On the impact of wave directionality in the Agulhas surface current : Thanks to CFOSAT wave data

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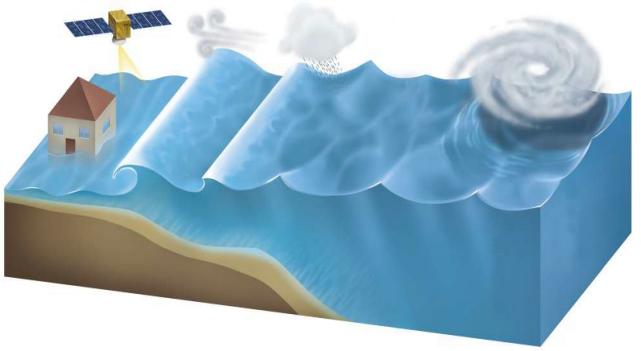
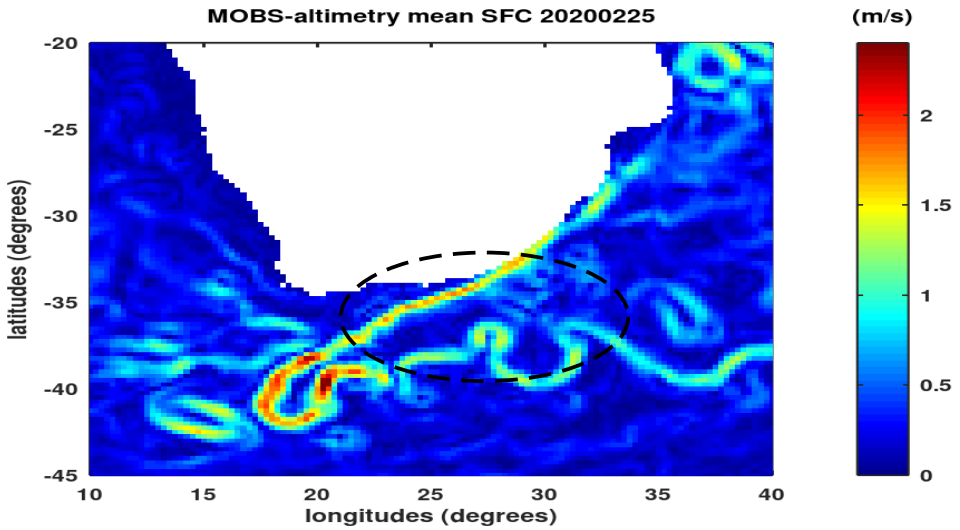
5th workshop on Waves and Wave-coupled Processes, ECMWF, Reading, 11 April 2024

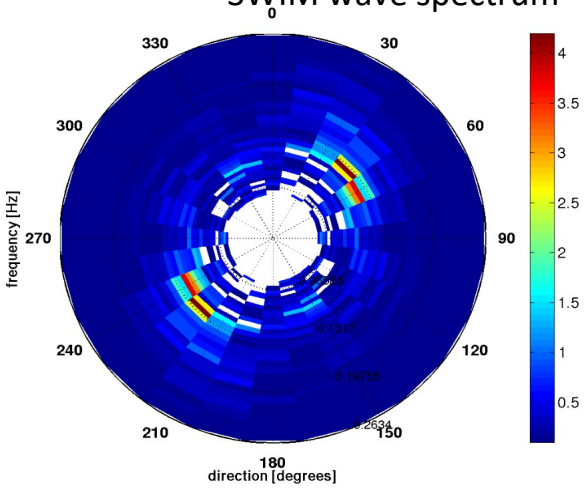
Motivation



- The Agulhas Current is a major player in the exchange of warm waters between the Indian Ocean and the southern Atlantic Ocean.
- Investigating the impact of wave directionality on the ocean/wave coupling : Better sea state prediction with SWIM directional wave spectra
- Evaluate consequences on upper ocean mixed layers particularly on typical strong surface currents ocean regions such as Agulhas current.

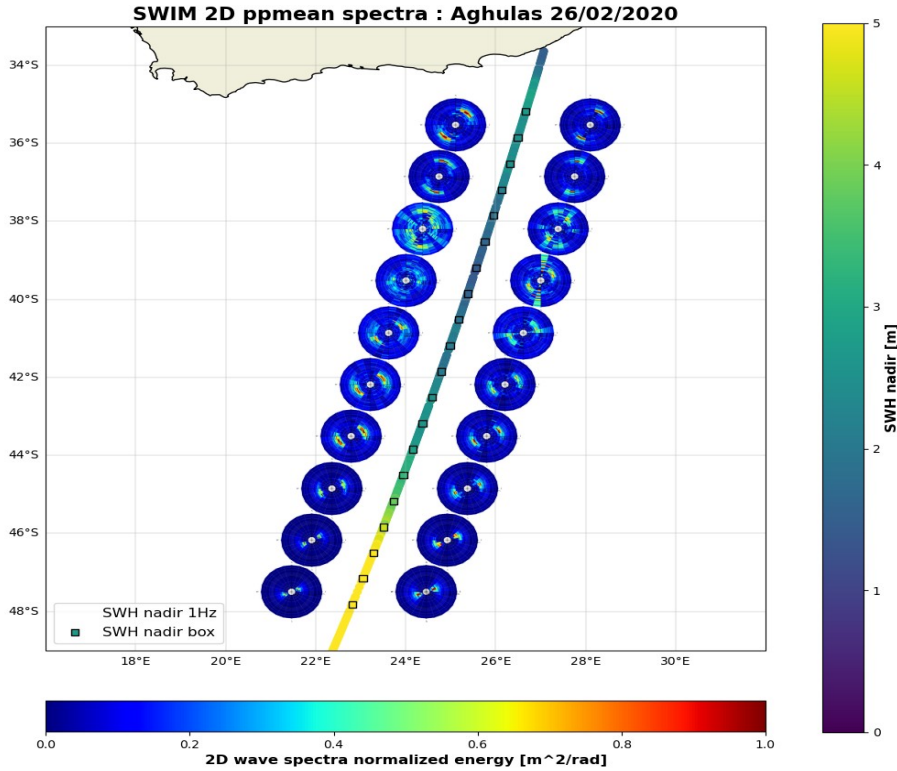


SWIM wave spectrum

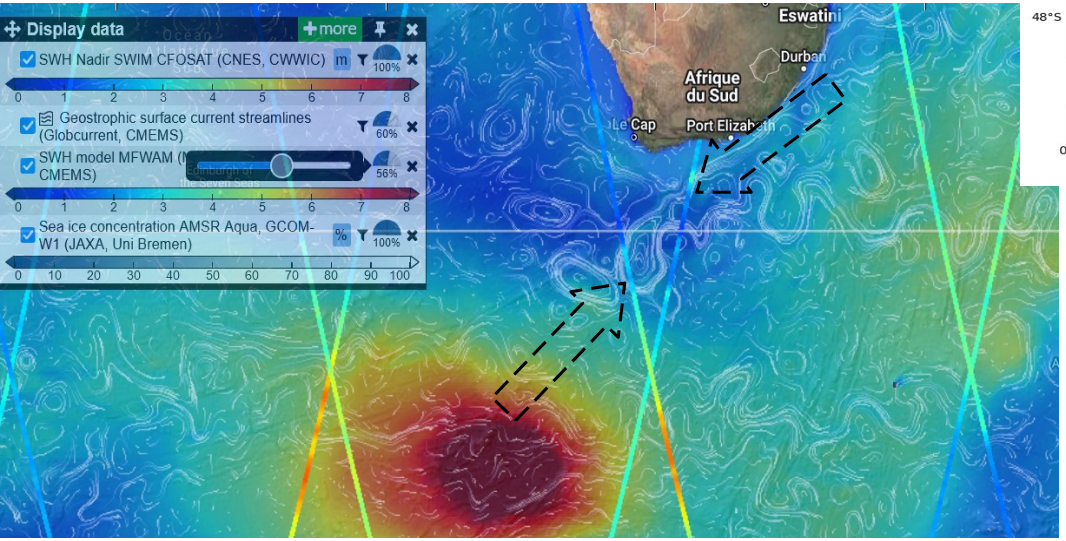


The context

CFOSAT wave data



Coupled simulations MFWAM/NEMO with improved wave forcing (Assimilation of SWIM spectra and SWH) and stand alone wave forcing (no DA)
The region of interest is agulhas ocean current region : strong surface current southward and complex wave systems with long swell in opposing direction. Analysis on 25 feb. 2020 with storm event in SO south-west of South Africa.



Assimilation of directional spectra :
- **partitionning to wave systems**
- **mean parameters Kx and Ky for each Partition from SWIM and model**
- **Optimal interpolation on Kx and Ky**

Dashed arrows indicate opposing direction between surface current and dominant wave direction

Framework of model runs

- **Wave model MFWAM configuration :**

-global scale with grid size 0.5°, ST4 physics, spectral resolution of 24 dir, 30 freq
- atmospheric forcing IFS-ECMWF
- period of run : January-June 2020

- **MFWAM model run with with DA of SWH and directional wavenumbers from SWIM wave spectra**

- control run without assimilation

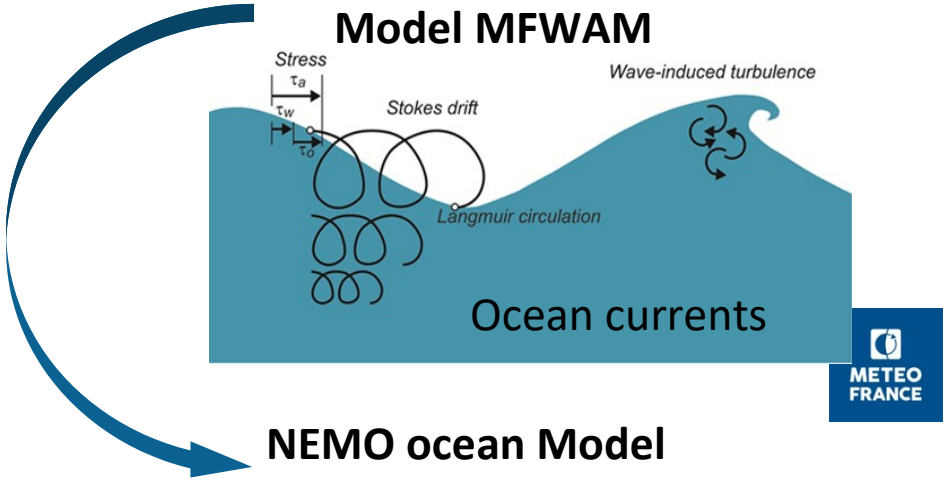
1-way

- **NEMO model runs : configuration ORCA25 (0.25°)**
- **wind forcing from IFS-ECMWF**

1- ALL NEMO run : improved wave forcing With DA
2- Free NEMO run : wave forcing without DA
3- Control NEMO run : No wave forcing

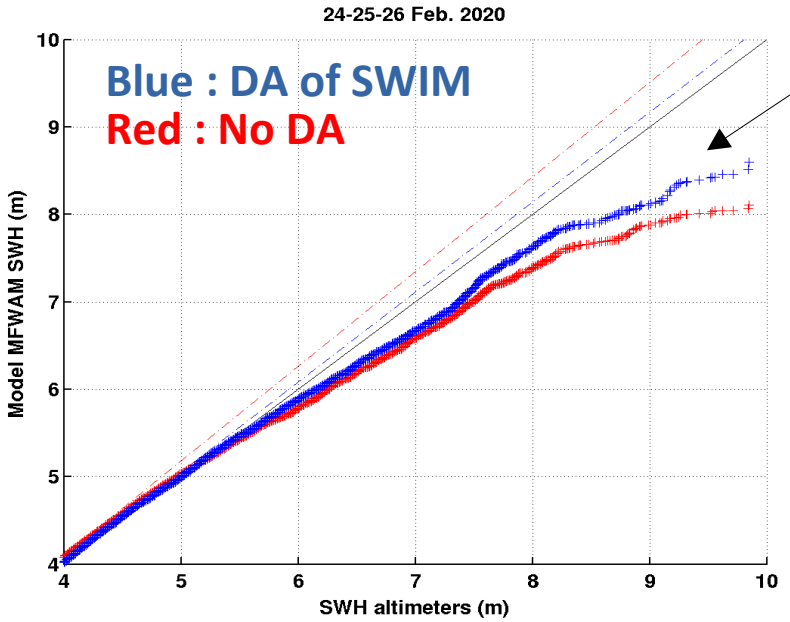
Coupling processes :

- **Surface stress released to ocean τ_{oc}**
- **Stokes-Coriolis forcing and Stokes advection**
- **wave breaking inducing turbulence**



