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The impact of wave physics in the CMEMS-IBI ocean system Part A : Wave forcing validation.

Romain Rainaud[1], Lotfi Aouf[1], Alice Dalphinet[1], Marcos Garcia Sotillo[2], Enrique Alvarez-Fanjul[2], Guillaume Reffray[3], Bruno Levier[3], Stéphane LawChune[3], Pablo Lorente[2], Cristina Toledano[4]

[1]Météo-France
[2]Puertos del Estado
[3]Mercator-Ocean International
[4]Nologin Consulting

Abstract

The Iberian Biscay Ireland (IBI) wave system has the challenge to improve wave forecast and the coupling with ocean circulation model dedicated to western european coast. The momentum and heat fluxes at the sea surface are strongly controlled by the waves and there is a need of using accurate sea state from wave model. This work describes the more recent version of the IBI wave system and highlight the performance of system in comparison with satellite altimeters and buoys wave data. The validation process has been performed for 1-year run of the wave model MFWAM with boundary conditions provided by the global wave system. The results show on the one hand a slightly improvement on significant wave height and peak period, and on the other hand a better surface stress for high wind conditions. This latter is a consequence of using a tail wave spectrum shaped as the Philipps wave spectrum for high frequency waves.

1. Introduction

Waves constitute the interface between ocean and atmosphere and have an important role in term of exchanges through this interface (Cavaleri et al., 2012). Their representation is necessary to compute with accuracy the different air-sea fluxes of heat and momentum (Janssen et al., 2004). However, waves are generally parameterized from 10-m local wind. While there is a correlation between wind and waves, their relationship is not exclusive. Indeed, waves are also present without wind and for a given local wind speed, the local wave field is variable (Hanley et al., 2010). Moreover, it is generally accepted that wind directly generates surface currents because about 90% of the wind momentum input to waves is immediately passed to the ocean (Cavaleri et al., 2012). In fact, waves absorb energy and momentum from the wind during their formation and growth, and return it when they break (Breivik et al., 2015). This explains why it is necessary to introduce an accurate sea state description, from wave model (or database as for example Rascle et al., 2007), which control exchanges between ocean and atmosphere.

Waves affect the ocean surface layer through different processes (Breivik et al., 2015) :

- Waves induce current in surface via the Stokes drift, rapidly attenuated with depth. The Stokes drift velocity associated with the wave fields adds a term on the Coriolis effect in the momentum equation. This process is called Stokes-Coriolis forcing.
- A part of the atmospheric wind stress is used by waves to grow and is not provided to the ocean. This energy quantity must be subtracted from the oceanic wind stress which drives the ocean model.
- During wave breaking, turbulent kinetic energy is produced and induces to the ocean surface layer an enhanced turbulent mixing.A more accurate description of these processes will be given in the part B of this study.

Recent studies investigated the impact of the wave effect on the representation of the ocean surface layer at different scales of time and space. One of the major impact is the improvement of the Mixed-Layer-Depth (MLD) using wave-induced MLD parametrization (Fan et al., 2014) which lead to an important impact on the atmospheric surface temperature, pressure and precipitation (Babanin et al., 2009, 2012). In a climate scale, this can affect global sea-surface pressure patterns and atmospheric circulation. Breivik et al., (2015) showed that the use of wave forcing in oceanic surface induces a reduction of the global annual SST bias amplitude on a period from 1979 to 2010. They used a coarse 1° horizontal grid resolution of NEMO ocean model and wave forcing from ECWAM wave model. An important reduction of the amplitude of the diurnal cycle of SST and

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surface current had been exposed by Janssen (2012). At the interface of ocean and atmosphere, waves modify the surface layer and induce an increase of the roughness length, which enhances the wind stress (Thévenot et al., 2016). Ginis (2008) has advised the use of an ocean-waves-atmosphere coupled system to improve the representation of tropical cyclones intensity, structure and trajectories. Indeed, Chunxia et al., (2008) studied the effect of sea waves during typhoon Imodu (15-19 July 2003). They found that the waves had a small effect on the typhoon track but they revealed a relation between wage age and 10-m wind speed inducing impact on air-sea fluxes and precipitations. These changes obviously affect the oceanic surface layer behavior. The high-resolution NEMO-WAM system had been used by Staneva et al. (2017) for the Baltic and North Sea. They showed that when using a wave forcing on the ocean surface induces a Sea Surface Temperature (SST) closer to the one provided by MODIS satellite than without wave forcing. The NEMO-WAM system was also in better agreement with sea surface height and surface current observations during the Xaver storm event (06 December 2014).

