On the use of a high resolution wind forcing in the operational coastal wave model WW3

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Abstract

In the framework of the project HOMONIM, the wave model Wavewatch III (WW3) has been implemented at Météo-France for sea state forecasting on the french Atlantic and Mediterranean coasts. The model uses an unstructured grids up to a resolution of 200 meters. The model WW3 uses a dissipation source terms updated from the the recent work developed in the project “My wave” (See Aouf et al. 2014). The WW3 model is run daily in operations since March 2015. The goal of this study is to evaluate the impact of using a better wind resolution from the atmospheric model AROME in the wave model WW3. The operational coastal model WW3 is driven by winds from the atmospheric model ARPEGE of Météo-France with a resolution of 0.1°. The consequences of using a convective-scale model for winds in coastal wave models are not well-known, in particular for storms generated in west Mediterranean sea. The atmospheric model AROME is upgraded on April 2015 with improvement of the horizontal resolution up to 1,3 km and the vertical resolution (90 levels instead 60), in particular for the first layers.
Runs of the wave model WW3 have been performed on selected events and during few months with 0,1° and 1,3 km wind forcing. The significant wave heights from the runs have been validated thanks to the buoys and altimeters from Jason-2 and Saral/Altika.
The results showed a better estimate of mean wave parameters when AROME winds are used. It is also well identified that wave patterns are better described in strong dynamical systems in particular near the french Mediterranean coasts.

1 Introduction

High sea state and storm surge can cause severe damages near the shore. For the safety of people and industrial activities in coastal areas it is important to improve the sea state forecast under severe storm conditions. This is one of the main goals of the research project HOMONIM, conducted by Météo-France and SHOM since 2012, with the support of the french sustainable development ministry[1]. The project leads to the implementation of a high resolution wave model in operations at Météo-France for coastal applications.
Since 2011 Météo-France runs a global third generation wave model MFWAM, with nested regional versions. The model is based on the ECWAM code (IFS-38R2) with the wave breaking dissipation and swell damping by air-friction source terms developed by Ardhuin et al. (2010). The model MFWAM is updated on November 2014 with adjustments on the dissipation terms in order to improve the sea state dependency of the stress at the sea surface (Aouf et al. 2014). The global model MFWAM is among the best wave models regarding to the JCOMM/WMO monthly intercomparison with open sea buoys data developed by Jean Bidlot from ECMWF. The finer nested model MFWAM goes up to a resolution of 0,025° on the French coasts (Atlantic and Mediterranean sea). In order to complete such forecasts to the shore, the model WaveWatch III (WW3) developed by NOAA/NCEP (Tolman, 2002) with a resolution of 200 meters has been implemented. The model has the advantage of using irregular grid implemented by Roland (2009) and also the same physics of the model MFWAM (Ardhuin et al., 2010). The model WW3 runs operationally since March 2015 with a wind forcing from the atmospheric model ARPEGE with a resolution of 0.1°.
Since April 2015, a new version of the atmospheric model AROME has been implemented in operations and it highly improves the resolution, horizontally from 2,5 to 1,3 km and vertically by 1.3 times. The lowest level becomes 5 meters instead of 17 meters in the former version. The assimilation of observations is also improved and becomes hourly and the runs go to 42-hours forecast. The better

representation of the first layers of the atmosphere should improve the sea state description at the sea surface.
The first section of this paper describes briefly the configuration of WW3 and the difference between the two tested wind forcing. Runs of WW3 with both wind forcing were performed over 3 months from May until July 2015. The validation of model outputs with altimeters and buoys data is discussed in section 2 separately on Atlantic and Mediterranean sea. high sea state events and significant discrepancies from the two runs are commented in section 3. Finally conclusions and future works are discussed in section 4.

2 unstructured WaveWatch III

WaveWatch III (version 4.18) has been developed following the WAM model development, but with different code structure and numerical methods for propagation (Tolman, 2002). WW3 uses as wind input term the parametrization described by Janssen (1991) that assumes that even for young wind sea the wind profile has a logarithmic shape. The nonlinear wave interactions source term is given by the discrete interactions approximation developed by Hasselman et al. (1985). The wave breaking dissipation and swell damping by air-friction source terms are issued from Ardhuin et al. (2010) with an adjustement developed in the EU project (Aouf et al 2014). The model takes into account an unified parametrization of wave breaking from open sea up to coast (Filipot et Ardhuin, 2012), coast reflection (Ardhuin et Roland, 2012), refraction due to current and bathymetry (Ardhuin et al, 2012) and bottom friction.
The model WW3 is set for an irregular grid, from few kilometers in deep sea to 200 meters on the coast. An example of mesh grid is shown on figure 1 for the Mediterranean sea. This particularly fits well the distorted coastlines such as the Mediterranean and Brittany ones. The model WW3 is forced by the wave spectra of the nested model MFWAM with a grid size of 0.1° at boundaries. In this study two wind forcing from the atmospheric models ARPEGE and AROME have been tested.

