Implementation of the new French operational coastal wave forecasting system and application to a wave-current interaction study

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I. Introduction

The modelling of key physical processes affecting waves in coastal zones requires the use of wave models at high spatial resolutions. This is possible with nesting approaches, or with the implementation of variable resolution grids, like curvilinear or non-structured grids.

In the framework of the "HOMONIM" research project (History, Observation, Modelling sea levels, a joint project with SHOM and Météo-France, supported by the French Ministry of Ecology and Sustainable Development), the second approach was used to develop and implement an operational forecasting capacity of sea states, current and water level in the French coastal areas (Atlantic ocean and Mediterranean sea). In this paper, we focus on the sea state aspect. The Wavewatch III © (WW3, Tolman 2014) model is implemented to extend on the coastal zones the MFWAM (Lefèvre et al., 2011) model already used operationally at regional scale. Two unstructured grids were created on the Atlantic and Mediterranean facades.

The main goal of this study is to present the performance of this new coastal wave forecasting system. The second objective is to study the impact of the wave-current interactions on wave and water level on these operational configurations. Thus, a case study on the Xynthia storm[1] is presented where we use in a first attempt the two operational grids of wave and current. We then improve the experiment by refining the configurations around the Pertuis-Charentais area, through a coupled and embedded approach using the OASIS coupler and the circulation model HYCOM (Bleck, 2002, Baraille and Filatoff, 1995).

The wave model, the parameterizations and the configurations are described in part II, the performances of the model are then presented in part III. In Part IV, the wave/current interactions during the Xynthia storm are discussed. Finally, some perspectives and source of improvements are presented in part V.

II. Methods

The operational wave model MFWAM of Meteo-France is currently used for the forecast at regional and global scales with a resolution grid of 0.1°. It provides the boundary conditions to WW3 at the external borders of the coastal high resolution unstructured grids. The recent developments in WW3 (version 4.18) of parameterizations in shallow waters like wave breaking or bottom friction (Ardhuin et al., 2010) have extended the validity of this model from the regional scale to the nearshore scale. Two unstructured

[1]: a violent European windstorm which crossed Western Europe between 27 February and 1 March 2010, that has generated a storm surge of 7.5 m responsible for the death of 47 persons in France in Pertuis-Charente

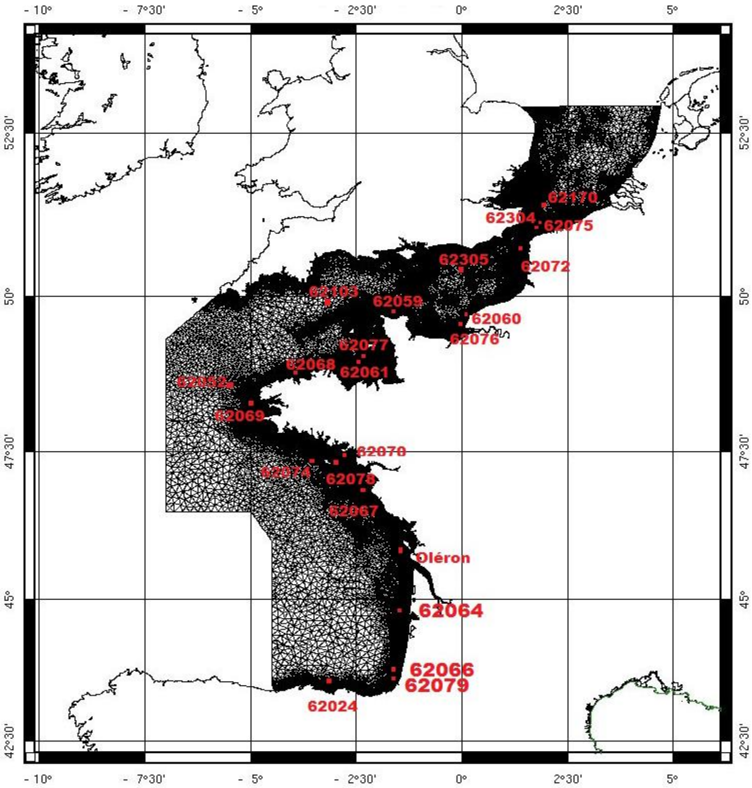

Figure 1: The NORGAS-UG mesh. Positions and names of buoys are written in red.

meshes ranging from 10 km resolution up to 200 m off the coast have been implemented respectively on the French Atlantic and Mediterranean coasts.

In the Atlantic and on the Mediterranean facades, two unstructured meshes were built (respectively NORGAS-UG with 92757 nodes (Figure 1) and MED-UG with 89695 nodes (Figure 2)). Their coverages fit the area of the atmospherical high-resolution model Arome of Météo-France. Meshes were generated with Polymesh © (the mesh generator developed by A. Roland (T.U. Darmstadt)), with CFL and DZ criteria, and the use of polygons to refine the grid resolution over the areas of particular interest. Bathymetries were created, combining measurements of SHOM and Ifremer and in particular LiDAR measurements of 5 m of resolution (Biscara et al., 2014).