The Copernicus Marine Environmental Monitoring Service (CMEMS) is a strong European partnership with more than 50 marine operational and research centers in Europe involved in the marine monitoring and forecasting services. It provides a wide range of marine products of social and environmental value such as ocean currents, temperature, salinity, sea level, pelagic biogeochemistry and waves. The Monitoring Forecasting System (MFC) generates model-based products including analysis of the current situation, forecasts of the situation a few days in advance and the delivery of retrospective data records (re-analysis). In order to increase the quality of these ocean products, an evaluation of the impact of wave forcing on oceanic surface layer is needed. Météo-France has implemented the coupling between the wave model MFWAM and the ocean model NEMO. This aims to provide reference and accurate physical oceanic state on Iberian-Biscay-Irish (IBI, Figure 1) ocean area. . The goal of this paper is to evaluate the impact of waves forcing on ocean circulation for IBI ocean area during the year 2014, where there were a by several storms events. Validation and analysis on oceanic key parameters was performed in preparation of using NEMO V4 IBI-Wave system in the operational Copernicus CMEMS-IBI-MFC.

This study is splitted in two parts. The part A described in this paper, is dedicated to the MFWAM validation and is structured as follow. First, a description of the wave model MFWAM is given in section 2. Section 3 indicates a the different wave observations and performed model runs. Results on the validation is given at Section 4. Finally, a summary and concluding remarks will discussed in Section 5. The part B of this paper describes the impact of the wave forcing on the ocean circulation model.

2. Description of the wave Model MFWAM

The wave model of Météo-France MFWAM provides the mean wave parameters for the Copernicus Marine Environment and Monitoring Service (CMEMS) for Iberian-Biscay-Ireland seas domain. The model is based on the ECWAM-IFS38R2 computing code (ECMWF 2013) with two major changes related to the dissipation source terms. The model MFWAM uses the physics developed in Ardhuin et al. (2010) which is called ST4. The MFWAM model takes also into account a swell damping term related to to the air friction at the sea surface. Recently the model has been upgraded with adjustment of the dissipation source terms and also improvement on drag limitation by using a tail shape from the Philipps wave spectrum (Janssen et al. 2014). Table 1 gives the tuned coefficients of ST4 physics for the old and new version of the model referred to as V3 and V4, respectively. In this study the model MFWAM is set for a IBI domain (25°N to 64.6°N in latitude) with a grid size of 0.10°. The model uses a bathymetry from ETOPO2 and is driven by 6-hourly analyzed winds from the IFS-ECMWF atmospheric model. The wave spectrum is discretized in 24 directions and 30 frequencies starting from 0.035 to 0.57 Hz with increasing step of 1.1. Th boundary conditions are provided from the global model MFWAM run with a time step of 3 hours. The data assimilation is not activated for this study.

3. Observations and model runs

3.1 Wave observations

Satellite data

Two different SST satellite products, OSTIA and L3S have been used in this study. The OSTIA daily product of SST is a level 4 multi-sensor product at a resolution of 0.02° built by using optimal interpolation from several satellite missions such as AVHRR_METOP_B, SEVIRI*VIIRS_NPP, AVHRRL_19, AVHRRL_18, MODIS_A, MODIS_T, AMSR2. The hierarchy can be changed in time depending on the health of each sensor. The L3S product consists in a fusion of daily SST observations from multiple satellite sensors, over a 0.1° resolution grid. It includes observations by polar orbiting (NOAA-18 & NOAA-19/AVHRR, METOP-A/AVHRR, ENVISAT/AATSR, AQUA/AMSRE, TRMM/TMI) and geostationnary (MSG/SEVIRI,GEOS-11) satellites. The observations of each sensor are intercalibrated prior to merging using a bias correction based on a multi-sensor median reference correcting the large scale cross-sensor biases.

Satellite observations of significant wave height (SWH) for the year 2014 are provided by altimeters missions JASON-2 and SARAL. Altimeters SWH are interpolated in a box with a grid size of 0.1° and collocated with model MFWAM SWH with a time window of 3 hours.

Level 4 surface currents satellite data are from altimeter satellite gridded sea surface heights and derived variables. This product is processed by the SL-TAC multimission altimeter data processing system. It processes data from all altimeter missions: Jason-3, Sentinel-3A, HY-2A, Saral/AltiKa, Cryosat-2, Jason-2, Jason-1, T/P, ENVISAT, GFO, ERS ½. It provides a consistent and homogeneous catalogue of products for varied applications, both for near real time applications and offline studies. The resolution of the product is 0.25°.