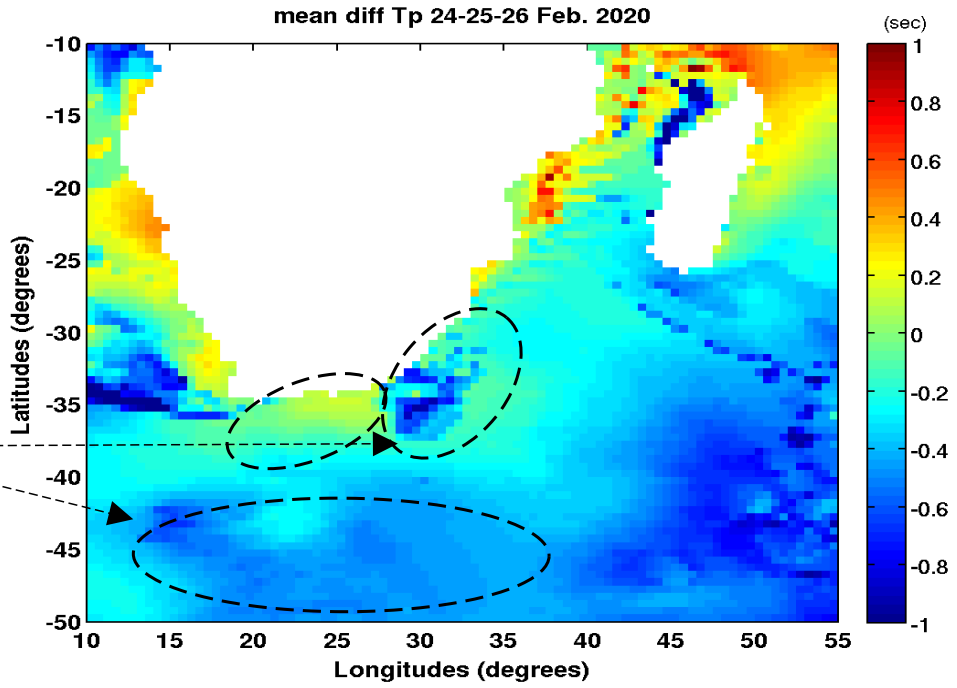
Improved sea state forecast by the assimilation of SWIM in the Agulhas Current region

QQ-plot of SWH model and altimeters In agulhas region 24-26 Feb. 2020



Significant improvement of SWH PDF particularly For high waves compared to altimeters

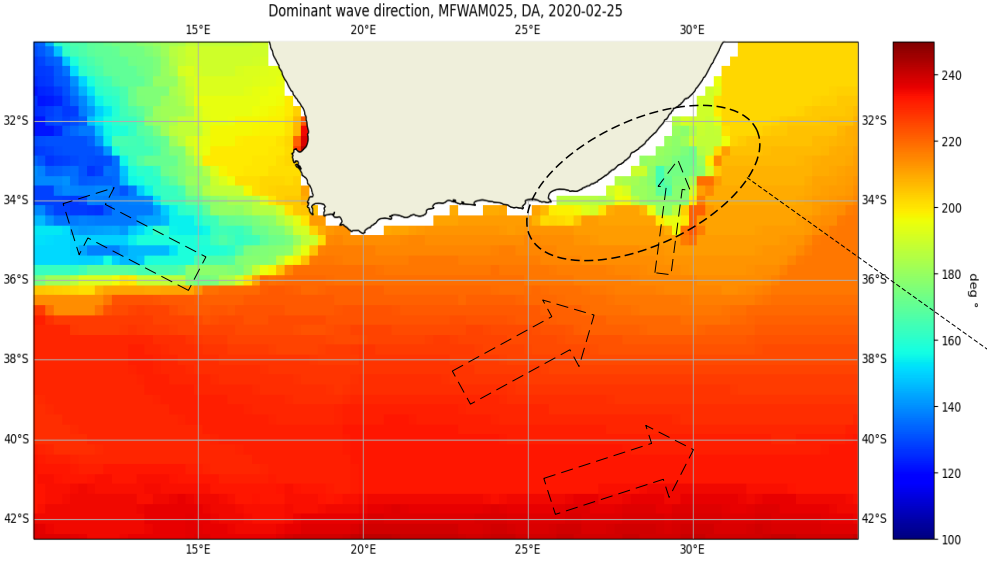
Mean difference of Tp w/wo DA of SWIM



Blue color indicates overestimation of Tp near the storm location and the northern part of the agulhas current

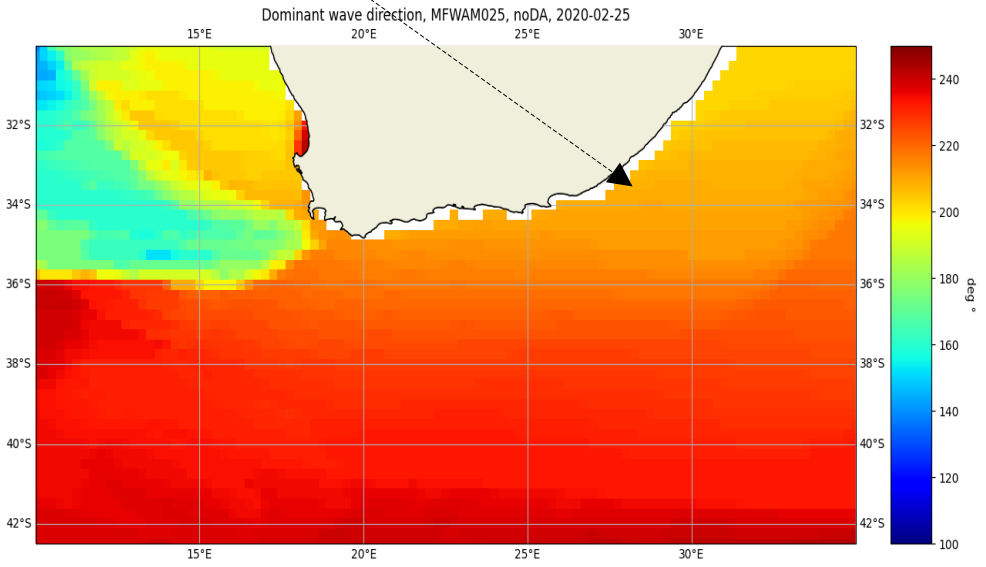
Average of dominant wave direction from 25 to 26 Feb. 2020

Dominant wave direction with DA



Significant directional impact in the area affected by the Agulhas current

Dominant wave direction No DA

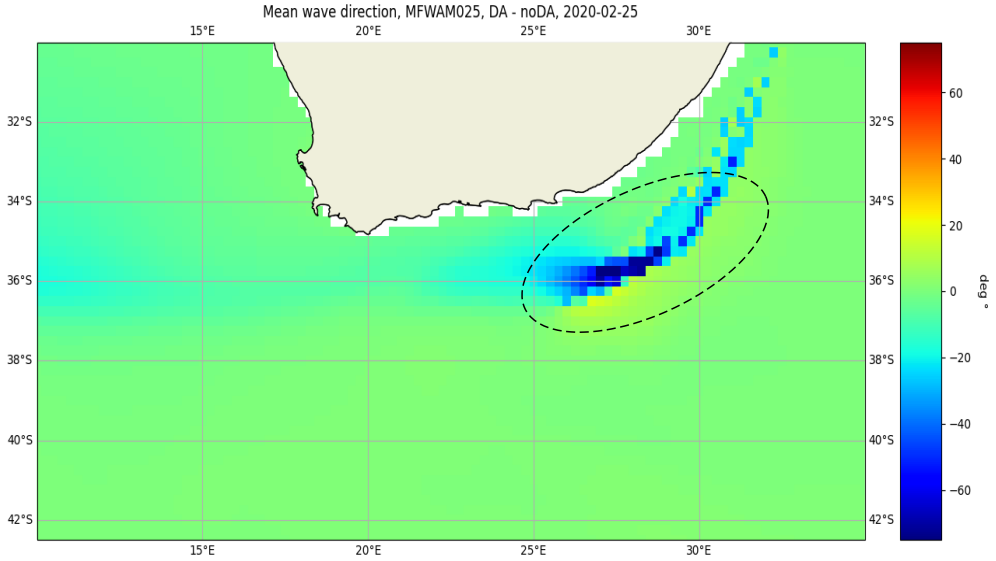


0° is north and direction from convention

Impact of DA on wave directionality during the event

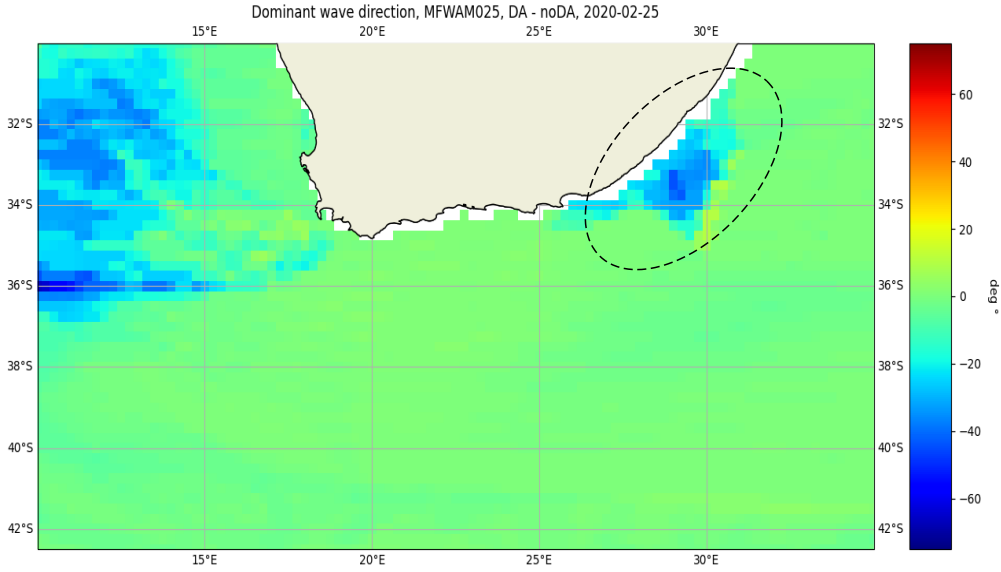
mean wave direction

Mean difference w/wo DA of SWIM from 2020-02-25 00UTC to 2020-02-26 9UTC



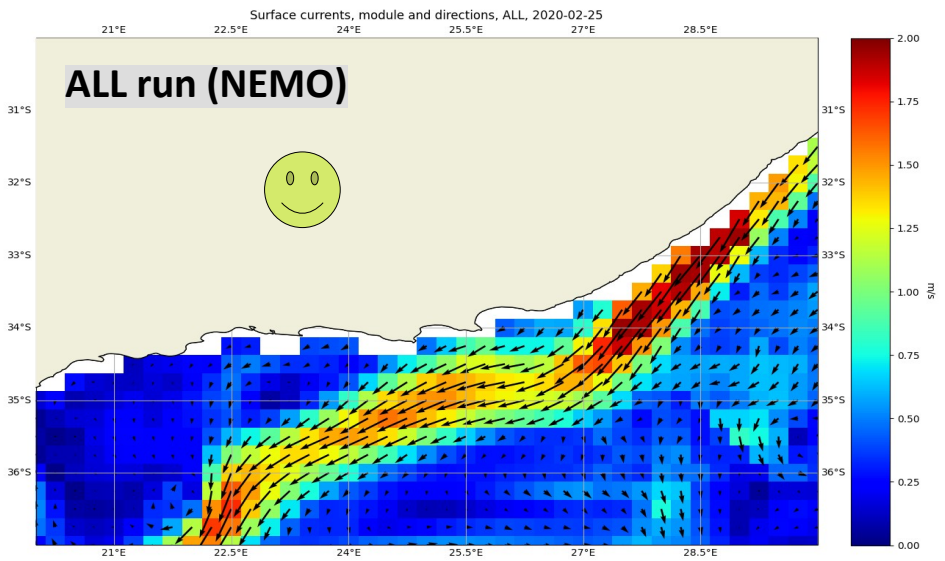
Red and blue colors stand for turning clockwise and anti-clockwise, resp.