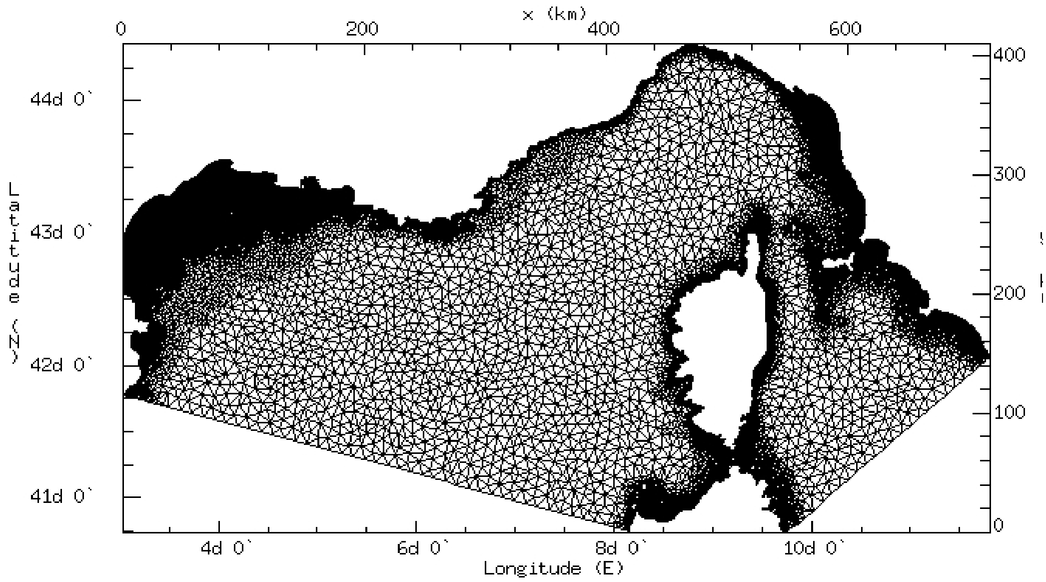

Figure 1 **: irregular mesh covering Mediterranean french and north western Italian coast used as grid by WW3**

The winds provided by a convective-scale model are well skilled to describe sea state generated by storms in the west Mediterranean sea. The atmospheric model AROME is in operations since 2008. The model has a non-hydrostatic dynamical core with a 3D VAR data assimilation scheme. Since April 2015 the model AROME is upgraded inducing a better horizontal resolution up to 1,3 km and the vertical resolution (90 levels instead 60), in particular for the first layers.
The first run of WW3 called run 1 uses the ARPEGE wind forcing with a resolution of 0.1°, while the second run called run 2 is driven by AROME winds with a resolution of 0.025°. The resolution of the wave spectrum is 24 directions and 30 wave numbers. Both runs have been performed from May until July 2015.

2 Validation with wave observations

The 3-hourly significant wave heights from the model runs are compared with those provided by altimeters Jason 2 and Saral/Altika. The altimeters wave data are controlled and projected over regular grid size of 0.1°. In this study we recall that the regional model MFWAM providing the boundary conditions for the model WW3 is not using any assimilation of altimeters data. The model outputs have also been compared to coastal buoys data managed by CEREMA[3]. These observations are located close to the shore (see figure 2) and will be complementary to altimeters data.