Wave buoys

In-situ buoys are also used to evaluate model outputs. These buoys provide data of surface atmosphere, wave and ocean parameters. Data are from the network of Puertos del Estado for spanish buoys, Météo France for french buoys and from irish buoys. The Table 2 and Figure 1 summarize the names, locations, nationality and reference code used in the following for the different buoys.

3.2. Wave model runs

The first wave experiment, called MFWAM-V3, was performed with the version 3 of the MFWAM-IBI code. One year run of the model has been performed starting from 27 November 2013, until 31 December 2014. The wave model is driven by 6-hourly analysed wind forcing from ECMWF-IFS atmospheric system. The boundary conditions are provided every 3 hours by a global MFWAM model run with a grid resolution of 0.5°.

The second wave experiment, called MFWAM-V4, is performed with the most recent version 4 of the MFWAM-IBI code. This latter has an adjustment of the dissipation source term in order to improve the surface stress for high winds. the physics parameter settings include the sheltering parameter Su, non-dimensional growth parameter βmax, the dissipation coefficient Cds (a negative constant). Also a tail factor was reduced in order to account the Phillips wave spectrum for high frequency waves. These parameters are calibrated following the ST4 physics developed in Ardhuin et al. (2010). Table 2 summarizes physical settings of the two model MFWAM versions 3 and 4.

Figures 2a and 2b show the variation of the surface drag coefficient with 10-meter wind speed. It is clearly observed that the MFWAM V4 reduces significantly the drag coefficient for high wind speed larger than 20 m/s. The scatter diagram shows more consistent sea state dependency from the model V4 than V3.

Significant wave heights provided by the wave model runs are validated by comparison with altimeters satellite wave data for the entire year 2014. The wave forcing provided to ocean model NEMO includes the following parameters : significant wave height, drag coefficient, Stokes velocity components, mean wave period, and wave number, normalized wind stress, Craig and Banner coefficient, energy flux and significant height of wind waves. The impact of these parameters on the ocean surface will be investigated in the part B of the study.

4. Validation of the wave output fields

The validation of the wave model MFWAM is based on a statistical analysis of significant wave heights from the model compared to altimeter wave data (JASON-2 and Saral/Altika), as mentioned in previous section. Metrics used in this study are normalized scatter index and bias. Figure 3 shows the scatter plots of SWH from altimeters and models for the year 2014. This reveals a slightly better slope for V4, but overall good performance of the MFWAM-IBI wave model for V3 and V4 versions. The scatter index of SWH is roughly of 12.5% and the bias is negative and roughly 15 cm. The model MFWAM underestimates SWH which is mostly induced by the underestimation of the surface wind speed from the atmospheric model in the IBI domain. Table 3 highlights the very good and close performance of both versions during 2014. Figure 4 and 5 show maps of average scatter index and bias on the IBI domain, respectively. Most of scatter index are ranged between 8 to 15% depending on the ocean area. However, we can mention that wave model V3 and V4 have a better skill on the Atlantic ocean than on North and Mediterranean seas. The maps of bias also show a general underestimation of SWH except on Gulf of Biscay where the model MFWAM induced an overestimation of SWH for both V3 and V4. A detail analysis is given by the monthly variation of the model performance, as illustrated in figure 6. For V3 and V4 versions, the scatter index is ranging between 11 and 14% during all the year, which indicates that the good performance of the MFWAM-IBI wave model is for the entire year. Monthly scatter index are slightly better for MFWAM-V4, which confirms the better performance of this version on the IBI domain.

Performances of the model MFWAM are also investigated depending on regional domains. Three domains have been selected depending on latitudes as indicated in figure 8. Zone 1 concerns latitudes between 25°N-35°N (called Canarias domain), while Zone 2 considers latitudes 35°N-49°N (called Spain-France domain). Zone 3 accounts for northern latitudes ranging between 49°N-64.5°N (called GB-Ireland domain). For all zones during 2014, the scatter index and bias of SWH is ranging between 12% and 13% and between -10 cm and -20 cm, respectively. One can indicate that the scatter index of SWH is better for zones 1 and 3 while the bias is better for zone 2 during 2014. Table 4 shows also a slightly better performance for MFWAM-V4, in particular for the scatter index, for the three zones. This confirms what was previously mentioned concerning differences between the two versions. Figure 8 shows monthly scatter index and bias during 2014 for the three ocean zones. The scatter index of SWH is ranging between 10% and 15% and the best performance is obtained during summer for months june and july. While during winter with intense storms in North Atlantic ocean the scatter index of SWH is larger for zones 2 and 3.

