JAMA, Vol. 1, 61-63 , 2017

Development of a high-resolution nearshore wave forecasting system for the Algerian coasts

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Abstract
This paper describes a research aimed to the development of a high-resolution nearshore wave forecasting system for the Algerian coasts. The model uses the results of the large scale meteorological forecasting system named ALADIN/AROME managed by, the numerical weather prediction group (P.N.T) at the Algerian Met Office (ONM), as wind input for WW3 (Wave Watch 3 model) and SWAN models. The traditional technique One way is used for different grid points on the bay of Algiers. One intermediate SWAN grid and two nested grids have been used.

Keywords:
Wave Forecasting — Nearshore — WW3 — SWAN — Algerian coasts

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1. Introduction

Wave predictions in deep waters have experienced significant developments during the last few decades and the skill of the state of the art models has been shown to be generally improving.

However, the predictions are very sensitive to the used wind fields, as demonstrated by various authors Teixeira et al. (1995b) Holthuijsen et al. (1996). Wave predictions near the coasts are subjected to more complicated physics than in deep water, due to the greater influence of bathymetry and breaking processes near the shore, which, combined with the uncertainty from wind models, make wave modelling in coastal waters as a challenge.

Many meteorological centers produce wave forecasts for the Mediterranean Sea. Most of these tend to underestimate the wind velocity and consequently the wave height. The reason is that global meteorological models have poor spatial resolutions for restricted seas such as the Western Mediterranean Sea. Cavaleri and Sclavo (Cavaleri and Sclavo (2006)) have shown that the results can be highly improved using nested models with high resolution. This motivated the implementation of Limited Area Models over the Mediterranean Sea as the one used in this work. High quality wind data from the ALADIN and AROME models are used in this study.

However, while it is generally accepted that wind predictions can improve using higher resolution models, it is not clear if the grid resolution does play an important role in wave prediction modules. In deep waters areas, where the water depth is larger than 100 meters, it is unlikely that a better description of the bathymetry, that could be achieved using high resolution models, can give significant improvements. On the contrary in shallow waters regions as those near to coasts, it is reasonable to expect that nested small scale grids can give better results than coarse ones.

The key point of this work is that a new high-resolution wave forecasting system, based on multi-nested on-way chains of WW3/SWAN models Holthuijsen et al. (1989), running on one near shore grids covering the bay of Algiers has been applied. The boundary conditions for the SWAN finer grids are obtained using the results of the larger scale runs based on the WW3 model in the Mediterranean Sea, while the wind field is that produced on the large scale at 08 km resolution by ALADIN for the coarse grid and on the high resolution at 03km by AROME for the Intermediate grid Swan.

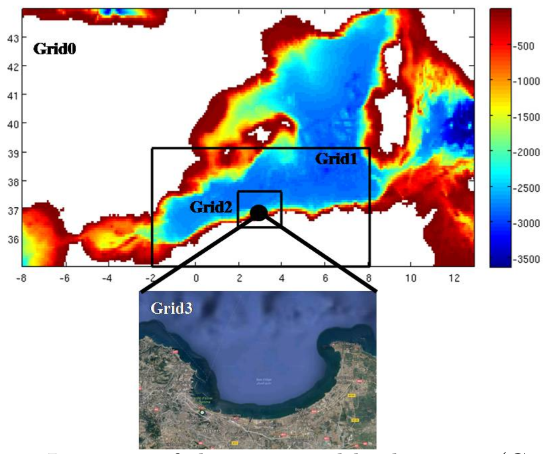

Figure 1. Location of the areas and bathymetry (Grid0), resolution 1/12 degree used for WW3 model.

The forecasting models

The forecasting system is composed by a sequence of numerical atmospheric and oceanographic models. The limited area meteorological model used in the system are called ALADIN (Aire limitée Adaptation dynamique Développement International) and AROME (Application de la Recherche à l'Operationnel à Meso-Echelle). It is composed by two high-resolution and very-high-resolution meshes, one coupled into the other one-way. The run with the coarsest resolution, 08km , is called ALADIN, the run with the finest resolution, 03km, is called AROME. It is nested on the grid of the previous run and it covers part of the Mediterranean Sea. Its outputs temporal resolution is 3 hours.