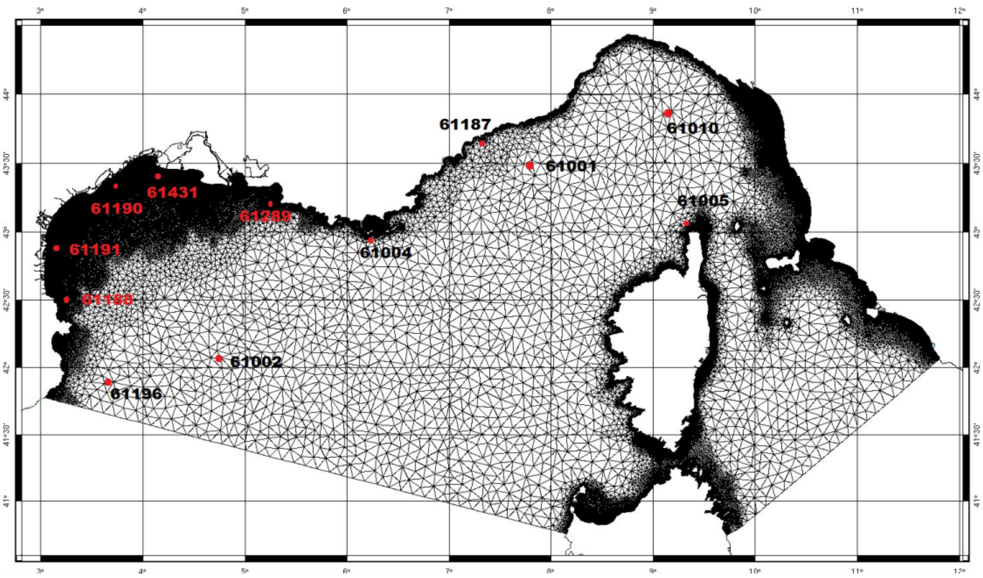

Figure 2: The MED-UG mesh

The physical parameterizations corresponding to TEST 451 (Ardhuin et al., 2010) and TEST 405 are used respectively for NORGAS-UG and MED-UG. These two tests are modified to take into account some coefficients in the wind source and dissipation terms described in Janssen et al. (2014), and to be coherent with the version TEST 463, implemented in the operational wave model MFWAM since November 2014. The different versions are described in table 1 (see Ardhuin et al, 2010 for further informations). Comparisons with measurements from altimeters and wave buoys have showed that bias and scatter index of wave height were reduced in MED-UG using parameters from TEST 463 presented in Table 1 (Dalphinet et al., 2015). The spatial propagation uses the implicit N scheme (Roland, 2009).

For both configurations, wave spectrum is discretized on 24 directions and 30 frequencies exponentially spaced from 0.0345 Hz to 0.5473 Hz at an increment of 10%. The model is forced by the operational Meteo-France Arpege wind model at a resolution of 0.1° with a time step of 3 hours. A map of median grain size

TEST	405	451	463
C_{ds}	-2.2	-2.2	-2.8
S_u	0	1	0.6
β_{max}	1.55	1.52	1.52
$z_{0,max}$	0.002	0.0	0.0
Br	0.00085	0.0009	0.0009
f_{FM}	2.5	9.9	9.9

Table 1: Differences between the parameterizations used for the 2 meshes. We use TEST405 for MED-UG and TEST 451 for NORGASUG. We only modify these 6 parameters in our parameterizations by taken ones of TEST463.

has been established from the SHOM database (Garlan 1995, 2009, 2012) for the two configurations. As suggested by Roland and Ardhuin (2014), we prescribed for NORGAS-UG and MED-UG the bottom friction parameterization created from the "SHOWEX" experiment (Ardhuin et al., 2003a) instead of the classical empirical linear Jonswap parameterization (Hasselmann et al. 1973), and a constant Nikuradse roughness length of 12 cm is applied for rocks.

III. Performances of the operational configurations

Both configurations are assessed on real storm cases of the last decade and also on a simulation running from July 2011 to June 2012. Validation is performed by comparing simulation results to wave buoys of Météo-France, SHOM, Cerema and buoys of neighboring countries, and altimetric data for the one-year simulation (Jason 1/2, Envisat). The performances of the reference configurations are given in Table 2, showing a good correlation coefficient (Corr) comprised between 93 and 99 %.

Configuration	Satellite/buoy	Bias	RMSE	SI	CORR
MED-UG	ENVISAT	-0.002	0.235	0.134	0.988
	JASON1	0.027	0.231	0.132	0.989
	JASON2	-0.025	0.229	0.154	0.986
	All Buoys	-0.005	0.194	0.111	0.937
NORGAS-UG	ENVISAT	0.006	0.210	0.109	0.988
	JASON1	0.01	0.222	0.115	0.989
	JASON2	-0.026	0.207	0.104	0.992
	All Buoys	0.0426	0.151	0.172	0.956

Table 2: Performances of the two reference configurations

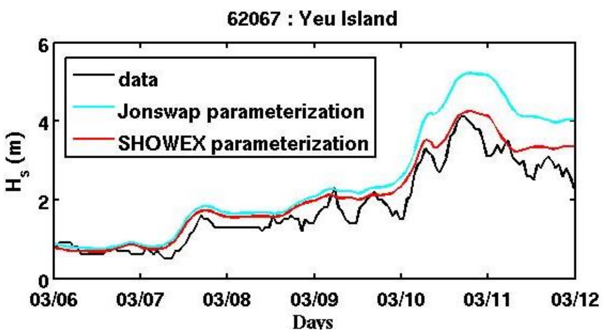

Figure 3: Impact of bottom friction parameterization and rocky platform at Yeu Island.