The significant wave height from MFWAM runs has also been evaluated with buoys measurements. Histograms of Figure 9 show the monthly scatter index during 2014. At BelmA buoy, the scatter index is lower than 15% during the entire year except on June and November. Moreover, the performance of the two runs is globally the same during all the year despite a slightly increase of MFWAM-V4. However, at BI buoy, the performance of MFWAM-V4 is generally better MFWAM-V3 during the entire year. At this location, the scatter index oscillate between 10% and 20% because of storm occurrence in this area.

The validation of the MFWAM V3 and V4 has indicated good skills during the year 2014. This opens the use of accurate description of the sea state and consequently good wave forcing to drive the ocean model NEMO. Moreover, in term of differences between MFWAM-V3 and MFWAM-V4, the validation showed an general increase of the quality thanks to the physical settings of MFWAM-V4.

5-Conclusions

The wave model MFWAM V4 version has been upgraded with physical adjustments that induced a more consistent surface stress dependency with 10-meter wind speed. The use of tail shape of Philipps spectrum aslo induces a better high frequency waves and consequently a better estimate of Stokes drift. The validation with altimeters wave data has been shown a slight improvement of bias and scatter index over IBI domain. The model MFWAM induces a negative bias that indicate an underestimation of significant wave height mostly because of uncertainties related to strong winds during winter and fall season from the ECMWF atmospheric system. The bias of significant wave height in summer season is small roughly less than 5 cm. The regional statistical analysis has revealed the best improvement of the model MFWAM V4 on the zone 2 which includes portuguese, spanish and french coasts. The validation with buoys has indicated a significant improvement of SWH at Belle-ile buoys located in coastal area of brittany french coast.

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The model MFWAM V4 is suited to well describe surface stress, stokes drift and the dissipation by wave breaking inducing turbulence in the ocean mixed layer.

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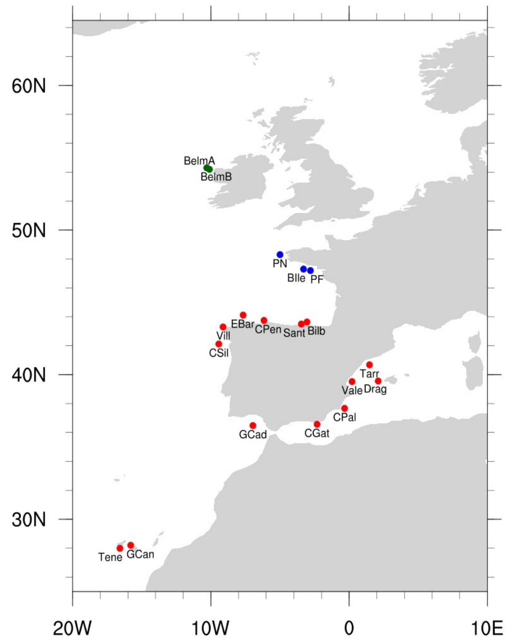

Figure 1 : Name and location of buoys in the IBI domain.

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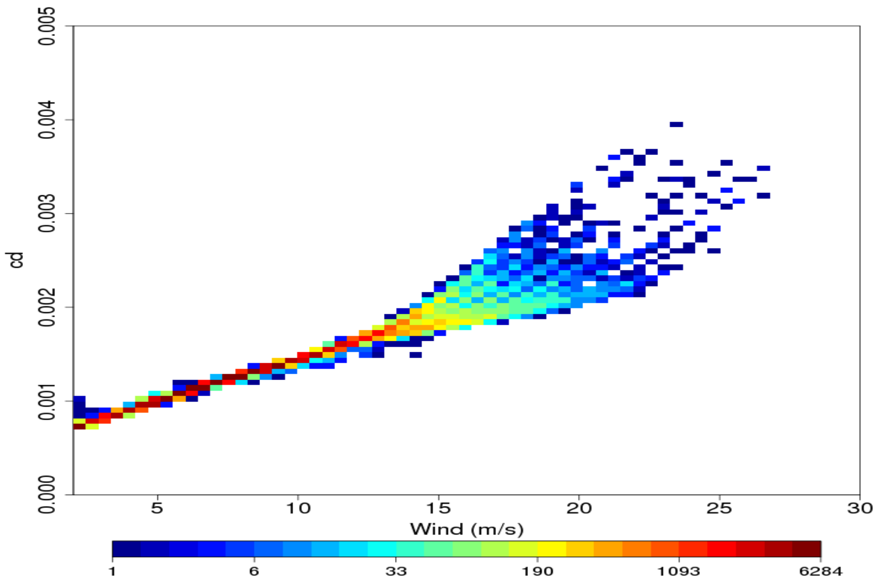

