Performance of CMEMS wave reanalysis WAVERYS in the Southern Ocean and challenges for next version

L. Aouf[(1)], S. Law-Chune[(2)], A. Dalphinet[(1)]

[(1)] Météo France, DirOP-MAR
[(2)] Mercator Ocean International

CCI Sea State : Users Consultations meeting #2, 23-25 March 2021

OUTLINE

1- Introduction

2- WAVERYS in SO

3- CCI sea state data and DA

4- discussions and results

5- conclusions

Motivation

➔ WAVERYS V1.1 has been released in early 2020 and provide accurate wave products for world wide users (implementing wave climate studies, Coastal applications, ...etc). Preparation of Version 2.0

➔ Providing accurate boundary conditions for nesting CMEMS regional wave reanalysis (IBI, MED, Artic,...etc)

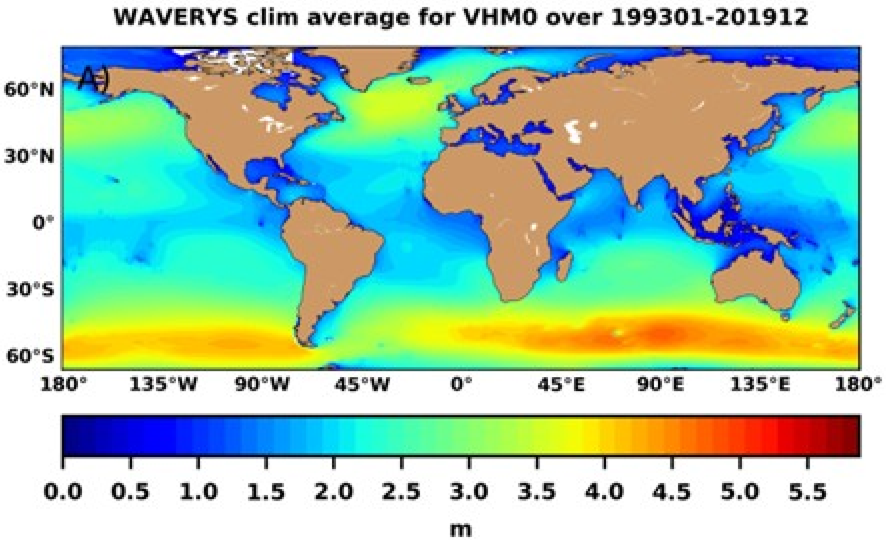
➔ Need of precise description of sea state For relevant users applications (coastal environment, seasonal variability, O/A coupling, SSB estimate,...)

METEO FRANCE

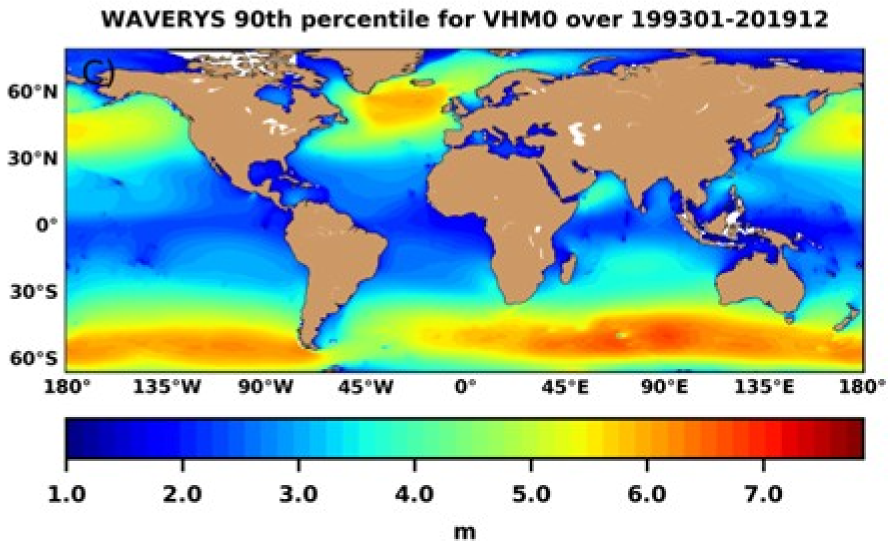
WMEMS global wave reanalysis WAVERYS (1993-2019)

- 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

Average of SWH

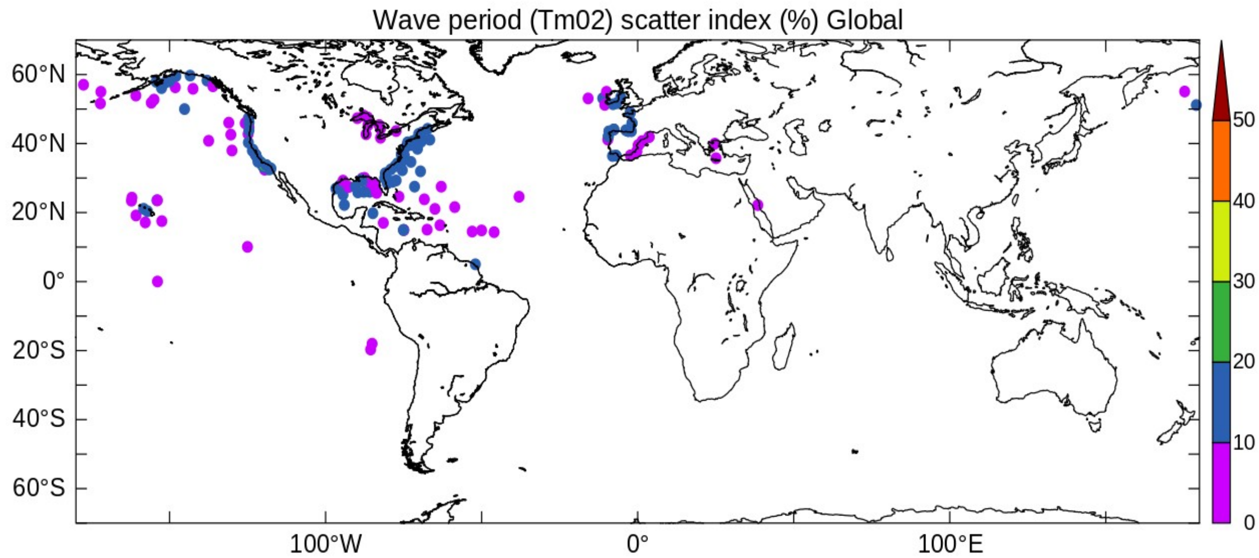


SWH percentile 90th



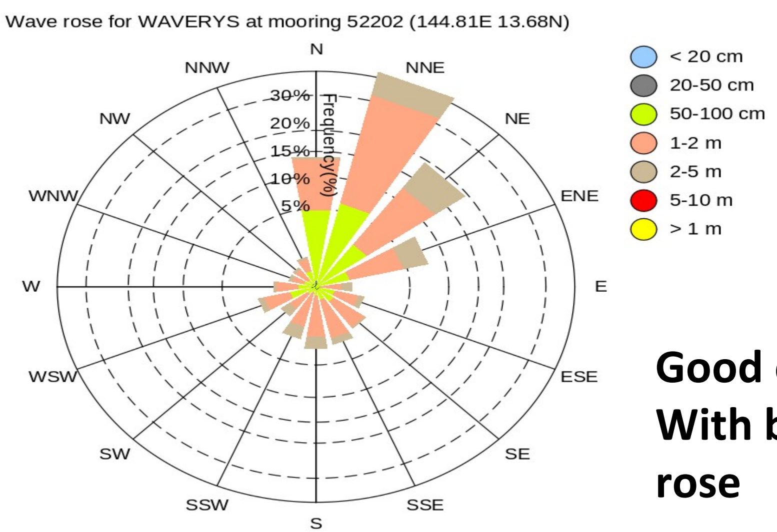
Validation with HY2A SWH indicates globally a scatter index of ~8.5% and Small bias of 5 cm
(see Law-Chune, et al. 2020)

Accurate forecast for Mean wave period (Tm02)



