Comparison of wave spectra in the Agulhas current system using spectral wave models and SAR

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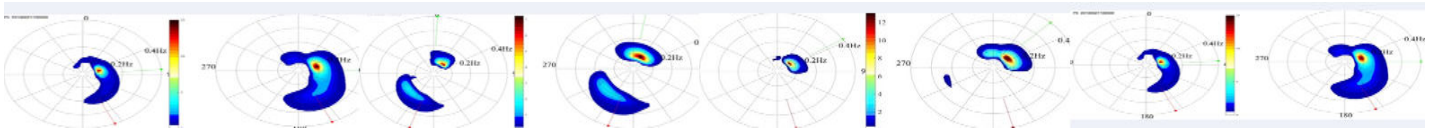
Introduction

• The effect of the Agulhas current on waves deserves attention for several reasons related not only with the science itself, but also with industry (maritime activity and ship routing).

• The Agulhas current plays a key role in the global interchange of water masses (Lutjeharms 1981). Moreover, the Agulhas Current system has been described as one of the strongest western boundary currents (up to 2 m/s) in the world's oceans (Johannessen et al., 2008).

Some of the studies performed in the Agulhas region are listed below:

Marechal and Ardhuin (2021), Barnes and Rautenbach (2020), Aouf et al. (2019), Quilfen et al., 2018, Krug et al., 2017, Ardhuin et al., (2017), Johannessen et al. (2016), Rouault et al. (2010), among many other authors.



Objectives

Analyze the sensitivity of two spectral wave models to the ocean current data.

Study the influence of the Agulhas current on the wave spectral shape using high resolution simulations and SAR observations.

Data & Methods

$$\frac{\partial F}{\partial t} + (\boldsymbol{C_g} + \boldsymbol{U}) \cdot \nabla F = S_{tot}$$

Energy Balance Equation

F-wave spectrum, *t*-time, C_g-velocity group, S_{tot}-source function

Spectral wave models

WAM (Gunther & Berenhs, 2012), GKSS, Germany

SWAN (Booij et al., 1999; SWAN Team 2019)

Configuration:

# of directional bands: 36, # of frequencies: 38,
Frequency range: 0.03 – 1.0201 Hz.

Boundary conditions:
Era5 reanalysis wave model (ECMWF).

WIND:
Era-5 ECMWF wind reanalysis (Hersbach et al., 2019).

Period of study:

15 June 2018-15 June 2019.
Simulations were performed with and without current.

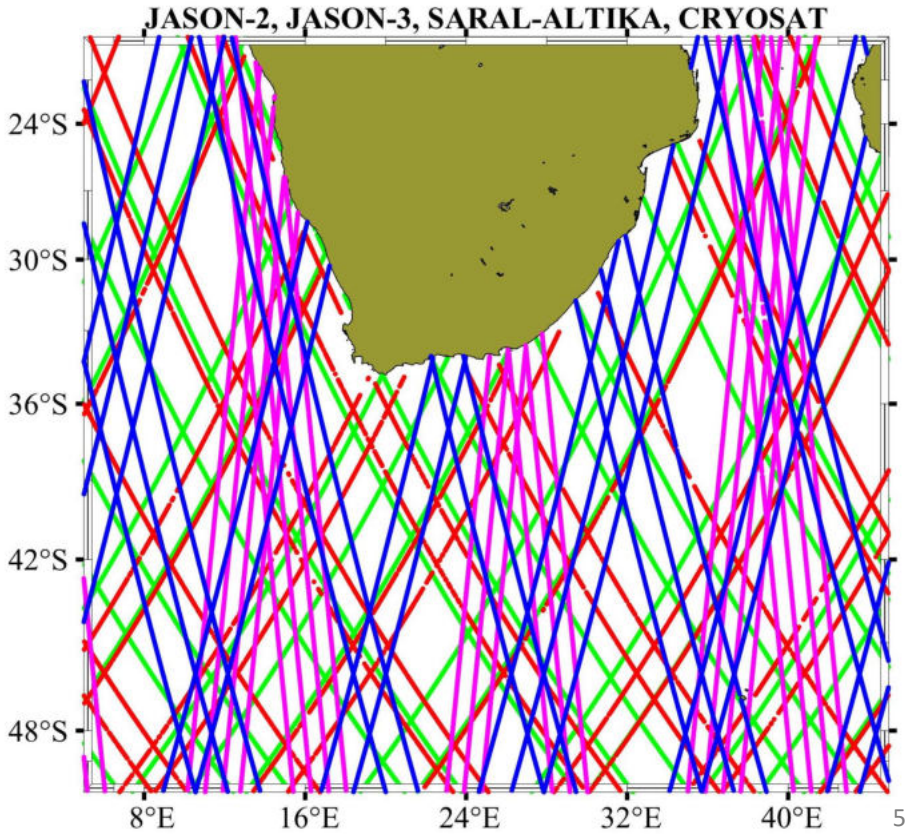
Ocean current data comes from MERCATOR (NEMO model).
https://www.mercator-ocean.fr

Data and Methods

• For the validation of the simulations are used the altimeter multimission **Hs** (*Significant Wave Height*) which is a merged global altimeter Hs data set from the altimeter missions *Jason3, Jason2, Saral-Altika and Cryosat* (produced by AVISO).

Orbit segments of Jason-3 (blue), Jason-2 (red), Saral-Altika (black) and Cryosat (magenta).

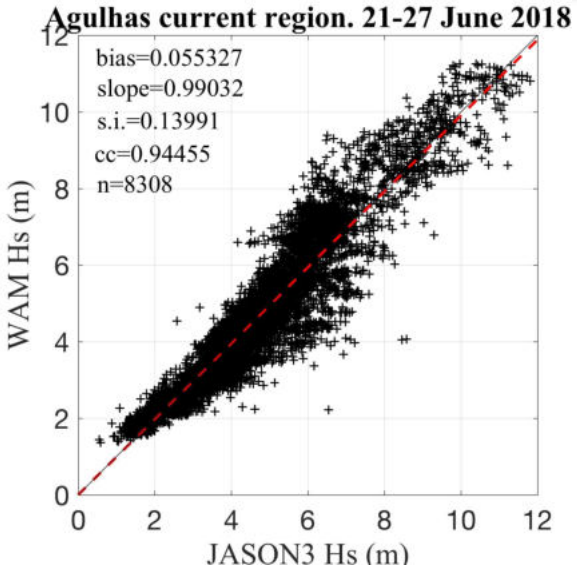
(21-27/June 2018)



Validation of the WAM simulations using satellite altimetry data

- **Table 1**. Statistics for the Hs (21-27/June 2018). S.I.-Scatter Index; RMSE-Root Mean Square error, cc-correlation coefficient. Bias, the best-fit scatter index and slopes between satellite altimeters observations and modelled Hs.

Results from simulations without currents only and considering currents (**LEFT-WAM&Only waves** (**WaOn**); **RIGHT**-WAM&MERCATOR (**WaMer**)).



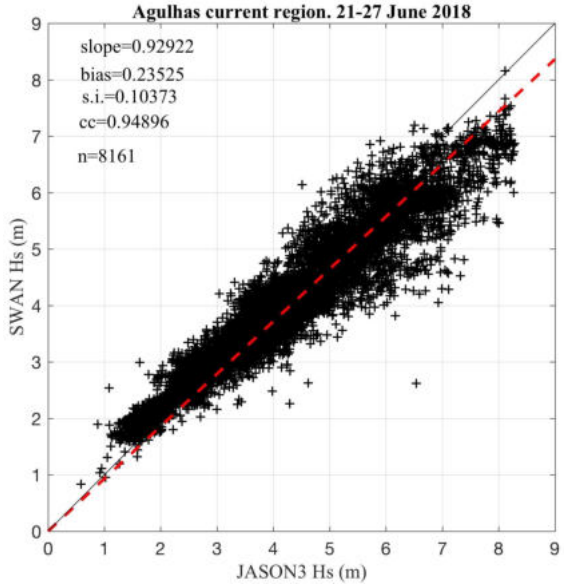
Parameter	Jason-3		Jason-2		Saral-Altika		Cryosat	
simulation	WaOn	WaMer	WaOn	WaMer	WaOn	WaMer	WaOn	WaMer
bias	0.0104	0.055	0.1660	0.2103	0.1537	0.1922	0.2432	0.2986
slope	0.9977	0.9903	0.9598	0.9508	0.9604	0.9546	0.9334	0.9240
S.I.	0.1475	0.1399	0.1387	0.1221	0.1450	0.1341	0.1463	0.1346
RMSE	**0.6583**	0.6232	**0.6643**	**0.6286**	**0.7079**	**0.6813**	**0.7146**	**0.6941**
cc	0.9379	0.9445	0.9206	0.9379	0.9281	0.9383	0.8991	0.9140

The best slope corresponded to Jason-3. Although the systematic deviation (bias) seems to be similar for both simulations. The absolute errors, as measured by the RMS error is lower for the simulation considering currents which also improves the Scatter Indexes and the correlation coefficients.