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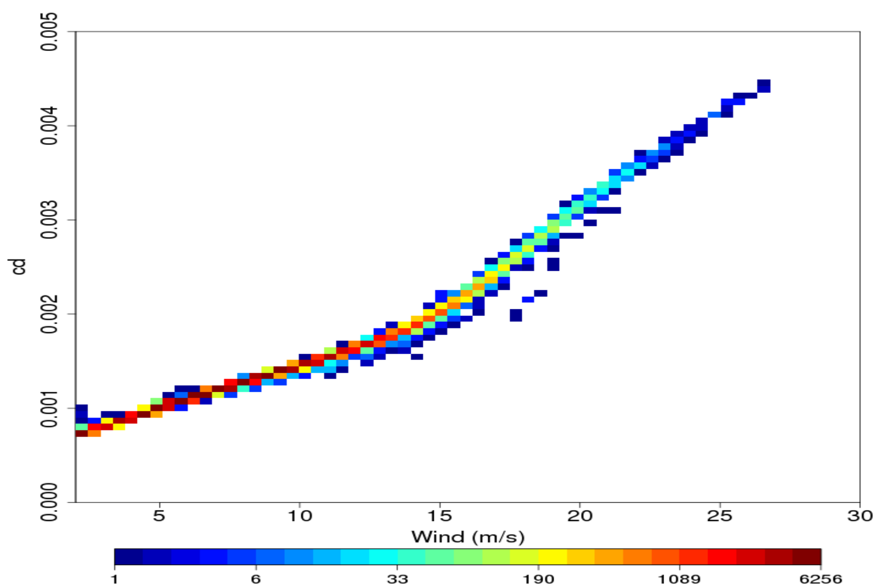

Figure 2 : Scatter diagram of drag coefficient from model runs with 10-meter wind speed during 2014. (a) and (b) stand for MFWAM-V4 and V3, respectively.

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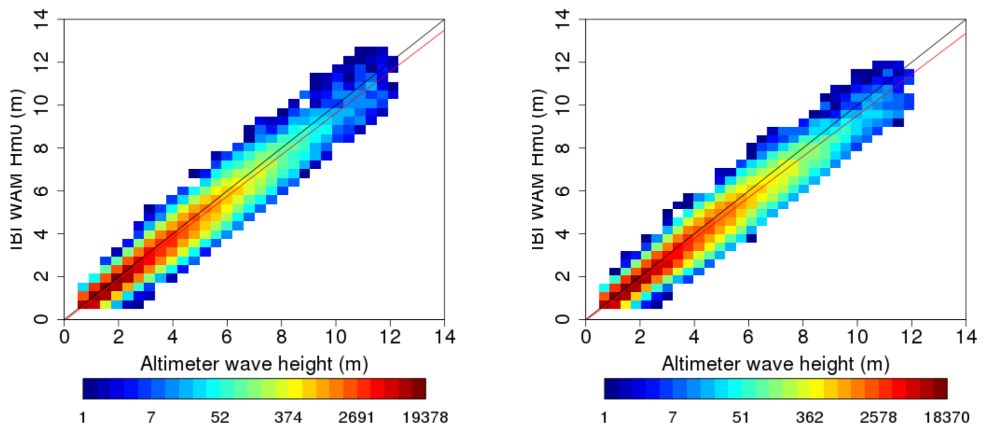
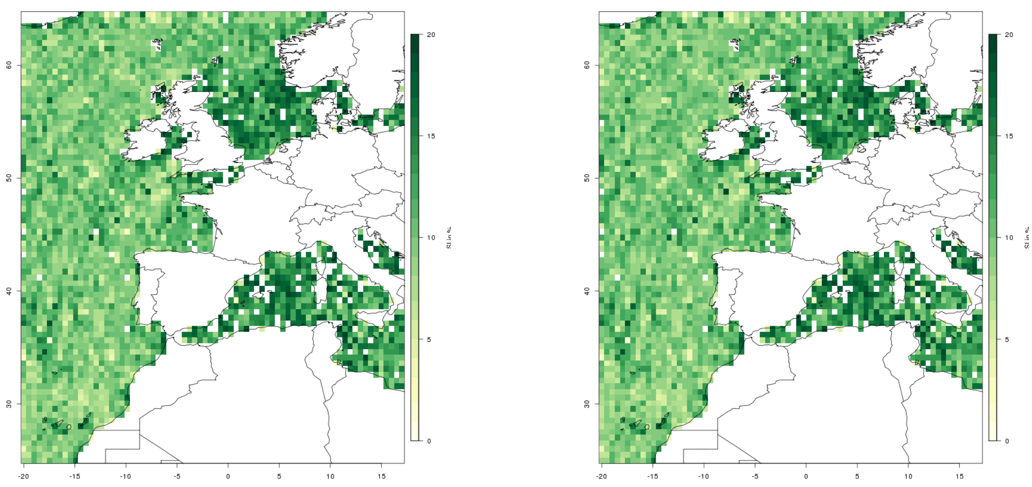


(a) (b)

Figure 3 : Scatter plots of significant wave heights from model and altimeters during 2014. (a) and (b) stand for MFWAM-V3 and MFWAM-V4, respectively. Satellite altimeters are JASON-2 and SARAL.



