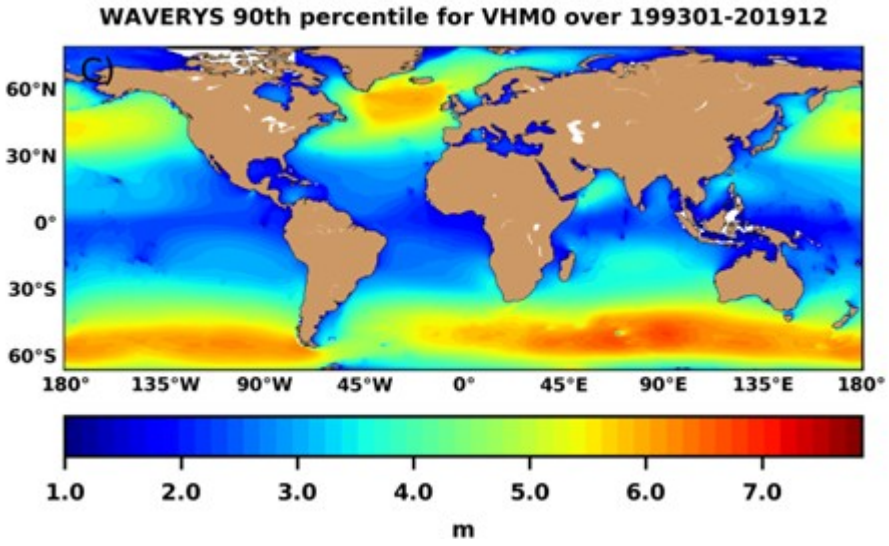
- Global grid of 20 km (Etopo2 bathymetry)
- Upgraded wave physics for better surface stress (MFWAM 2019)
- 3-hourly wind forcing ERA5
- 3-hourly assimilation step of altimeters and SAR wave spectra from Sentinel-1
- 3-hourly surface currents forcing from CMEMS ocean reanalysis GLORYS
- 3-hourly output of wave parameters (including partitionning wind-wave and swell partitions) : 20 parameters CMEMS catalogue

Validation with HY2A SWH indicates globally a scatter index of ~8.5% and Small bias of 5 cm (see Law-Chune, et al. 2021)

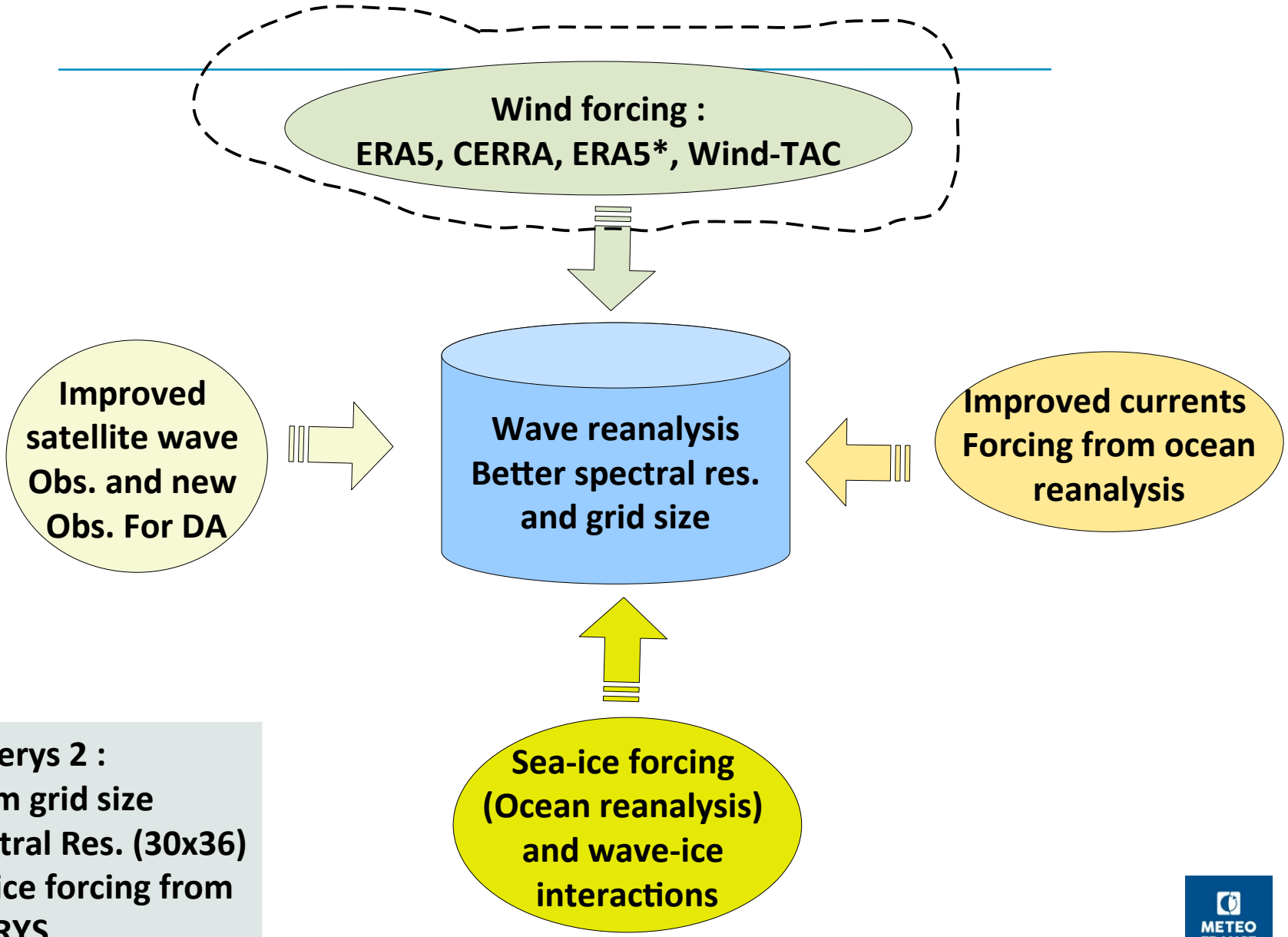
Average of SWH



SWH percentile 90th

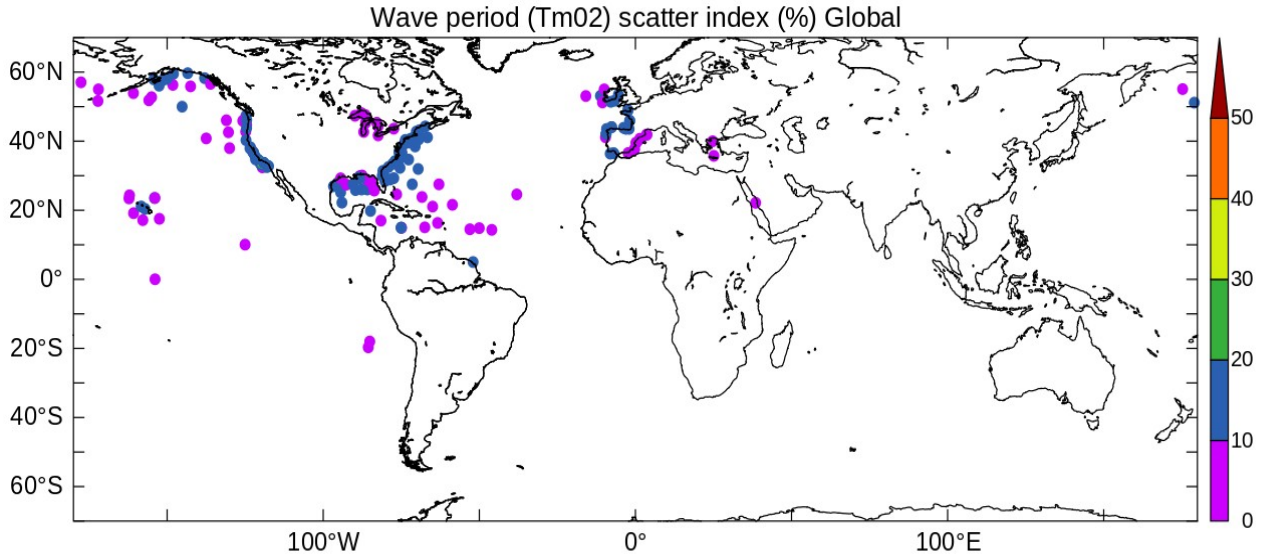


Wave reanalysis and dependencies



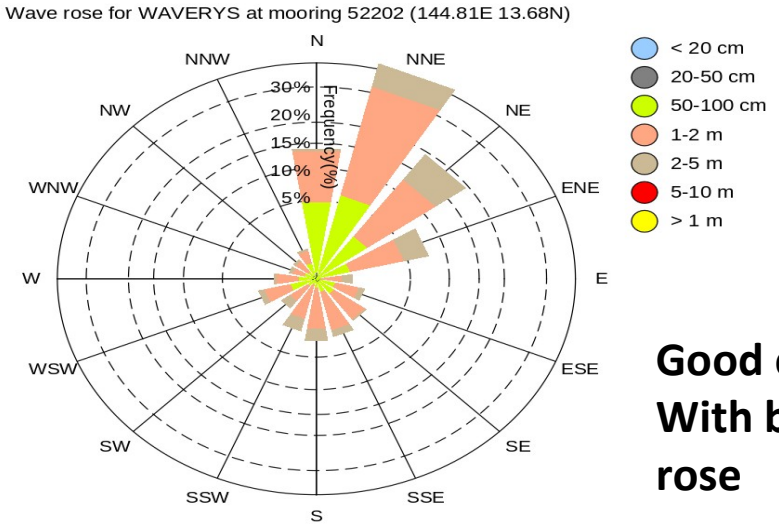
Waverys 2 :
10 km grid size
Spectral Res. (30x36)
Sea-ice forcing from GLORYS