Winds resulting from these models are then used as inputs for WW3 Wave Model Tolman et al. (2014) and SWAN model Teixeira et al. (1995a) to predict wave fields in the Mediterranean Sea (Figure 1). The grid resolution

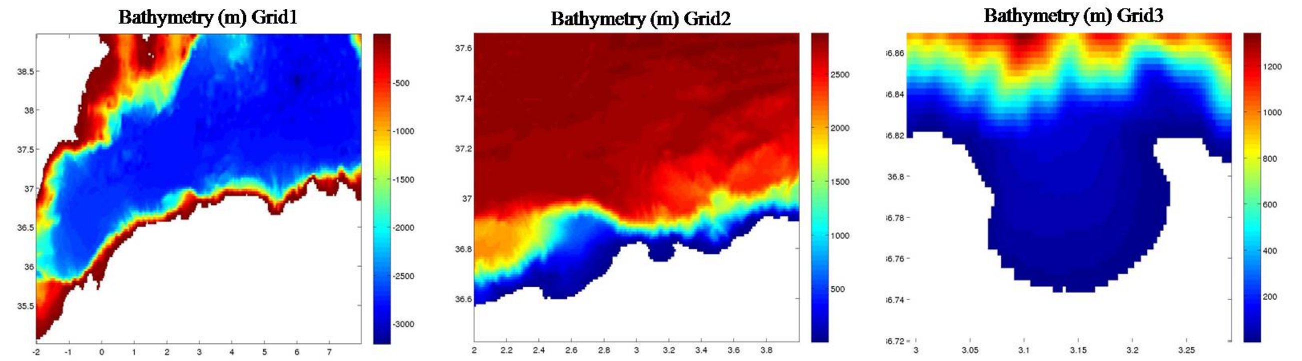

Figure 2. Bathymetry: Intermediate grid Swan(Grid1, $\frac{1}{133}^{o}$) - Nested grid (Grid2, $\frac{1}{100}^{o}$) - Nested grid (Grid3, $\frac{1}{333}^{o}$).

is of 08 km and the outputs temporal resolution is 3 hours. Wave forecasting is run every 24h with a 72 hours advance forecasting.

It is underlined that the spatial resolution of the available WW3 model is not suitable when studying near shore processes, because in this case a resolution of the order of at least 400 m is required, allowing to evaluate with more accuracy wave generation and propagation as well as shoaling and refraction. In order to overcome this problem the SWAN model (Simulating WAves Nearshore) is used in this work. It is a non-stationary third-generation wave model Holthuijsen et al. (1989) aimed to obtaining realistic estimates of wave parameters in coastal areas, lakes and estuaries from given wind, bottom and current conditions. However, SWAN can be used on any scale relevant for wind-generated surface gravity waves. It uses both frequency and directional spectra and it is based on the wave action balance equation with sources and sinks. The model can simulate wave propagation in time and space, shoaling, refraction due to currents and depth. It also considers several sources and sinks: wave generation by wind, dissipation due to white capping, bottom friction and depth- induced breaking, reduction of spectral energy due to non-linear interactions (three and four wave interactions). Diffraction and reflection are not modelled by SWAN, so the accuracy of the model near obstacles or inside harbours is poor.

The two dimensional wave spectrums can be described by the spectral action balance equation as follows:

$$\frac{\partial N}{\partial t} + \frac{\partial c_x N}{\partial x} + \frac{\partial c_y N}{\partial y} + \frac{\partial c_\sigma N}{\partial \sigma} + \frac{\partial c_\theta N}{\partial \theta} = \frac{S}{\sigma} \quad (1)$$

Where N is the action density spectrum, which is equal to the energy density spectrum divided by the relative frequency. In this equation, σ and θ are wave relative frequency and wave direction, respectively. The first term in the left-hand side of the above equation represents the local rate of change of wave action density spectrum in time. The second and third terms represents propagation of wave action in geographical space with velocities c_x and c_y in x and y directions, respectively. The fourth term represents shifting of the relative frequency due to variations in depths and currents with propagation velocity c_σ in σ-space. The fifth term represents depth-induced and current-induced refraction with propagation velocity c_θ in θ-space. The expressions for all of propagation velocities are taken from linear wave theory. The term at the right-hand side of the wave action balance equation is the source term of energy density representing wave generation, energy dissipation and non-linear wave-wave interactions.

SWAN has been used in one configuration in the Algiers Sea, couples SWAN with 3km resolution, serial run of WW3 model, considering at the boundary the waves calculated by the WW3 and also the wind evaluated by AROME as a source. This procedure allowed us to implement a forecasting system of waves near the coast that needs to be validated and improved.

2. The Algiers Sea

Wave propagation in the Agiers Sea has been studied applying a chain of SWAN runs nested on four different grids (Figure 2). The largest one, grid 0, covers the whole Mediterranean Sea and two in the Algiers Sea.

The coarsest grid has a resolution of 1/12 degree and the coordinate system used is spherical. The finest domains have a resolution of 1/33, 1/100 and 1/333 degrees, corresponding to 03, 01 km and 300 m.

The bathymetry has been interpolated on the 2 grids using Etopo1 (1 Arc-Minute Global Relief Model) provided by the National Geophysical Data Center (NGDC), an office of the National Oceanic and Atmospheric Administration (NOAA), and for the third and fourth grid by GMRT (The Global Multi-Resolution Topography) provided by the IEDA/NSF Interdisciplinary Earth Data Alliance funded by the US National Science Foundation which deliver bathymetry data (100-m resolution) near the coast. In figure 3 it is possible to observe the increase of resolution of the four grids for the Mediterranean Sea.