Validation of the SWAN simulations using satellite altimetry data

- **Table 1**. Statistics for the Hs (21-27 June 2018). S.I.-Scatter Index; RMSE-Root Mean Square error, cc-correlation coefficient. Bias, the best-fit scatter index and slopes between satellite altimeters observations and modelled Hs.

Results from simulations without currents only and considering currents (**LEFT**-SWAN&Only waves (**SWAOn**); **RIGHT**-SWAN&MERCATOR (**SWAMer**)).



Parameter	Jason-3		Jason-2		Saral-Altika		Cryosat	
simulation	SWAOn	SWAMer	SWAOn	SWAMer	SWAOn	SWAMer	SWAOn	SWAMer
bias	-0.7890	0.2352	-0.6128	0.4318	-0.686	0.29076	-0.6367	0.25685
slope	1.1586	0.9292	1.1167	0.8885	1.1337	0.91695	1.1319	0.92829
S.I.	0.1531	0.1037	0.1341	0.0964	0.1529	0.1109	0.1499	0.0956
RMSE	0.9972	0.5637	0.8232	0.6872	0.9242	0.6294	0.8733	0.5210
cc	0.9257	0.9490	0.9352	0.9486	0.91451	0.9327	0.9175	0.95101

The best bias corresponds to Jason-3 (SWAMer model). The best Scatter Index, CC and RMSE were obtained for Cryosat&SWAMer.

Parameters	SWAN + Current Collocated with Hs from altimeters	WAM + Current Collocated with Hs from altimeters
BIAS	0.235 JASON-3	**0.055 JASON-3**
SI	0.095 CRYOSAT	0.122 JASON-2
RMSE	0.521 CRYOSAT	0.623 JASON-3
Cor.Coef.	0.951 CRYOSAT	0.945 JASON-3

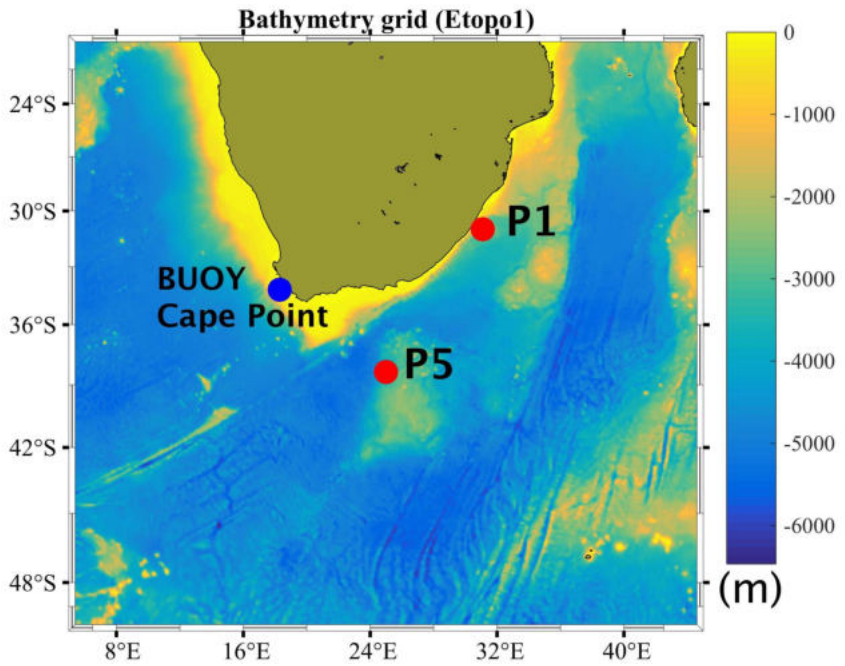
When both models were compared, statistical coefficients show that only BIAS has significant differences.

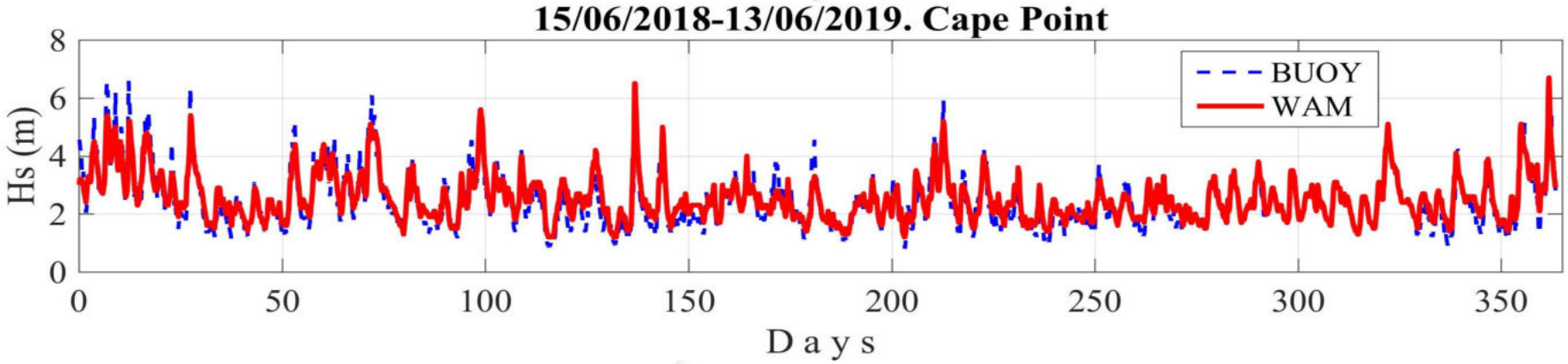
Results

Comparison of the WAM modeled Hs with the Cape Point wave BUOY (blue circle) for 1 year **in the coastal zone (70 m of depth)**.

Red circles-output of the modeled wave spectra.

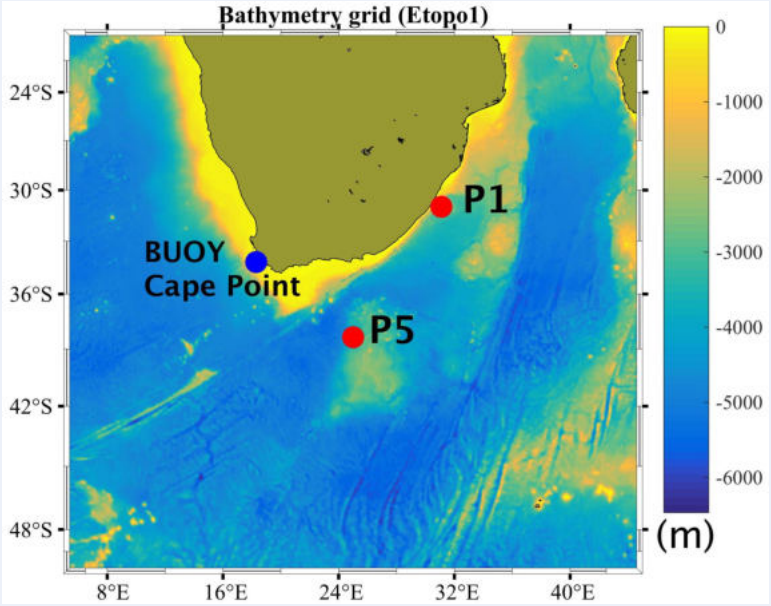
The bathymetry grid data Etopo1 (Amante et al., 2009) comes from the NOAA's National Geophysical Data Centre, with a resolution of 1 min of degree in latitude and longitude, linearly interpolated to the model grid.