The movable bed friction using medium sand grain sizes has little impact on wave results at buoys, which are often located at a depth over 20 m, and on altimeter tracks. It gives better results at nearshore scale and over rocky platforms such as Yeu Island (Atlantic) and near the Aresquiers Platform (Mediterranean coasts). At Yeu Island (buoy 62067), the SHOWEX parameterization and a constant Nikuradse roughness length of 12 cm for the rocks allow to match the data better than the JONSWAP parameterization (Roland and Ardhuin, 2014), which led to an overestimated Hs on the Johanna storm (March 2008) (Figure 3). This parameterization was also applied for the Mediterranean Sea but only affects very nearshore sandy or rocky areas (Figure 4).

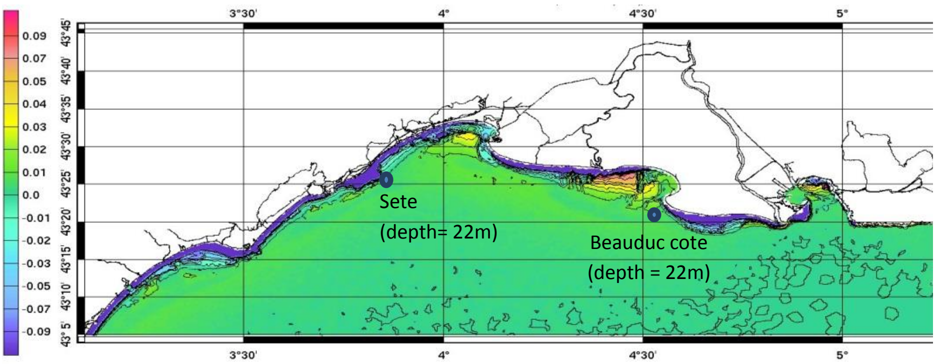

Figure 4: Difference in significant wave height (in m) at the storm apex between a model run using the JONSWAP bottom friction parameterization and another using the SHOWEX parameterization.

IV. Impact of currents and water level on waves

At coastal scales in the oceans, waves are influenced by strong tidal currents and water level modulation. We assess the impact of currents and water level on the NORGAS-UG configuration during the real storm test cases and in particular for Xynthia storm. The methodology chosen is the following: in a first guess, we use the barotropic circulation model HYCOM on the Atlantic configuration that is operationally run in the Meteo-France storm surge forecast system (Pasquet et al., 2014, Figure 6). The circulation model forces the wave model in a 1-way mode using the OASIS coupler (Valke et al., 2015). Since the resolution of the circulation grid is around 800m at nearshore scale, a second study is performed on the Pertuis-Charentais region using nested grids for both models with resolutions reaching 30 m and using OASIS in a 2-way mode.

1. A one way forcing between circulation and wave models

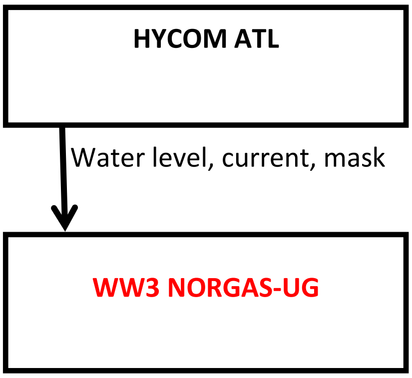

Figure 5: the 1st modeling strategy

For the first experiment, we force the NORGAS-UG configuration by the HYCOM ATL configuration using the coupler OASIS (Figure 5). The HYCOM grid sends to WW3 the current, water level and mask variables every 450 s. The HYCOM grid is curvilinear, and has a resolution ranging from 2 km to 500 m nearshore. The HYCOM model is used in a

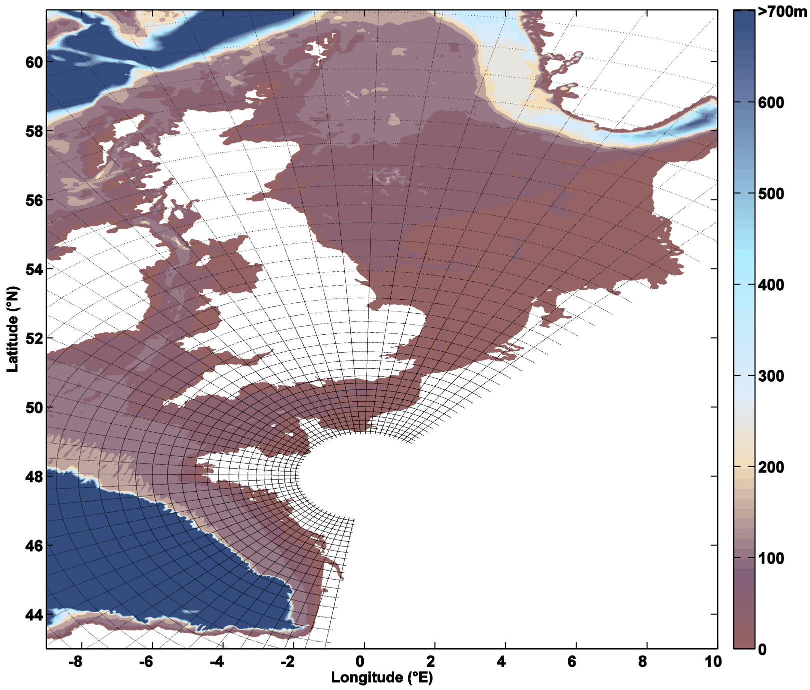

Figure 6: The HYCOM operational circulation grid for Atlantic (ATL). Only one contour each twenty contours is shown.