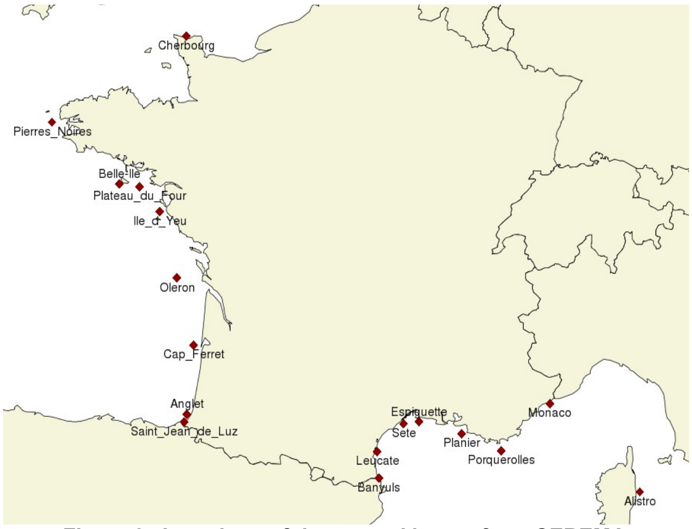

Figure 2 **: Locations of the coastal buoys from CEREMA.**

Table 1 shows the statistics of significant wave heights from the model and altimeters. It is indicated that same bias and root mean square errors (RMSE) are observed for both runs 1 and 2 in the Atlantic domain. A slightly better normalized scatter index of wave heights is obtained for the run 2. For the Mediterranean sea the statistical analysis reveals clearly a significant reduction of the bias and RMSE of wave heights for run 2, as shown in table 1. the scatter index of wave height is improved by roughly 17% when WW3 is using AROME winds (run 2). Figures 3a and 3b show the scatter plots between significant wave heights from the model and altimeters for the Mediterranean sea. It is clearly shown that the slope is well improved when WW3 is using the AROME winds.

	French Atlantic coast		
	Bias (m)	**RMSE (m)**	**Scatter index (%)**
Run 1	0,11	0,30	16,7
Run 2	0,11	0,30	16,4
density	1640		
	French Mediterranean coast		
	Bias (m)	**RMSE (m)**	**Scatter index (%)**
Run 1	0,07	0,35	23,1
Run 2	0,01	0,29	19,2
density	626		

Table 1 **: statistical analysis of significant wave heights from the model and altimeters from May until July 2015. RMSE stand for the root mean square errors and the scatter index is the normalized standard deviation.**

When wave heights are over 6 meters on Atlantic ocean in the 3 months period corresponding to the event on 14th May, the run 2 using AROME winds gives better results than the run 1. This situation will be discussed hereafter.

Table 2 shows the statistics of significant wave height from the comparison between the model and buoys for the Atlantic ocean. We can see the same trend as for the comparison with altimeters. The bias and RMSE are almost similar while the scatter index of significant wave height is slightly better for the run 2. This improvement is more pronounced for the buoys at the gulf of Biscay (Oléron, Cap Ferret, Anglet and Saint-Jean de Luz). In other respects, table 3 indicates the statistical analysis of significant wave height for the Mediterranean coast. The comparison with buoys confirms the trend that using AROME winds (run 2) improves significantly the estimate of wave heights. The RMSE errors are reduced for all buoys and also the scatter index is improved by more 10%.

Buoy	Bias (m)		RMSE (m)		SI (%)	
	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2
Cherbourg	0,1	0,11	0,18	0,18	27,6	27,1
Pierres Noires	0,32	0,34	0,46	0,48	21,3	21,6
Belle Île	0,2	0,23	0,31	0,32	17,7	17,2
Plateau du Four	0,15	0,15	0,25	0,24	20,6	19,7
Ile d'Yeu	0,21	0,21	0,28	0,29	20,1	20,4
Oléron	0,21	0,22	0,32	0,31	17,7	16.4
Cap Ferret	0,16	0,18	0,31	0,3	20,3	17,9
Anglet	0,17	0,2	0,29	0,28	20,6	18
Saint Jean de Luz	0,09	0,11	0,23	0,22	17,6	16,4

Table 2 **: statistical analysis of significant wave height for the comparison between model and buoys for the Atlantic ocean (period from May until July 2015).**