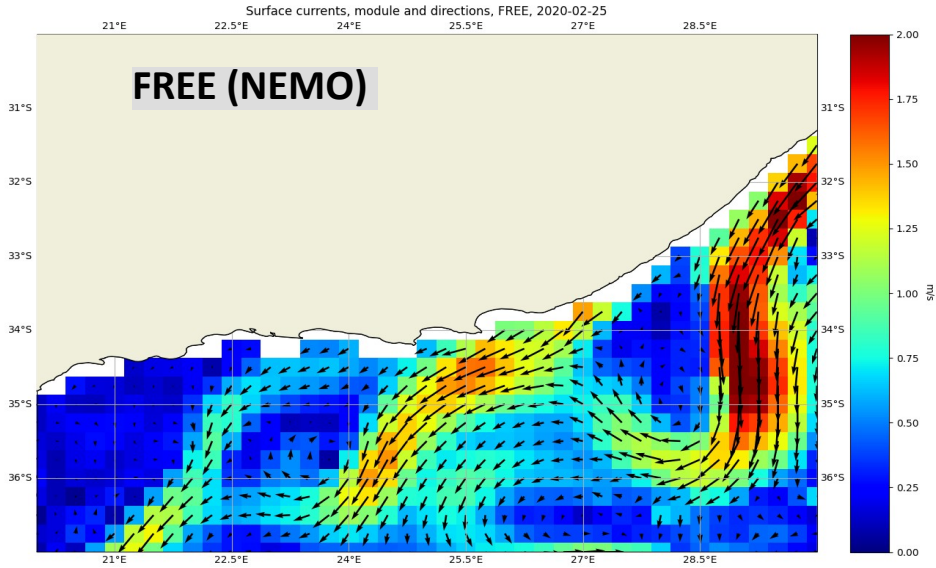
Dominant wave direction



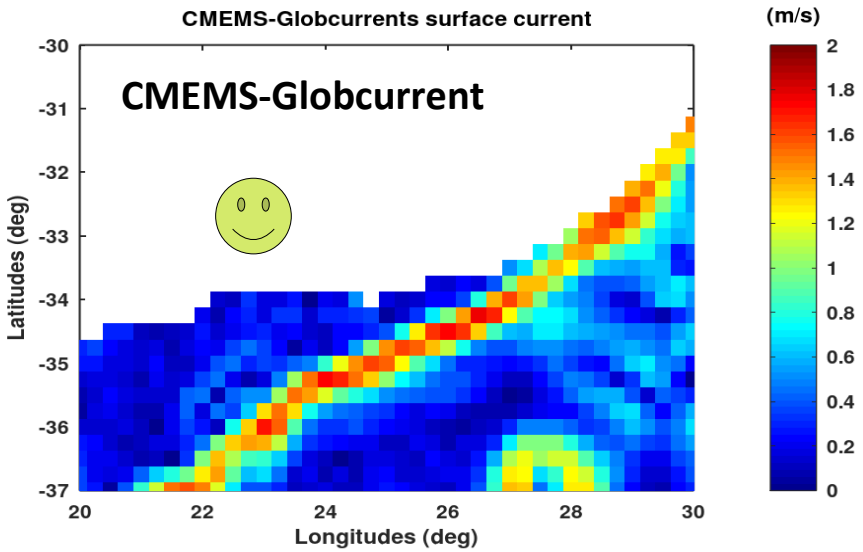
The dashed circles show the significant change in mean and dominant wave Direction in the vicinity of the Agulhas current (Natal bay and off shore)

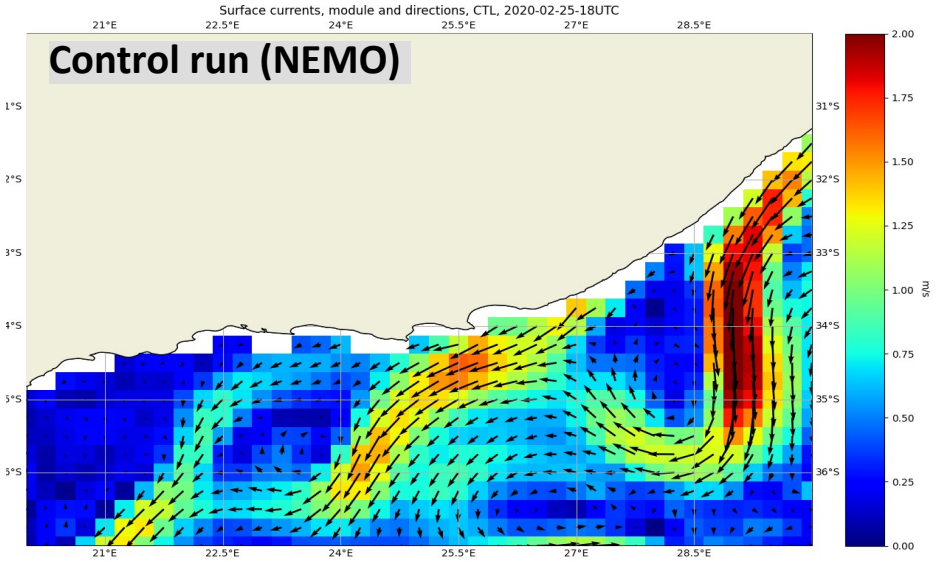
Agulhas surface current intensity and direction : 25 Feruary 2020 at 18UTC





Improved sea state by DA induces a more consistent trajectory of the Agulhas current

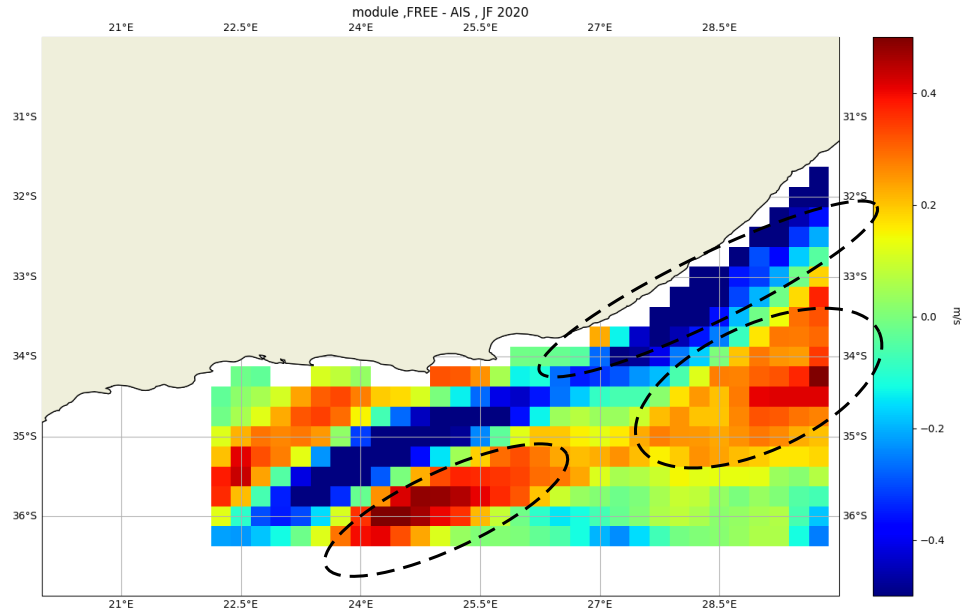




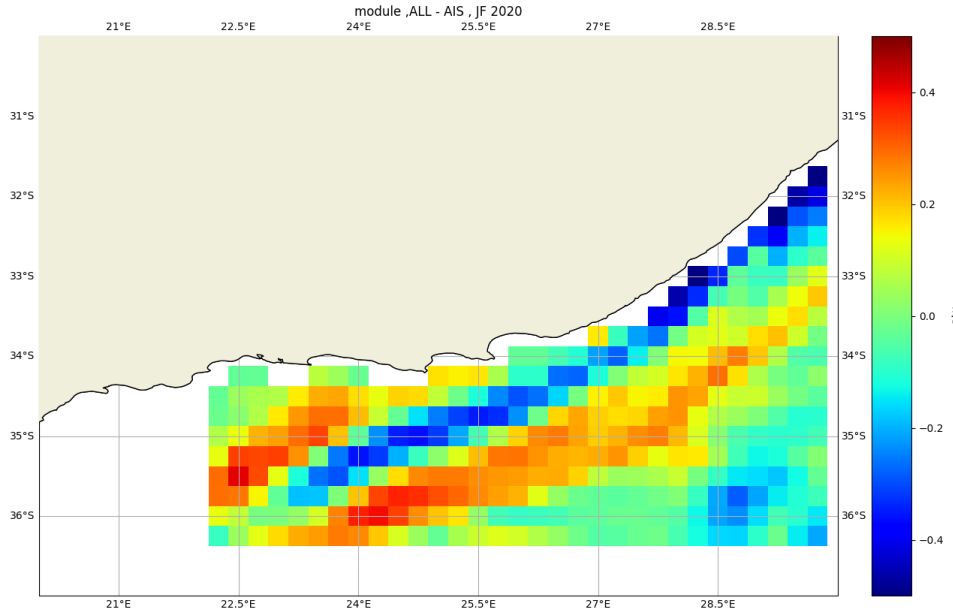
Validation of NEMO simulations with AIS surface currents data (Le Goff et al. 2021) 24-26 February 2020

Bias maps of current intensity (in m/s)

Free – AIS obs



ALL – AIS obs



bias : 0.24 m/s

bias : 0.15m/s

Coupled simulation with SWIM DA reduces significantly the surface current bias

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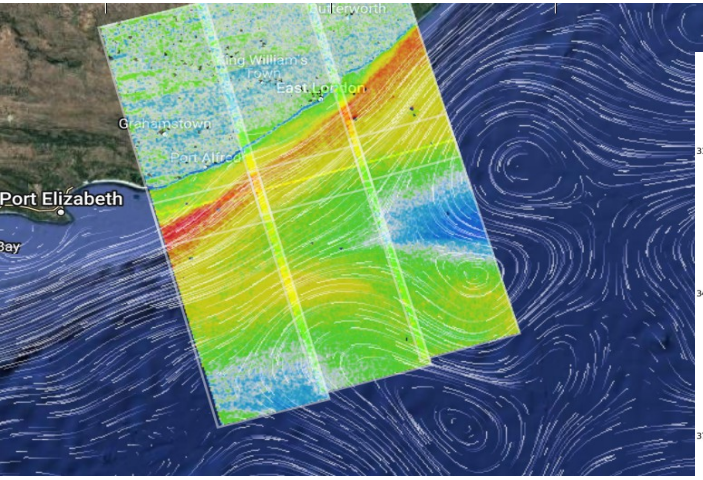
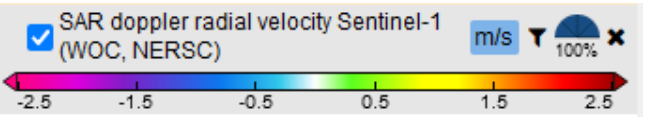
Validation ocean model runs : Zonal surface current component : 25 Feb. 2020 18UTC