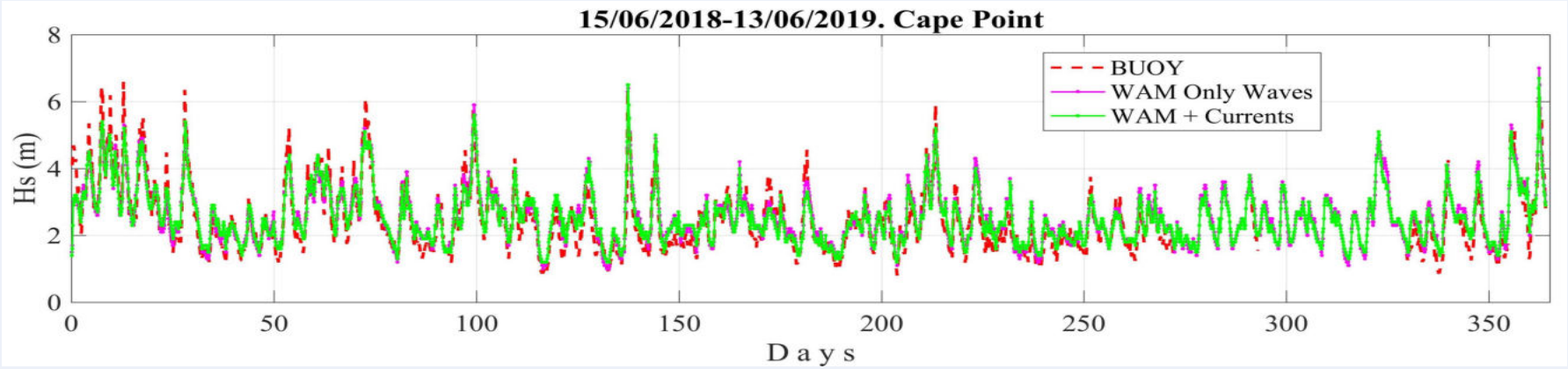




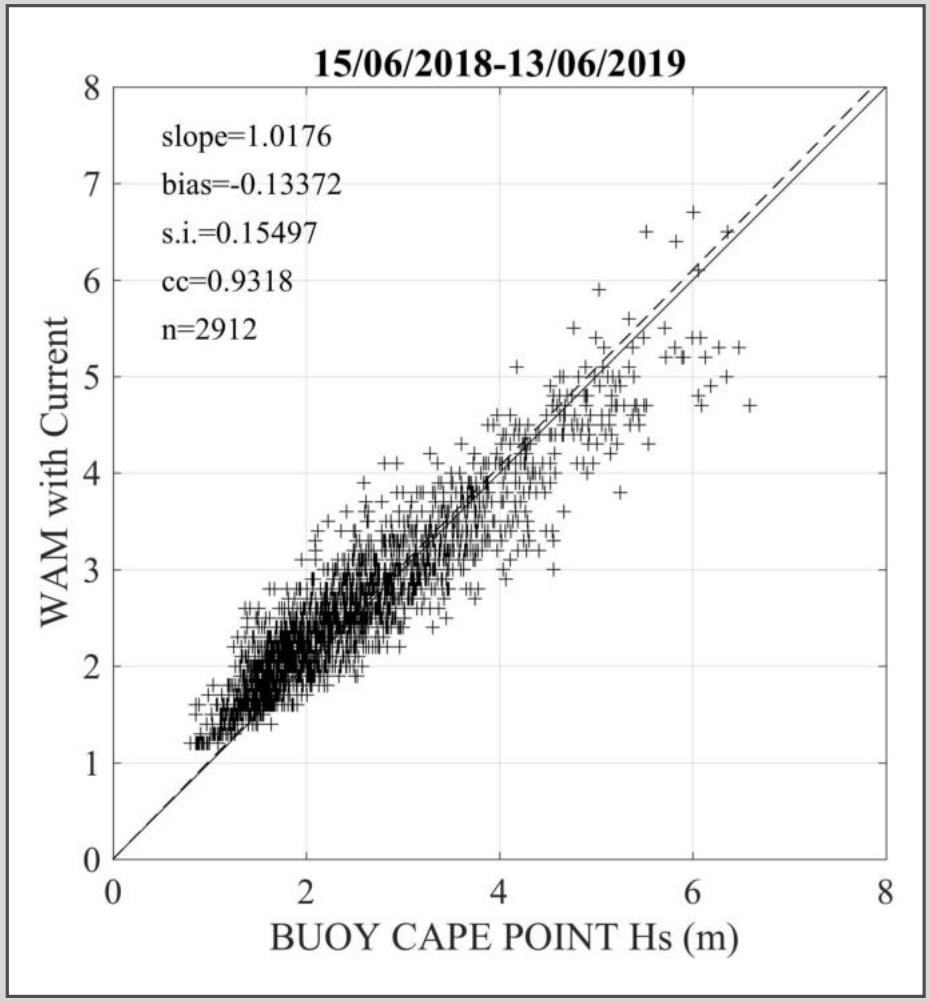
Results

Comparison of the WAM modeled Hs considering in the simulation waves only (magenta) and considering waves+current (green) against a coastal wave buoy (red dashed).

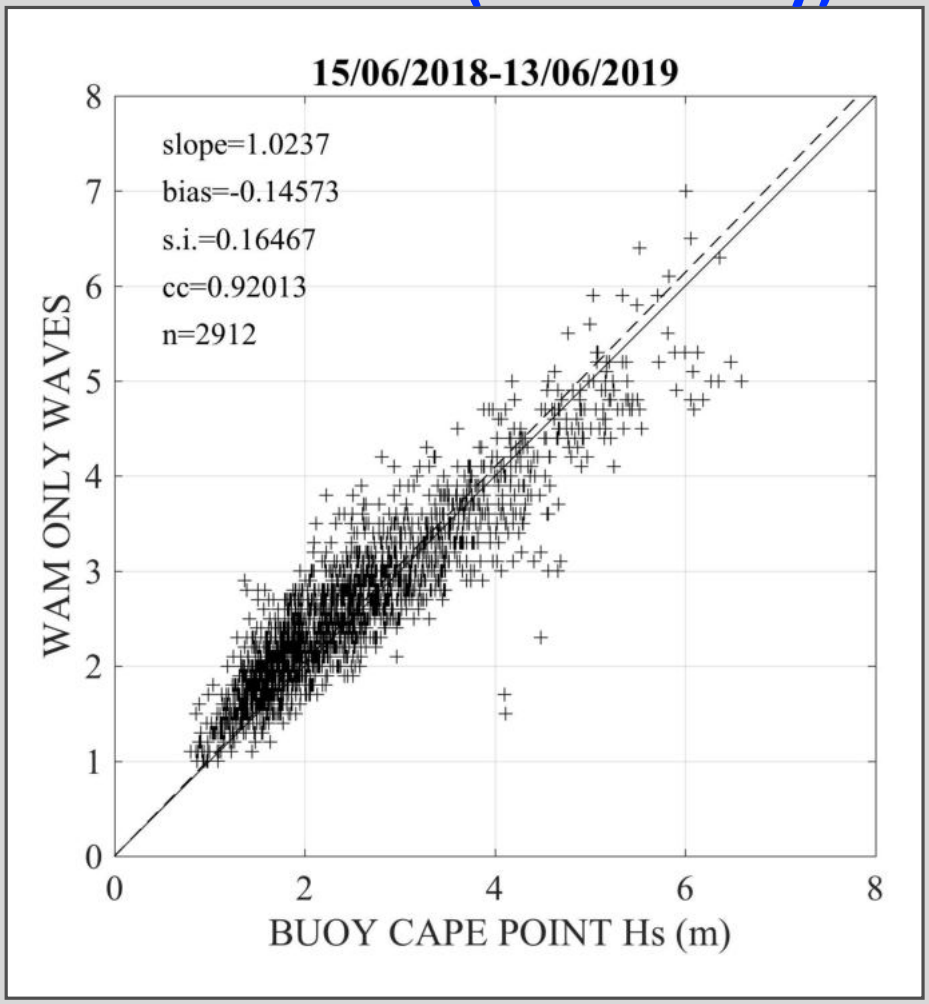




WAM+Current

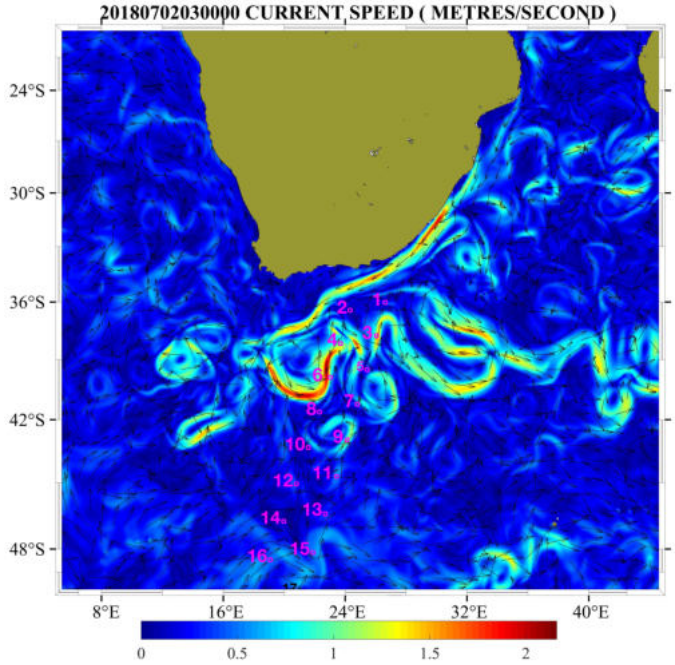


WAM (Waves Only)



Sentinel SAR wave mode

Comparison of the observed **S1 SAR swell spectra** (The Ocean Swell Spectra (OSW) component) and modelled **WAM** *swell* spectra.