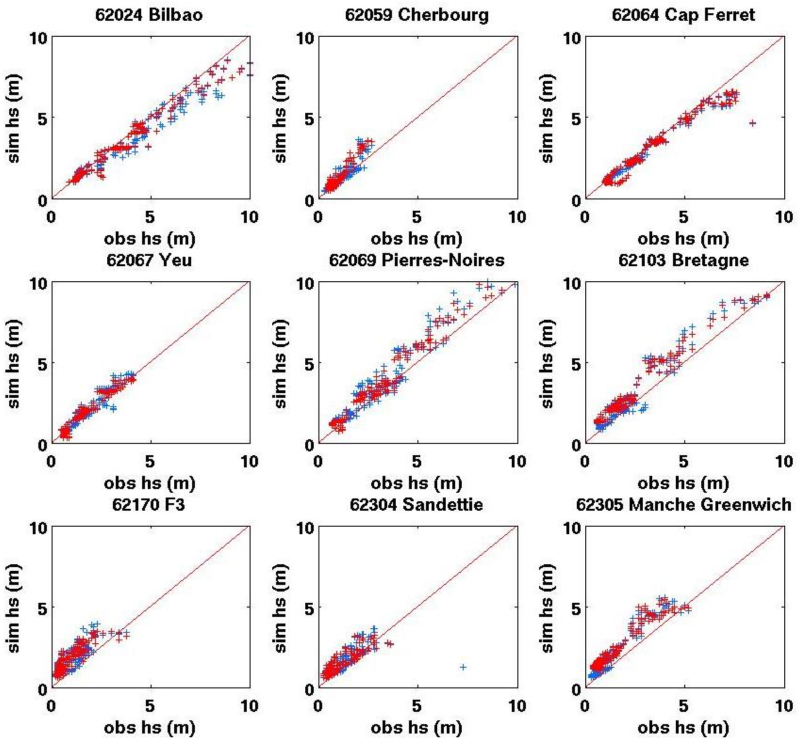

Figure 7: Scatter diagram of H_s at the different buoys for Johanna storm (03/2008). In blue the results without the HYCOM forcing and in red with the HYCOM forcing.

barotropic configuration. This experiment is done for Xynthia storm but also for all the other hindcasts of real storm cases of the last decade that are used to assess the performance of our grid in part III.

The correlation coefficient is increased at some buoys like Yeu (62067), Pierres Noires (62069) or Cherbourg (62059), which are in zone where tides have a great influence on circulation. For instance during Johanna storm (Figure 7), the correlation coefficient for Hs increases from 0.90 to 0.96 for Cherbourg buoy and from 0.69 to 0.85 for Manche Greenwich. This is however not so obvious for every storm. For Xynthia storm, the influence of the forcing is minor. However, this could be explained by the fact that the current of HYCOM is barotropic whereas we should have chosen a surface current, which is not possible with the operational model.

If we look at the Pertuis-Charentais zone (Figures 8 and 9) for the Xynthia storm, significant wave heights are modified, depending on the phase of the tide, and differences can reach 30 cm (for point5, see Figure 9). At the Oleron buoy, the difference is minor with or without the current effect and the two simulations fit the measurements (Figure 10). However, to have a better representation of the phenomena in this area, it is important to use grids with a better resolution than the operational ones.