Sentinel-1A

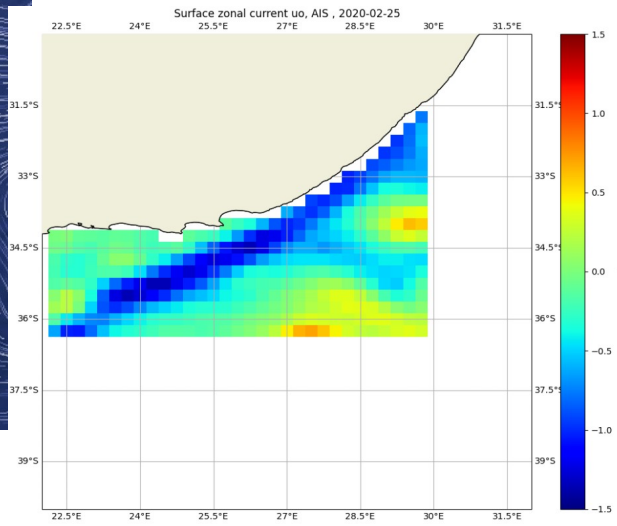




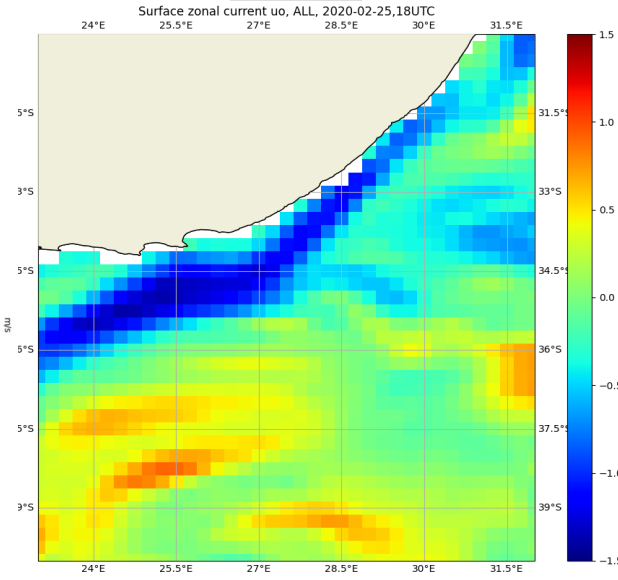
SAR Radial surface velocity

Good consistency between ALL coupled run and AIS and RVL from SAR

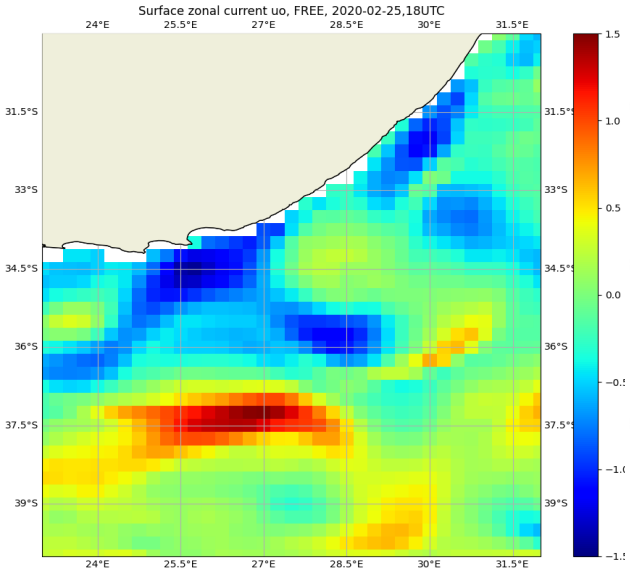
AIS observations



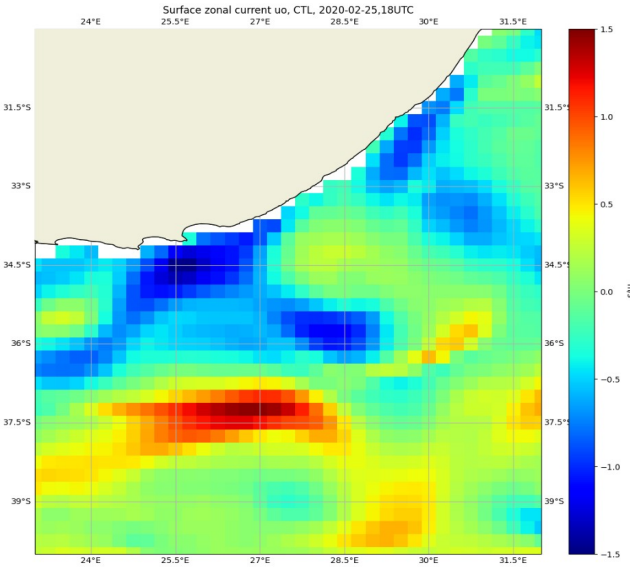
ALL run



FREE run



Control run

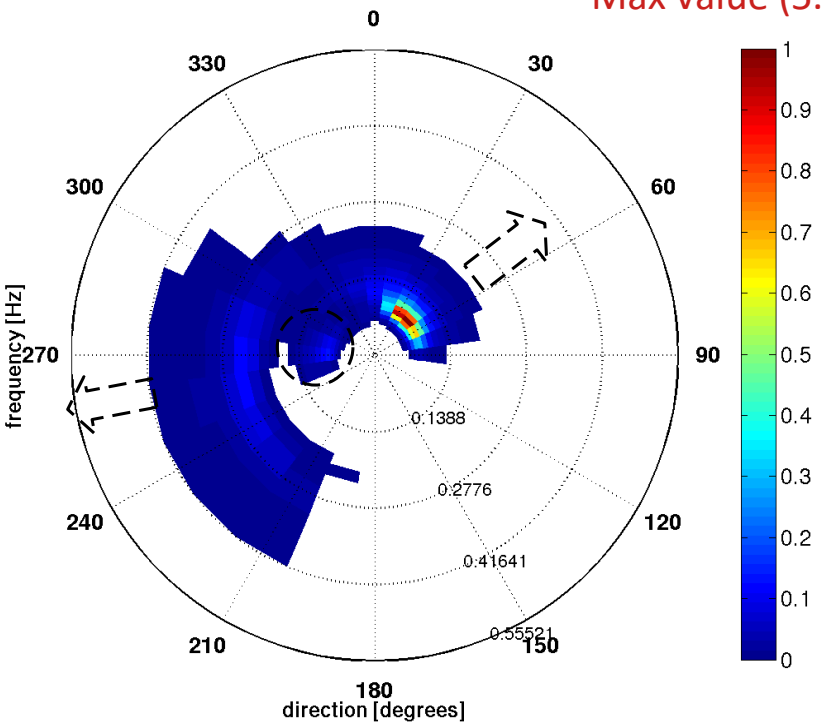


The misfit in the agulhas current is result of bad directional description of wave Systems

Location lon:27.1°E-lat:34°S

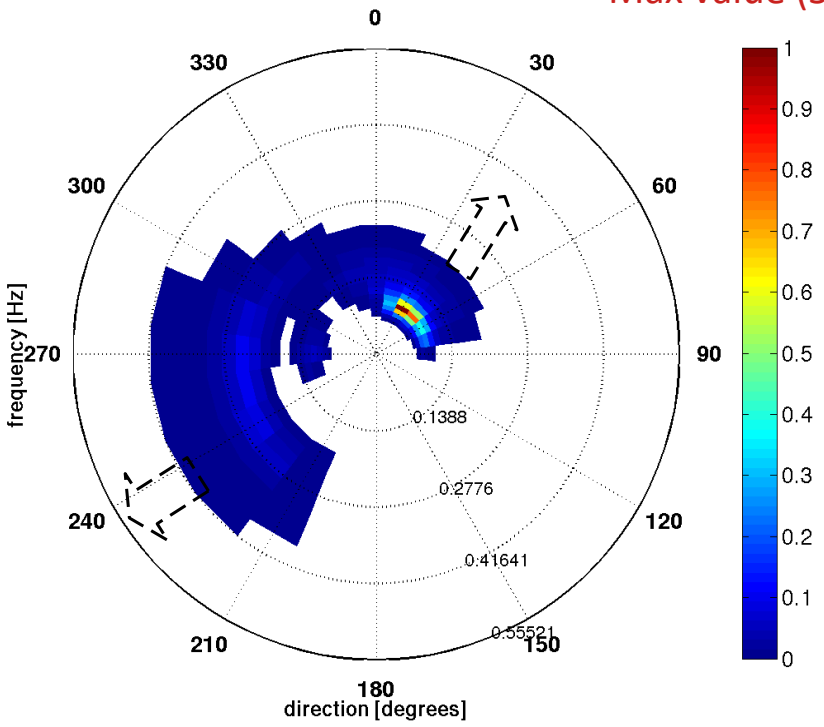
With DA of SWIM

Max value (5.38)



Without DA

Normalized Energy with Max value (5.81)



- Northwestward dominant swell : increase of peak energy for low frequency after DA
- Eastward wind-wave with increase of energy
- Eastward young secondary swell with increased energy after DA
- Dominant swell is aligned with wind axis

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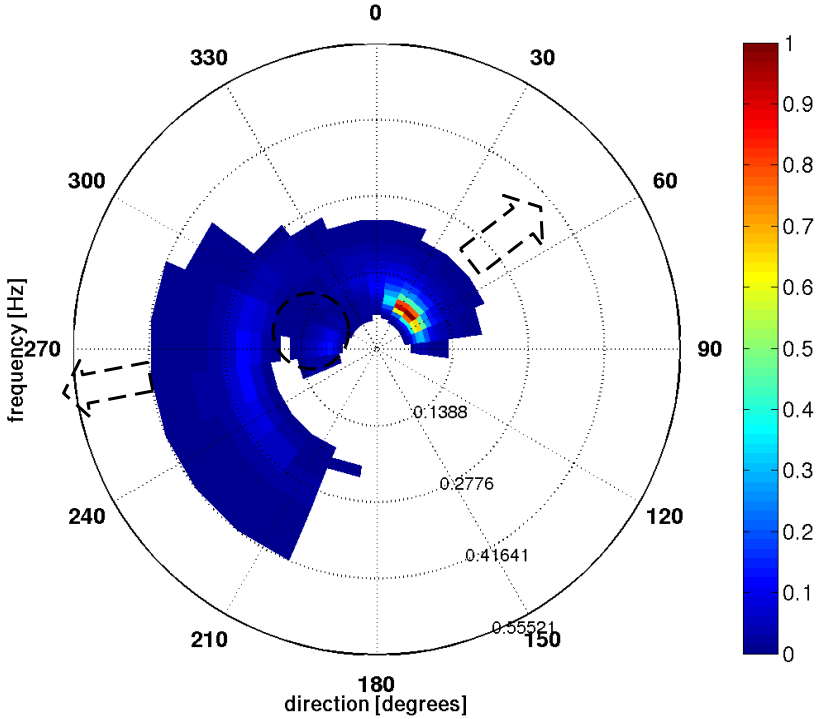
The misfit in the agulhas current is result of bad directional description of wave Systems

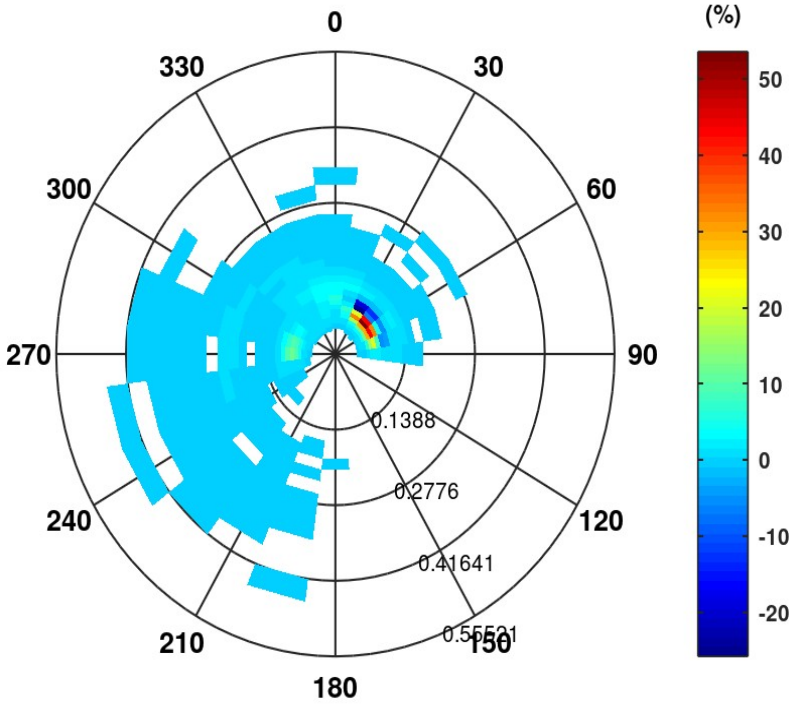
Location lon:27.1°E-lat:34°S

With DA of SWIM

Max value (5.38)



Difference w/wo DA

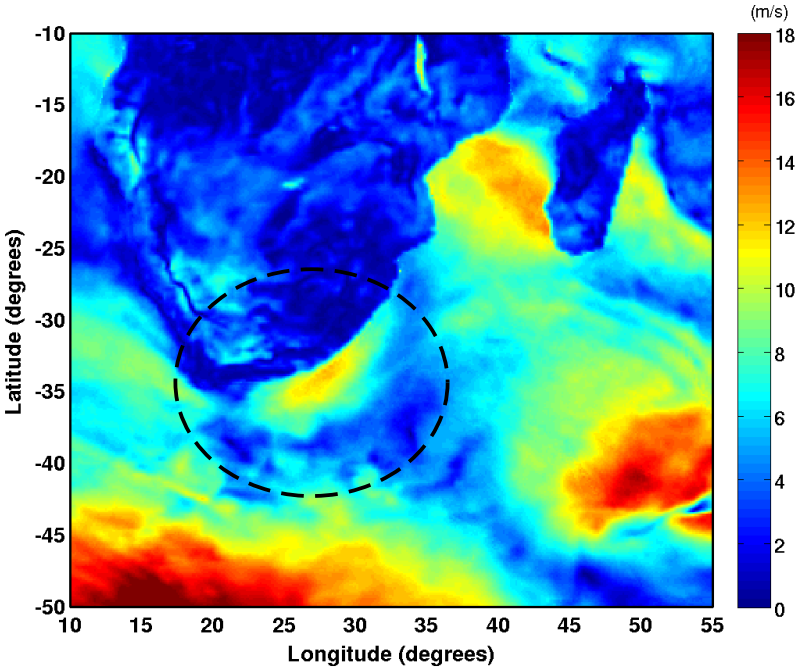


The polar plot of difference of spectra w/wo DA indicates an increase of 50 % of the Energy of dominant swell, and an increase by 24 % of the secondary swell in The same direction of wind-wave component