Accurate forecast for Mean wave period (Tm02)

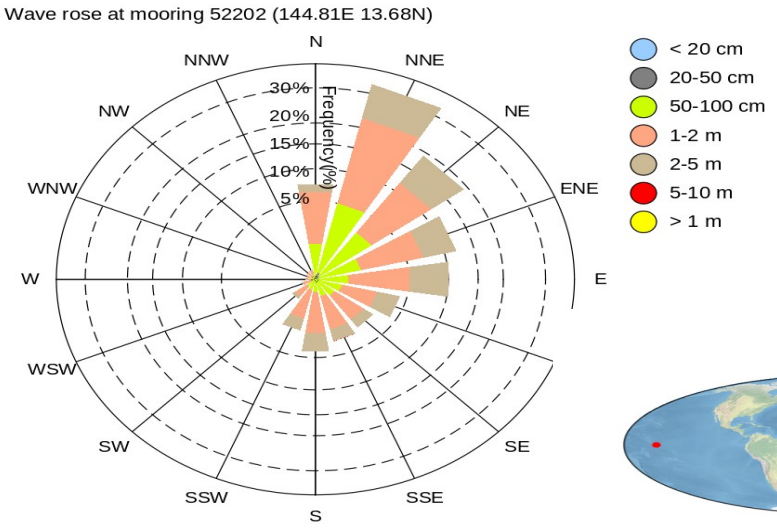


Scatter index of Tm02 is Ranging between 10-15%

WAVERYS



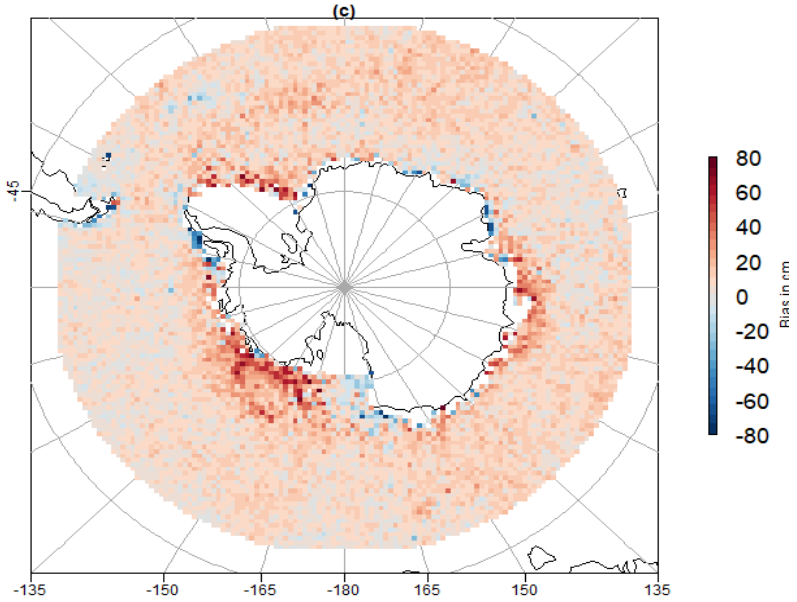
Buoy 51202 Hawaii



Good consistency With buoy wave rose

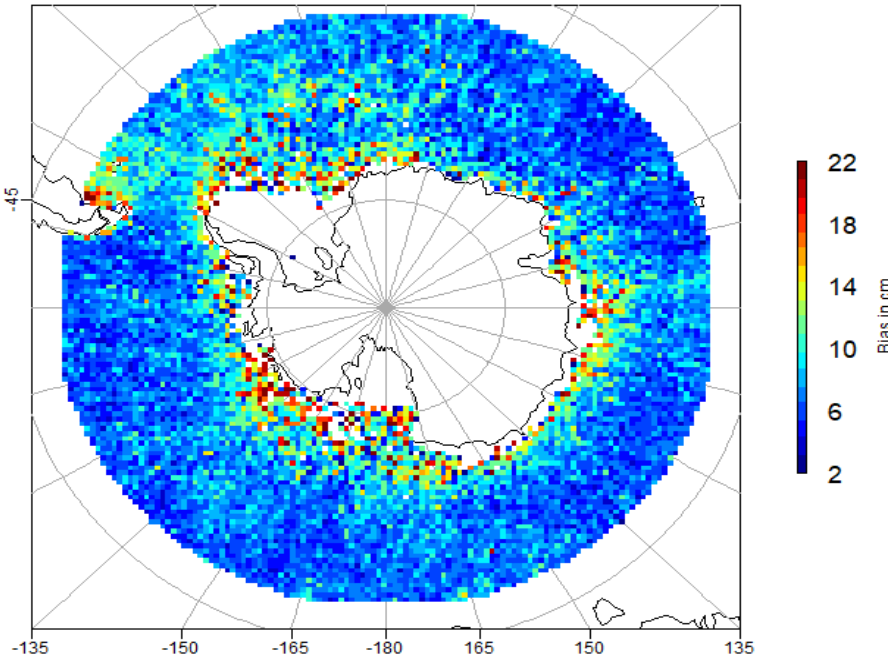
Performance of WAVERYS in Southern Ocean (2016-2018) : thanks to spectral DA Validation with HY2A

Bias of SWH



Very small bias is in average of 4 cm in the SO : thanks to the DA of altimeters and spectral from S1. The bias increases near the MIZ

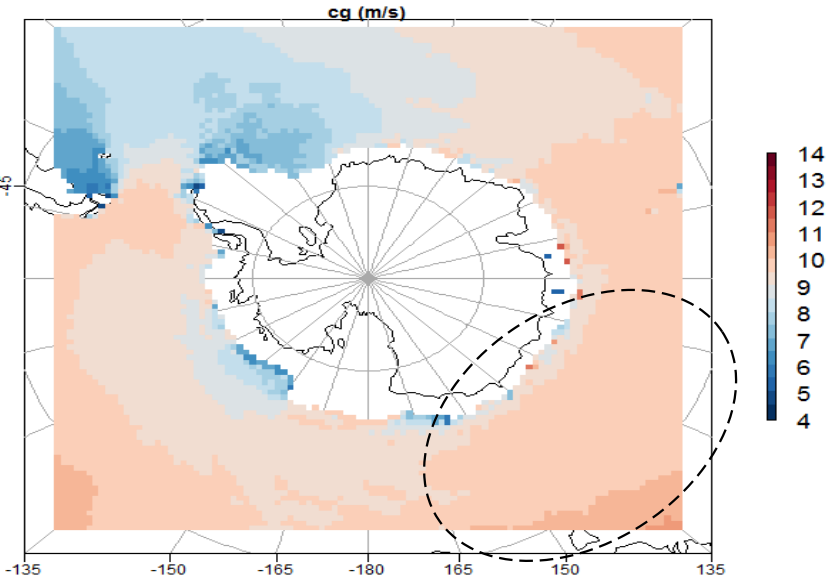
Scatter index of SWH



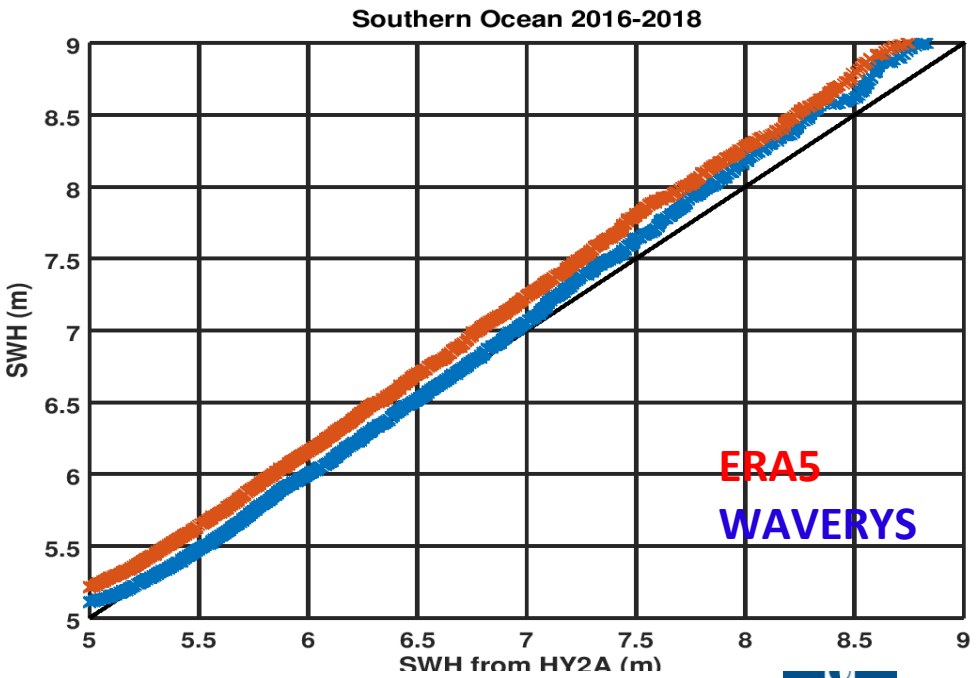
Remarkable SI in average of ~8%, and Increases near MIZ

Skillfullness of SAR directional wave observations from Sentinel-1

Mean wave group velocity during Southern winter 2018-2019.
faster mean Cg exceeding 14 m/s
In the Pacific sector and southern Australia



Directional observations from S1 is skilled To better capture high SWH under unlimited Fetch conditions in SO. Q-Q plot indicates WAVERYS is sharply following perfect for ranges of SWH 5-8 m