# spectra	Longitude	Latitude	SAR time	WAM time
S4	23.693714	-38.173283	20180702033800	20180702030000
S5	25.441198	-39.509636	20180702033800	20180702030000
S6	23.024385	-39.901814	20180702033800	20180702030000
S8	22.321478	-41.626610	20180702033700	20180702030000

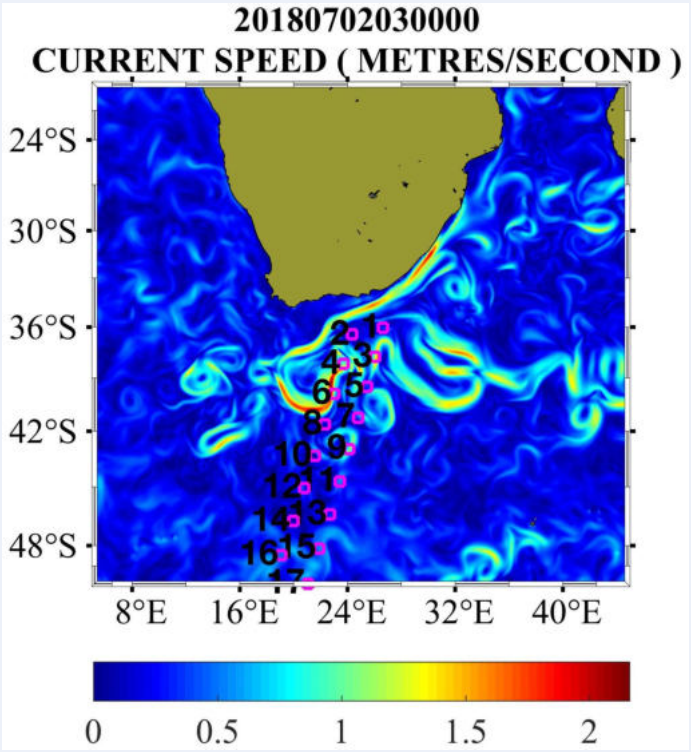
Current data from MERCATOR Ocean

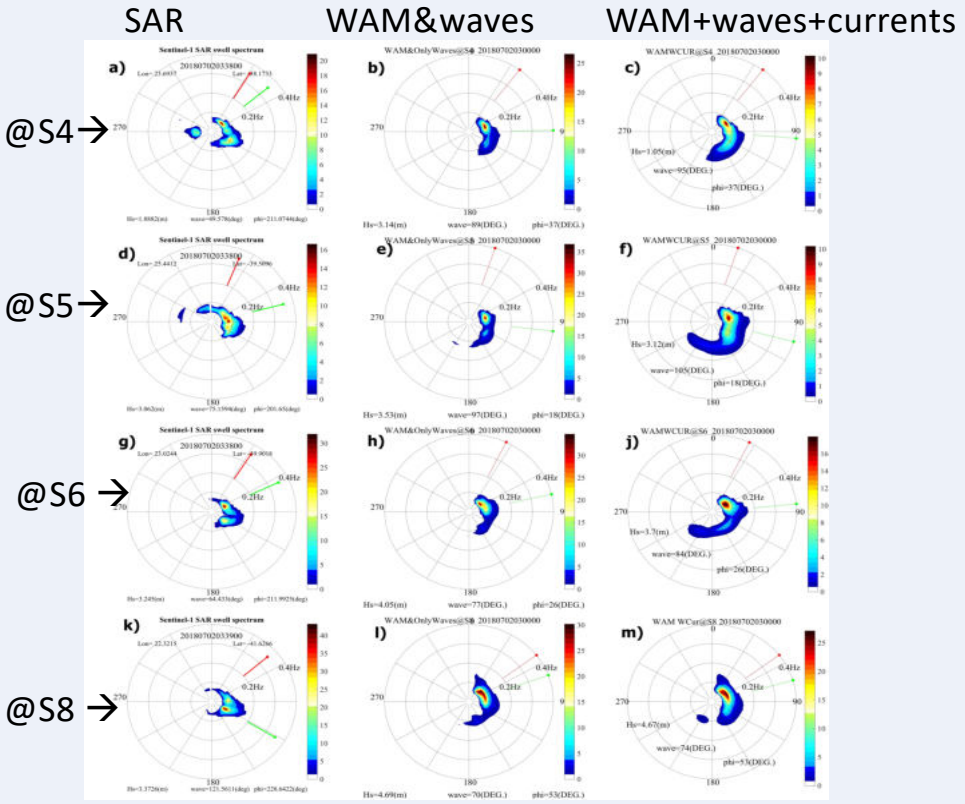
Mercator Ocean Current ocean data (Copernicus Marine Environment Monitoring Service, CMEMS).

The Global ocean analysis-forecast (**phy-0010024**) is an hourly product with a 1/12° of resolution (Lellouche et al., 2018).

Along track comparison between the observed S1 SAR swell spectra and modelled WAM spectra in the retroflection zone.

S1, S2…=SAR Locations





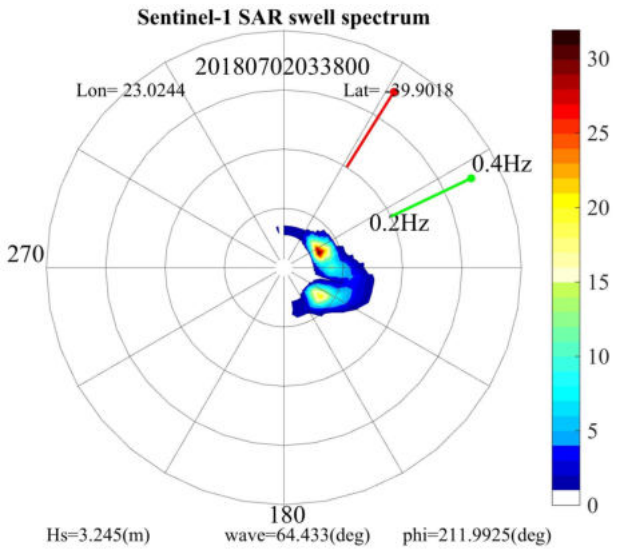
Hundreds S1 SAR OSW data were retrieved. Only those ones that matched the criterion of the selection of OSW spectra have been processed accordingly. The selection criterion consisted in selecting tracks that passed over meanders in the ACR. After this selection the same locations were defined in the wave model for the comparison.

- **Sentinel SAR wave mode & WAM swell spectra at SAR location S6**

To compare WAM and SAR wave spectra, the latter were transformed from wavenumber space *F(kx,ky)* to frequency-direction space *E(f,ϑ)* using the following formula (Holthuijsen, 2007):

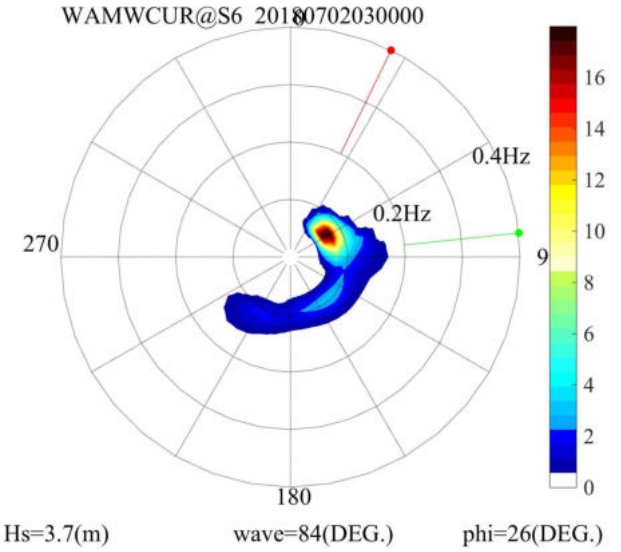
$F = c*Cg/f*E$

where *c* is the phase velocity and *Cg* the group velocity.