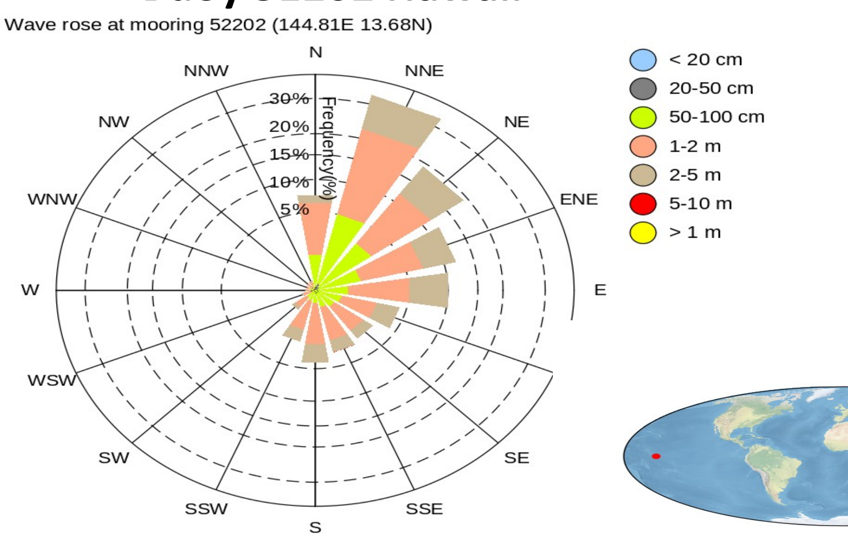
Scatter index of Tm02 is Ranging between 10-15%

WAVERYS



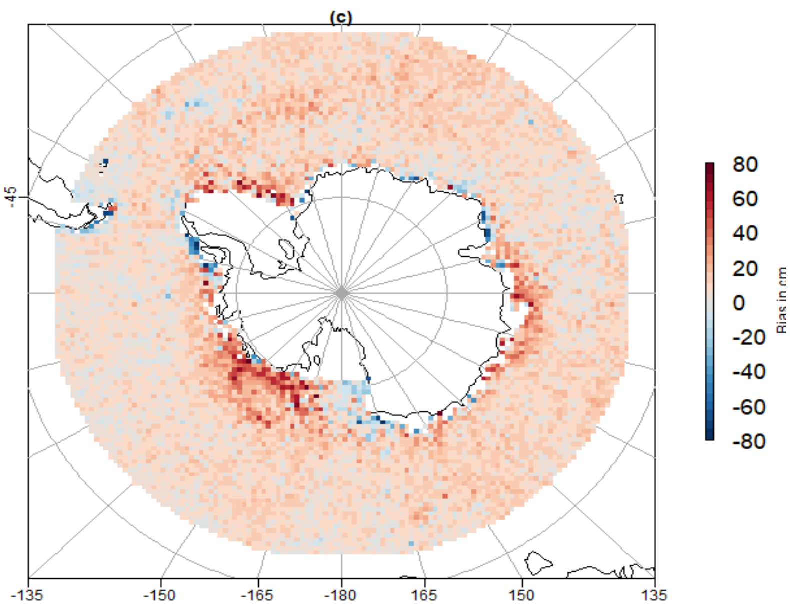
Good consistency With buoy wave rose

Buoy 51202 Hawaii



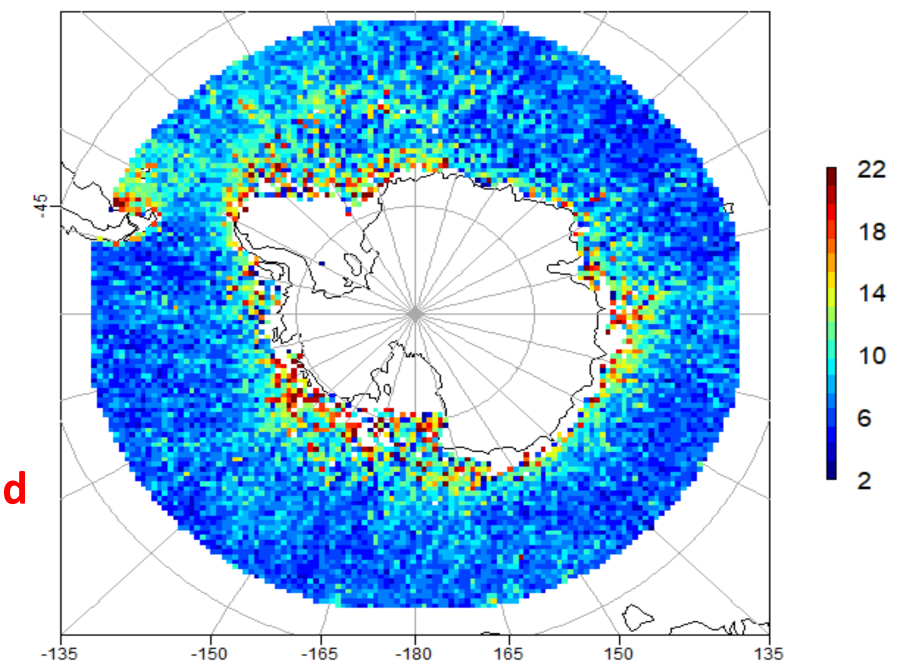
Performance of WAVERYS in Southern Ocean (2016-2018) Validation with HY2A

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

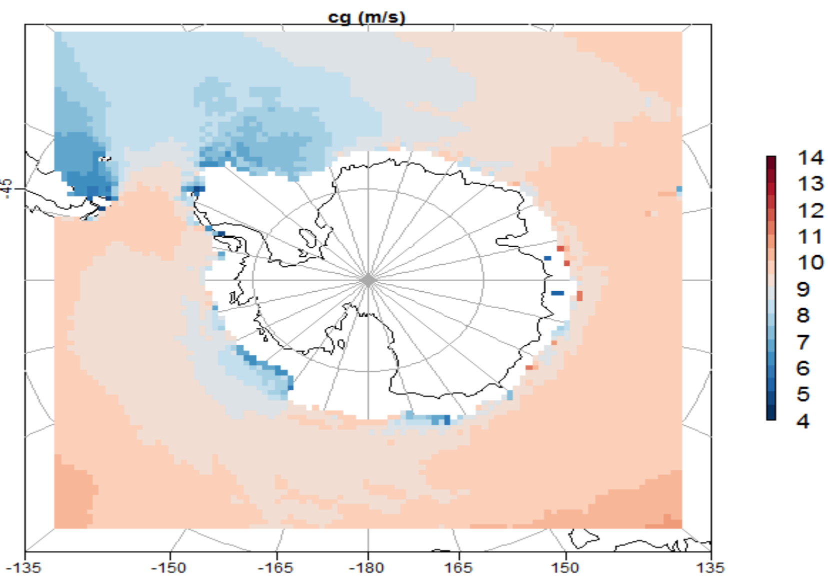
Scatter index of SWH



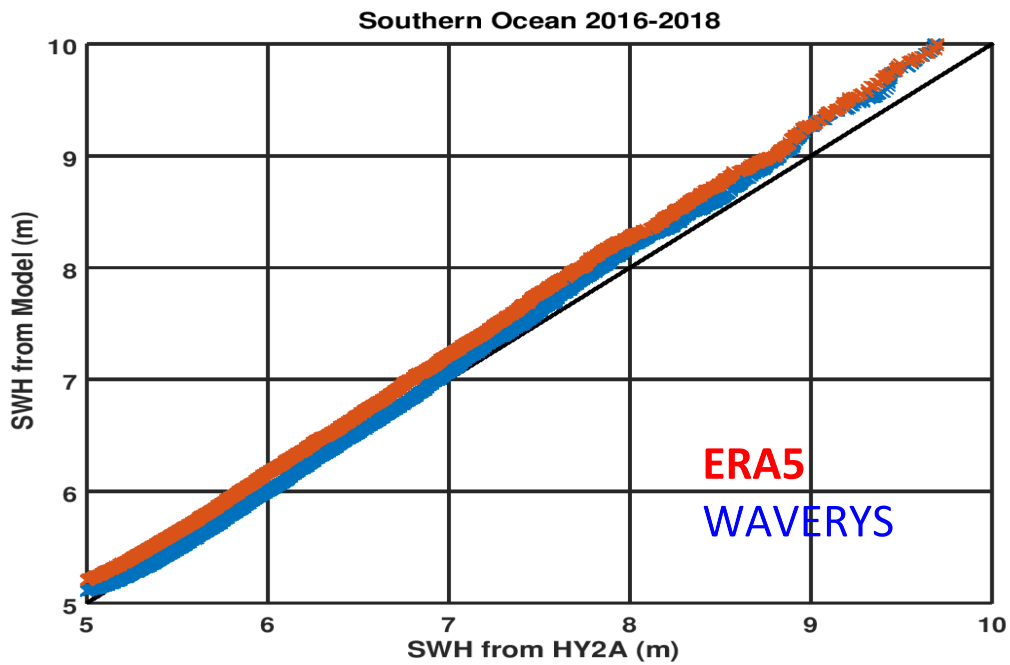
Remarkable SI in average of ~8%, and Increases near MIZ