From altimeter HY2A

***ERA5 is assimilating less altimetry data**

Preparation of WAVERYS Version 2

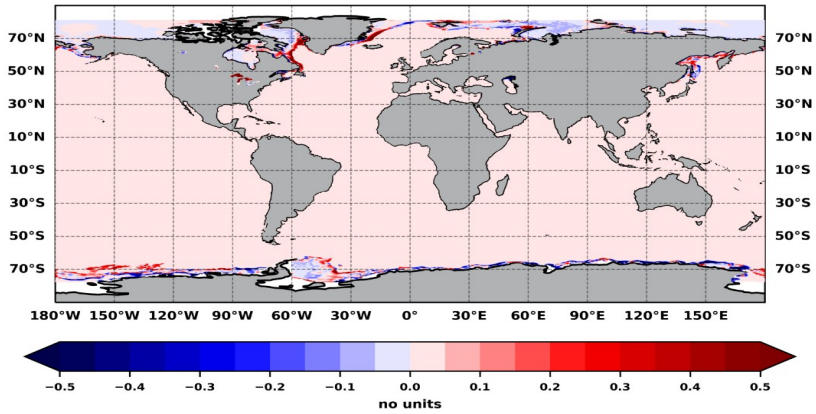
- **WAVERYS V1, 3 dec 2019 + yearly extensions (see Law-Chune et al 2021)**

- **WAVERYS V2, 2024**
  - **Resolution improvements: 1/10°, 36 directions, bathymetry update**
  - **Reprocessed altimetry data: CCI seastate**
  - **alti (wave-TAC) +SWIM+ SAR Envisat**

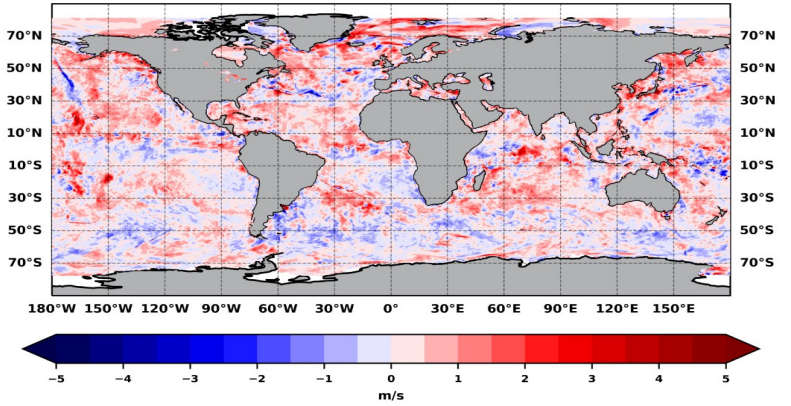
- **Current test runs on updating ERA5 (1/5°, 1h for wind forcing & daily for ice) forcing with :**
  - **ERA5* : 1/8°,1h, correct ERA5 persistent bias from scatterometer observations**
  - **GLORYS Ice (MOi) : 1/10°, daily, including**
  - **Wave-ice interactions (*Yue et al 2022)***

Updating wind and ice forcing for V2

GLORYS – ERA5 sea ice conc., 15th jan 2020 00:00

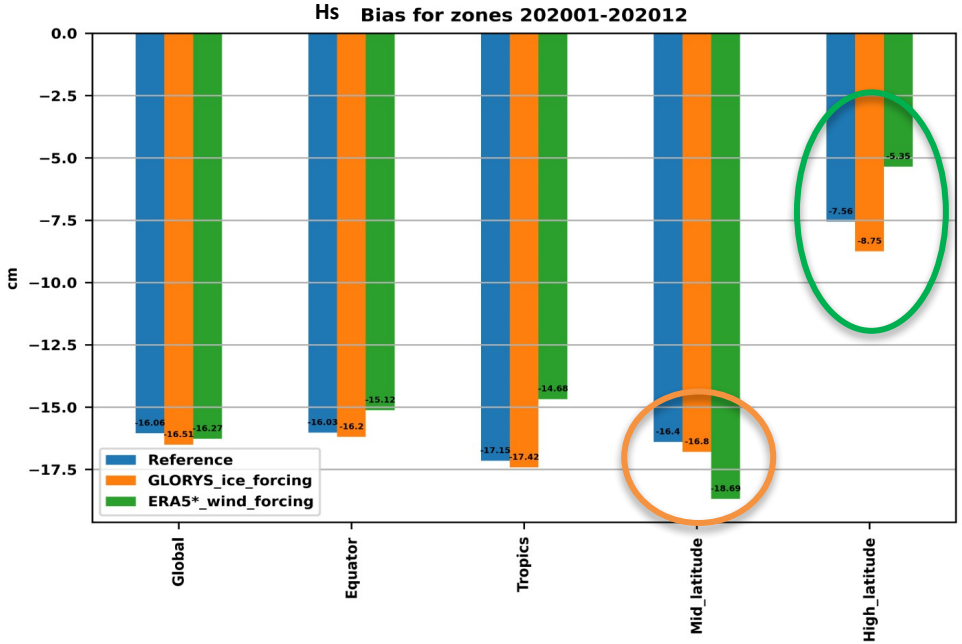


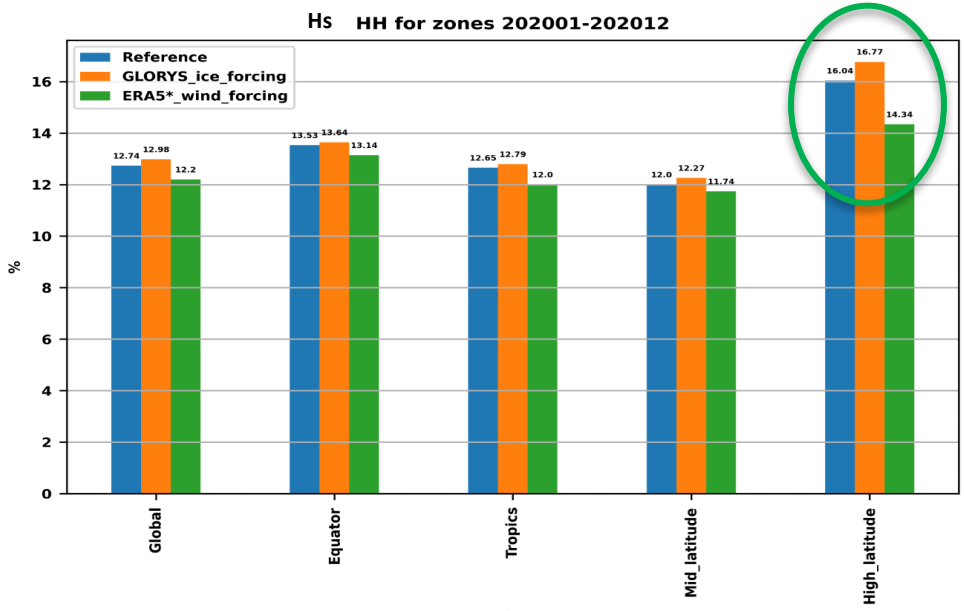
ERA5* - ERA5 10 wind module, 15th jan 2020 00:00



METEO FRANCE

1-year model run and validation with CFOSAT-SWH





- **GLORYS sea ice fraction doesn't improve results…but new ice-interaction source term is not included yet !**

- **ERA5* slighly improves results, especially for high latitudes (but degrades biais in mid latitude)**

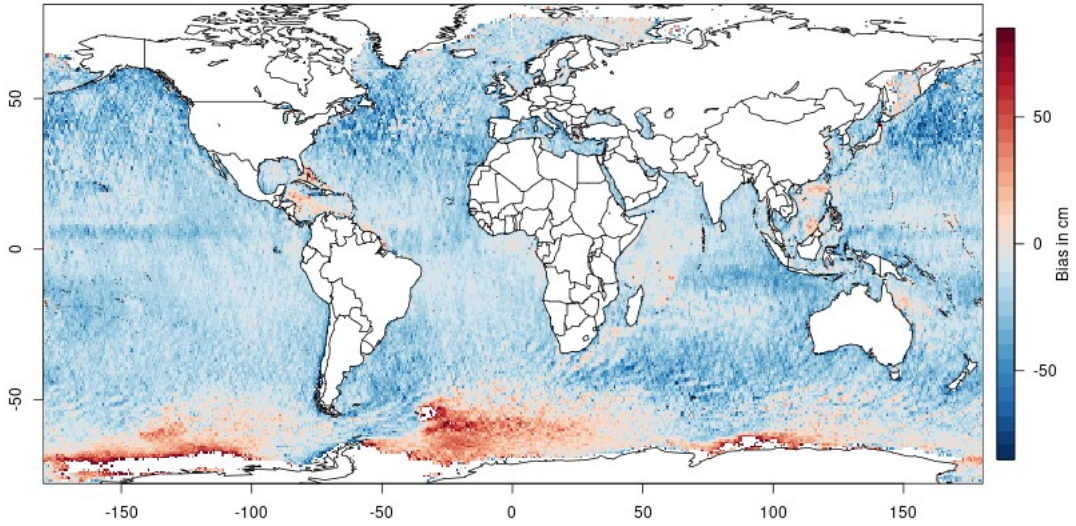
HH index: (Mentaschi et al. 2013), unbiased RMSE based metrics