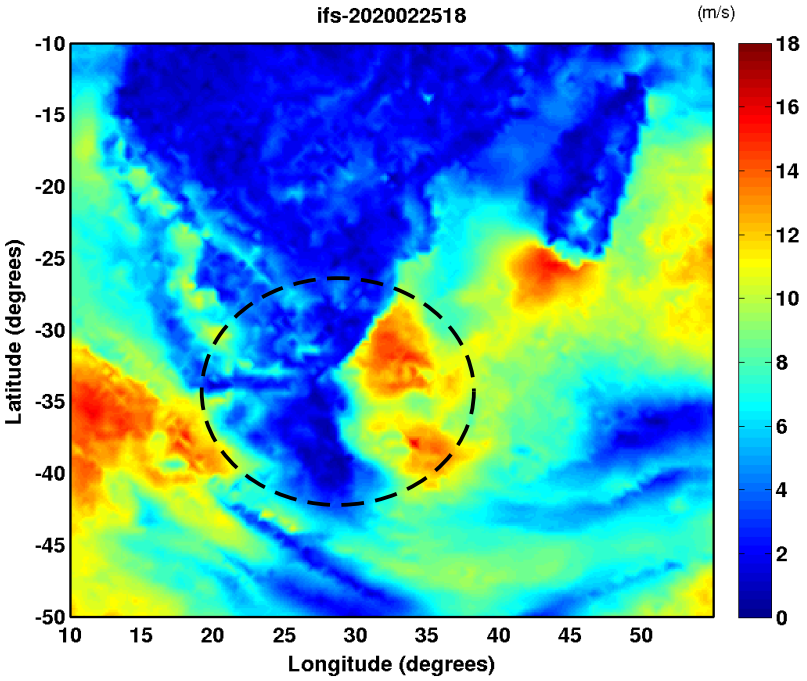
Wind forcing uncertainties in Agulhas region : 25 feb. 2020 18UTC

Wind speed

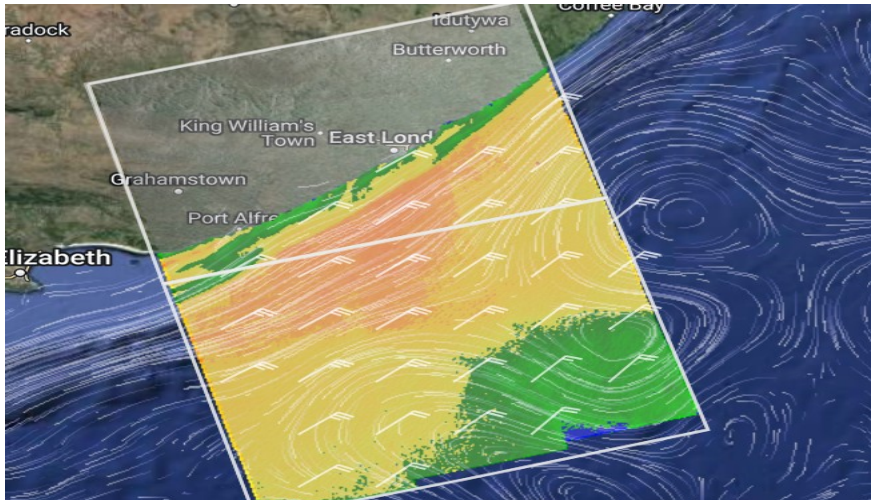
L4 scatterometers (CMEMS)



IFS-ECMWF



High resolution winds
From SAR of Sentinel-1A :
Rapid increase of the wind
Barbs show wind direction



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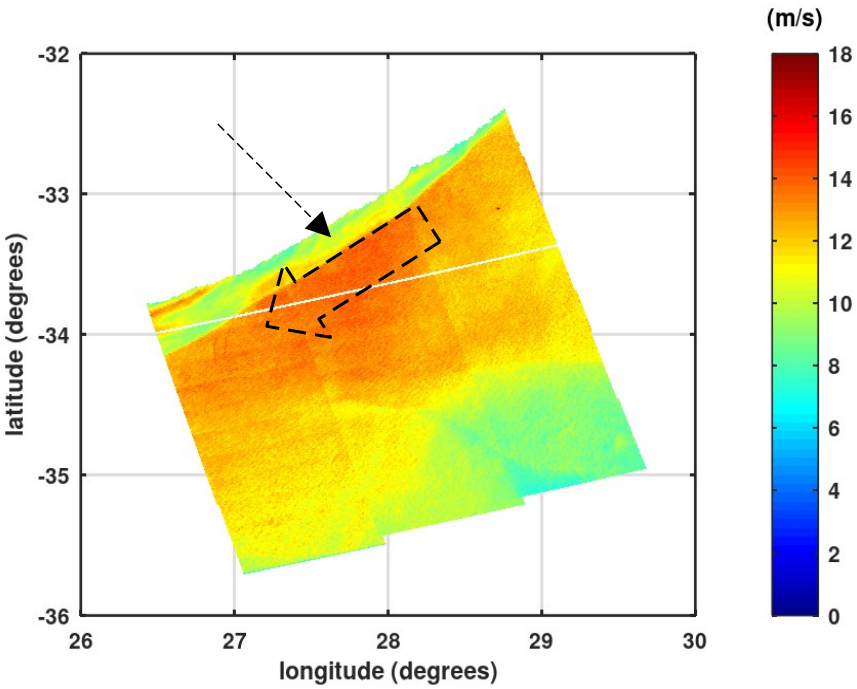
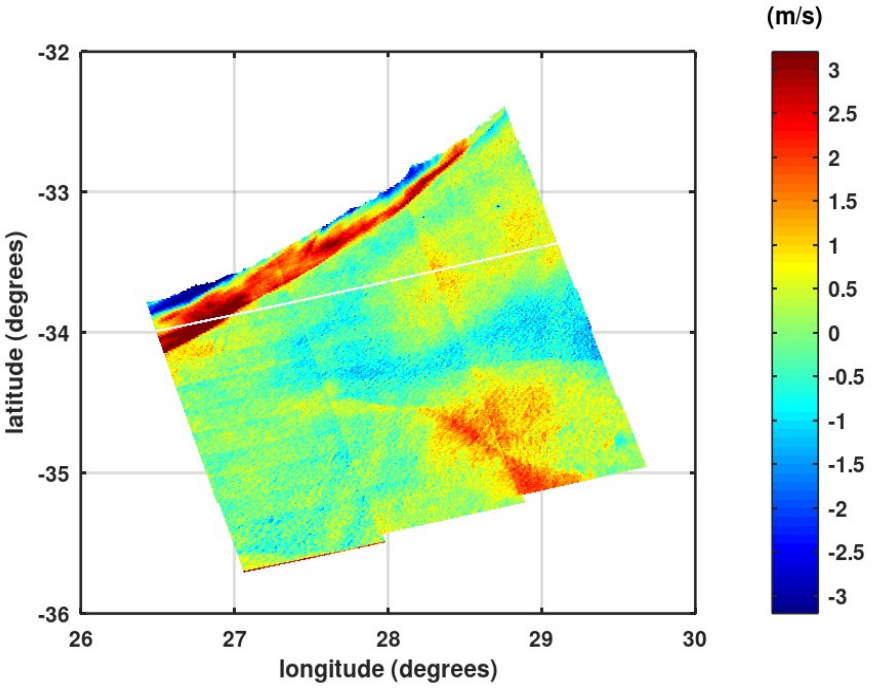
investigation with SAR winds from Sentinel-1 (image 25 Feb. 2020 at 16h53UTC)

High resolution wind speed from SAR



Difference with IFS wind



Intensification of wind speed at the Bank off-shore port Elizabeth

Red and blue colors shows overestimation and underestimatio Of wind speed, resp.

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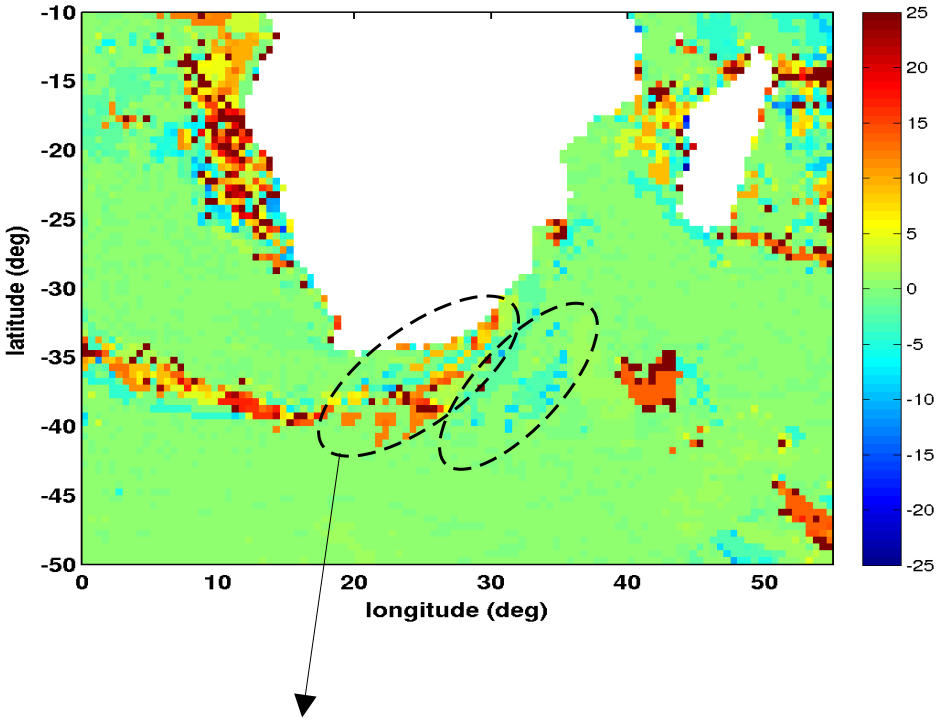
Impact of DA on surface stress during the event (24-26 Feb. 2020)

Average difference of stress w/wo DA

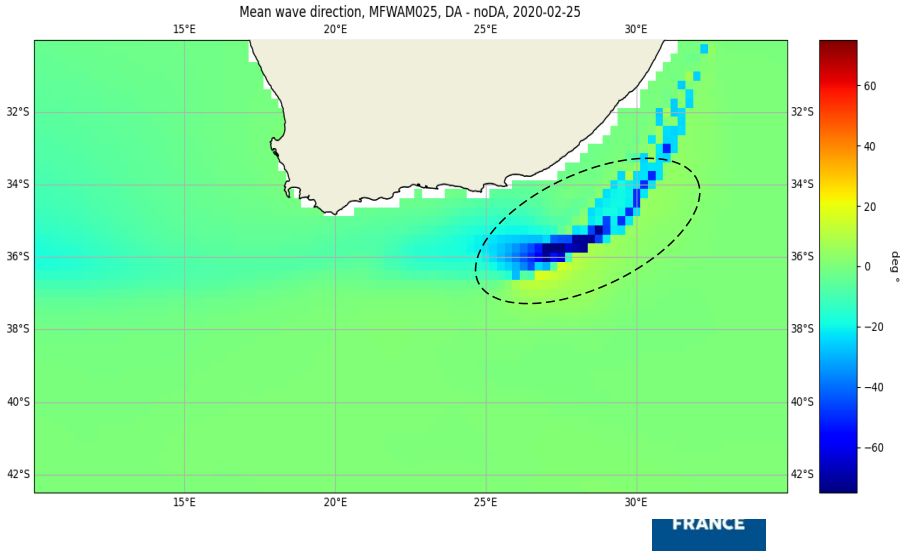


$$\tau_x = \rho C_D U |U|$$
$$\tau_y = \rho C_D V |V|$$

Impact of DA on wind stress is correlated to impact on mean wave directions

The dashed circles is correlated with uncertainties related to wind forcing : DA of SWIM is compensating the wind forcing misfit