Number of frequencies=60
First Frequency: 0.0361 Hz
Final Frequency: 0.2281 Hz

Directional bins: 71
Resolution width: 5 deg.



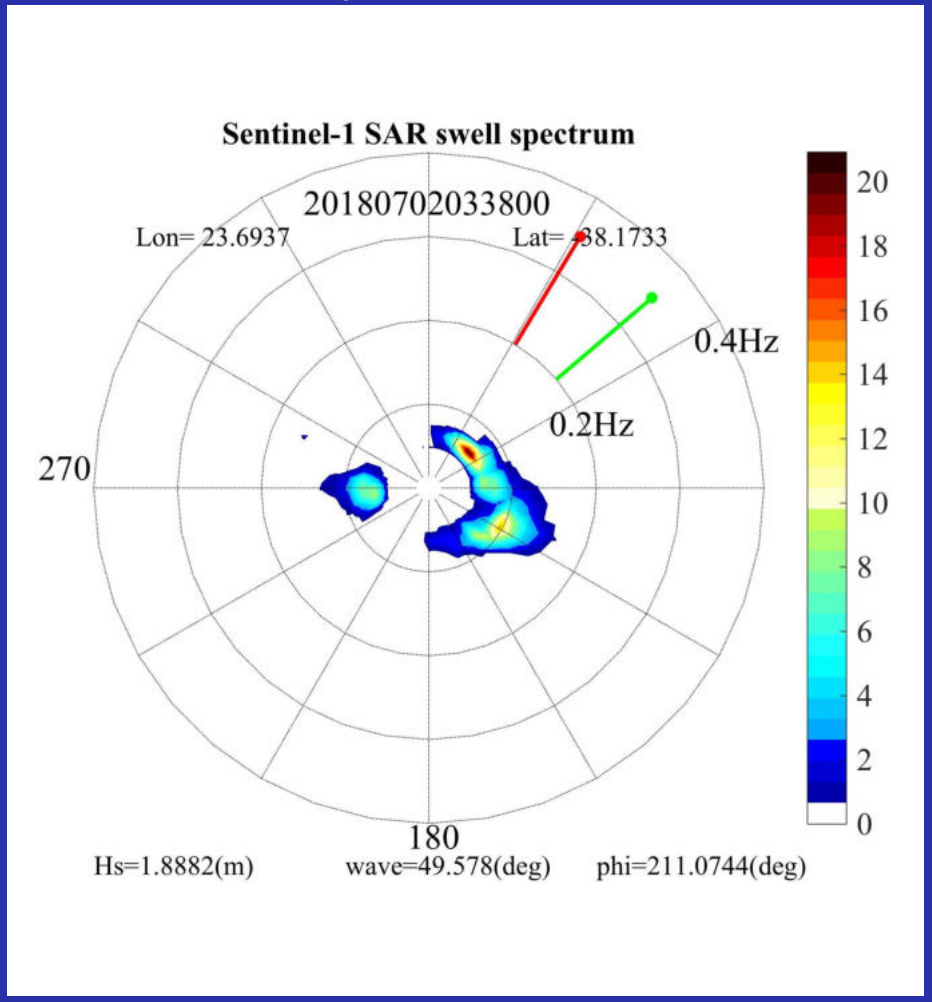
Number of frequencies=38
First Frequency: 0.03 Hz
Final Frequency: 1.0201 Hz

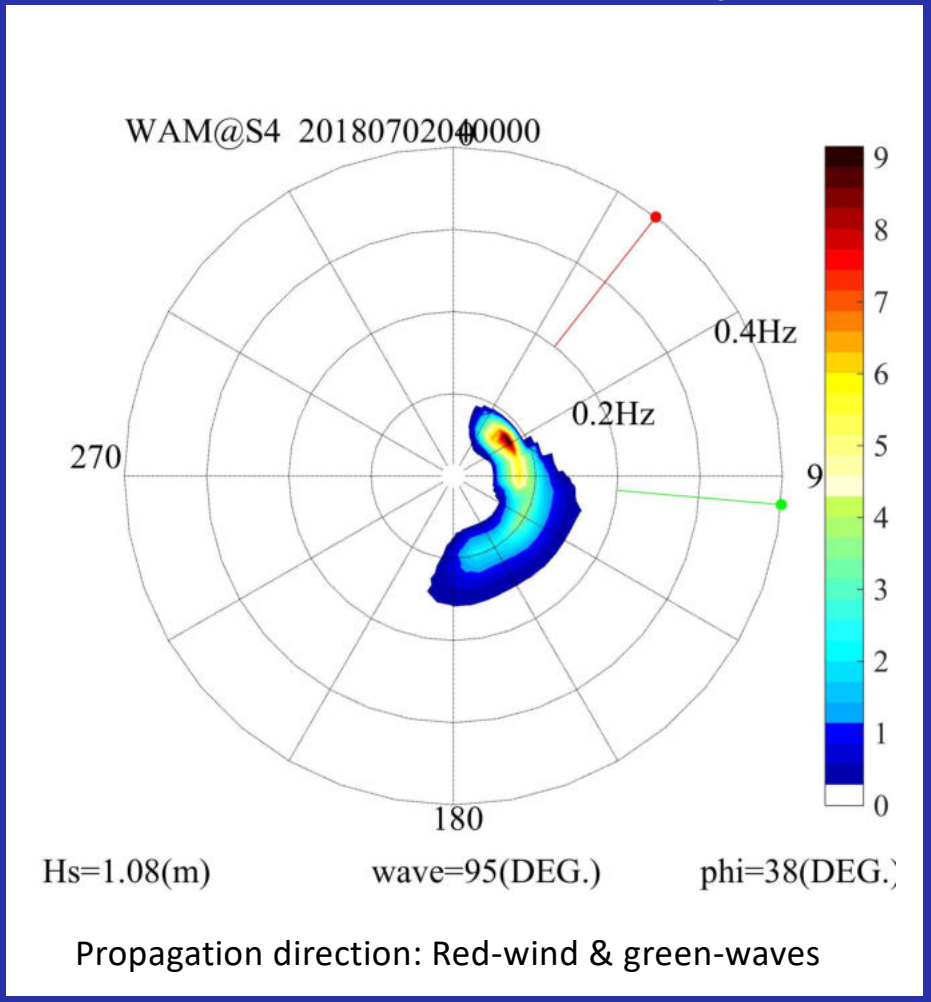
Directional bins: 36
Resolution width: 10 deg.

SAR swell spectrum

location S4

WAM+current swell spectrum





Propagation direction: Red-wind & green-waves

Relative errors between **SAR** swell spectra and **WAM** swell spectra.
(**Wwav**-Only waves; **WCurMER**cator)