METEO FRANCE

Comparison between ERA5 and ERA5* : Jan-Feb 2021

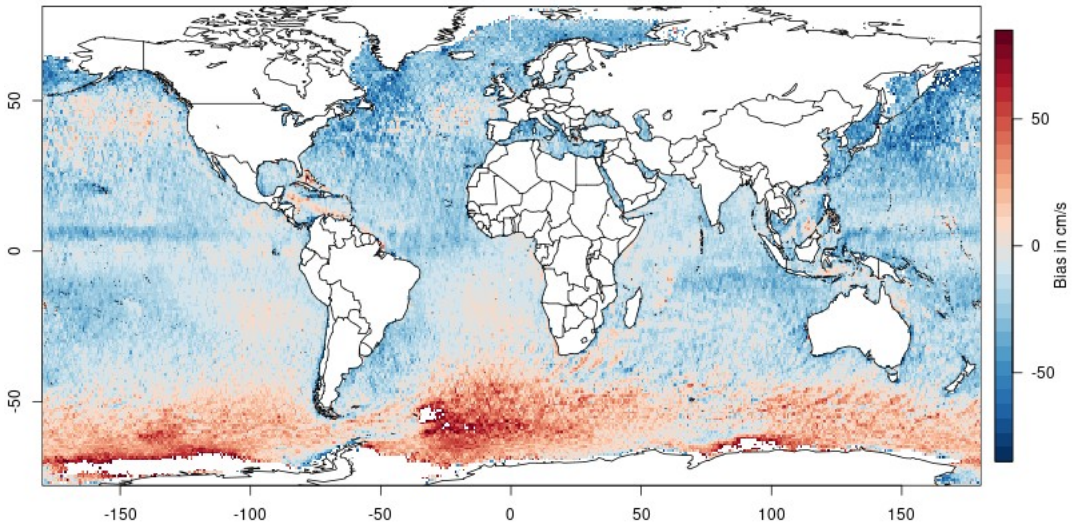
MFWAM-ERA5*

SWH bias maps (in cm)



Significant bias reduction in Southern Ocean and tropics

MFWAM-ERA5

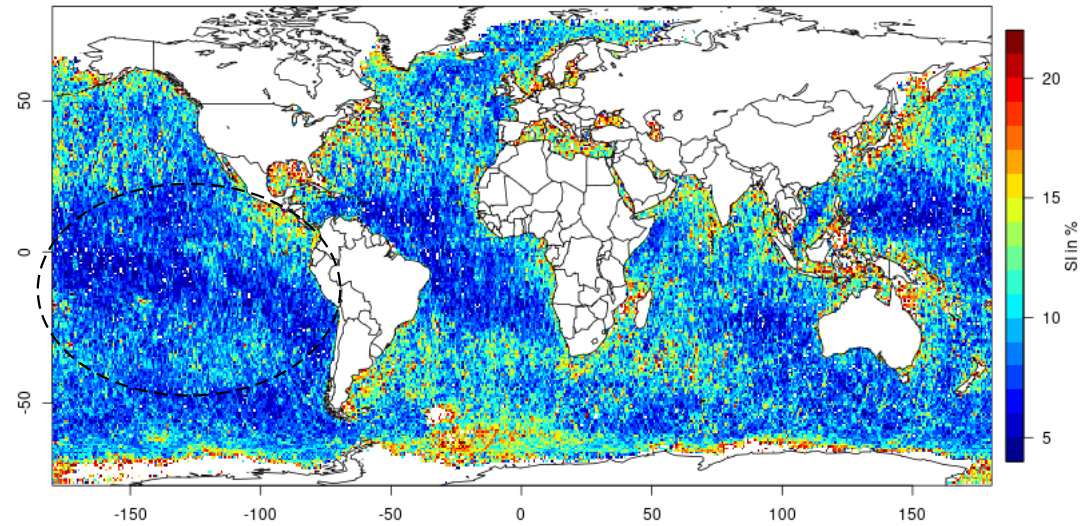


Validation with SWH from Jason-3, Saral, S3, CFO

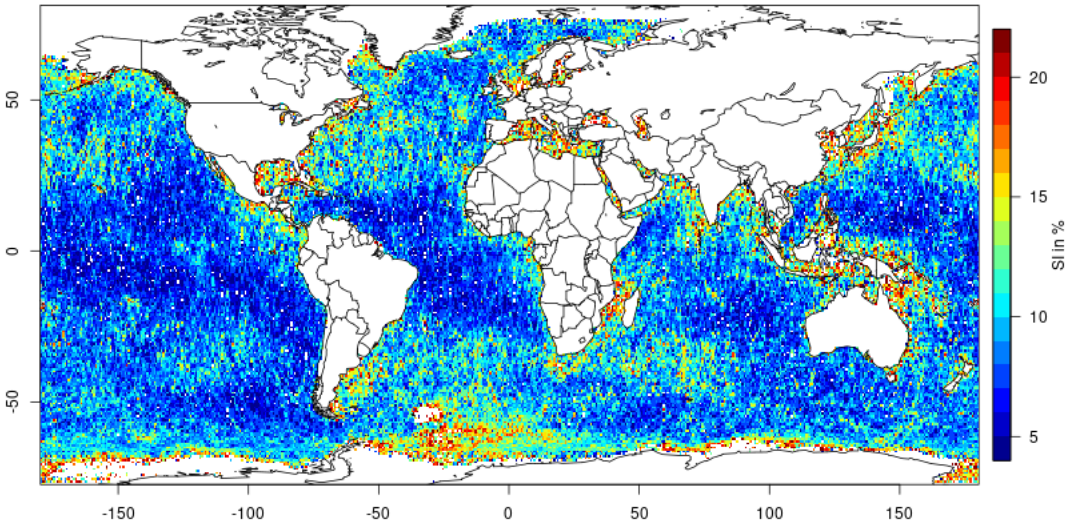
Comparison between ERA5 and ERA5* : Jan-Feb 2021

Scatter index of SWH maps (in %)

MFWAM-ERA5*

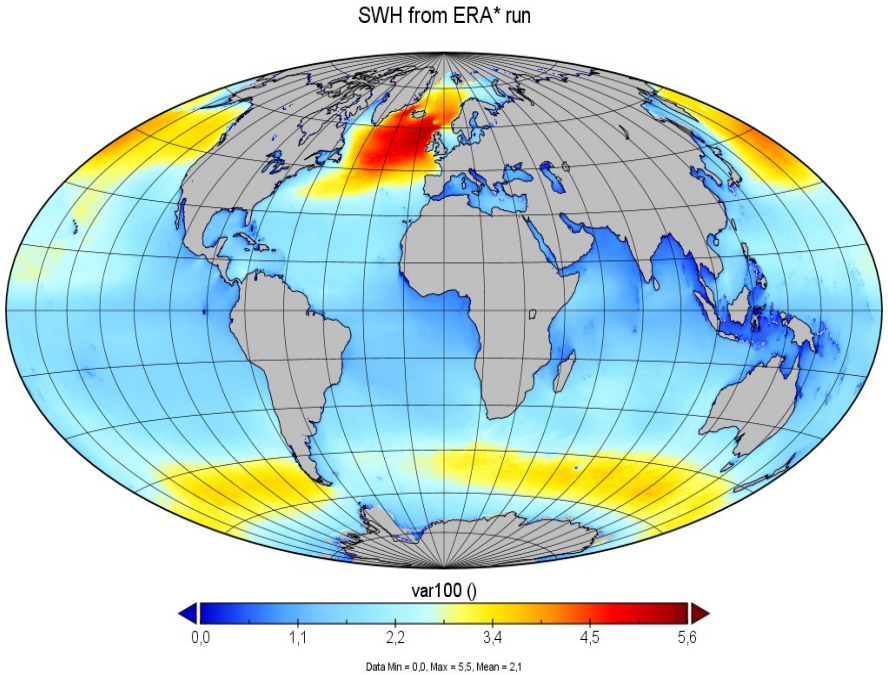


MFWAM-ERA5



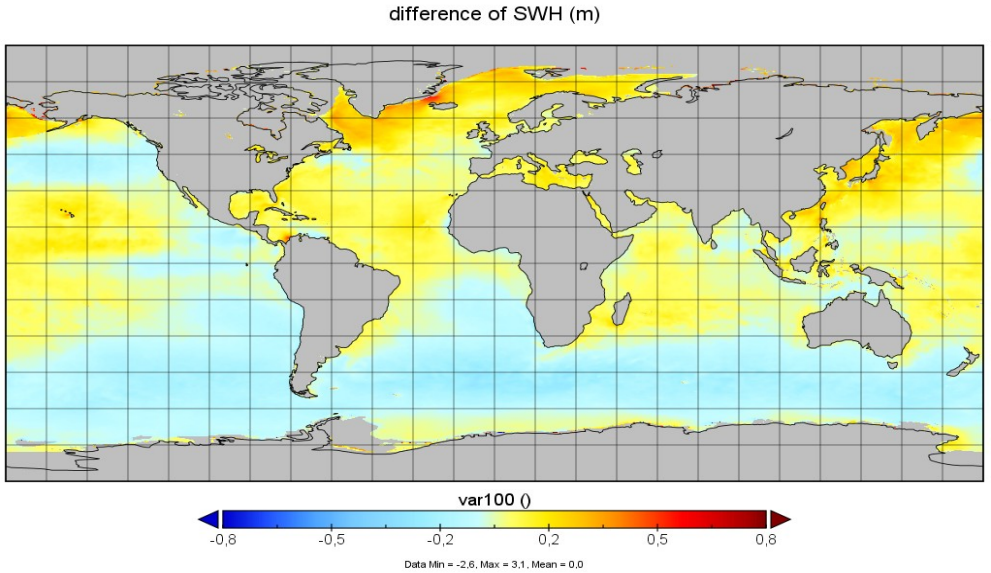
Validation of ERA* wind forcing : Jan-Feb 2020