Skillfullness of SAR directional wave observations from S1

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. Qqplot indicates WAVERYS is sharply following perfect for ranges of SWH 5-8 m



From altimeter HY2A

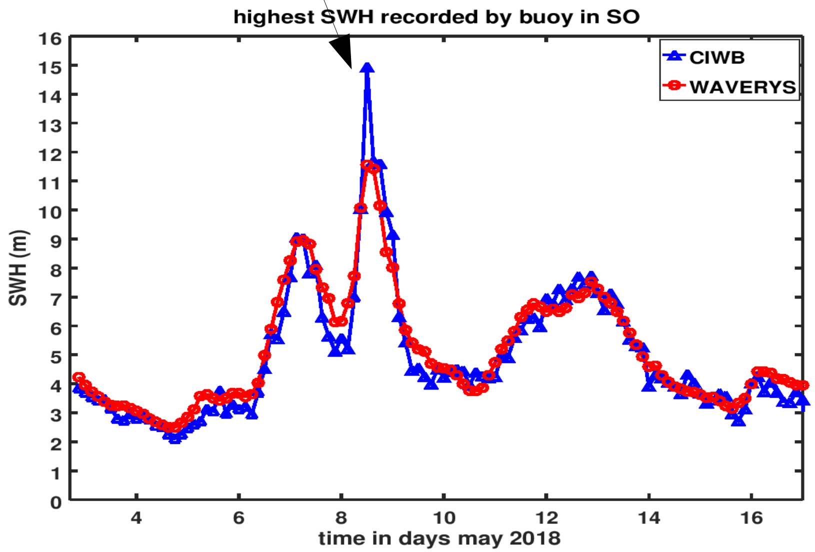
METEO FRANCE

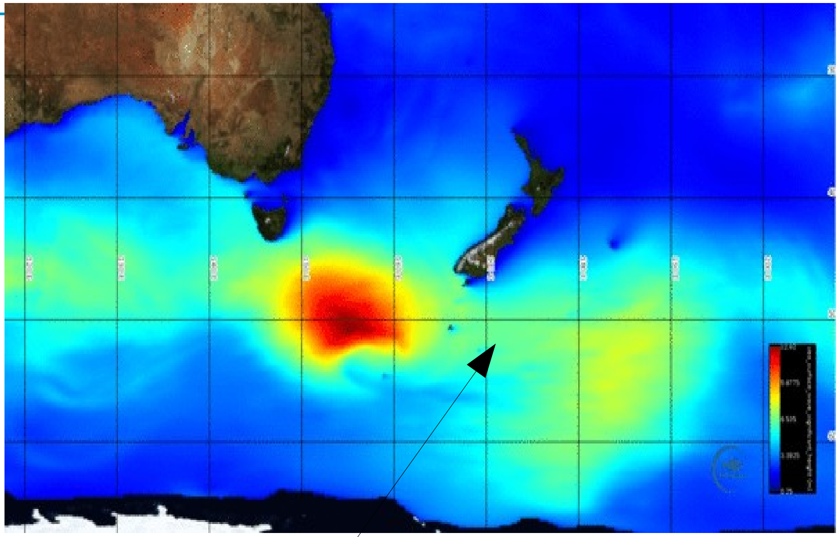
WAVERYS during Hmax record in Campbell Island (SO)

Snapshots of SWH-WAVERYS 8 May 2018 (3-hourly)

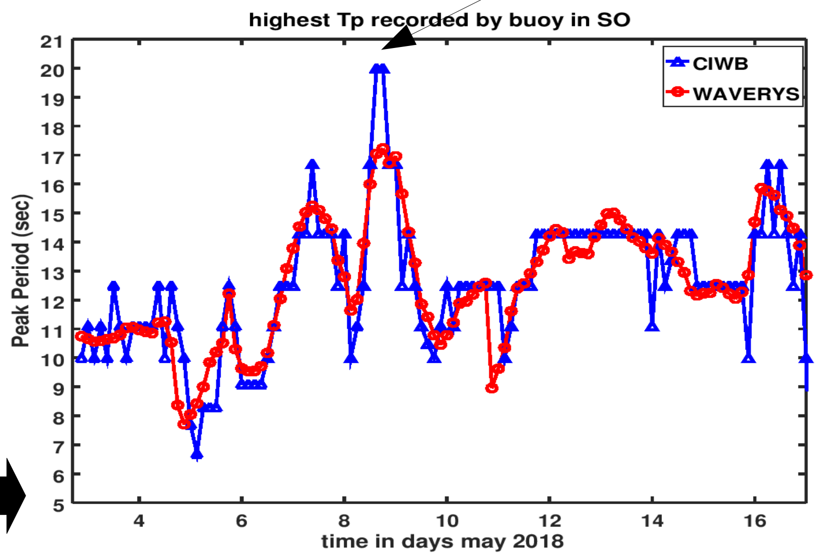
SWH at the peak of 14.6m and underestimated by WAVERYS

Time series of SWH at Campbell island





Long wave of Tp 20 sec

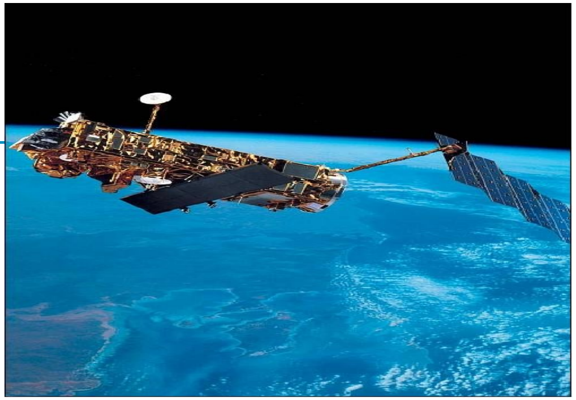


Good consistency between SWH and Tp From WAVERYS and buoys at Campbell Island during severe storm.

Peak period

CCI DATA (version 1.1)

ENVISAT



Quality control of data (Envisat-RA2, Jason-1 &2) based on :

→ SWH threshold 0.5-13 m
→ sigma0 threshold 4-30 db
→ RMS of SWH <0.8
→ sea ice fraction (<=0.3)

SWH original and denoised have been tested in DA experiments

Configuration of model MFWAM : global 0.5° grid size and spectral Resolution 24 directions and 30 frequencies. Atmospheric forcing From ERA5

DA experiments for period from September to December 2010:

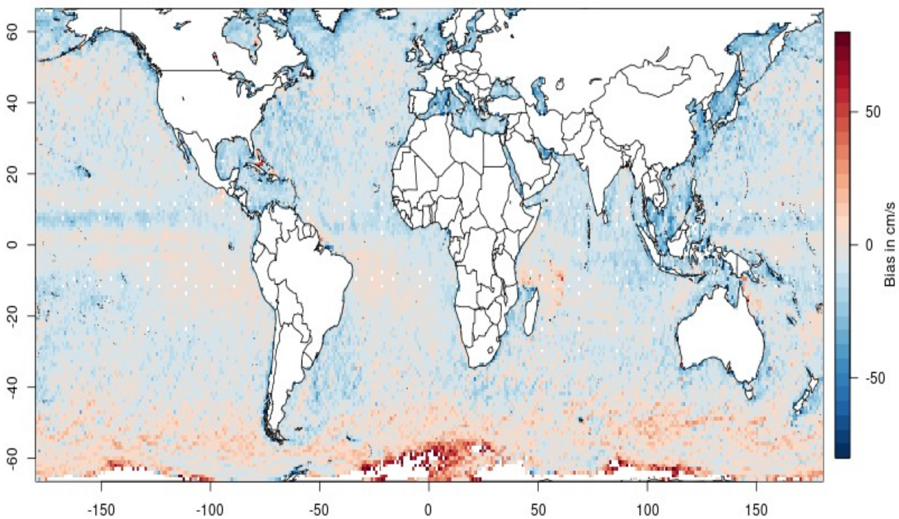
- Assimilation of Envisat-RA2 SWH-original
- Assimilation of Envisat-RA2 SWH denoised (EMD filtering)
- Assimilation of Envisat-RA2 SWH (denoised) and ASAR
- Control run without DA