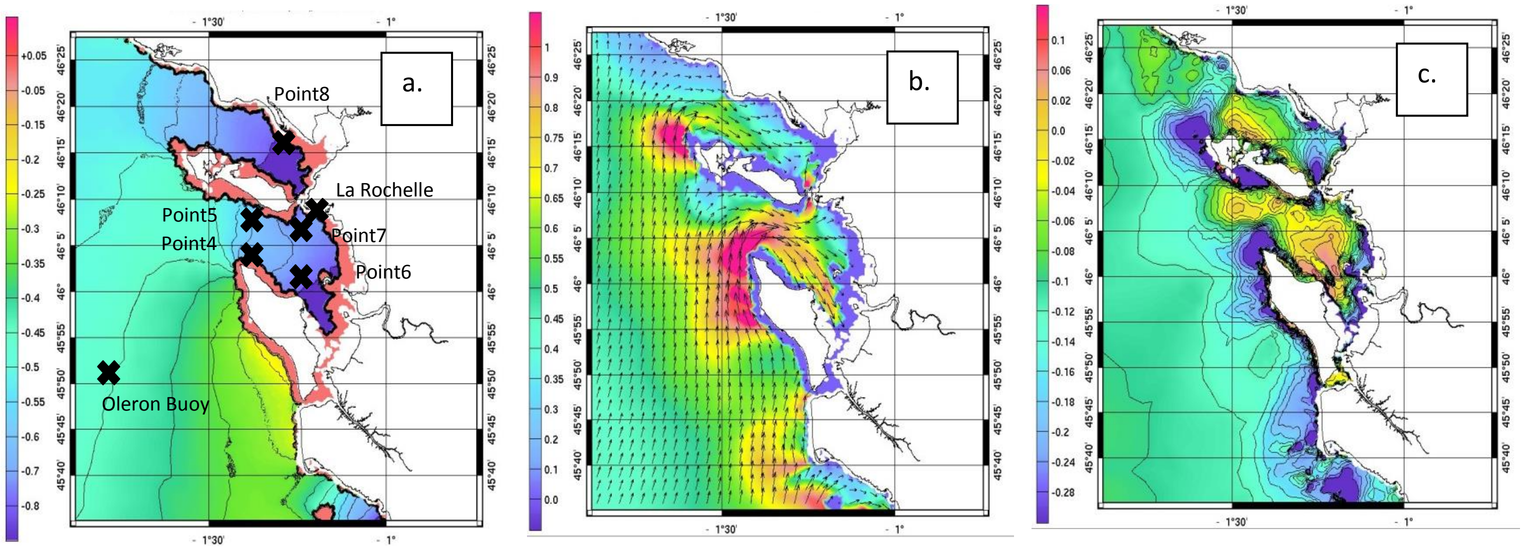

Figure 8: a. Sea surface height (in m), b. barotropic currents (in m/s) and c. difference in significant wave height (in m) between a simulation with the HYCOM forcing and without on 02/27 at 11 p.m.

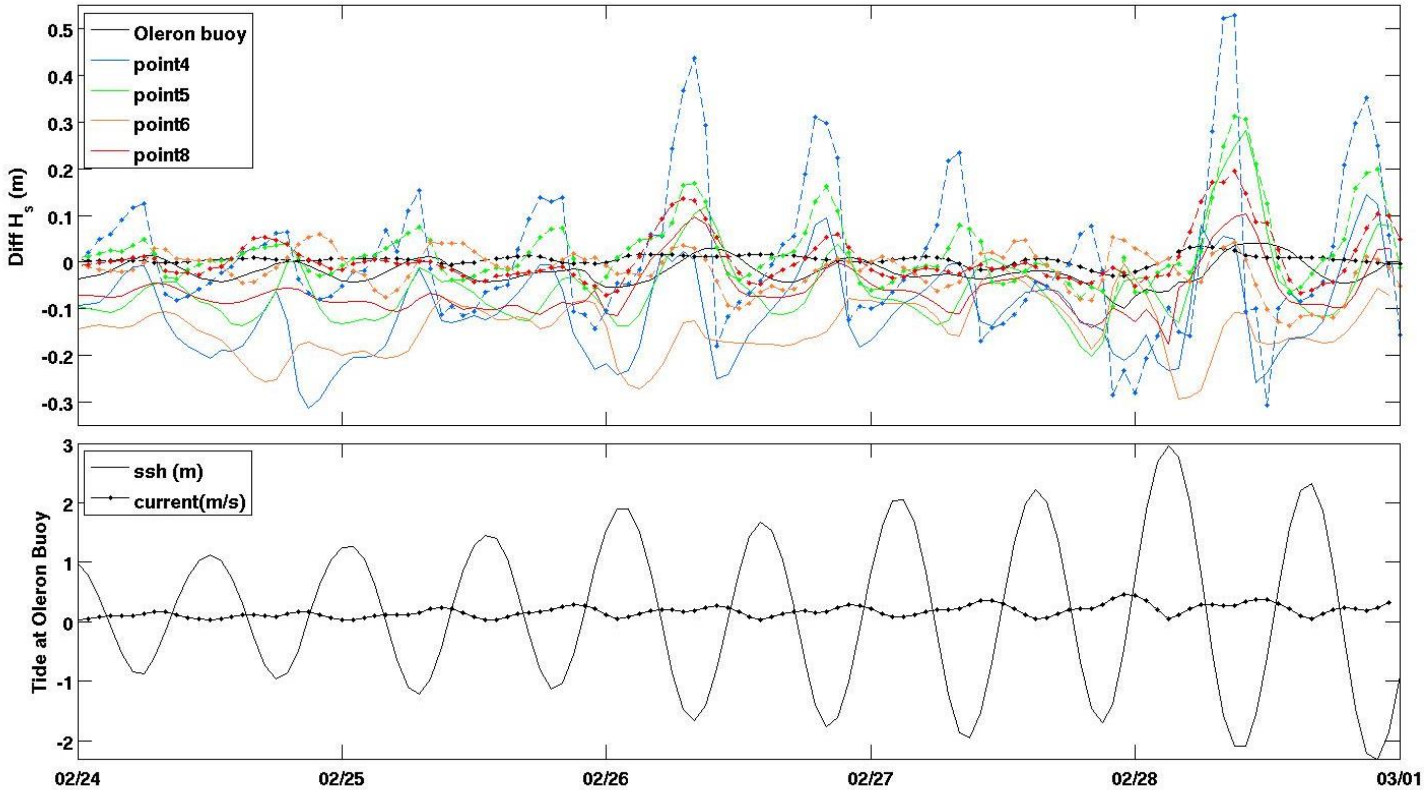

Figure 9: (Up) Effects of current and water level on significant wave heights. Diff hs is the difference of significant wave height between a simulation with the forcing of the circulation model and without, for the full line with the NORGAS-UG simulation and for the dashed lines with the Charente simulation. Positions of the different points are shown in figure 6. (Bottom) ssh and current at the Oleron Buoy.