SWH from ERA5*

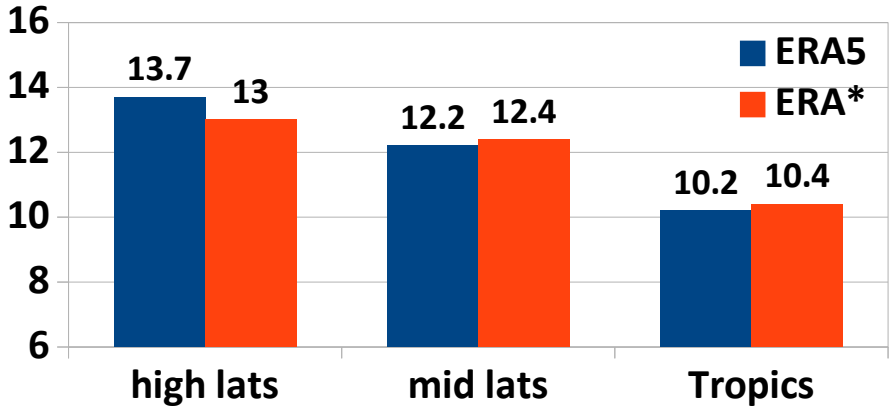


A* induces an increase of SWH in tropical oceans and rth atlantic ocean and north-west pacific. However ERA* creases in average SWH in Southern ocean

Mean difference of SWH : ERA* - ERA5



SI of SWH in different ocean bassins

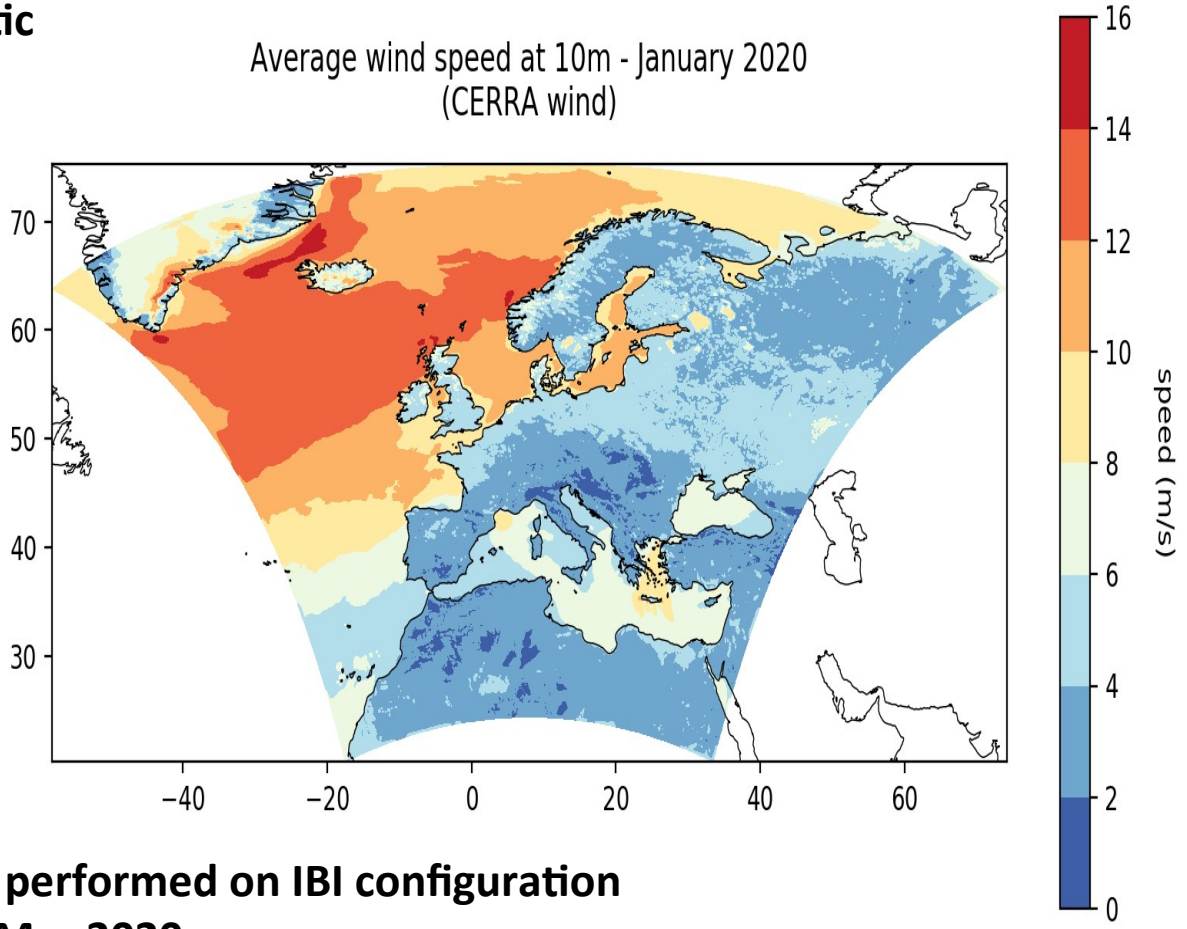


Validation with altimeters Ja3, Saral, S3,CFO

METEO FRANCE

CERRA : Downscaled atmospheric reanalysis for European seas

Harmonie model : Non-hydrostatic
Boundary conditions from ERA5
DA of scatterometers winds

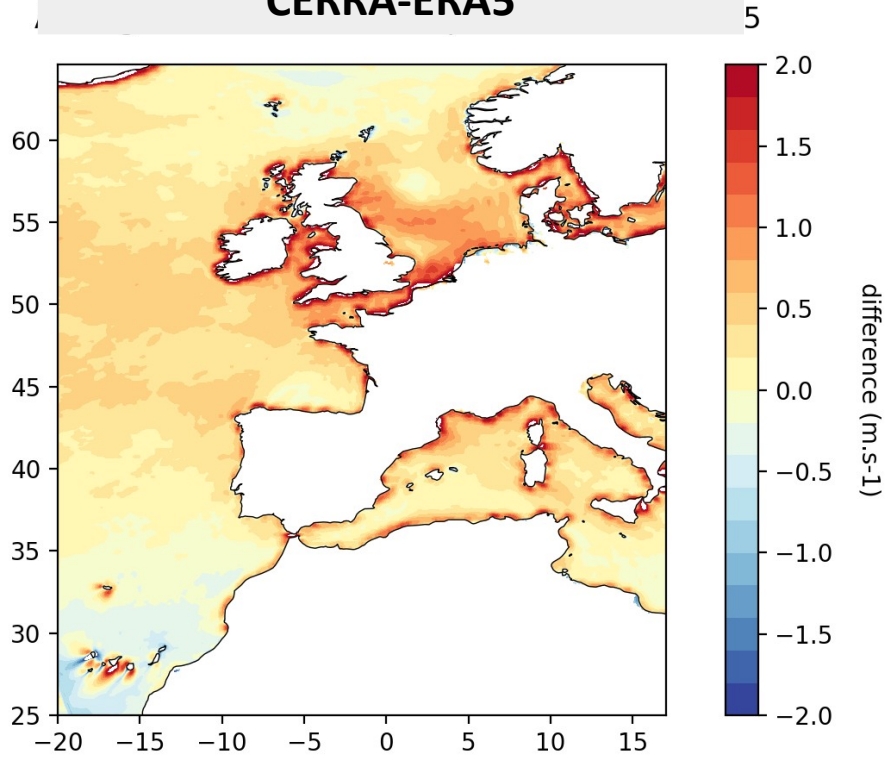


- **Model MFWAM run has been performed on IBI configuration With CERRA winds. Period Jan-Mar 2020**