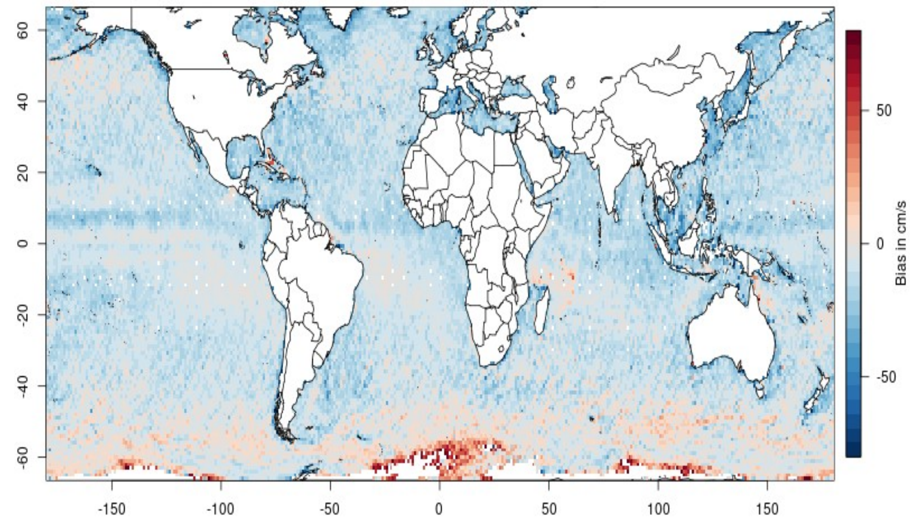
Validation with SWH denoised from Jason-1 & 2

METEO FRANCE

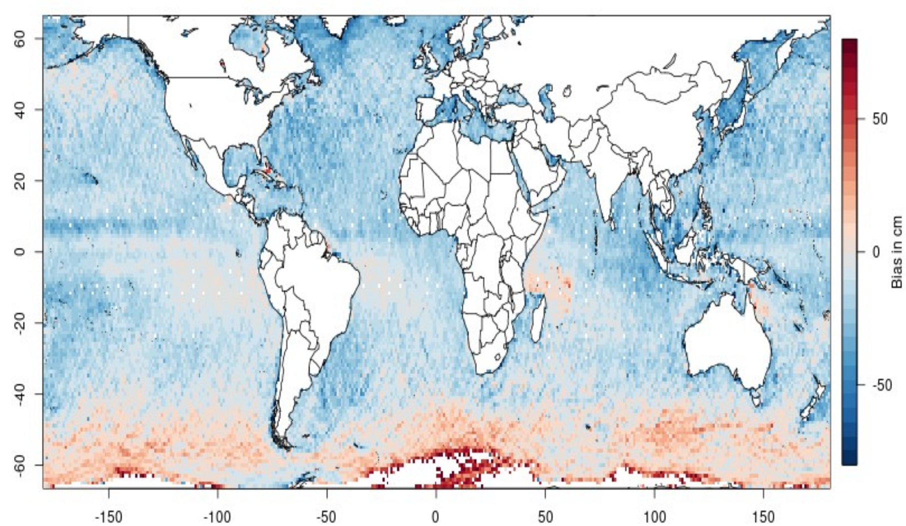
Bias maps of SWH (Sep-Dec 2010)

Assi-SWH denoised (Max bias 60cm) **Assi-SWH original**





Significant reduction of bias For SWH-denoised compared to original and No assi



Still underestimation of SWH for Assimilation of SWH original

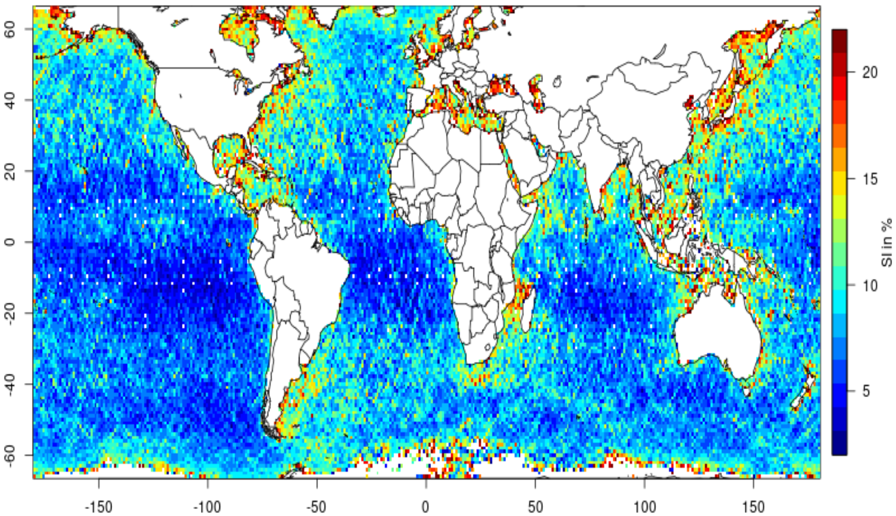
Without Assi

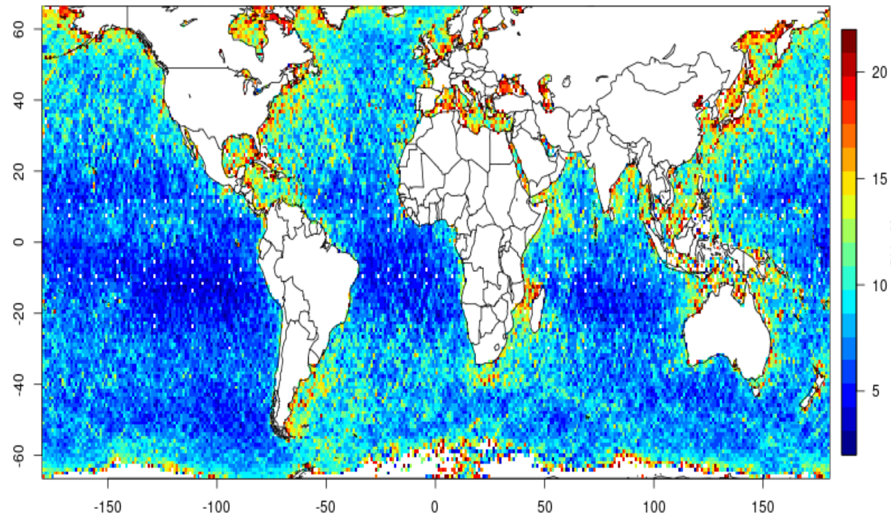
Validation with Jason-1&2 (denoised)

METEO FRANCE

Scatter index of SWH maps (Sep-Dec 2010)

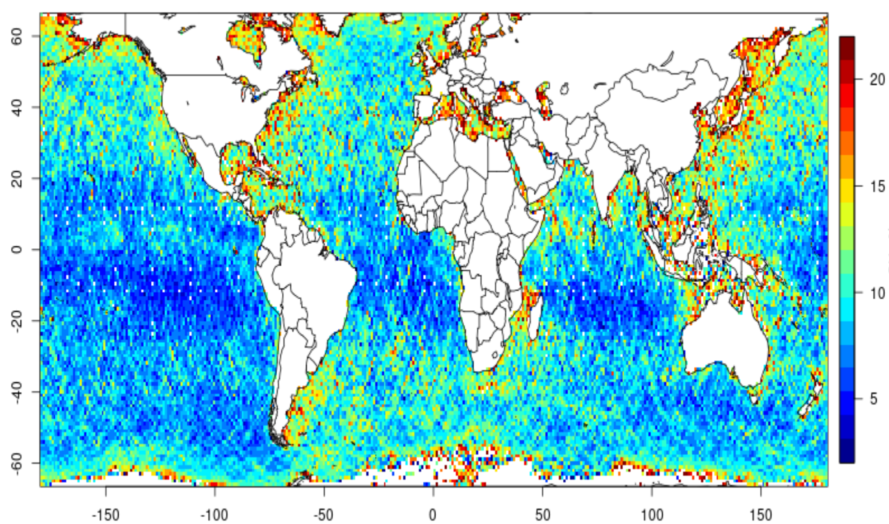
Assi-SWH denoised (Max range 20%) **Assi-SWH original**





Good reduction of SI after Assimilation compared to No assi.
EMD did not affect SI after Assimilation compared to original