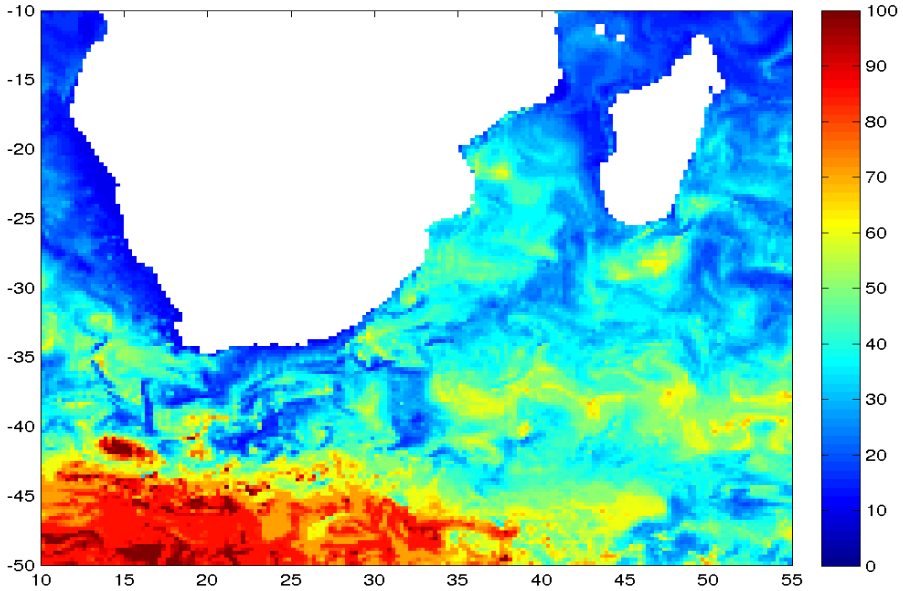
Mean wave direction w/wo DA

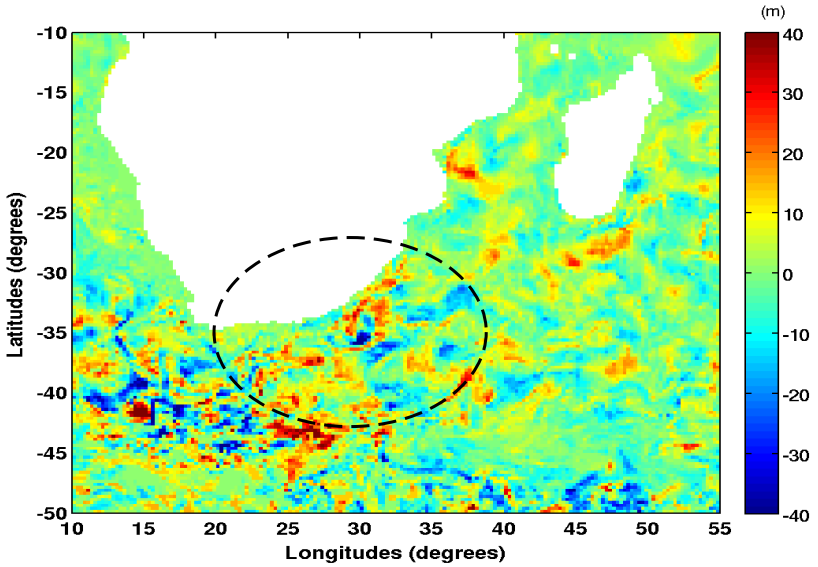


Impact on ocean mixed layer 24-26 February 2020

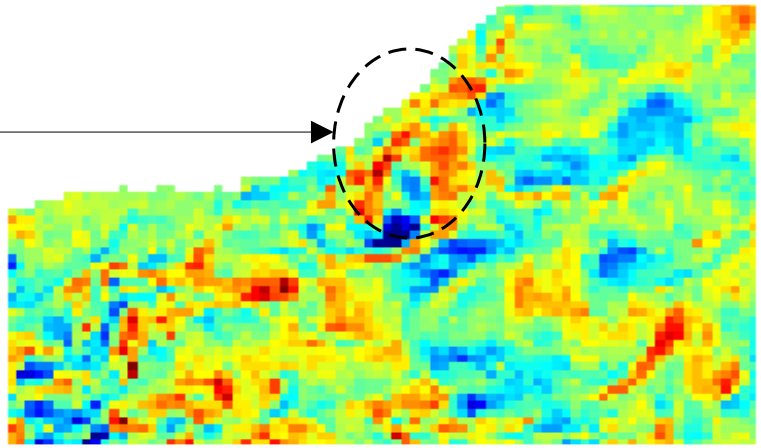
average difference MLD ALL-Free

Average ocean mixed layer depth (MLD) from run ALL





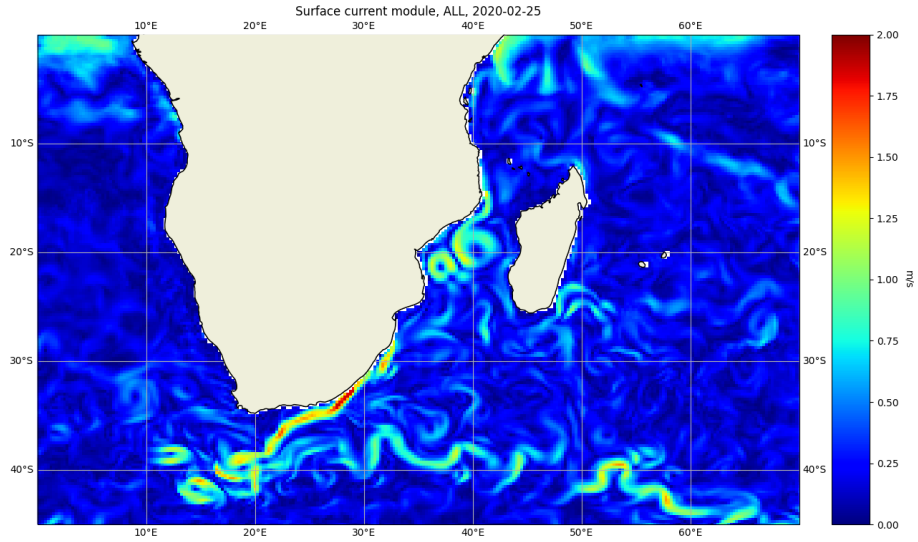
Zoom of difference MLD ALL – Free



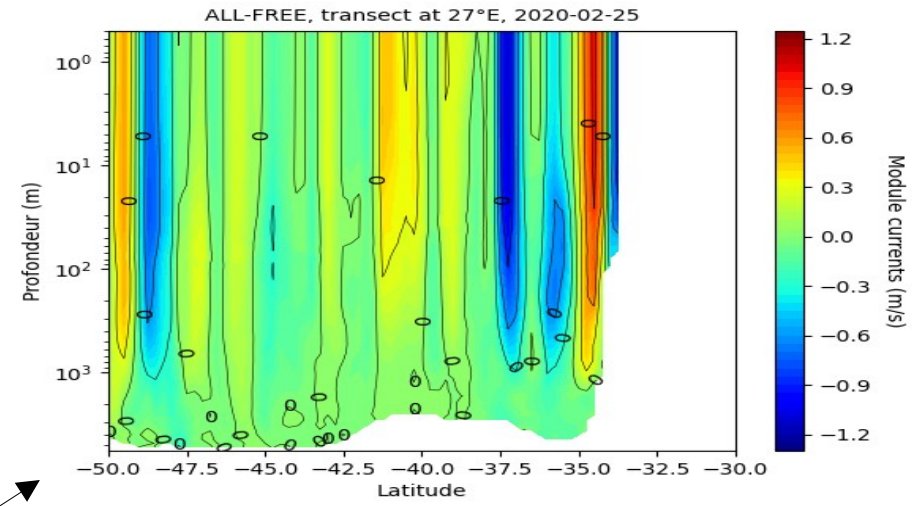
Improved waves deepens significantly MLD by ~40 %

Impact of SWIM DA in Agulhas Current - Surface currents : 25 feb. 2020

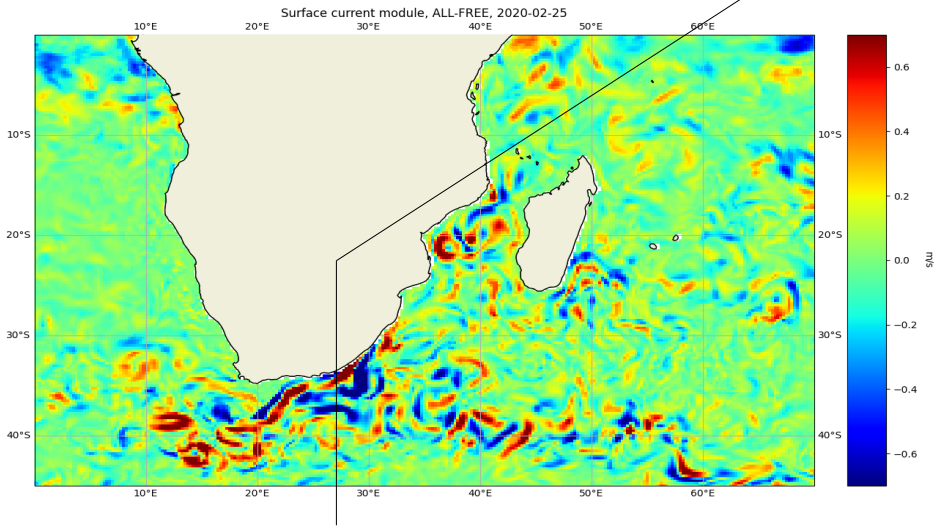
Surface current module
ALL



Transect current module at 27°E
ALL-FREE



Surface current module
ALL - FREE



Improved sea state from ALL induces a deep correction of the agulhas current (300-400 m)

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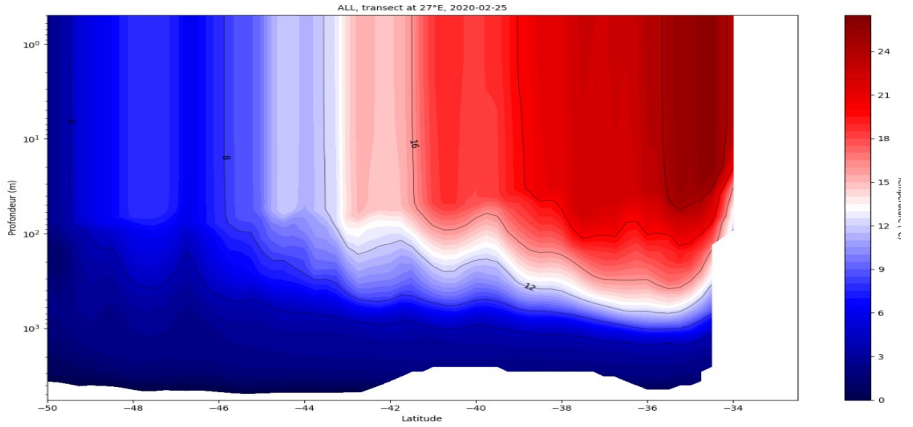
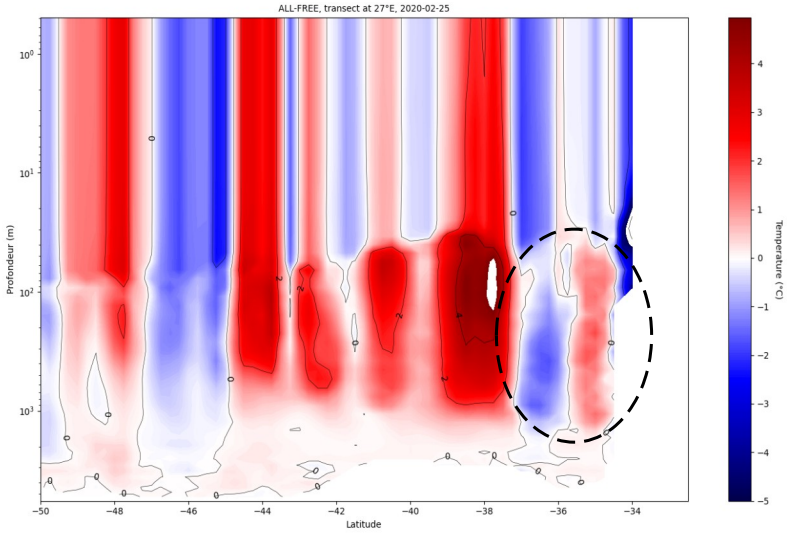
Impact of improved wave forcing by DA in Agulhas Current - Ocean Temperature