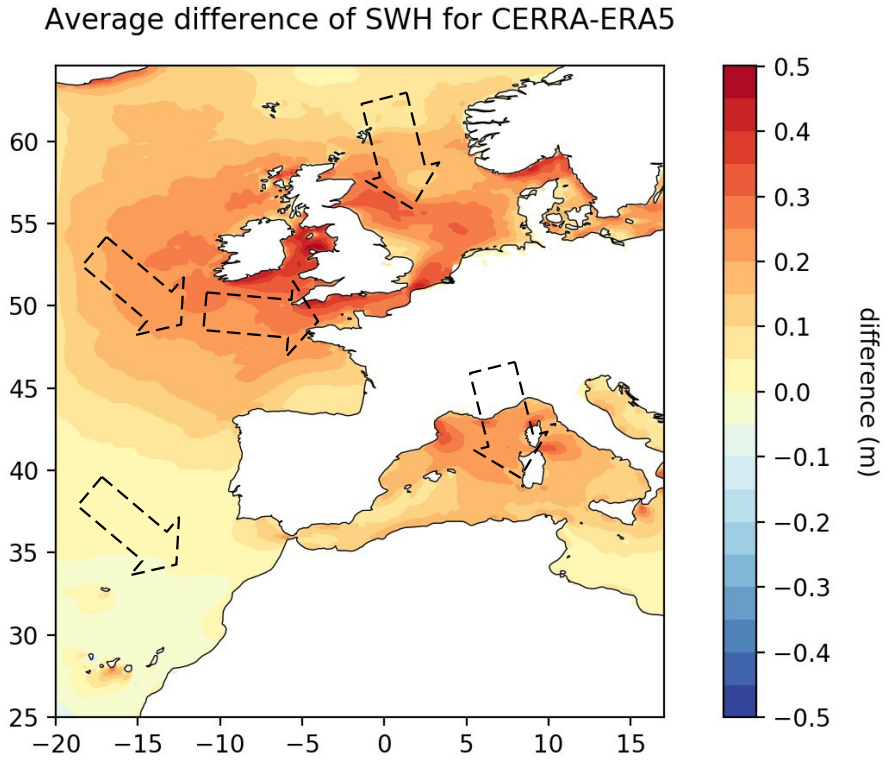
- **Validation with altimeters SWH**

Sensitivity to wind forcing : ERA5 vs CERRA
Jan-Feb 2020

Average difference of wind speed CERRA-ERA5



Average difference of SWH CERRA-ERA5



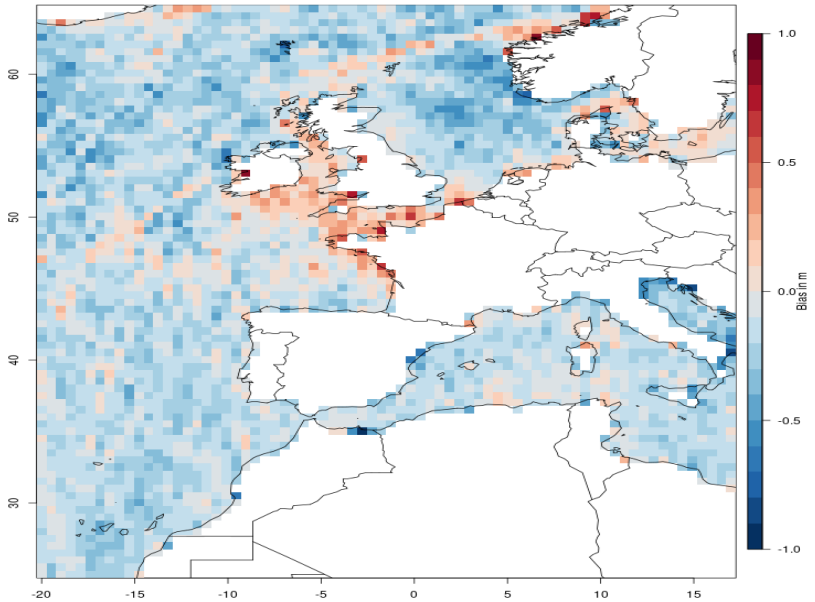
Using stronger winds from CERRA seems more consistent for wind variability in IBI coastal regions (for instance in the channel, celtic sea and Med Sea)

METEO FRANCE

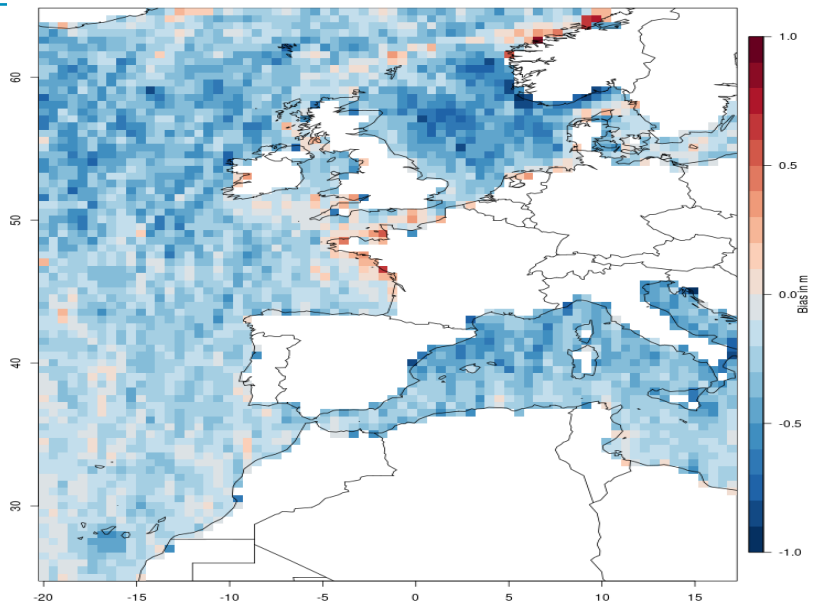
Impact of wind forcing on sea state forecast : ERA5 vs CERRA

Bias of Significant Wave Height maps (in m)

CERRA

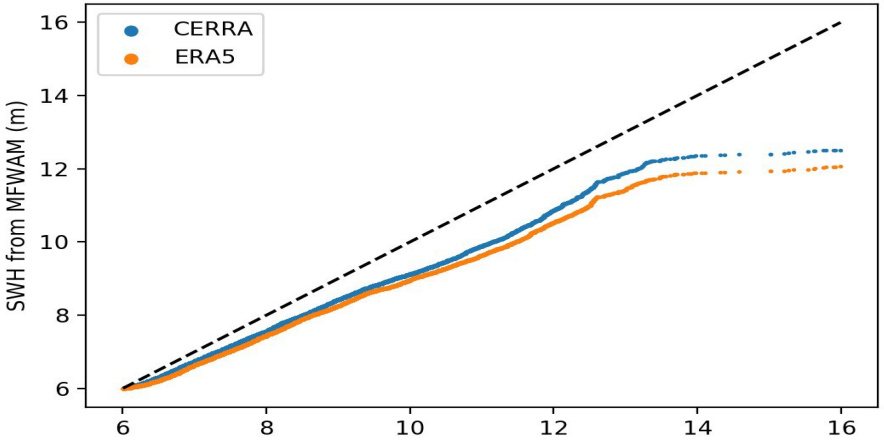


ERA5



Significant reduction of bias when using CERRA wind forcing, particularly on Med sea and Swell tracks in the Atlantic and North sea.

Q-Q plot of SWH

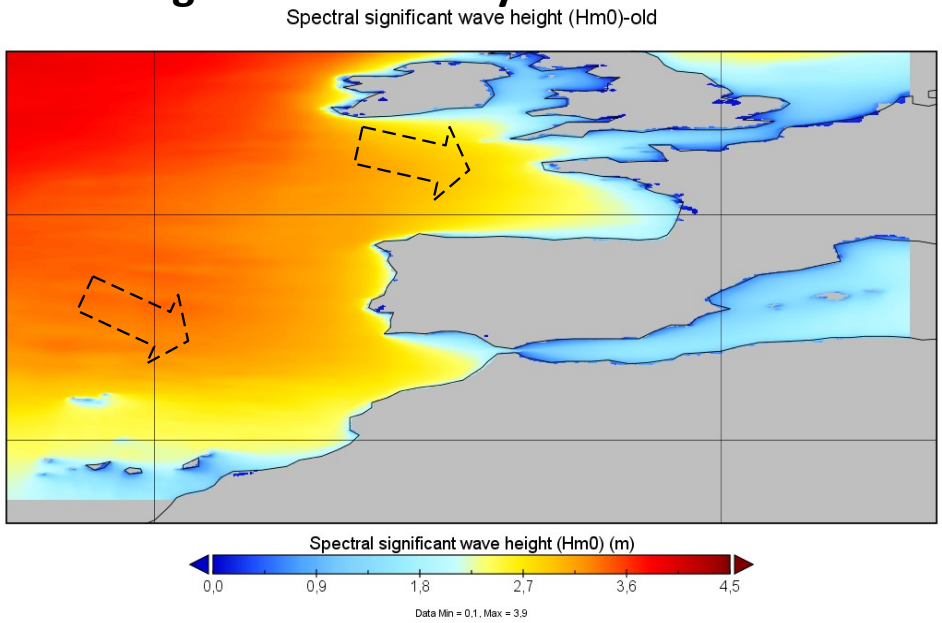


Improvement of SWH PDF for high SWH. Better scatter index of SWH when using CERRA (11.3 %), while for ERA5 11.8 %

Validation with altimeters SWH (Jan-Mar 2020)

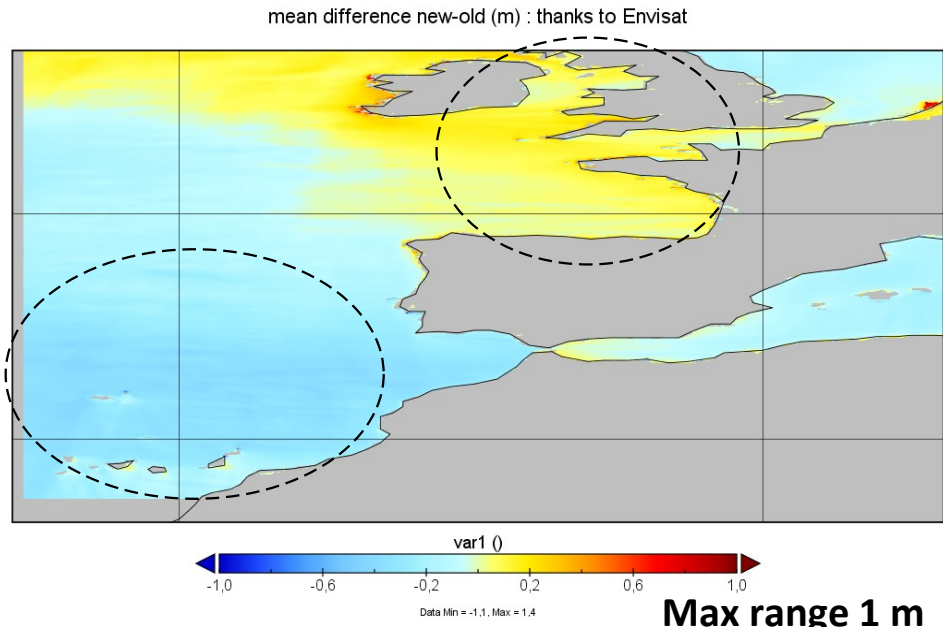
Assimilation of directional wave observations from past mission ENVISAT (2002-2012)
IBI wave reanalysis