(a) (b)

Figure 4 : Normalized scatter index of significant wave height for IBI ocean domain during 2014. (a) and (b) stand for MFWAM-V3 and MFWAM-V4, respectively.Comparison has been performed with altimeters Jason-2 and SARAL.

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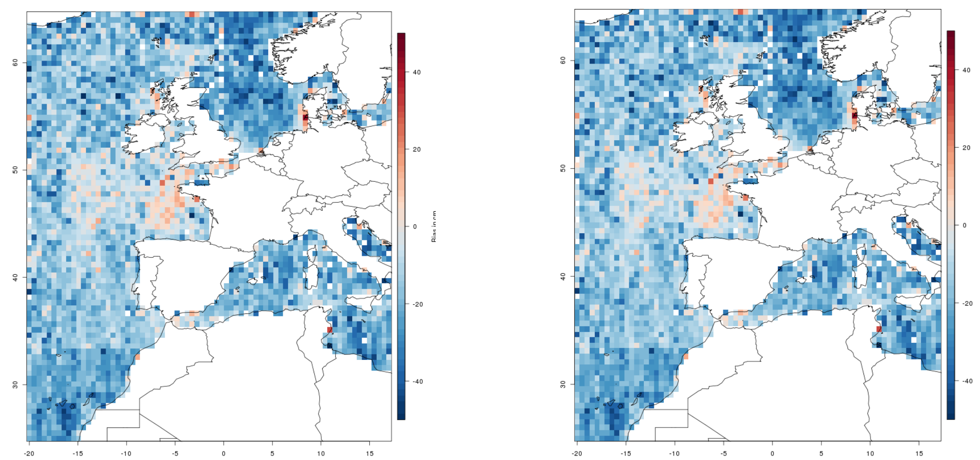

(a) (b)

Figure 5 : Bias of significant wave height for IBI ocean domain during 2014. (a) and (b) stand for MFWAM-V3 and MFWAM-V4. Comparison has been performed with altimeters Jason-2 and SARAL.

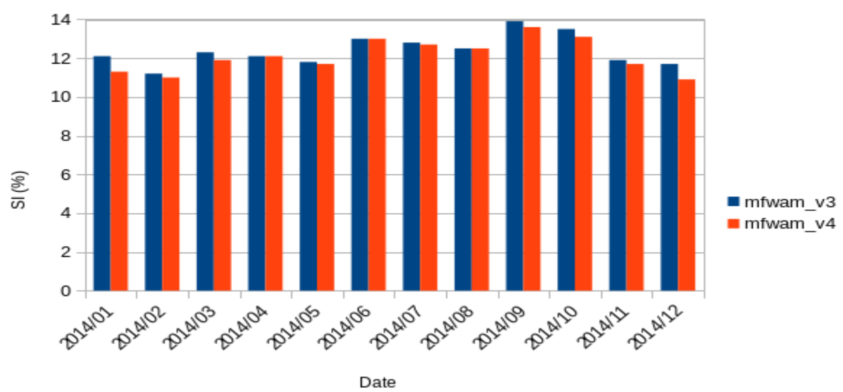

Figure 6 : Monthly evolution of the normalized scatter index of SWH from model MFWAM during 2014. Blue and red histogram bars indicate MFWAM-V3 and MFWAM-V4, respectively.

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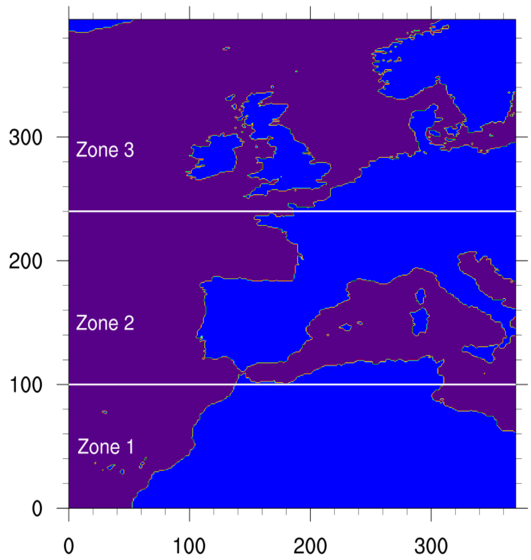

Figure 7 : Regional domains for the validation of IBI wave heights.