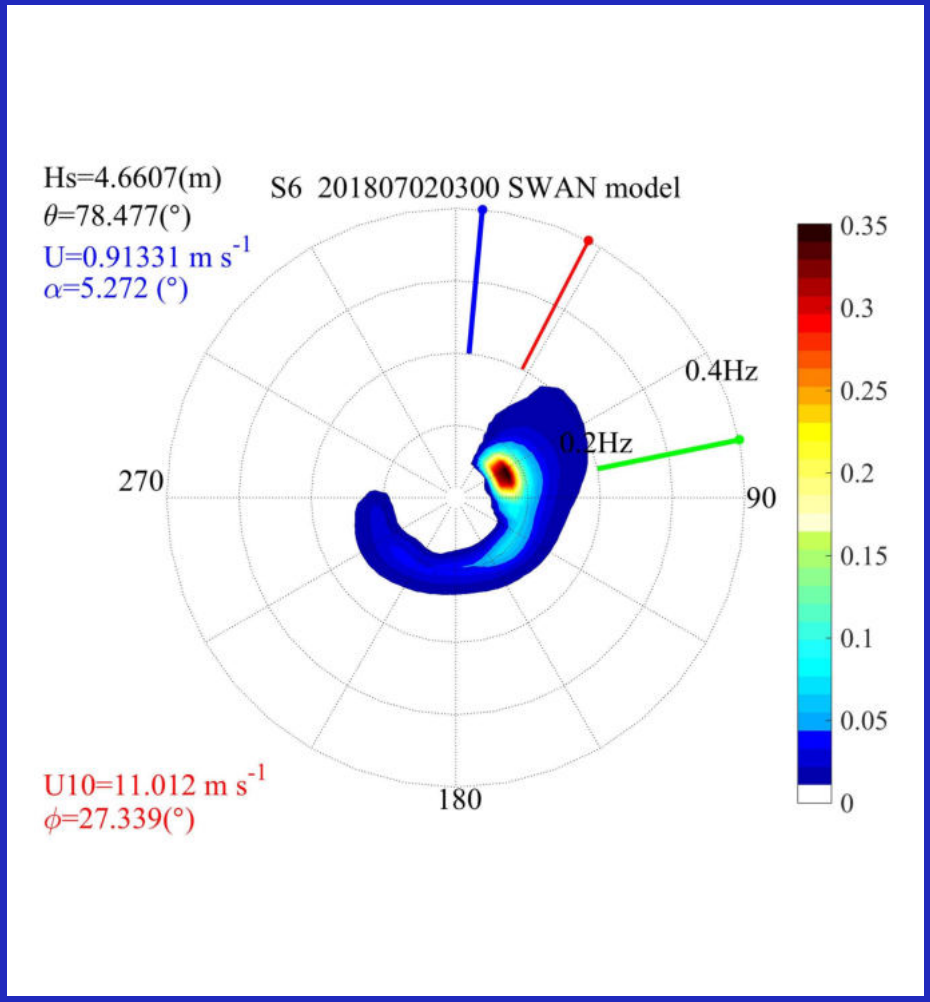
Location/Simulation type	WWav	WCurMER
S4	0.1546	0.0983
S5	0.1953	0.1022
S6	0.2468	0.1583
S8	0.3052	0.2682

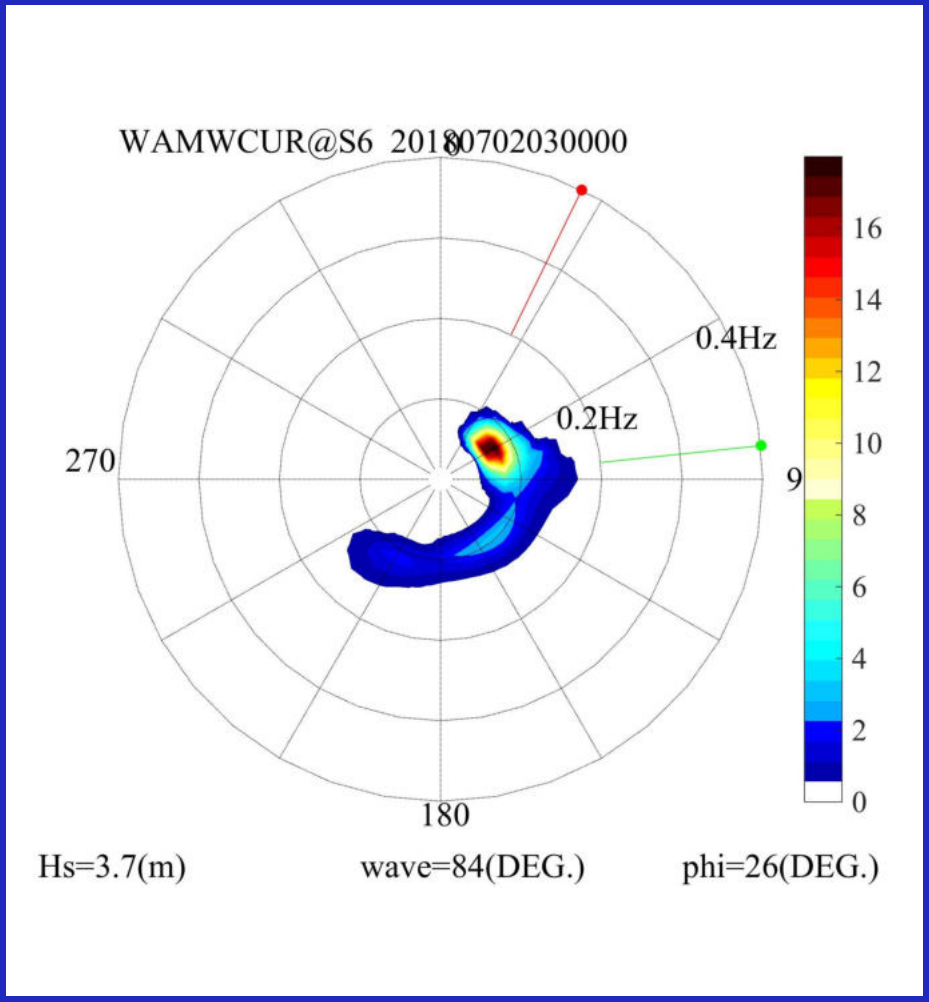
The error was computed by summing the squared difference between spectral levels $F(f,\theta)$ at each (f,θ) pair for all pairs and dividing this sum by the sum of the SAR spectral levels at each (f,θ).

$$\text{Error}=(\sum (F_{WAM}-F_{SAR})^2)^{1/2}/\sum F_{SAR}$$

Errors are implicit in any numerical simulation but considering currents errors are reduced.

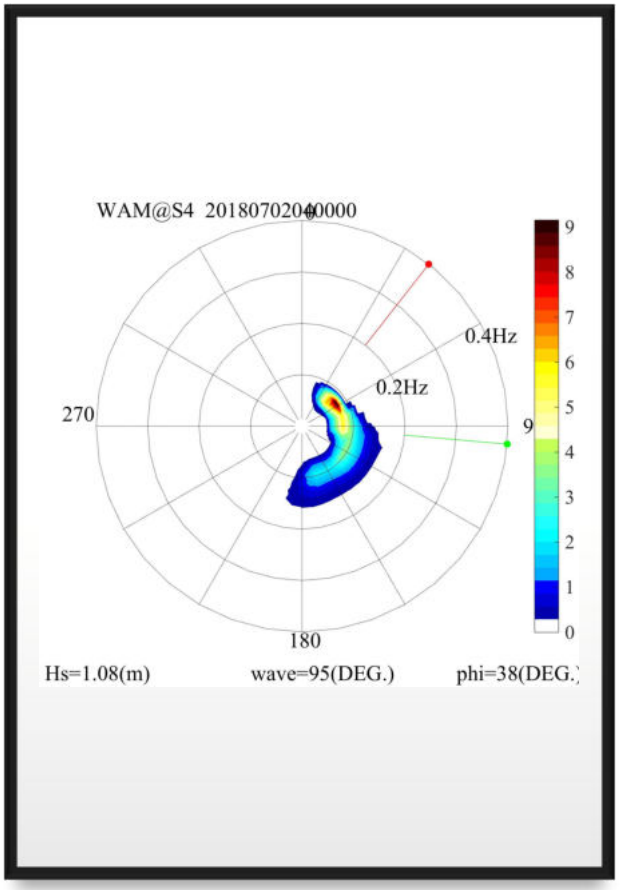
SWAN+current total wave spectrum location **S6** **WAM+current** swell spectrum