Average SWH : January 2010



New IBI-wave reanalysis :
DA of Envisat wave spectra
Grid size 2.4 km

Average difference of SWH : New-Old January 2010

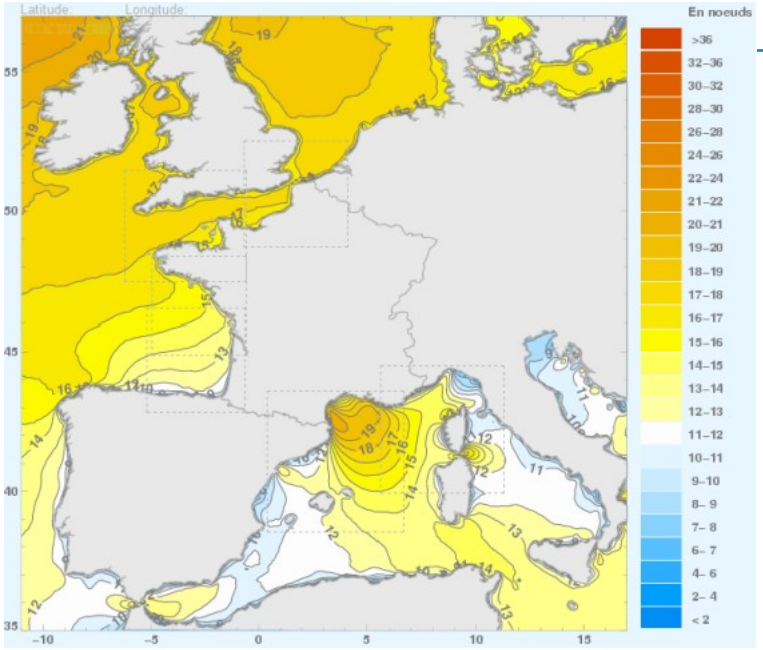


Increase of SWH in the channel and gulf of Biscay, while decrase of SWH on south-west Of IBI domain (swell tracks morrocan coast And Canaria islands)

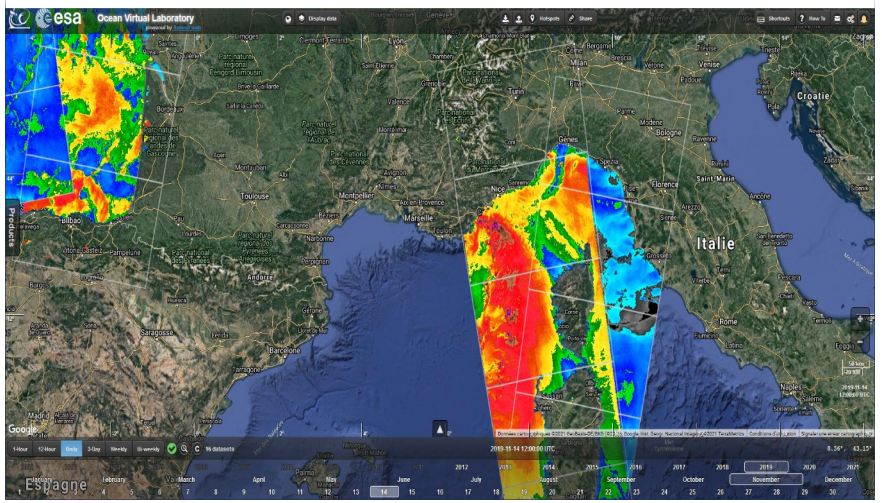
Max range 1 m

Wind forcing in Mediterranean Sea

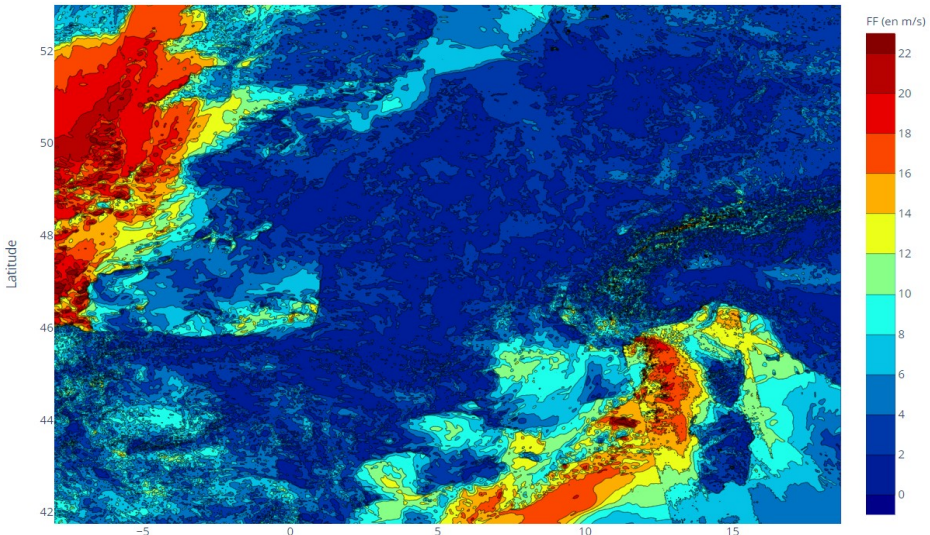
Wind climatology



SAR wind after Sentinel-1 passage 14 Nov. 2019
Resolution 1km



AROME wind (fusion with SAR)



Strong uncertainties related to small Scale wind variability in Med sea, Particularly in fast storm events (Mistral/Tramontane)

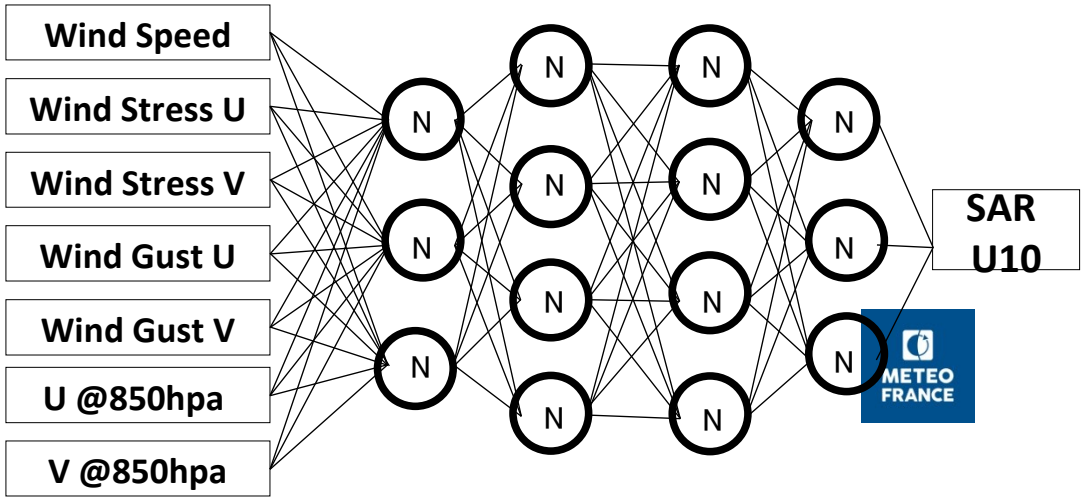
METEO FRANCE

Wind speed correction by Deep learning DNN

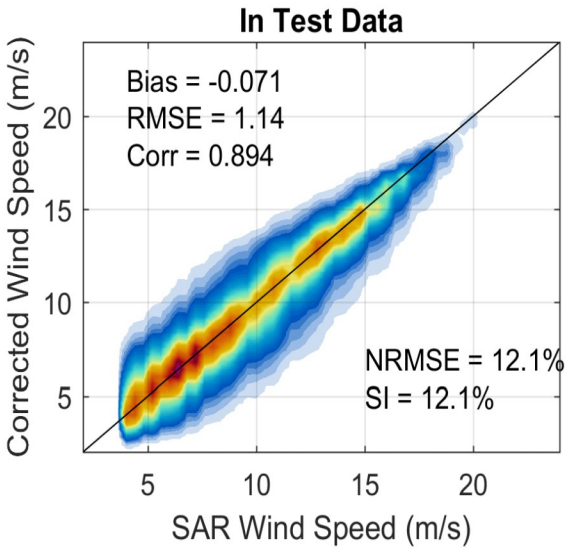
Scheme	Input	Bias	Imp. %	RMSE	NRMSE	Imp. %	SI	Imp. %
Original	/	0.601	/	1.90	20.3	/	19.3	/
1: Input# 1	AROME Wind Speed (WS)	0.01	97.8 %	1.70	18.2	10.3 %	18.2	5.7 %
2: Input# 3	WS+850hpa U/V	-0.02	97.3 %	1.55	16.6	18.2 %	16.6	14.0 %
3: Input# 3	WS+Gust U/V	-0.01	97.7 %	1.55	16.5	18.7 %	16.5	14.5 %
4: Input# 3	WS+Stress U/V	0.01	97.7 %	1.45	15.5	23.6 %	15.5	19.7 %
5: Input# 5	WS+Stress U/V+850hpa U/V	-0.00	99.5 %	1.38	14.7	27.6 %	14.7	23.8 %
6: Input# 7	WS+Stress U/V+850hpa U/V+Gust U/V	-0.02	97.2 %	1.39	14.8	27.1 %	14.8	23.3 %

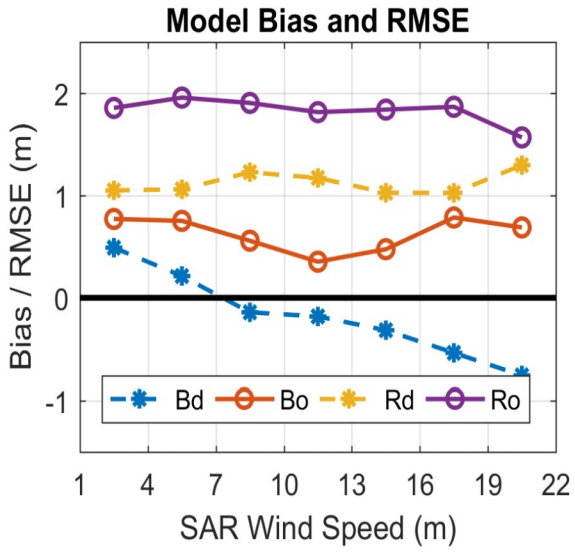
Dataset: 2019.11
50% for training, 50% for validation