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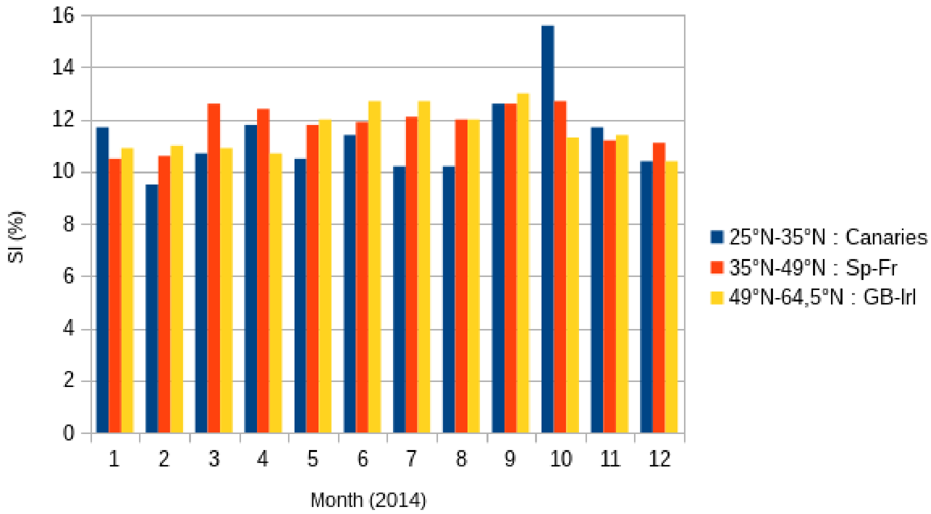
(a)



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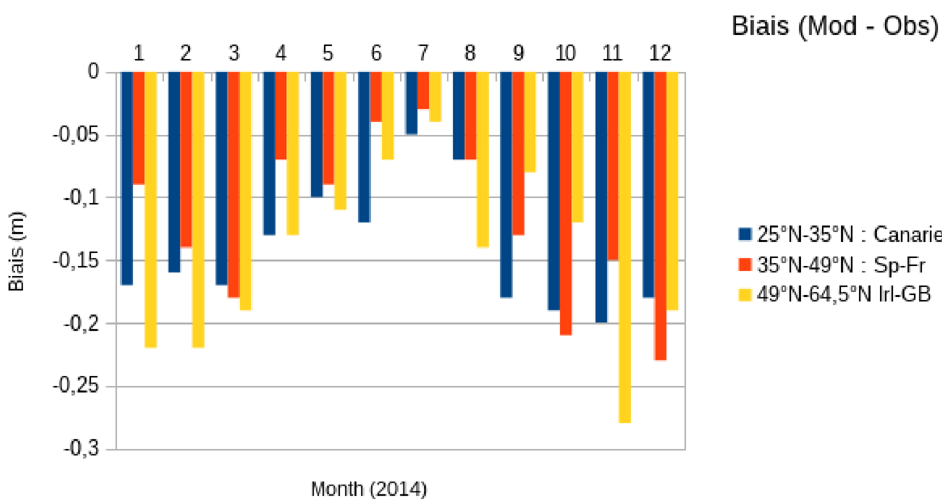

Figure 8 : monthly variations of statistical parameters during 2014. (a) and (b) stand for normalized scatter index of SWH and bias, respectively. Blue, red and yellow histogram bars indicate zone 1, zone 2 and zone 3, respectively.

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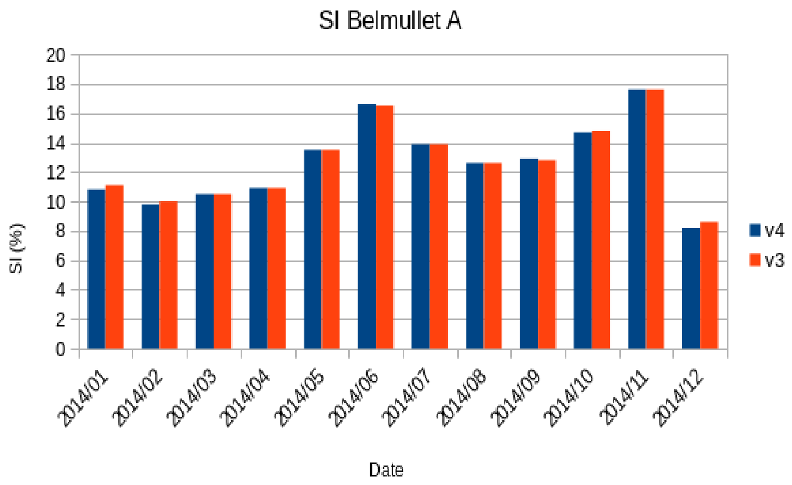