a) ***b)***

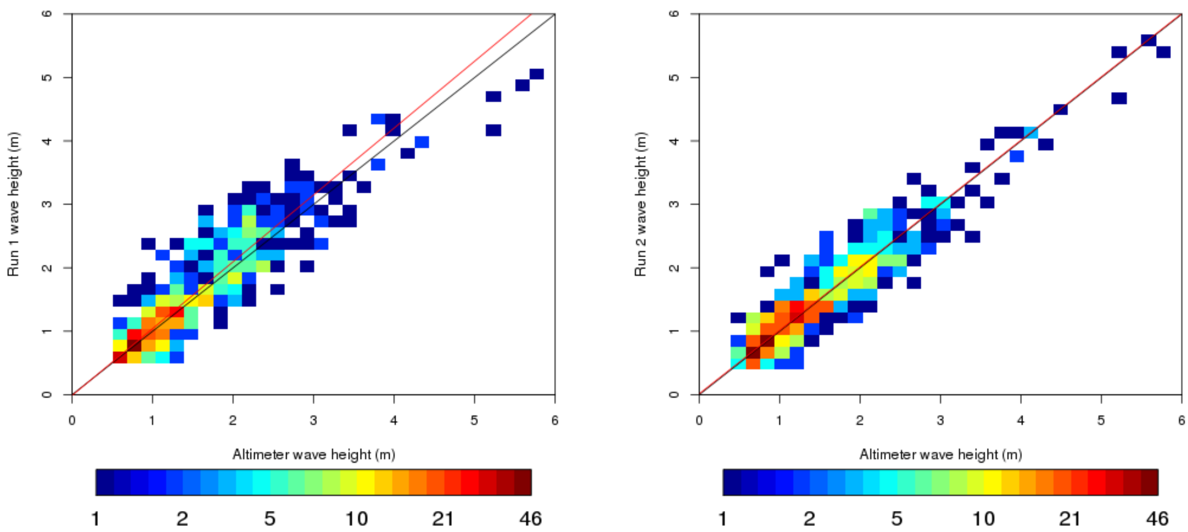

Figure 3 **: Scatter plot of significant wave heights from the model and altimeters for the Mediterranean coast from May until July 2015. (a) and (b) stand for run 1 and run 2, respectively. The red line shows the slope between model and altimeters. The slopes are 1.05 and 1 for ARPEGE and AROME wind forcing, respectively.**

Buoy	Bias (m)		RMSE (m)		SI (%)	
	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2
Lion	0,0	0,0	0,25	0,22	35,6	31,0
Azur	0,09	0,03	0,29	0,22	23,1	18,3
Banyuls	0,11	0,13	0,20	0,21	33,6	32,5
Leucate	0,13	0,08	0,21	0,16	36,2	30,4
Sète	0,05	0,07	0,13	0,14	32,5	30,7
Espiguette	0,07	0,09	0,16	0,15	31,6	27,3
Le Planier	0,07	0,06	0,21	0,18	30,0	27,1
Porquerolles	0,23	0,23	0,38	0,36	45,4	42,4
Monaco	-0,04	-0,03	0,18	0,17	34,1	32,5
Alistro	0,0	0,0	0,13	0,13	40,7	39,9

Table 3 **: statistical analysis of significant wave height for the comparison between model and buoys for the Mediterranean coast, from May until July 2015.**

3 storms cases

Two cases of storms have been considered in this study. High sea state have been recorded with discrepancies from the model runs 1 and 2. A meteorological perturbation with a low pressure system reaches the Atlantic coast on 14 and 15 May 2015. Surface winds blow in average at 20 m/s during this storm. Coastal buoys in Gulf of Biscay recorded 6 meters during the event. Strong winds move to Mediterranean Sea blowing from the west and significant wave height reaches 2.8 meters at Porquerolles on south-east coast of France. The winds from the model ARPEGE are underestimated on the Atlantic coast. Consequently The run 1 has underestimated the wave height on coastal buoys, by 5 to 160 cm. The run 2 induces a better fit and corrects the bias for all buoys, as illustrated in figure 4. Figure 5 shows snapshots of wind speed for both atmospheric models on 14 May 2015 at 18:00 UTC. The model AROME identifies well cells of high wind speed, whereas the field is more homogeneous for the model ARPEGE. In this case the active wind pattern from the model AROME enhanced the wave height in comparison with the model ARPEGE.

The bias of significant wave height at the peak of the event is well reduced by the run 2 regarding to the buoys located in the gulf of Biscay. For instance at Saint Jean-de-Luz and Anglet the bias drop down from -0.6 to 0 meters and -1.6 to -1 meters, respectively.

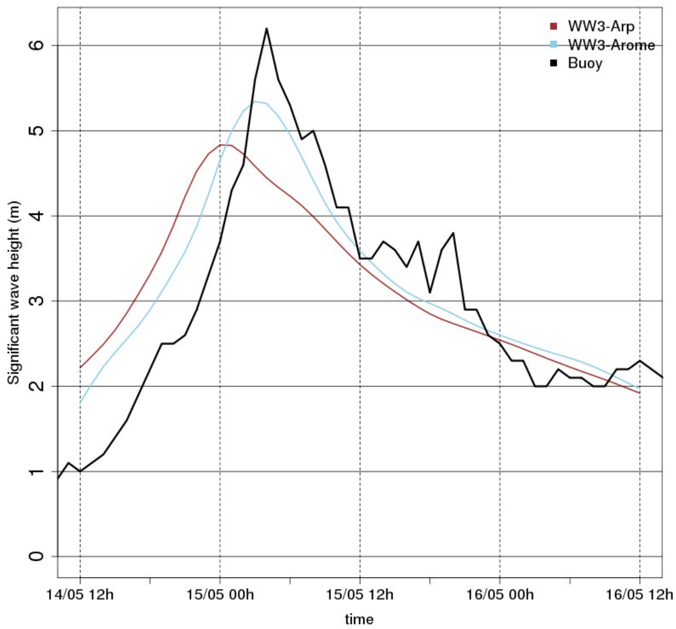

Figure 4 **: Time series of significant wave heights from buoy and models during the storm of 14-16 of May, at Cap Ferret.**

The second storm case happened on 12 june 2015. A southerly flow bring convective cells on south of France early and stay active during the day. At the peak of the event, the buoys of Sète, Espiguette and Monaco recorded significant wave heights of 1,9, 2,1 and 1,9 meters, respectively.