Blue is good
Red is bad



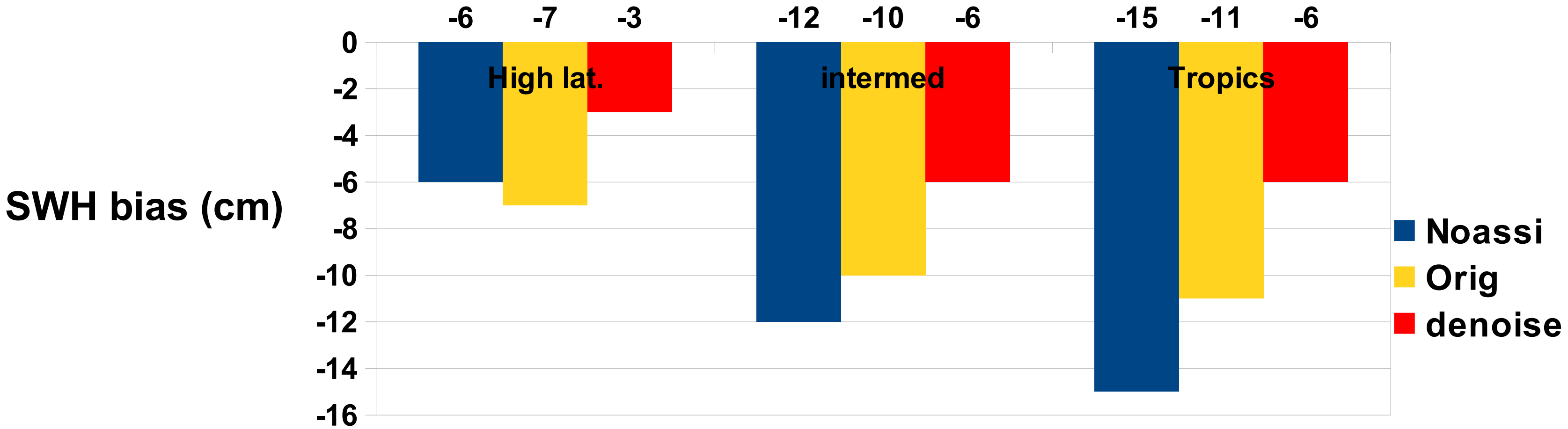
Without Assi

Validation with Jason-1&2 (denoised)

METEO FRANCE

SWH bias in different ocean basins Sep-Dec 2010

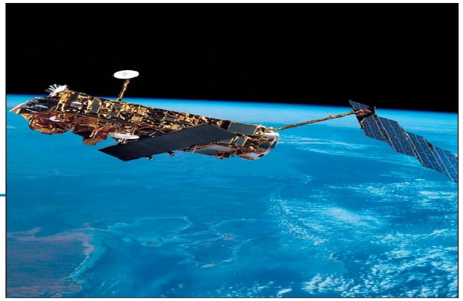
High Lat |Φ|> 50°
Intermediate lat 20°<|Φ|<50°
Tropics |Φ|<20°



Strong reduction of SWH bias in particular in high lats

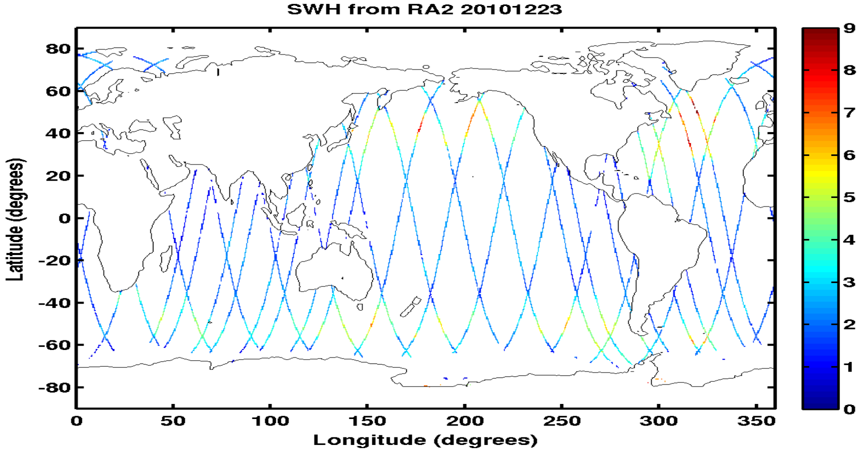
Comparison with SWH Jason-1 & 2 (Denoised)

Back to the past : ENVISAT mission

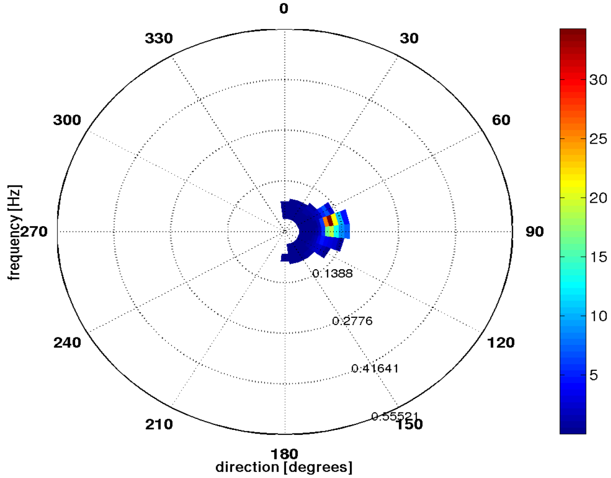


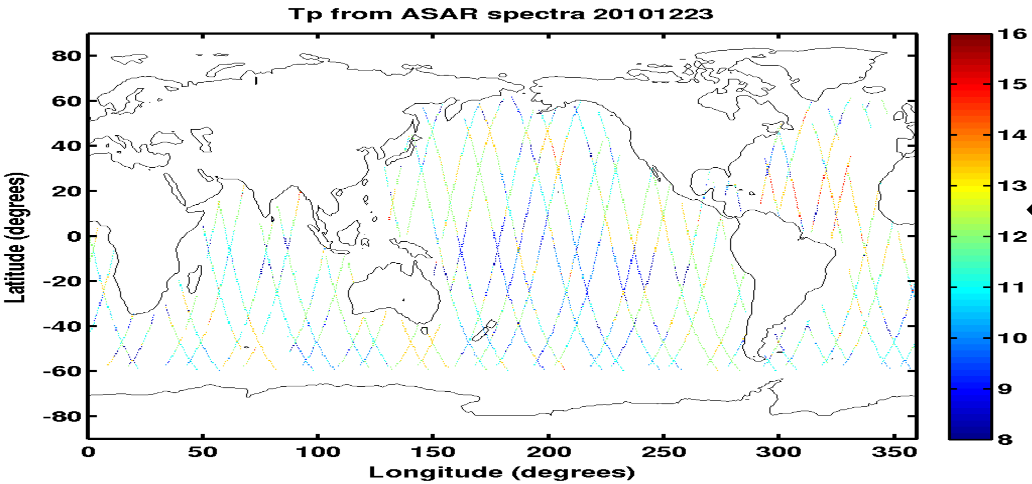
Envisat provides SWH from RA2 and wave spectra from ASAR 200 km off-nadir.

SWH from RA2



ASAR wave spectrum long=184° lat=61°



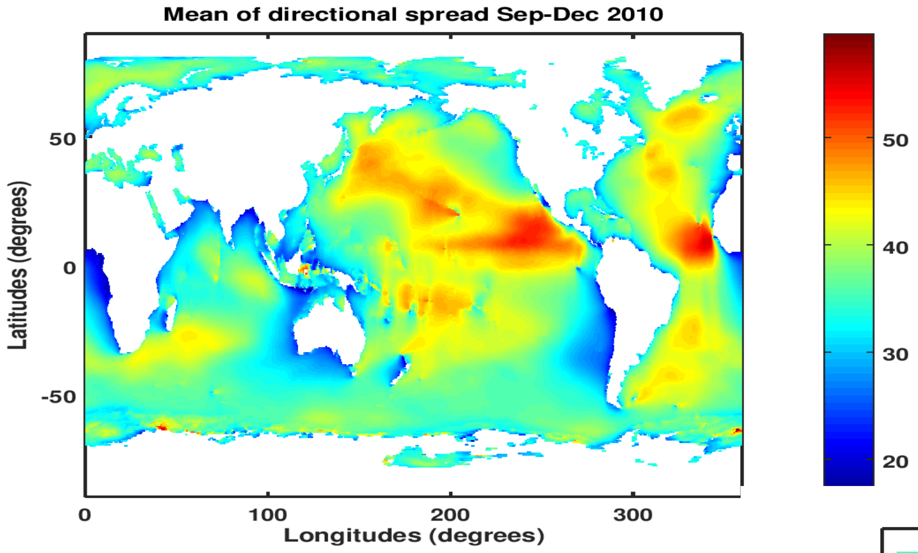


Peak period from ASAR Wave spectra (23 Dec 2010)