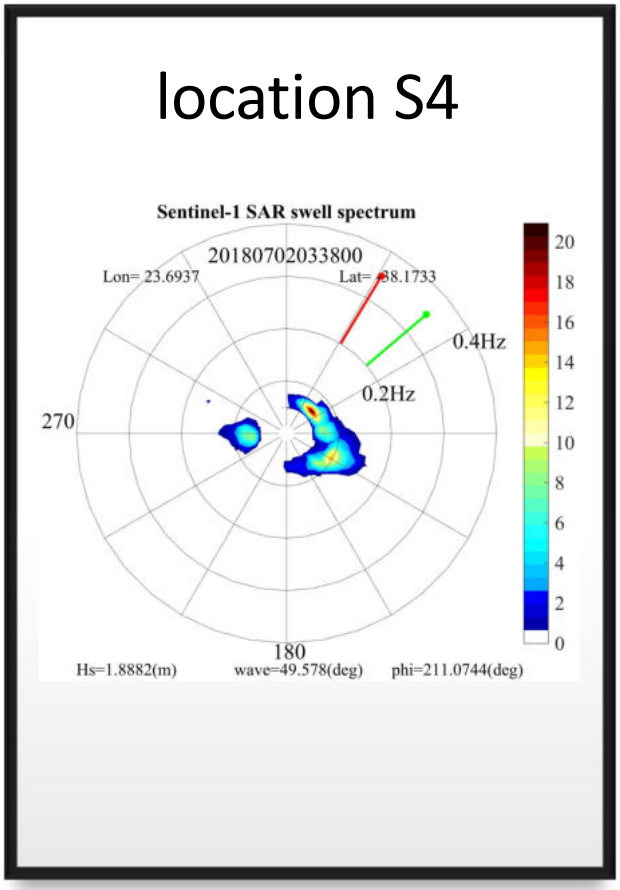
Blue-current, red-wind, green-waves

WAM+current

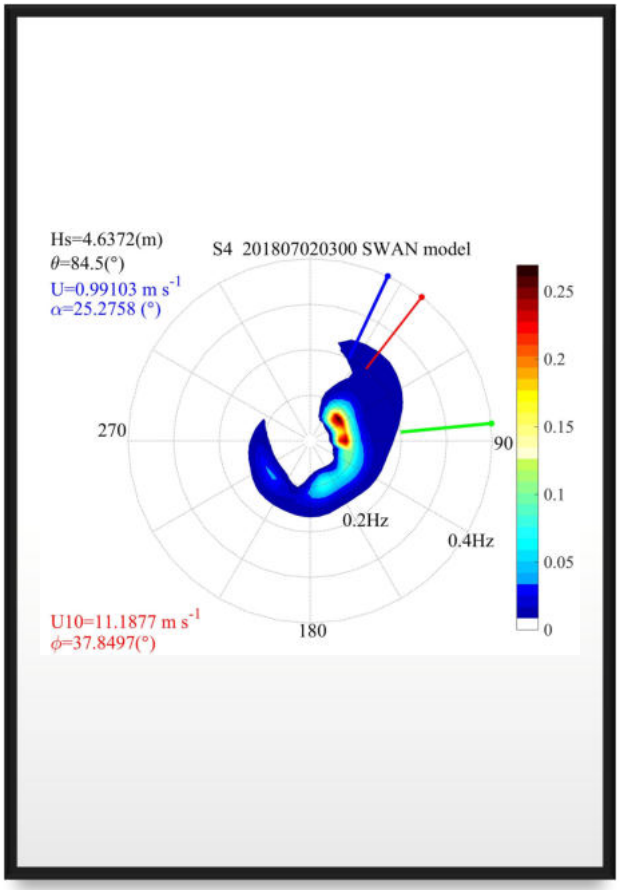


SAR

location S4



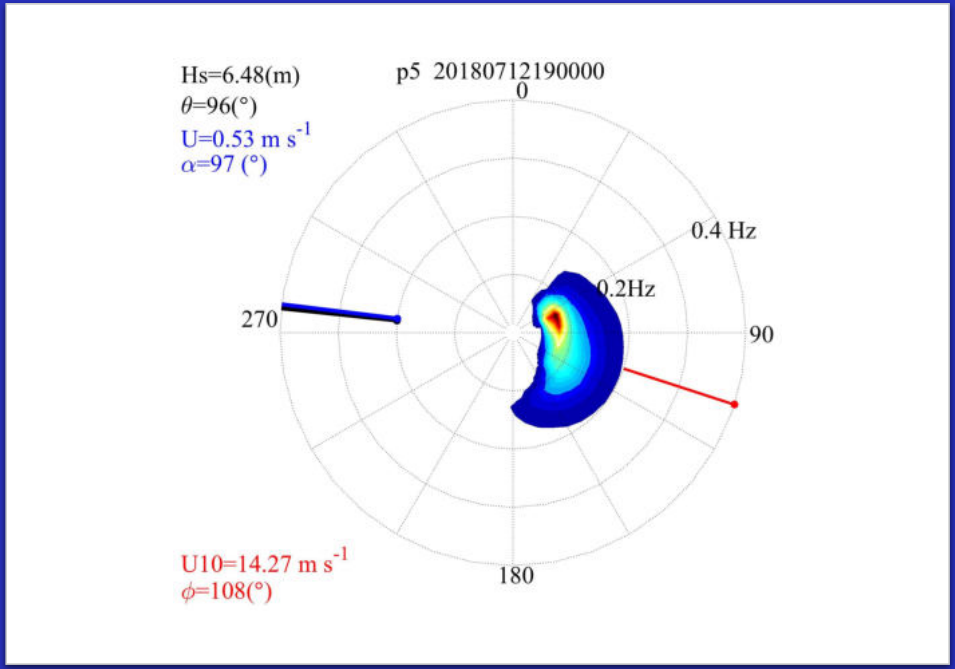
SWAN+current

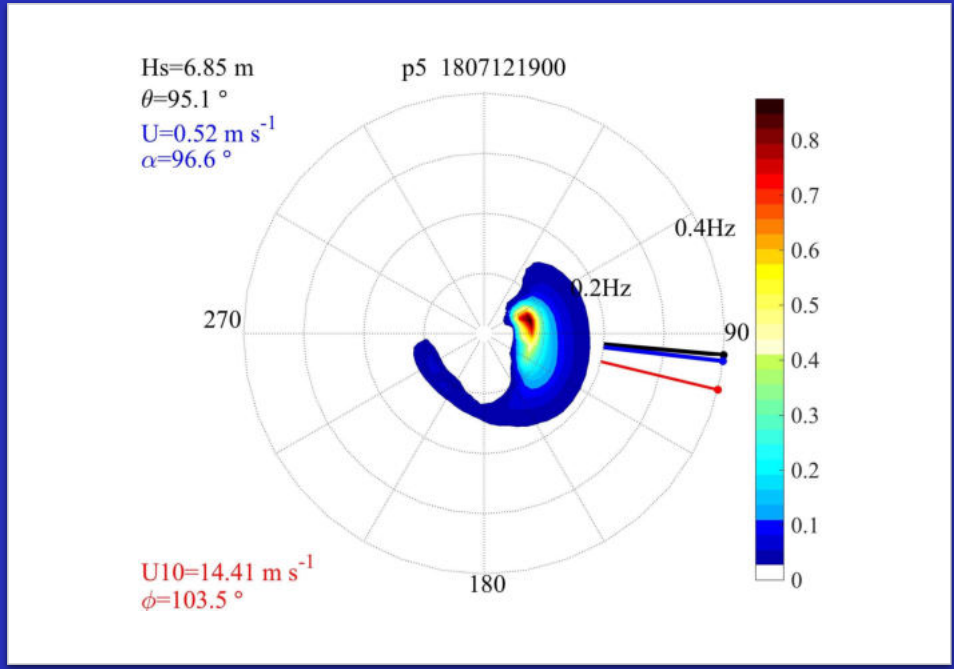


Blue-current, Red-wind, Green-waves

WAM +current 12 July 2018 19 UTC SWAN+current

Location P5





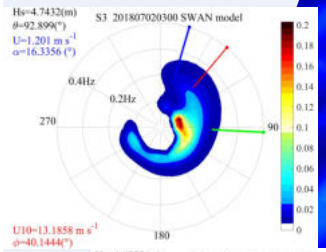
Blue-current, Red-wind, Black-waves

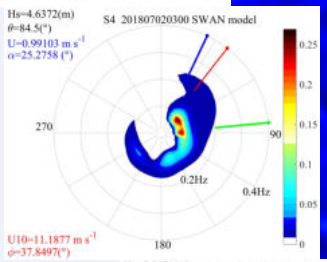
Broad wave spectra are INSIDE of the Agulhas current

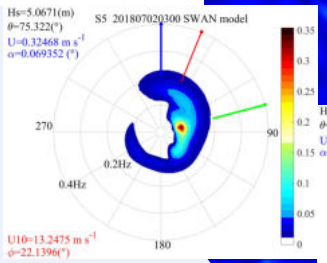
Transformation of the total wave spectra in the Agulhas current Retroflection