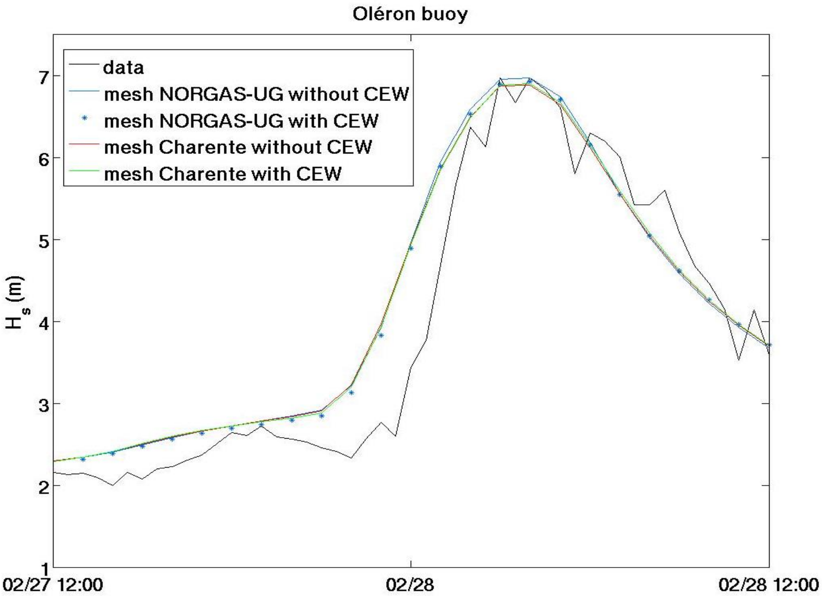

Figure 10: Comparison of simulations at the Oleron Buoy with the data. CEW = current effects on wave

2. *A two way coupling between embedded circulation and wave models*

A second study is then performed, the objectives are to refine the resolutions of our grids and study the impact of a one way and a two way coupling. A mesh called WW3-Charente is generated with 50367 nodes with Polymesh, with a resolution of 20 m near the coasts and islands (Figure 12) around the Pertuis-

Charentais. Three grids are built for the Hycom model, with resolutions going from 100 m to 30 m. A dedicated bathymetry is created for this study with a resolution of 5 m (Biscara et al., 2014).

Three simulations are performed:

- the REF simulation: the wave model is not used, and only the 4 HYCOM grids are run (black arrows in Figure 11). Every HYCOM zone is forced in elevation by the superior zone using OASIS, every 360s. On the Pertuis-Charentais area, thanks to this embedded approach, the resolution goes from 1.2 km (ATL) to 30 m (zone4).
- the 1-way simulation (black and green arrows in Figure 11): it is the REF simulation, including a wave forcing of current (WEC) at the zone4, every 10 min. The wave forcing theory used is the one of Ardhuin et al. (2008); Michaud et al. (2012) (equations are integrated since we use a barotropic configuration of HYCOM). The wave parameters are calculated on the Charente mesh which is forced by spectra from the NORGAS-UG configuration.
- the 2-way simulation (black, green and orange arrows in Figure 11): we add to the 1-way simulation a forcing of currents on waves (CEW). The currents are calculated in zone 3 and given to the wave model.

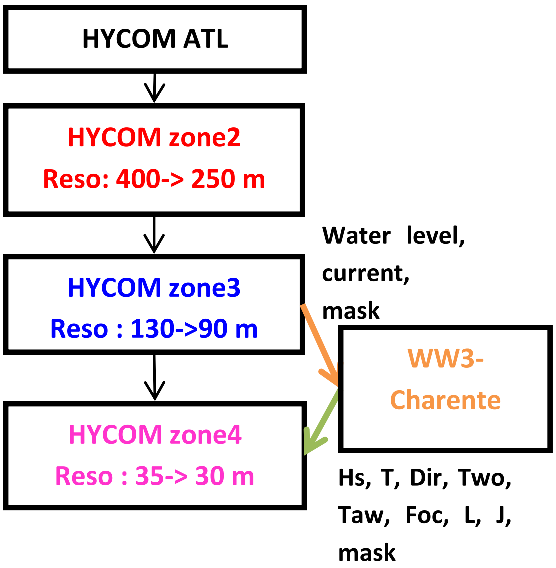

Figure 11: The 2nd modeling strategy

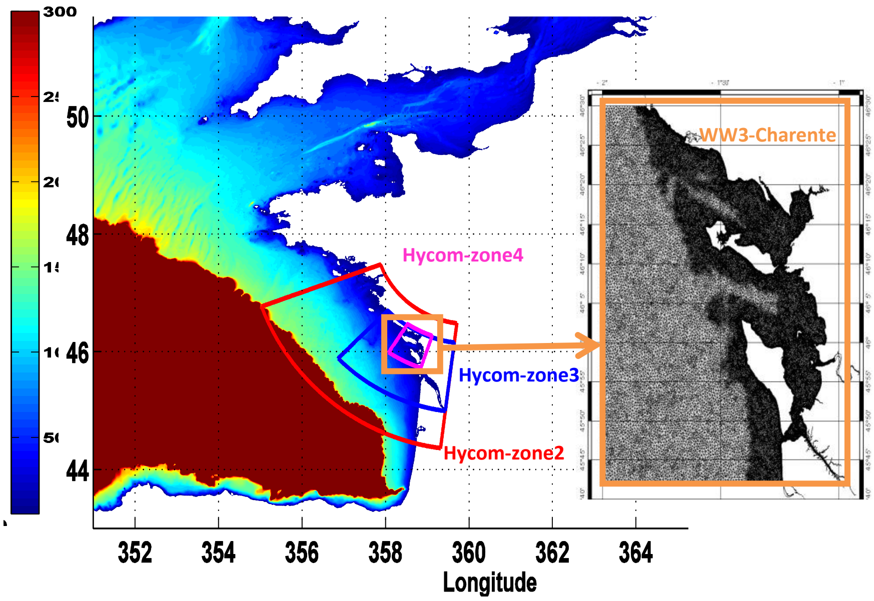

Figure 12: Coverage of the different HYCOM grids and the Charente mesh.