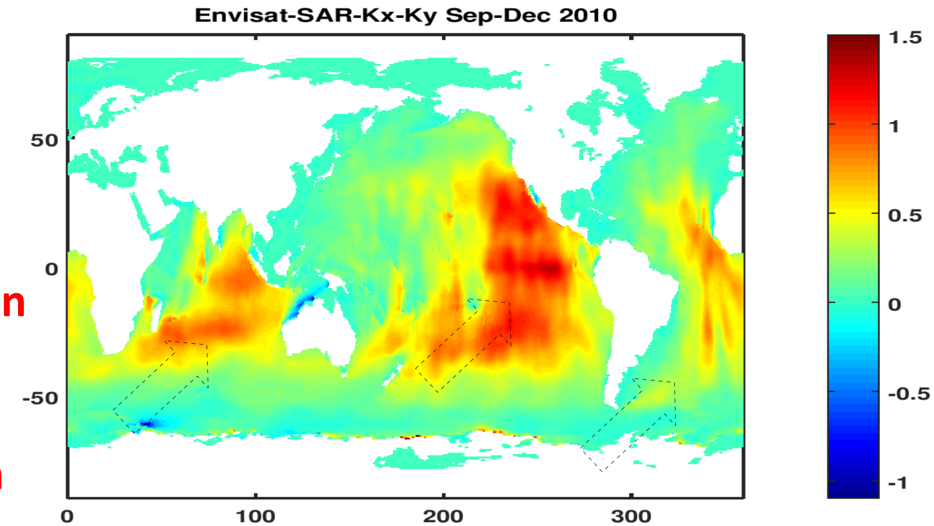
METEO FRANCE

Impact of the assimilation of Kx-Ky from ASAR-ENVISAT Sep-Dec 2010

Mean of directional spreading from Assimilation of Envisat (RA2+ASAR)



Mean of difference of spreading With and without assimilation of ASAR



Two trends in the impact induced by wavenumbers assimilation :

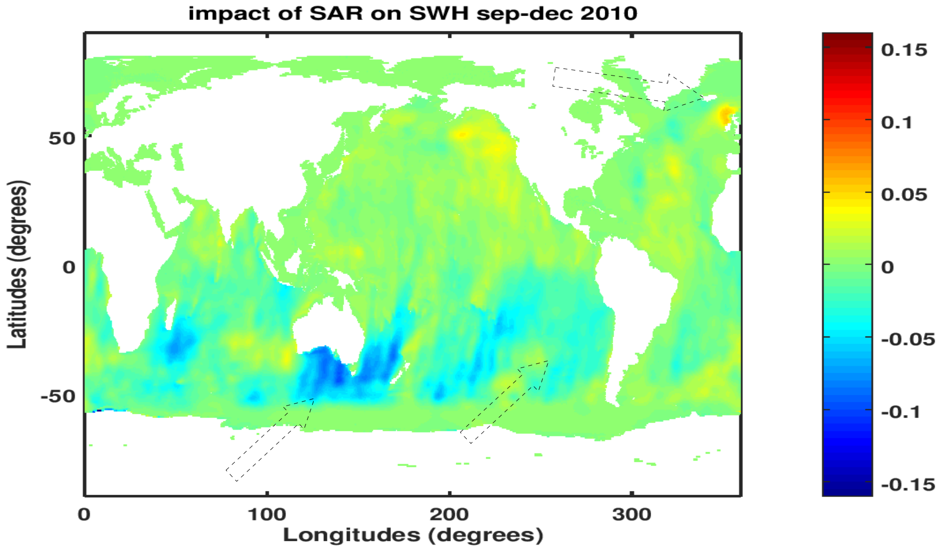
1- positive difference indicates the correction of underestimation of the model mostly in swell dominant regions

2- negative difference reveals the correction of overestimation of the model for example in SO (unlimited fetch conditions)

FRANCE

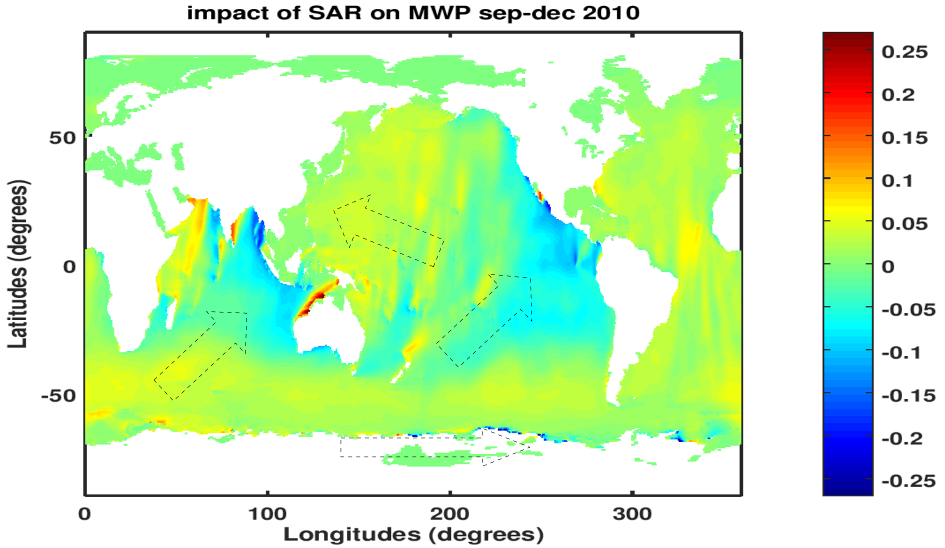
Impact of DA wavenumbers components on integrated parameters : Sep-Dec 2010

Mean of difference of SWH
With and without ASAR spectra



Positive impact means underestimation of the model MFWAM, while negative means overestimation

Mean of difference of mean period
With and without ASAR spectrav

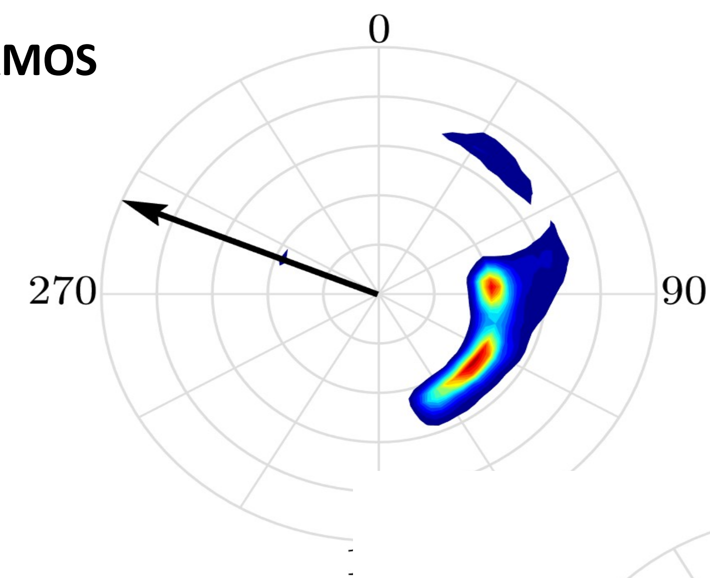


Significant impact on swell propagation Tracks and hurricane/typhoons tracks. Very important to include 10 years of ASAR spectra

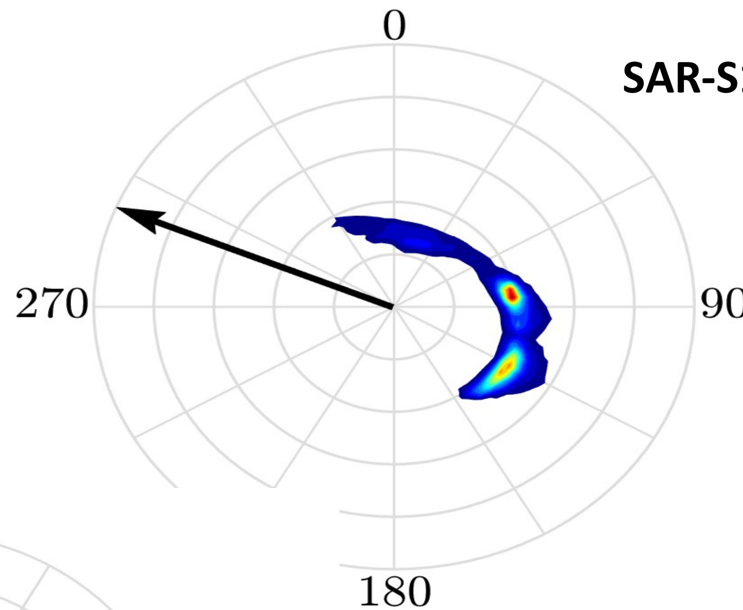
Need for finer spectral resolution in the model particularly in direction

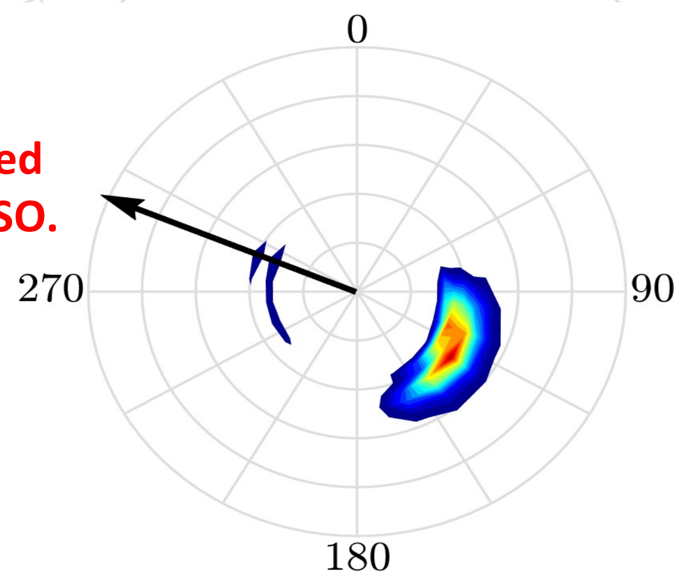
Currently WAVERYS uses a spectral resolution of 24 directions. SAR spectra are provided with 72 directions (step by 5°) from S-1.