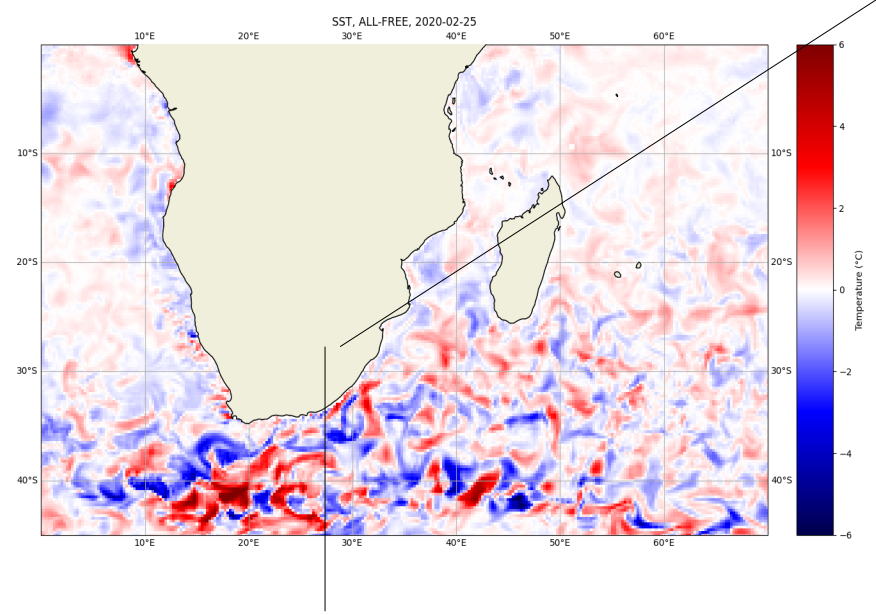
SST : ALL



Transect at 27°E theao : ALL - FREE



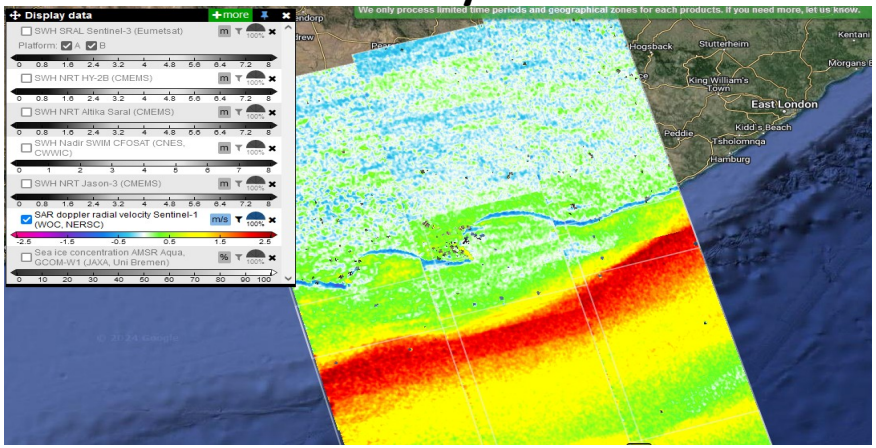
SST ALL- FREE



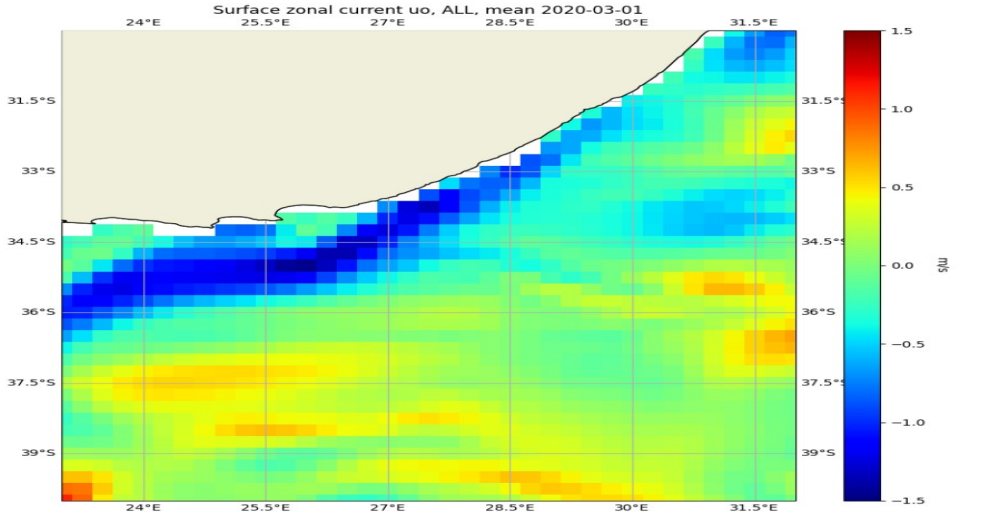
- Cooling of ocean temperature in blue induced by improved waves
- Waves induce a significant dipole variation ocean temperature in deep water (~300m)
- Significant impact on MLD in the first 300-400 meters below the surface

Imporved sea state by DA of SWIM induced a nudging on upper ocean Circulation : 1 March 2020

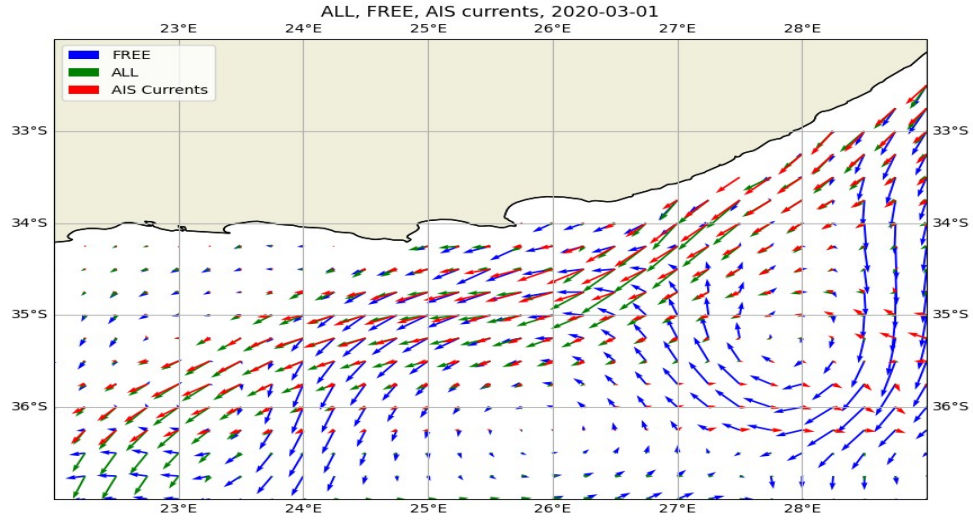
Radial surface velocity SAR Sentinel-1



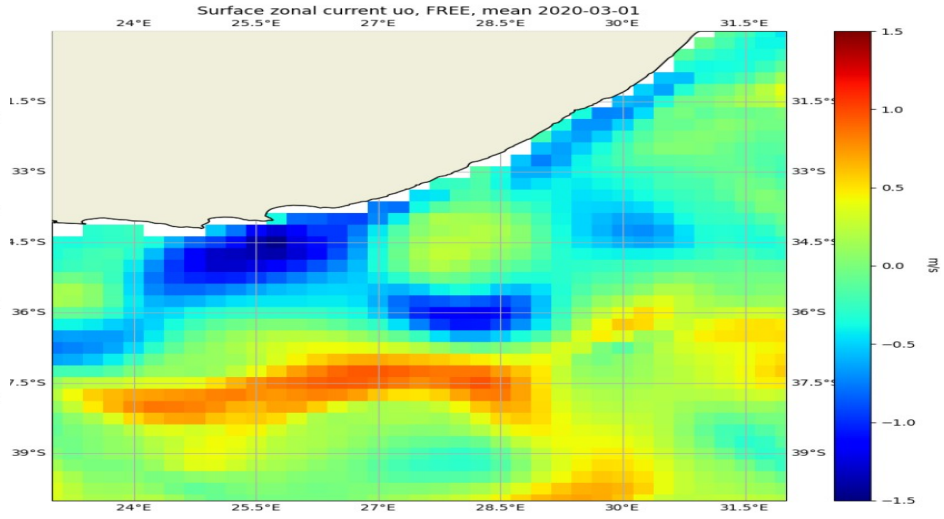
Zonal surface current : ALL run



Surface current from ALL agrees well with AIS and SAR (red and green arrows)

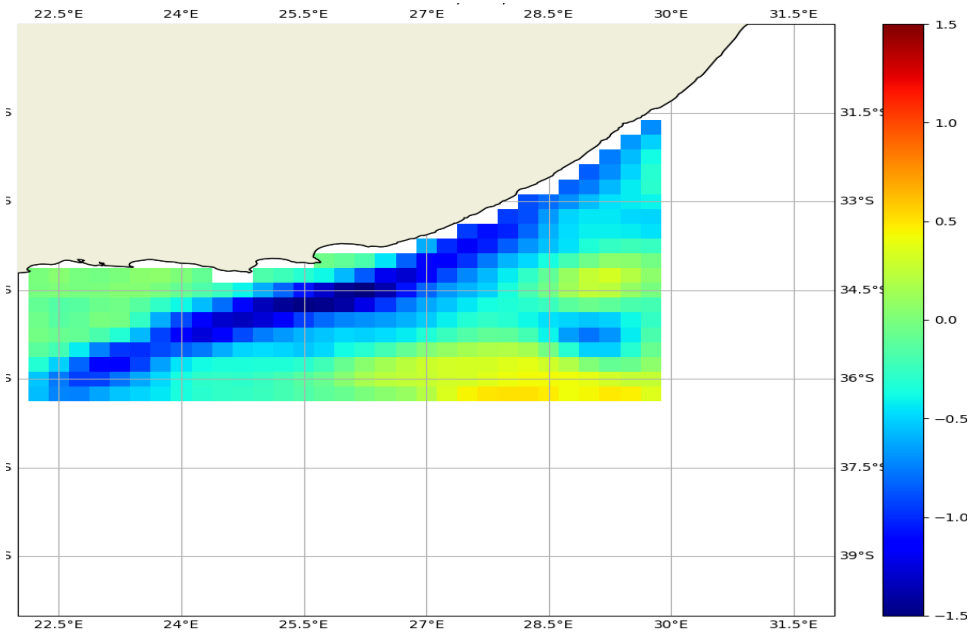


Zonal surface current : Free run

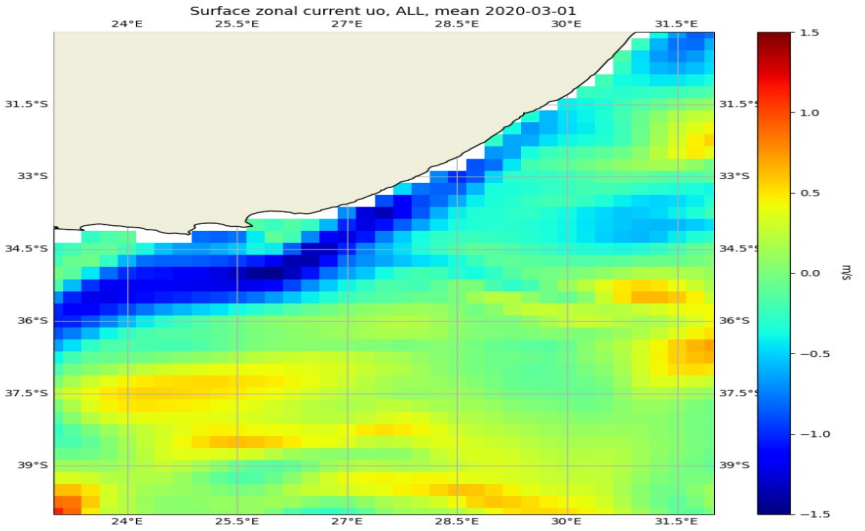


Improved sea state by DA of SWIM induced a nudging on upper ocean Circulation : 1 March 2020

AIS Zonal surface current



Zonal surface current : ALL run



Good consistency of ALL coupled run with AIS observed Agulhas current.