This is a typical case of convective event in the Mediterranean sea. The atmospheric model ARPEGE gives continuous wind field, however the model AROME shows more realistic convective cells. Figure 7 indicates snapshots of surface wind patterns for both atmospheric models. The wind field is more variable with AROME, that is expected from a non-hydrostatic model. Thus the model AROME shows a very active storm in the west part of the domain, near Leucate, at 0:00 UTC, as indicated in figure 7. large difference between the models wind speed is observed. The wind speed from AROME goes up to 20 m/s while ARPEGE stays at 4 m/s.

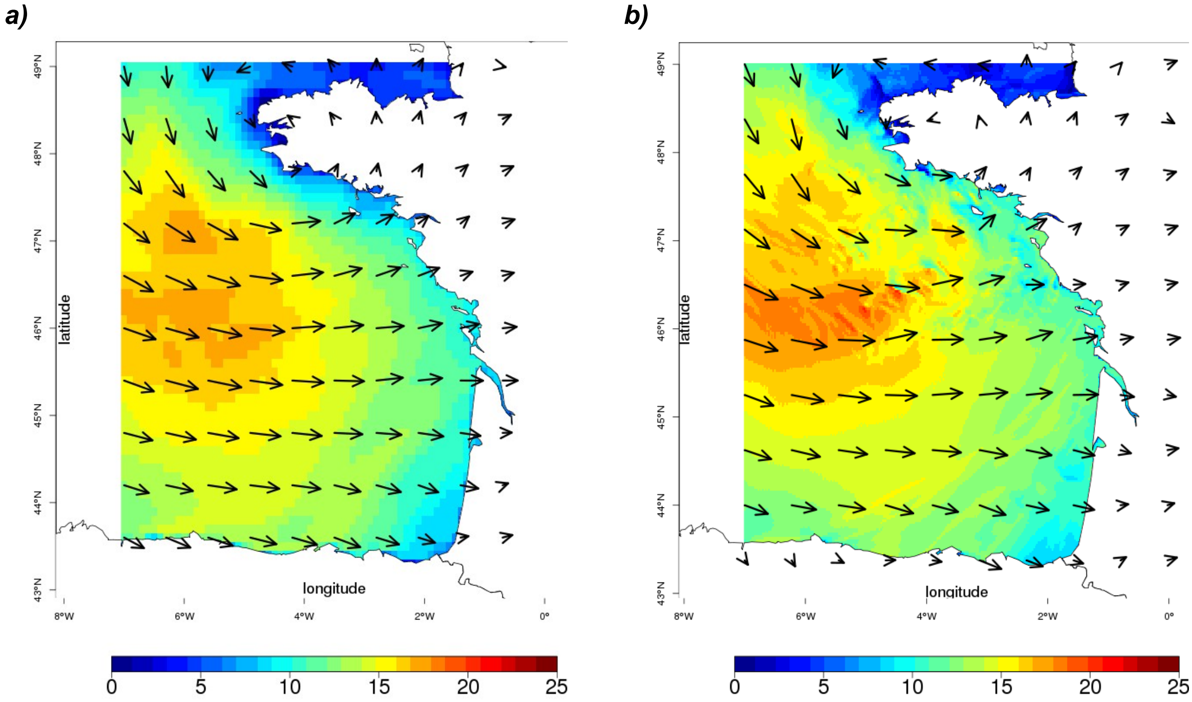

Figure 5 **: snapshots of wind speed at 10 m (in m/s) on 14 May 2015 at 18:00 UTC. (a) and (b) stand for ARPEGE and AROME.**

The storm reaches the Mediterranean sea one day later. The westerly wind propagates high waves to Porquerolles on the south-east part of France. Both runs 1 and 2 overestimate the significant wave height, as illustrated in figure 6. However the run 2 using the AROME winds is slightly closer to the buoy at the peak of event.

Figure 8 shows the variation of significant wave height during the storm of 12 June 2015. Surprisingly, Run 2 misfits the wave height at 0:00 (UTC). This unrealistic increase of the wave height (up to 2 meters) demonstrate that the wind forcing from AROME has been badly located at Leucate. In such storm the wind forcing from AROME can increase the dispersion of wave parameters because of the rapid response of the model AROME to event of intense convection. The model ARPEGE has the disadvantage to keep continuous wind field whereas the wind direction is changing because of stormy cells. This is well illustrated in figures 9 and 10. The convective cells described by the model Arome are less in favor of wave growth at the opposite of the steady winds given by the model ARPEGE. The significant wave height of Run 1 is higher by 70 centimeters than the one from Run 2 near Marseille. Unfortunately there are no wave observations available at the buoys of Le Planier and Porquerolles during this storm.