WAMOS



SAR-S1



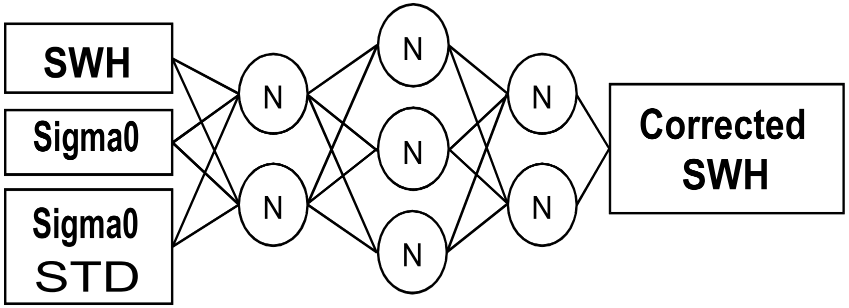


Assimilation of SAR

Two partitions peaks captured In SAR and WAMOS data in SO. The assimilation of SAR has difficulties to reproduce the two peaks because of 24 Directions of resolution

Courtesy of Derkani M. for WAMOS data

Deep Neural Network model (Wang et al. 2020)



Two DNN schemes have been tested

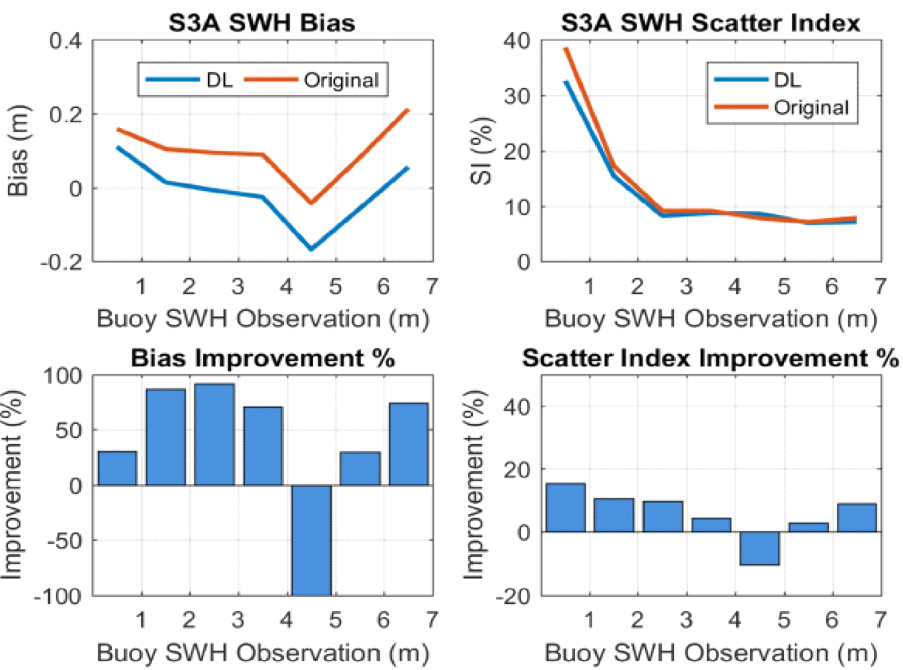
schemes	Deep Learning inputs
1	SWH
2	SWH+Sigma0+STD-Sigm0

The DNN is trained with NDBC and french buoys SWH and 6 layers have been used for the neural network.
70% of data for the training and 30% data for the validation of the DNN

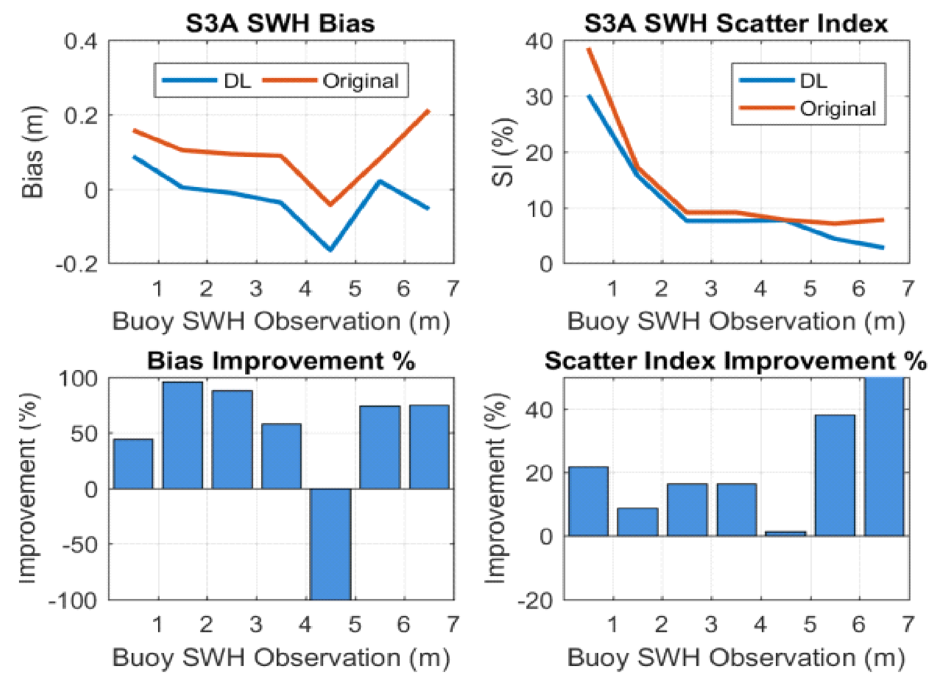
METEO FRANCE

Deep Neural Network model (Wang et al. 2020)

Improvement with scheme 1



Improvement with scheme 2

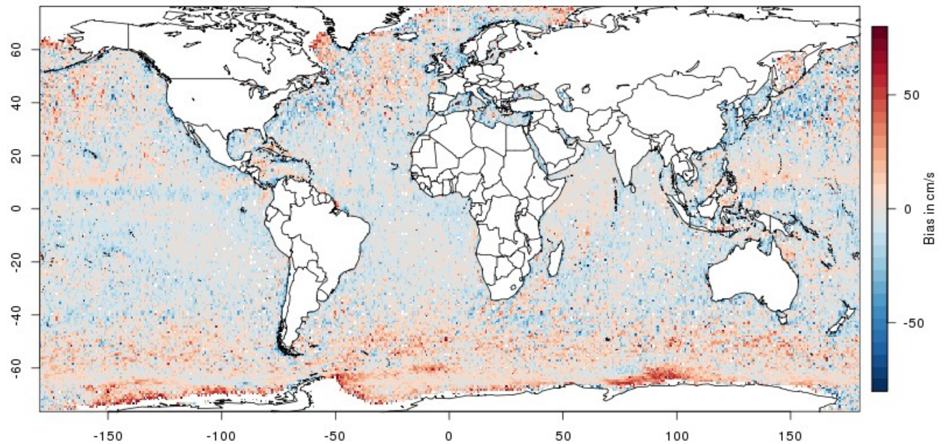


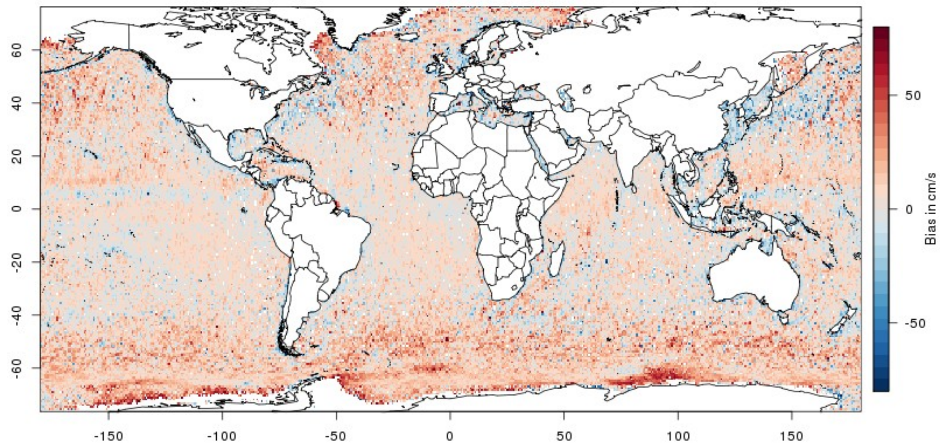
SWH bias completely removed with DL : scheme 2 is significantly better
Enhanced improvement when adding sigma0 and STD-sigma0 in the DNN