The impact of current on waves is assessed through the study of the 2 way and the 1 way simulations. It is still negligible at the Oleron buoy (Figures 9 and 10), as in the first study. Figures 13 and 14 show that the current influences waves in the entire coastal zone, at low and high tides. In onshore locations, the wave and circulation grid refinements allow to observe differences of up to 50 cm between a simulation with CEW and without (point 4, Figure 10), instead of the little 10 cm obtained with the NORGAS-UG configuration. However, measurements in this nearshore area are missing to assess the validity of these results.

The effects of waves on water level are mainly represented by a set down in the nearshore region (Figure 16). A comparison at the tidal gauge of La Rochelle (location is shown in Figure 8.a.) shows however that all the simulations have an underestimation of the SSH around 25 cm, and it is worse with the WEC (Figure 15). Besides, the CEW has a very limited impact on the SSH. Increasing the resolution of our grids, using the 3D version of HYCOM and taking into account the wave roughness of sea surface by adding the charnock parameter in the coupling (which can be responsible of a wave setup) can be potential sources of improvements. Nicolle et al (2009) have for instance shown that the peak surge in the night on 23–24 October 1999 has been amplified inside the Pertuis Charentais by about 20 cm due to the wind-wave interactions with the tide-surge currents.

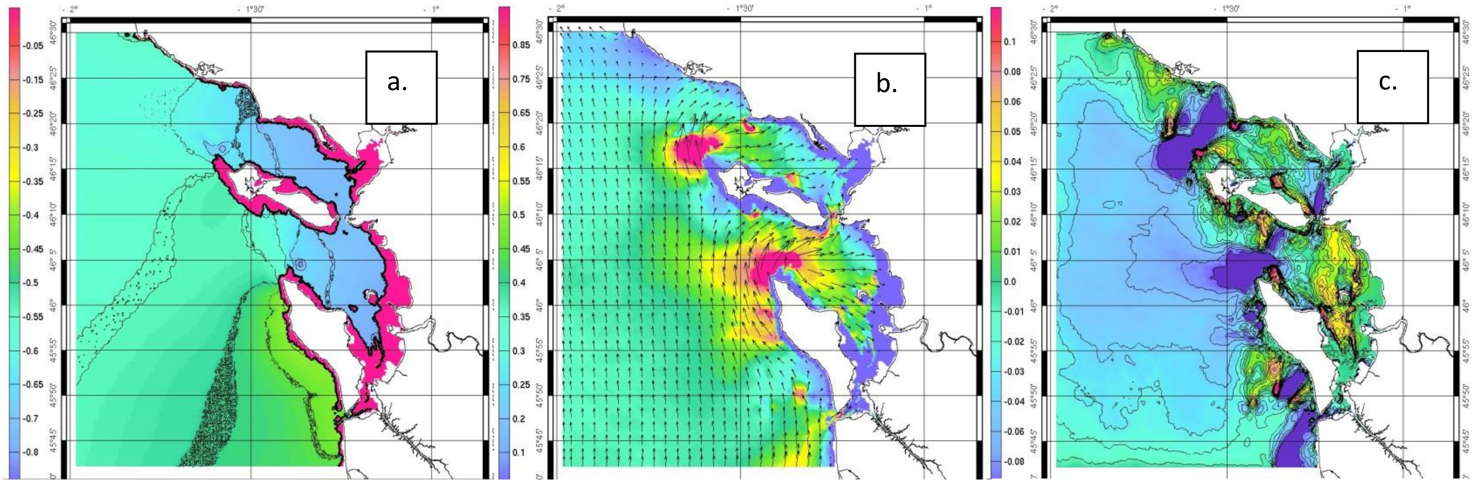

Figure 13: a. Sea surface height (in m), b. barotropic currents (in m/s) and c. difference in significant wave height (in m) between a simulation 2 way and 1way on 02/27 at 11 p.m (low tide).