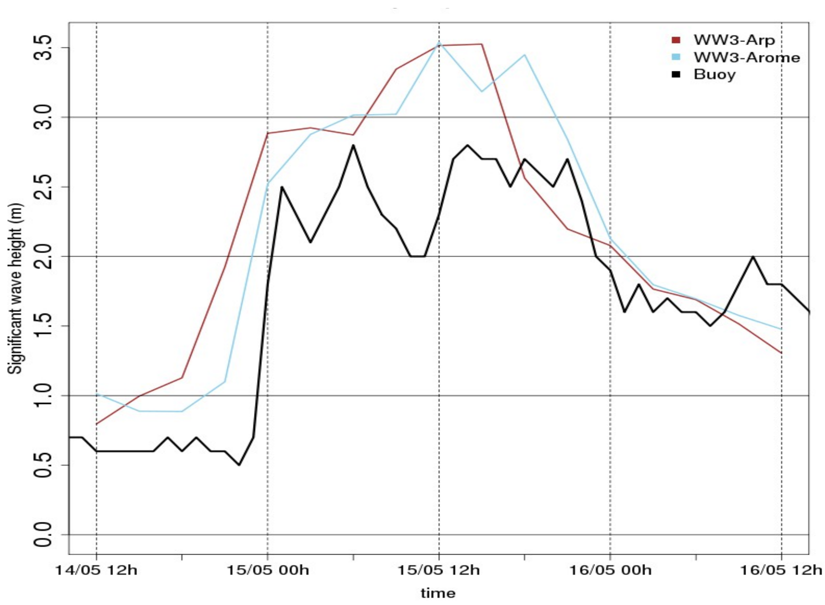

Figure 6 **: Time series of significant wave heights from the buoy and runs 1 and 2 at Porquerolles.**

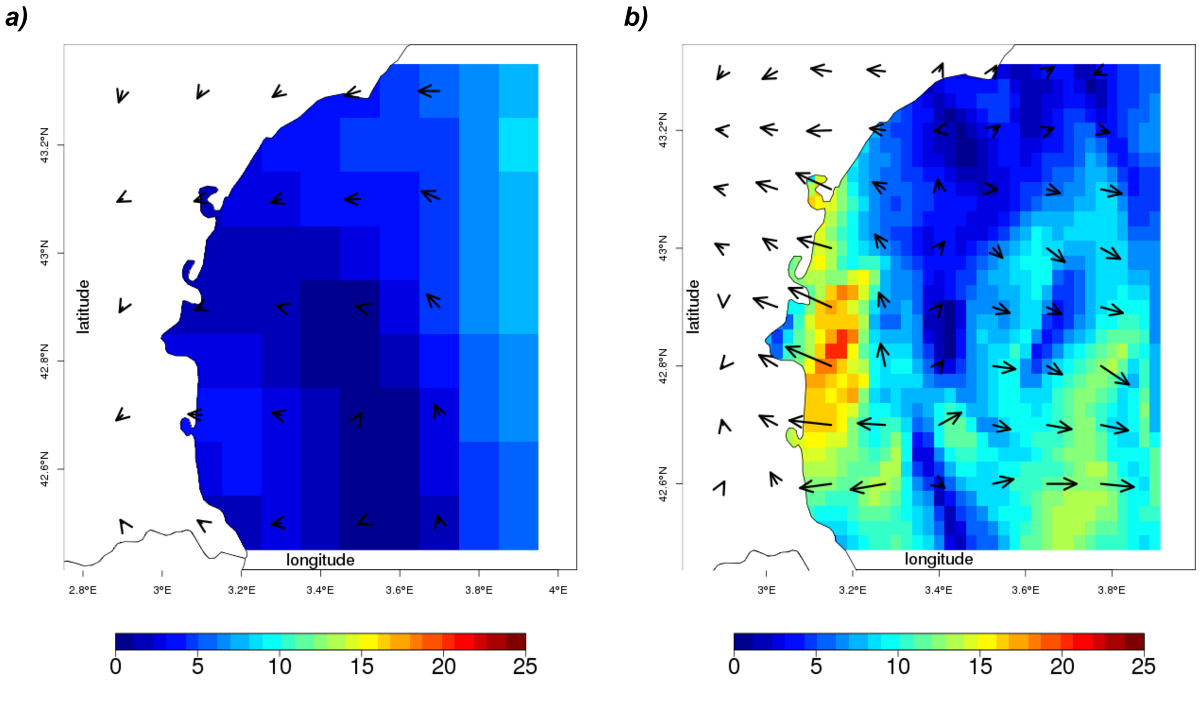

Figure 7 **: Snapshots of wind speed at 10 m (in m/s) from atmospheric models on 12 June 2015 at 00:00 (UTC) for the western part of the french Mediterranean coast. (a) and (b) stand for ARPEGE and AROME, respectively.**