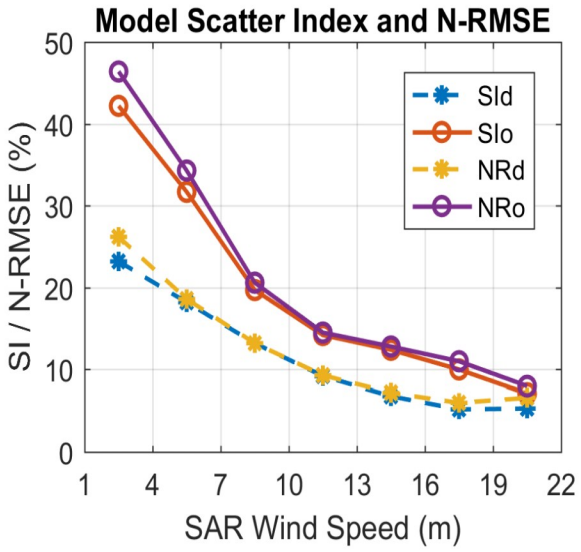
7 DNN Inputs:
Wind speed from AROM,
Wind stress U/V
Wind U/V @ 850 hpa
Wind gust U/V

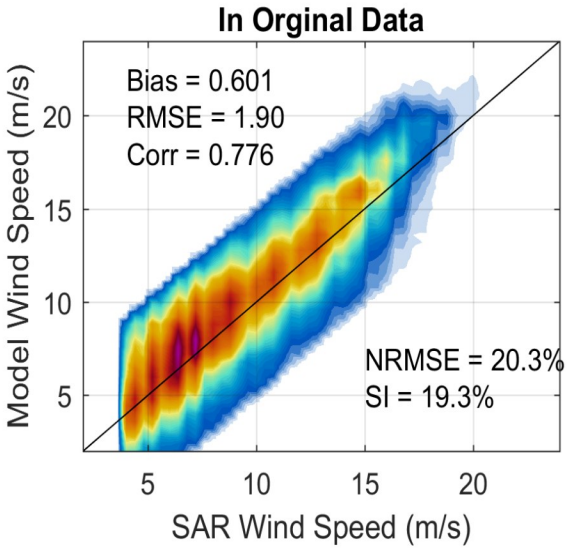


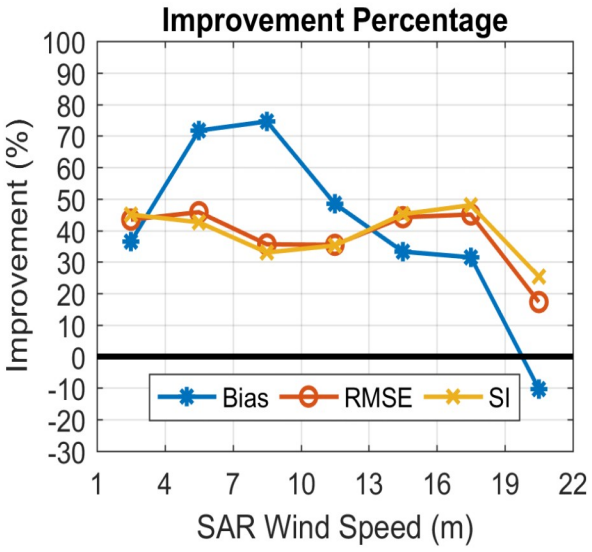
Better correction with Random forest

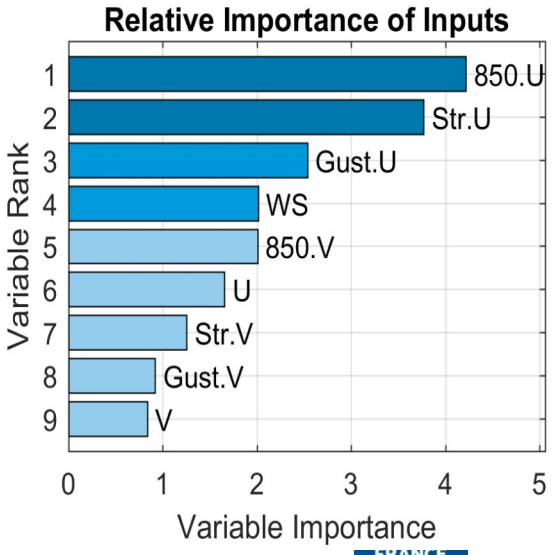






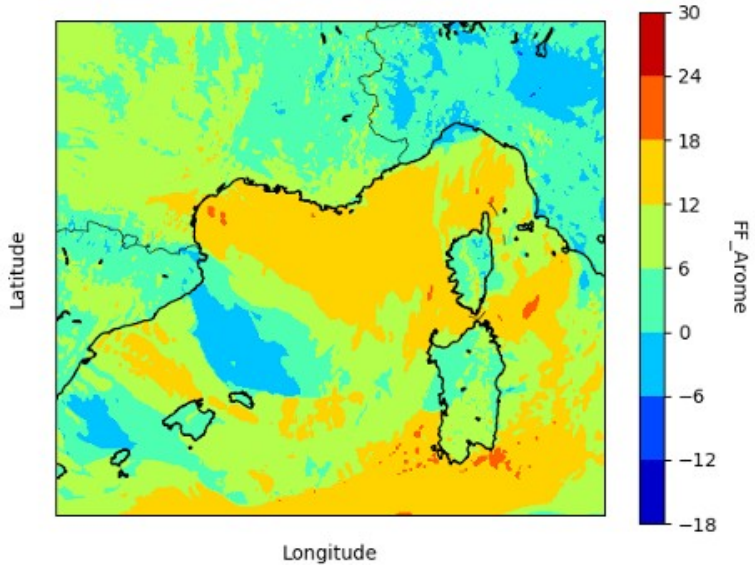




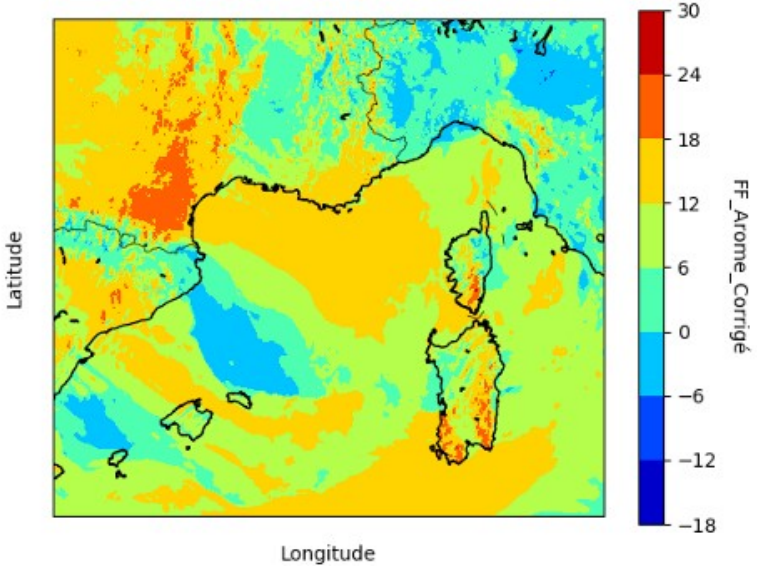


Impat on wave forecast during storm Amelie (Nov. 2019) Mediterranean case

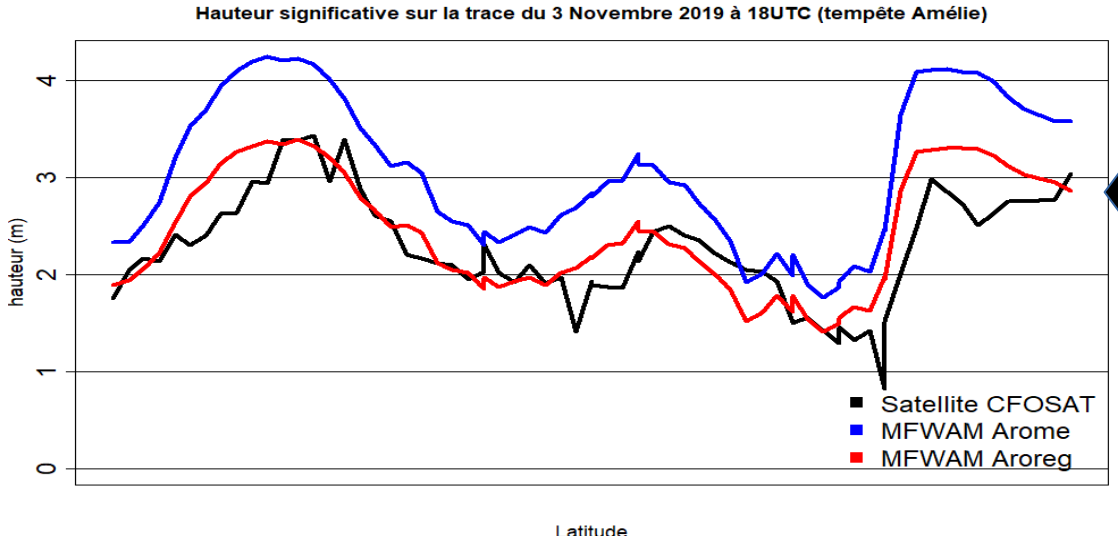
U-Arome



U-Arome-corrected-DL



Validation of SWH on CFOSAT track



Good fit of SWH with Corrected wind

Overestimation showed By the blue line with Original wind

METEO FRANCE

Key messages

- ➔ **Good SWH bias reduction when using ERA5* wind forcing, however some ocean regions are affected by slight increase of scatter index.**

- ➔ **Downscaled atmospheric reanalysis (such CERRA) stand as a good alternative to ERA5 for regional wave reanalysis. This will better describe wind variability in coastal regions.**

- ➔ **Further model experiments will be performed with DA to evaluate the impact of ERA5*, and investigate the coupling with ocean model.**

- ➔ **WAVERYS version 2 will be performed in 2024, with wave products available by the end of 2024**

METEO FRANCE