METEO FRANCE

Impact of DL for the assimilation of S3A&3B (reproc SAR)
Validation with Ja3 and Saral : Jan-Feb-Mar 2019

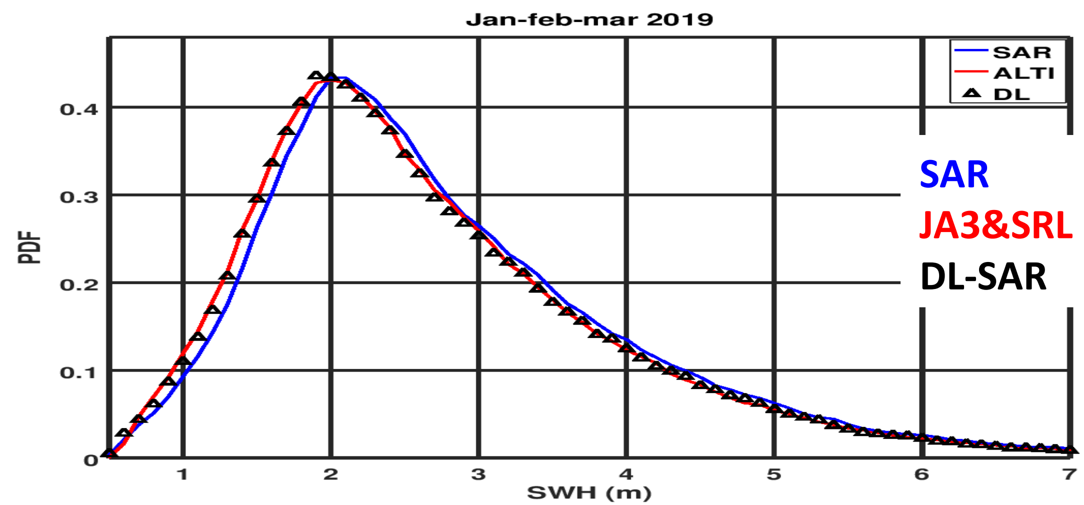
Assimilation of SWH-DL | **Bias (max 50 cm)** | **Assimilation of SWH rep.**





Significant reduction of SWH bias with the assimilation of SWH from DL

PDF of SWH



Analysis on PDFs shows the improvement induced by DL in different ranges of SWH

Conclusions and perspectives

→ WAVERYS V1.1 shows a good performance in the Southern Ocean.
For version 2.0 we address the following upgrade :

→ need for finer spectral resolution in direction (36 directions)

→ better capturing of high SWH in DA

→ Include CFOSAT wave spectra in DA : enhanced impact on Wind-waves systems in SO

→ update the DA of altimeters SWH with EMD filtering from CCI-Sea state V2

→ reprocessed SAR wave spectra from S1 (full mission) is highly recommended

→ Include ASAR wave spectra from ENVISAT 2002-2012 (reprocessed data and complete). Too many missing days have been remarked in what is available now

→ EMD filtering shows a good reduction of SWH bias (Envisat, Jason-1 & 2). We will check the impact for S3 in CCI-Sea State V2.

METEO FRANCE

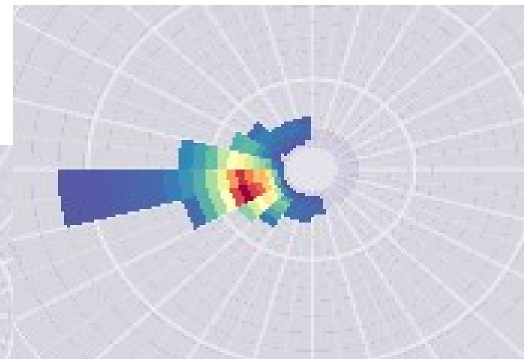
➔**The use of Deep Learning technique as proposed by Wang et al. (2020) is efficient For SWH bias reduxtion and improvement of scatter index. Intercomparison With EMD filtering for S3 will be investigated.**

Storm in southern ocean on 23 June 2017 : Warning for swell at La Réunion

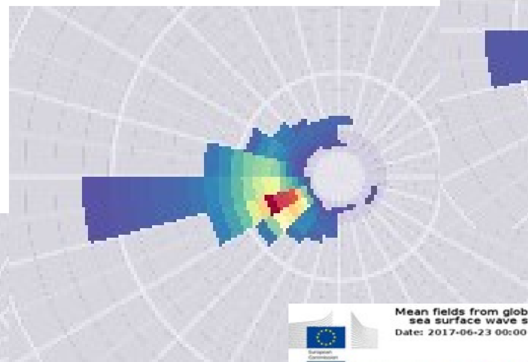
Sentinel-1A and 1B tracking the long swell generated by the storm Off shore of South-Africa (Peak Energy=172.2 and Peak eriod of 16 sec)

S1 in the peak of the storm

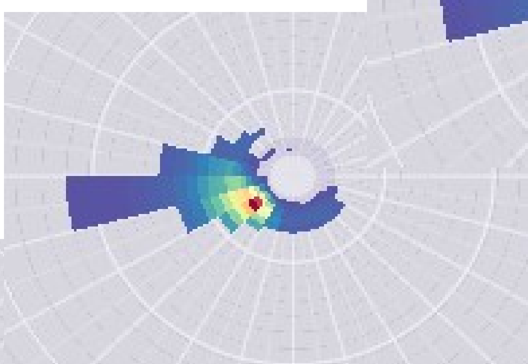
Max=115.1
Tp=13.1sec



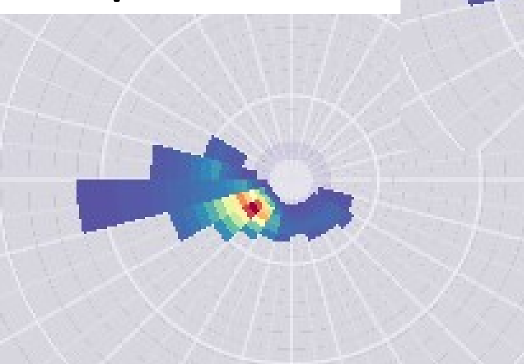
Max=129.6
Tp=13.3sec

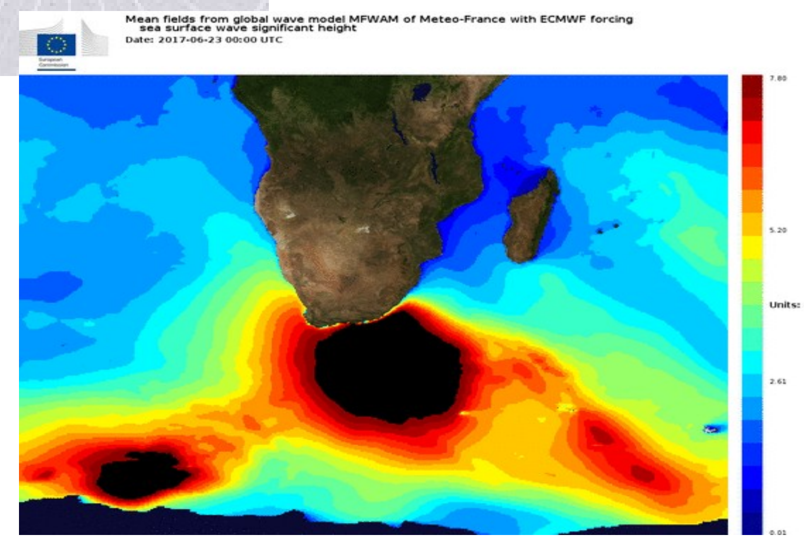


Max=172.2
Tp=16.1sec



Max=101.5
Tp=16.1sec





Snapshots from CMEMS-GLO 23 to 24 June By step of 6h