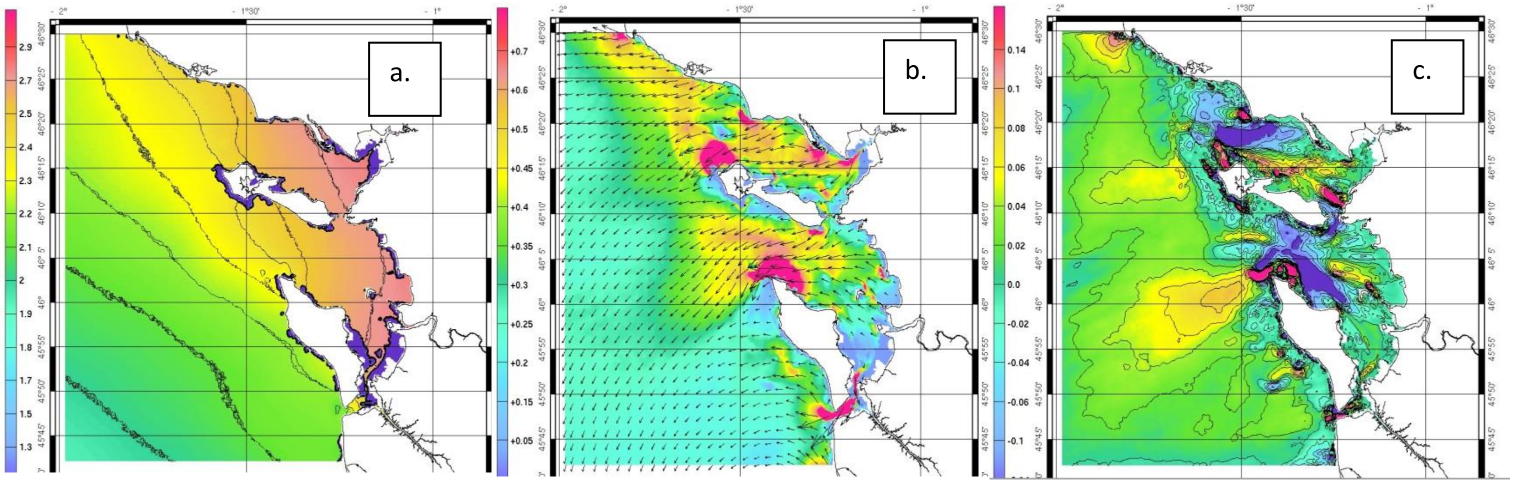

Figure 14: a. Sea surface height (in m), b. barotropic currents (in m/s) and c. difference in significant wave height (in m) between a simulation 2 way and 1way on 02/28 at 5 a.m (high tide).

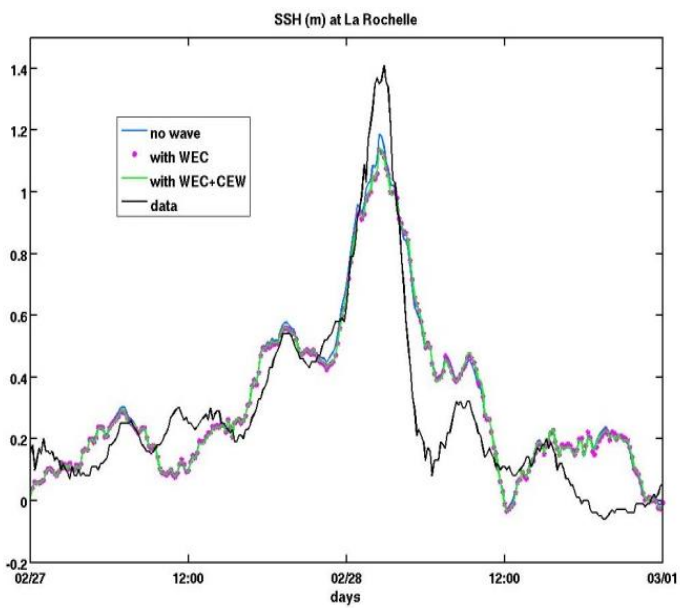

Figure 15: SSH at la Rochelle

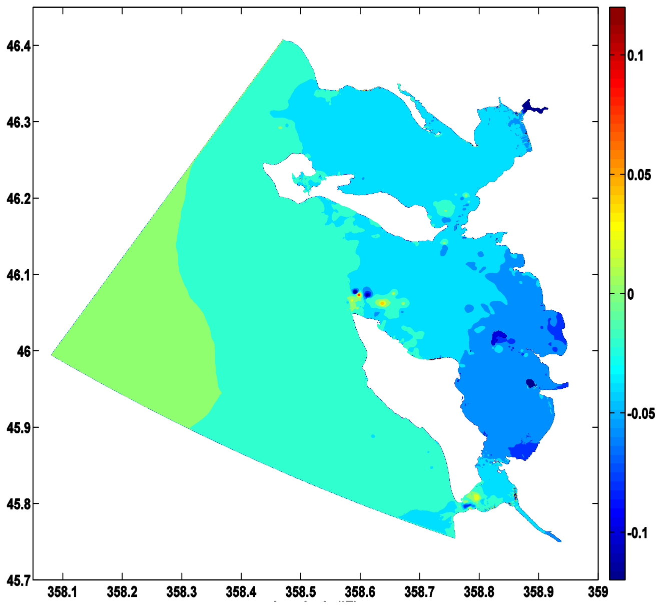

Figure 16: Difference of SSH (in m) between the 2way simulation and the REF simulation on 02/28 at 3 a.m.

V. Conclusions & Perspectives

We have presented in this paper the new French operational coastal wave forecasting system and assessed its performances. A study on the impact of the wave-current interactions on these operational configurations is then described. We improved the experiment by refining the configurations around the Pertuis-Charentais area, through a coupled and embedded approach using the OASIS coupler and the circulation model HYCOM. Some discrepancies are nevertheless observed when regarding at the sea surface height at a tidal gauge during the Xynthia storm. To improve the results, future works will focus on the following aspects: implement the HYCOM 3D model in this coupling strategy and add the Charnock parameter in the coupling parameters. Another study on the Iroise Sea during the 2013-2014 winter storms will also be performed, since an intensive field campaign with measurements of wave, current and water level was conducted (PROTEVS campaigns).

Acknowledgements

This study is part of the Homonim project supported by the French Ministry of Ecology and Sustainable Development. We thank all the members of the Homonim team. We are also grateful to CEREMA and CERSAT for providing buoy measurements and altimeter data.

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