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Key messages

- ➔ Improvement of waves in frequency and directional scales induces a significant improvement of Agulhas surface current trajectory and intensity
- ➔ Improved sea state by DA of SWIM acts like a nudging for upper ocean circulation in the Agulhas ocean region and shows a good consistency with surface current observations from SAR and AIS
- ➔ The wave directionality plays a key role for enhancement of the surface stress in the Agulhas region. This compensate the uncertainties related to wind forcing.
- ➔ Longer coupled runs are ongoing with coverage of full mission CFOSAT (2019-until now)

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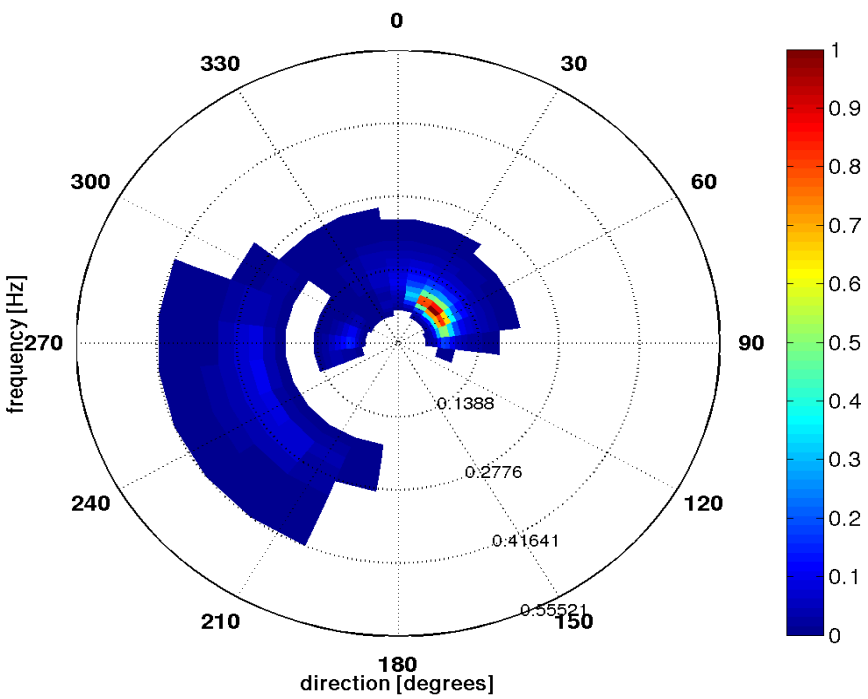
*A letter is under preparation GRL

The misfit in the agulhas current is result of bad directional description of wave Systems

Location lon:26.85°E-lat:35°S

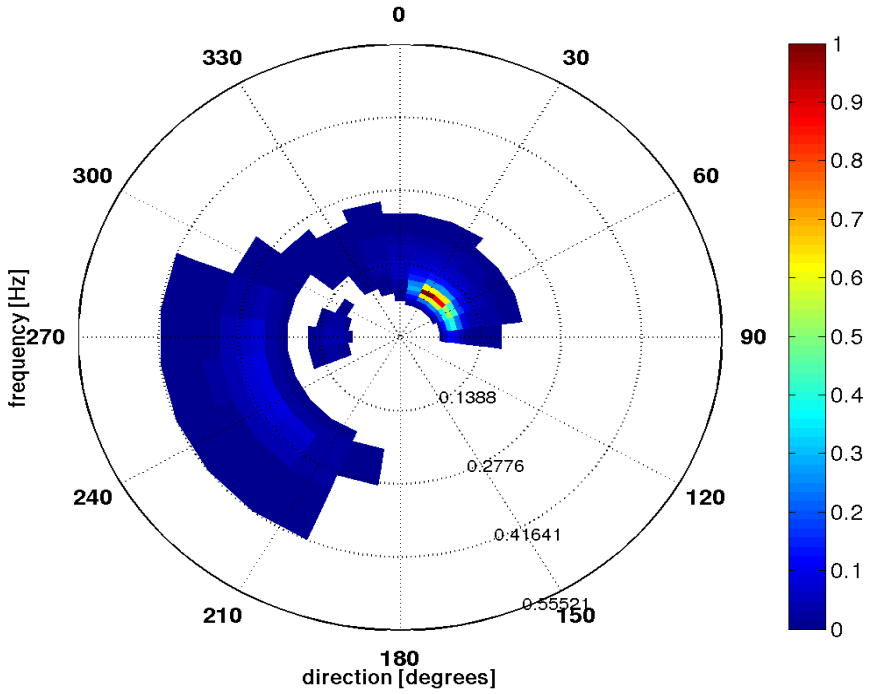
With DA of SWIM

Max value (5.41)



Without DA

Normalized Energy with Max value (5.73)



The assimilation enhances the secondary young swell propagating to the west which is close To the wind-wave component (West-South-West)

Very interesting increase of frequency spreading for the dominant swell induced by DA

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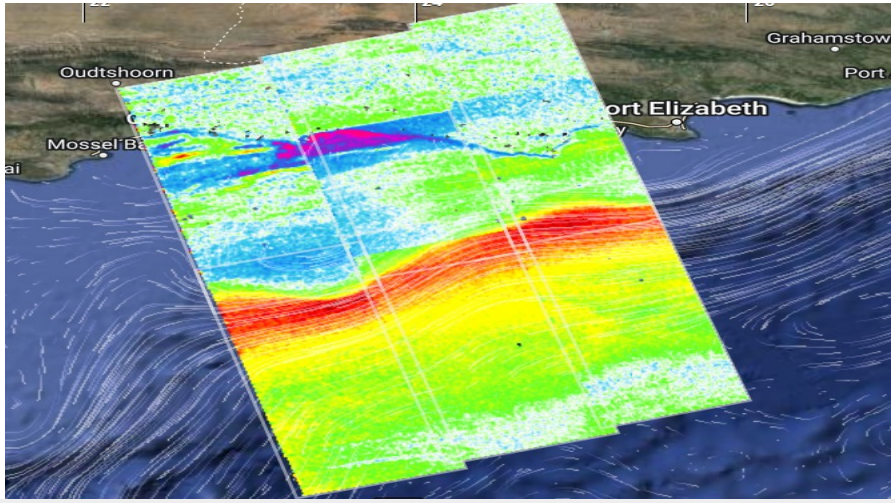
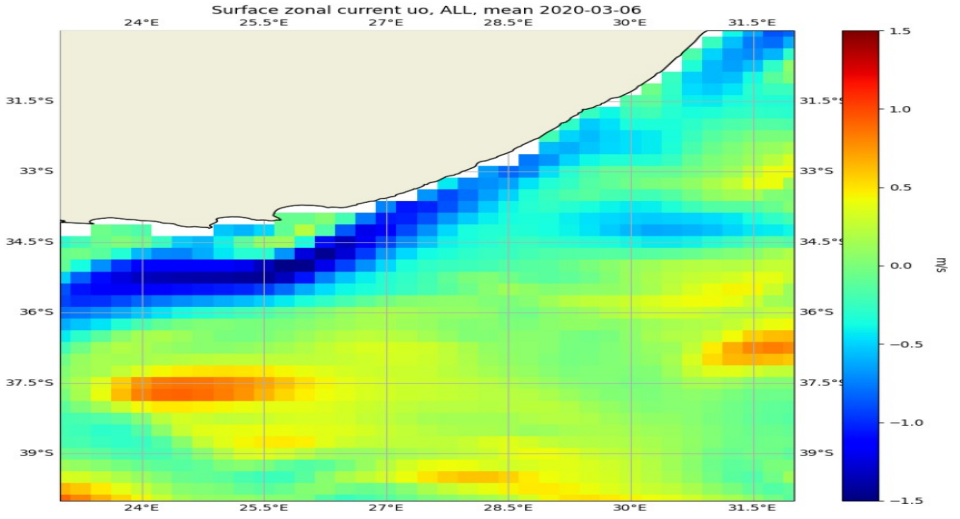
Imporved sea state by DA of SWIM induced a nudging on upper ocean Circulation : 6 March 2020

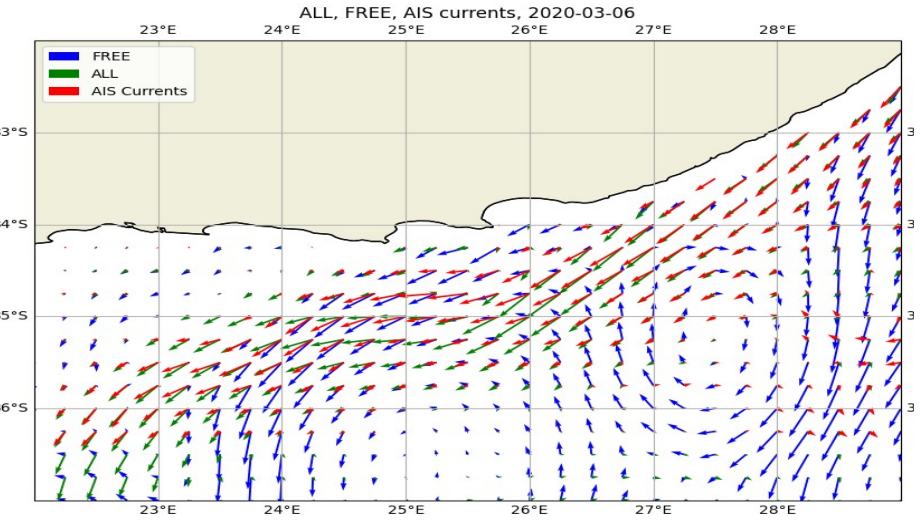
Radial surface velocity SAR Sentinel-1



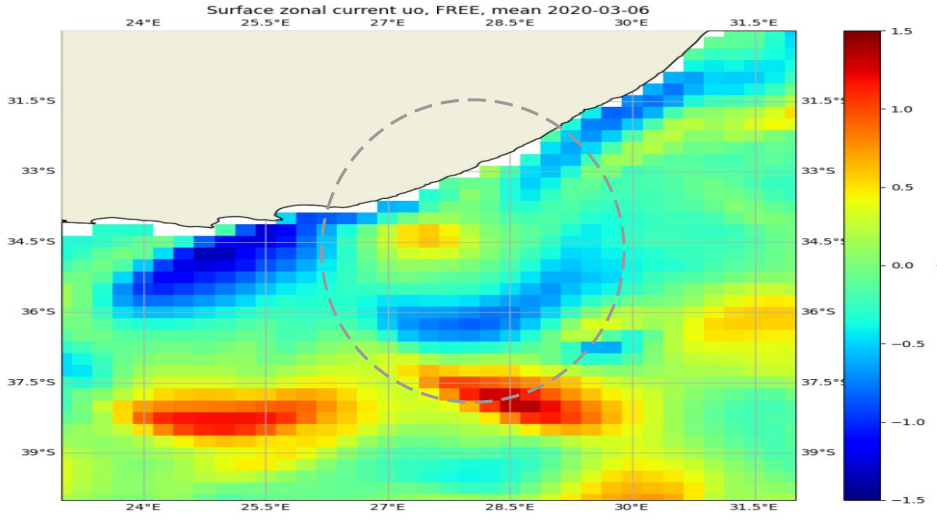
Zonal surface current : ALL run



Surface current from ALL agrees well with AIS and SAR (red and green arrows)

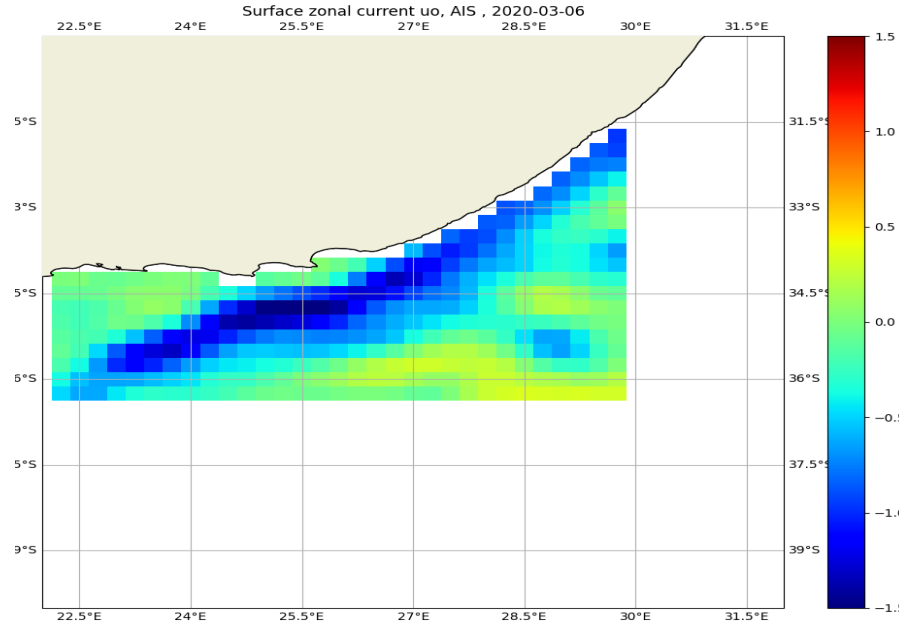


Zonal surface current : Free run



Imporved sea state by DA of SWIM induced a nudging on upper ocean Circulation : 6 March 2020

AIS Zonal surface current



Zonal surface current : ALL run