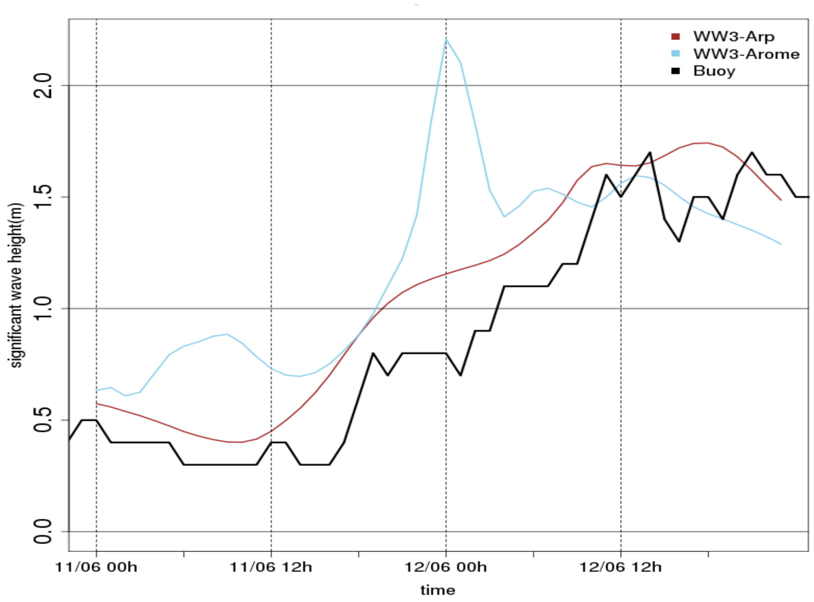

Figure 8 **: Time series of significant wave heights from Leucate buoy and models on 12 June 2015.**

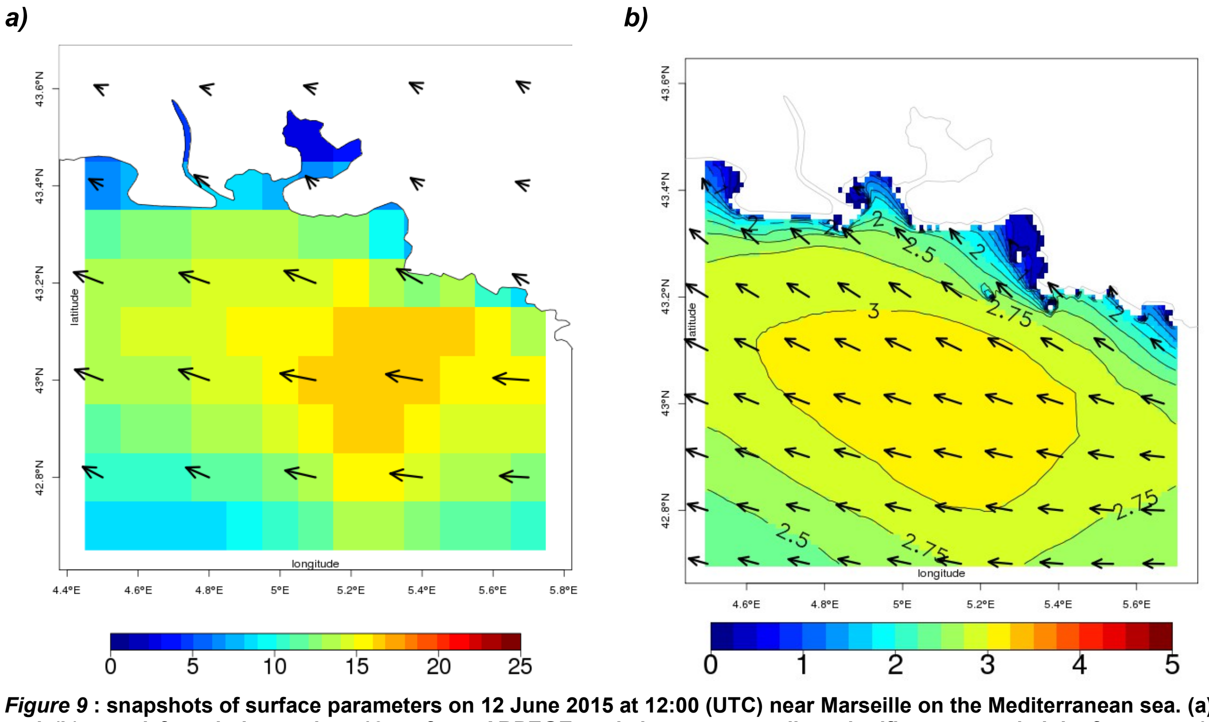

Figure 9 **: snapshots of surface parameters on 12 June 2015 at 12:00 (UTC) near Marseille on the Mediterranean sea. (a) and (b) stand for wind speed at 10 m from ARPEGE and the corresponding significant wave height from run 1, respectively. Black arrows describes wind sea direction.**