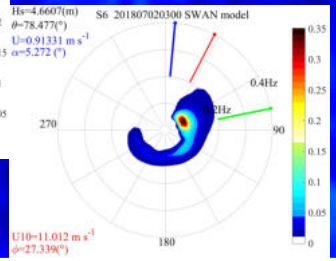
Date: 2 July 2018, 03 UTC

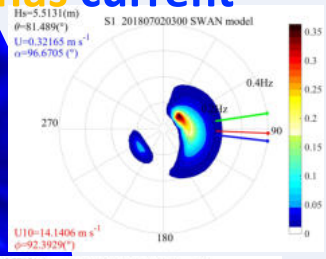
Narrow wave spectra are OUTSIDE of the Agulhas current

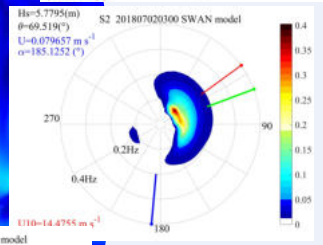


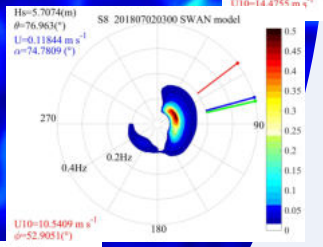


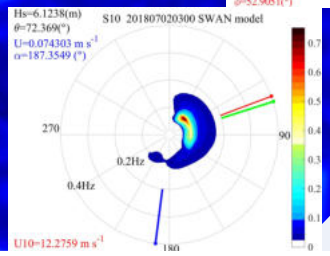








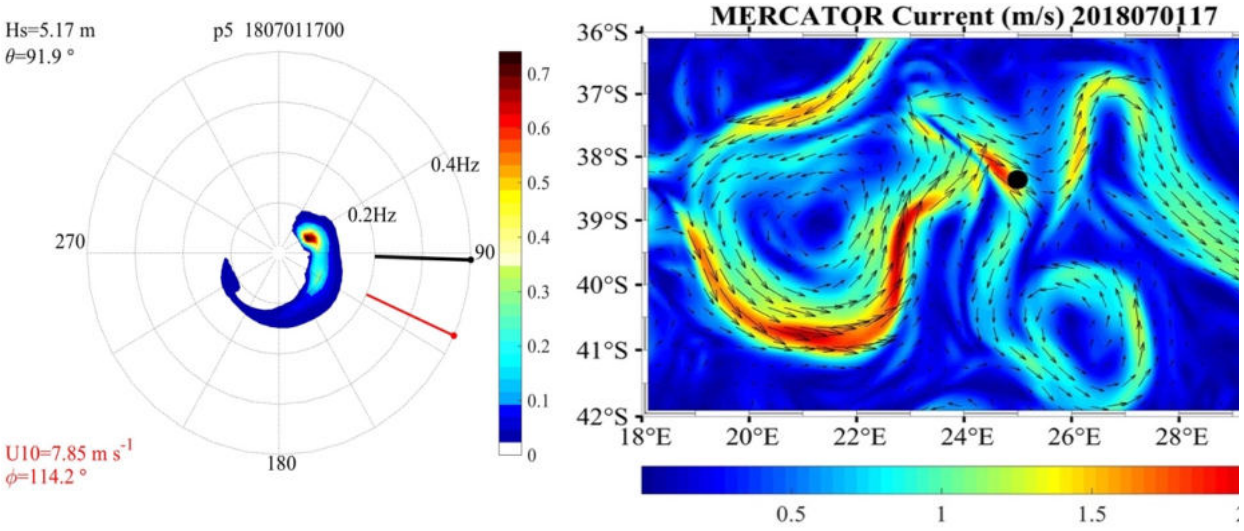


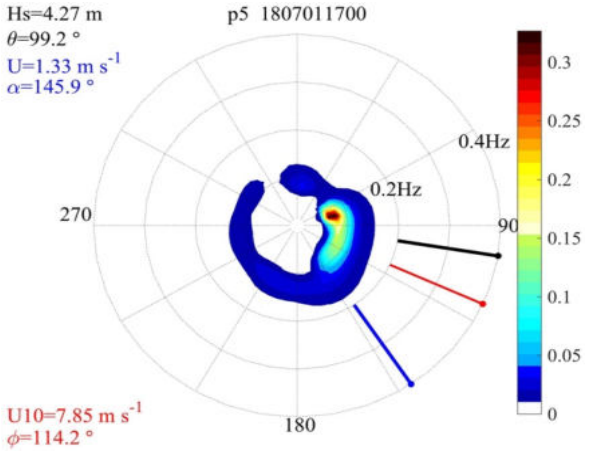


Modeled directional wave spectra

- **SWAN Only waves (Left)**
- **SWAN+current (Right)**

Location P5 = black circle



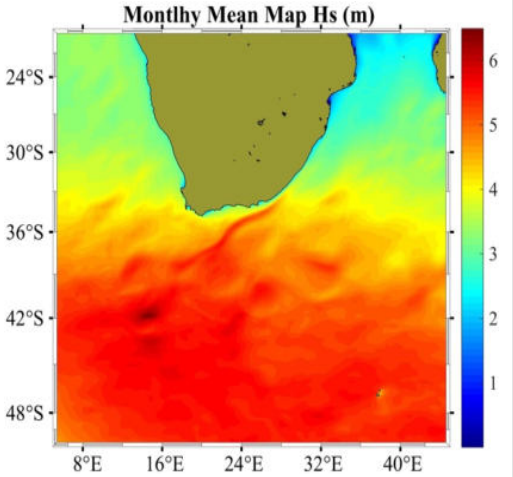


Blue-current, Red-wind, Black-waves

From the monthly composites (June-July 2018) can be seen that SAR observations and wave modeling reveal **Relatively High values of the BFI** in the Agulhas Current Retroflection.

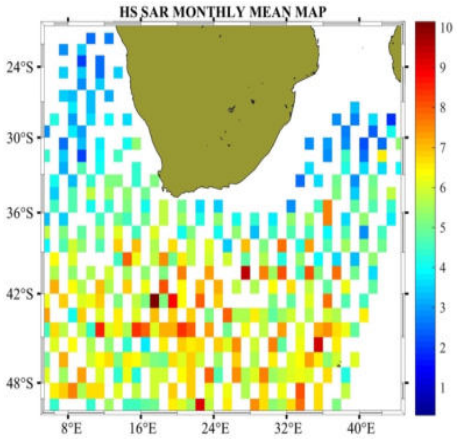
a)

Modeled **Hs** mean map



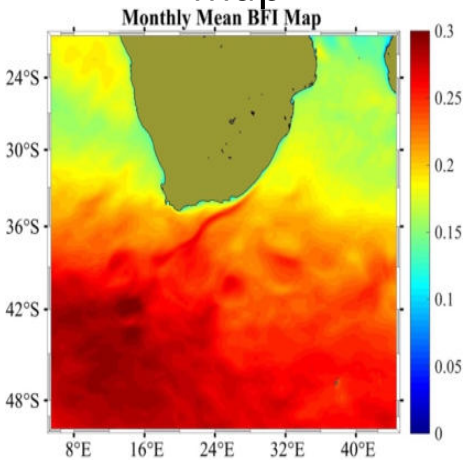
b)

Mean **Hs** from ***SAR*** observations



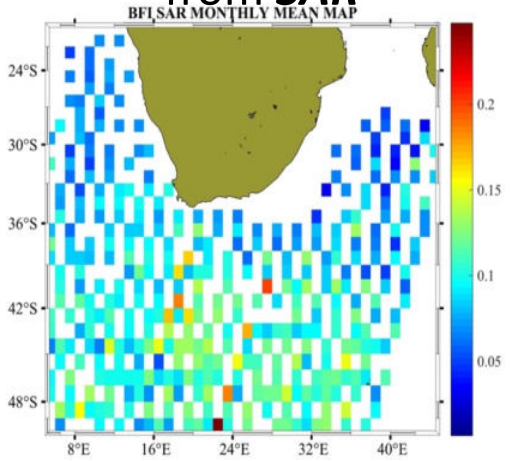
c)

Modeled **BFI** mean map



d)

Mean computed **BFI** from ***SAR***



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Conclusions and Future work

- The errors in the wave spectra are lower when currents are taken into account in the numerical simulation.
- Perform comparisons of the CFOSAT data and the modeled wave spectra.
- Extend the period of the study up to several years.

JMSE grant 10% discount for authors from CFOSAT workshop