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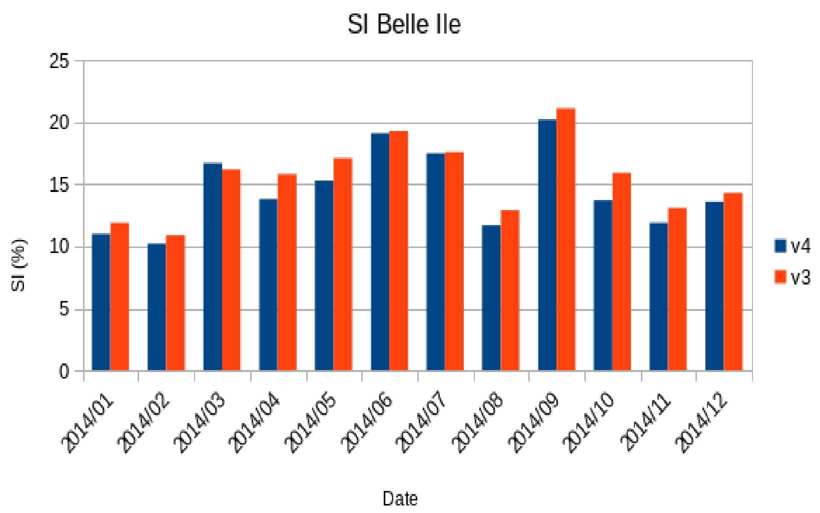

Figure 9 : Monthly variation of normalized scatter index of SWH during 2014 at buoys BelmA in (a) and Belle ile in (b). Red and blue histogram bars stand for MFWAM-V3 and MFWAM-V4, respectively.

	Cds	Su	βmax	Tail Factor
MFWAM-V3	$-2.8\ 10^{-5}$	0.6	1.52	9.9
MFWAM-V4	$-2.6\ 10^{-5}$	0.4	1.48	4.0

Table 1 : Values of the model settings of MFWAM V3 and V4 versions.

Buoy name	Location	Reference code	Nationality
Bilbao Vizcaya	43.64°N 3.05°W	Bilb	Spanish
Cabo de Gata	36.57°N 2.32°W	CGat	Spanish
Cabo de Palos	37.67°N 0.33°W	CPal	Spanish
Cabo Penhas	43.75°N 6.16°W	CPen	Spanish
Cabo Silleiro	42.12°N 9.43°W	CSil	Spanish
Drogonera	39.56°N 2.10°E	Drog	Spanish
Estaca Bares	44.12°N 7.67°W	EBar	Spanish
Golfo de Cadiz	36.48°N 6.96°W	GCad	Spanish
Gran Canaria	28.20°N 15.80°W	GCan	Spanish
Tarragona	40.68°N 1.47°E	Tarr	Spanish
Tenerife	27.99°N 16.58°W	Tene	Spanish
Valencia	39.52°N 0.21°E	Vale	Spanish
Villano Sisargas	43.3°N 9.12°W	Vill	Spanish
Santander	43.50°N 3.46°W	Sant	Spanish
Belle Ile	47.30°N 3.30°W	BI	French
Pierre Noire	48.30°N 5.00°W	PN	French
Plateau du Four	47.20°N 2.80°W	PF	French
Belmullet A	54.28°N 10.27°W	BelmA	Irish
Belmullet B	54.23°N 10.14°W	BelmB	Irish

Table 2 : Name, location, nationality and reference code of the moored buoys.

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	MFWAM-V3	MFWAM-V4
Scatter Index (%)	12,6 %	12,5 %
Bias (m)	-0,15 m	-0,15 m

Table 3 : Scatter index and bias for year 2014 and for the two versions of MFWAM.

	MFWAM-V3			MFWAM-V4		
	Zone 1	**Zone 2**	**Zone 3**	**Zone 1**	**Zone 2**	**Zone 3**
SI (%)	12.4	12.7	12.4	12.3	12.6	12.3
Bias (m)	-0.18	-0.12	-0.16	-0.18	-0.12	-0.16

Table 4 : Normalized scatter Index and biases of SWH from MFWAM V3 and V4 during 2014 for the ocean domains described on Figure 7.