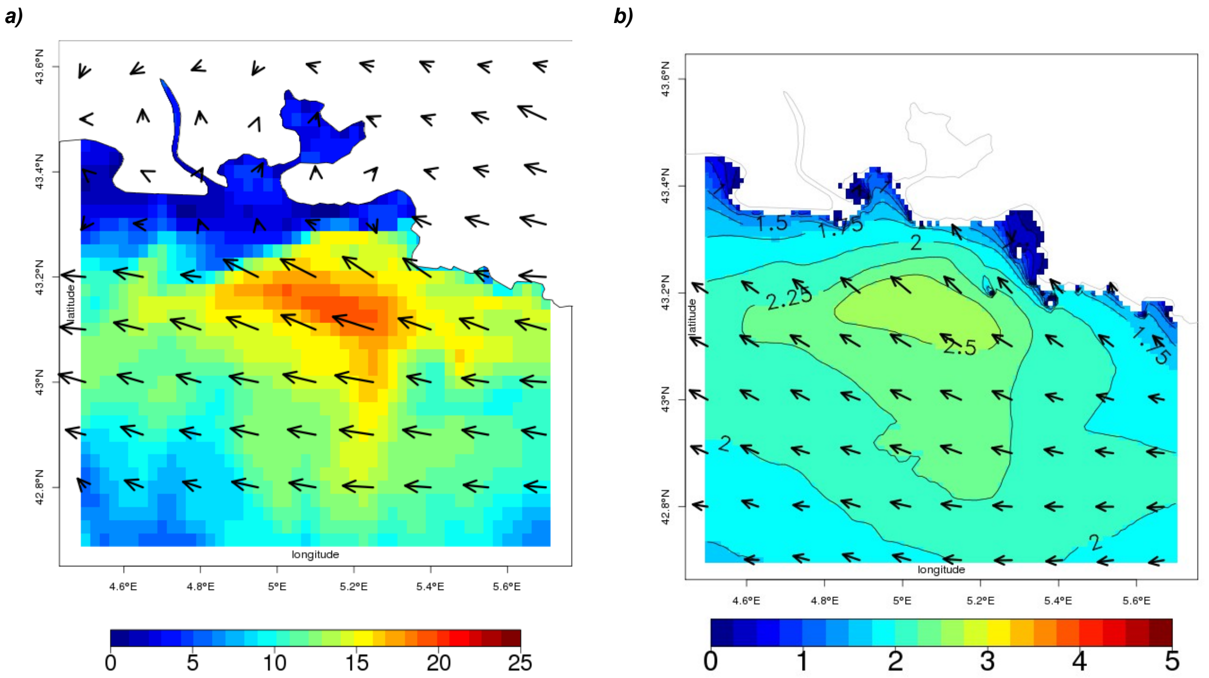

Figure 10 : snapshots of surface parameters on 12 June 2015 at 12:00 (UTC) for the Mediterranean sea. (a) and (b) stand for wind speed at 10 m from AROME and the corresponding significant wave height from run 2, respectively. Black arrows describes wind sea and wind directions.

Concluding remarks

A high resolution version of WW3 with an irregular grid has been successfully implemented at Météo-France since March 2015. The upgraded atmospheric model AROME solves better the first layer of the atmosphere in particular near the surface (10 m). The sensitivity of coastal WW3 on the wind forcing has been investigated during three months from May until July 2015. The statistical analysis on the Atlantic domain indicates that the two wind forcing give almost the same bias and RMSE errors in reference with altimeters. The use of AROME wind forcing induces a slightly better scatter index of wave height in particular in case of active Atlantic low pressure systems. In other respects, for the Mediterranean sea WW3 forced with AROME winds seems significantly more relevant. The RMS errors and scatter index of wave height are well improved in comparison with altimeters in deep sea and buoys near the shore.

The storm case in the Mediterranean sea has showed the discrepancies induced by the wind forcing related to a convective event. The AROME wind fields showed more realistic storm cells and takes into account the directional wind variability at the sea surface. It was observed that the model AROME can show dynamic cells that are not well located. The model ARPEGE is weak in case of changing winds, and thus induces no realistic wave propagation.

The wind forcing sensitivity tests are still on going for the fall and winter seasons where dangerous sea state can be investigated. However the use of the model AROME in operations is recommended for the next upgrade of the coastal model WW3.

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