The WW3 model, with a resolution of 1/12 degree, has been used covering all the Mediterranean Sea to provide the boundary conditions for the intermediate grid SWAN with a resolution of 1/33 degre, the second step consists on the nesting the third grid point to the intermediate one with a resolution of 1/100 deg and the last step consists on the nesting of the coastal grid point (grid3) to the nested one (grid2) with a resolution of 1/333 deg. Concerning the coastal grid points the SWAN model was used to simulate nearshore processes.

The scheme used for wave generation- whitecapping is the quasi-saturation scheme proposed by Van der Westhuysen van der Westhuysen et al. (2007). This scheme was developed in order to improve the SWAN results when sea-waves and swell are both present in the propagation process, which is useful when analyzing areas with long fetches, as for the Algerian coasts.

3. Results of forecasting

The results of the coupling SWAN-WW3 with 03km of resolution (Fig.5) and the results of the simulations produced by the WW3 model (Figure 4) does not differ from the values of Hs (significant wave height) and his direction, against the descent of scale at 1km shows a difference in the East of Algiers Bay , Hs = 0.7-0.8m near the coast (Fig. 6) , and $Hs = 0.3 - 0.4m$ (figure 5) this is due to the physical parameterization of the model Swan which takes into account the near-shore physical processes. The last grid point with a very high resolution (figure 7) doesn't present any difference from the previous two grids points, the system should be tested with different atmospheric situations to check the behavior of the forecasting system.

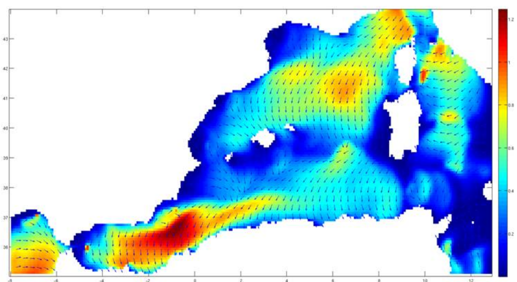

Figure 3. Forecasted Hs by WW3 model on the 15 SEP 2016 at 12:00

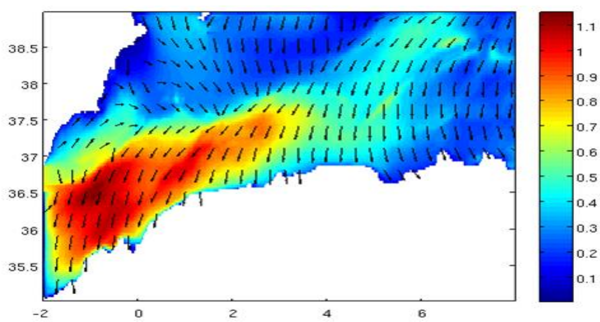

Figure 4. Forecasted Hs by SWAN model (Intermediate Grid 03km) on the 15 SEP 2016 at 12:00

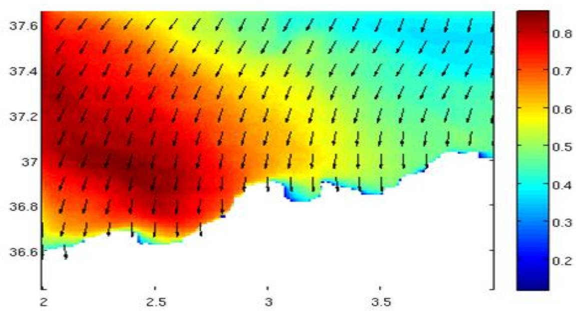

Figure 5. Forecasted Hs by SWAN model (Nested Grid 1km) on the 15 SEP 2016 at 12:00

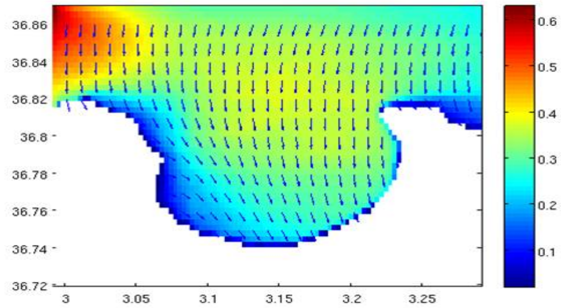

Figure 6. Forecasted Hs by SWAN model (Nested Grid 300m) on the 15 SEP 2016 at 12:00

4. Conclusion and perspective

This forecasting system needs to be validated by the observed data in-situ or by satellite data, to evaluate its performances.

So, the next step is to collect the observed data in one or more points on the used experimental field to validate this system.

The second step is to couple nearshore model (SWAN) with till shore model (SWASH) for increasing the accuracy of hydrodynamic parameters in the harbour areas.

This study showed that it is possible to increase the resolution from the regional scale to the local scale by coupling WW3 and SWAN models.

This work shows also the applicability of a high–resolution nearshore wave forecasting system for a selected coastal sea area on the Algerian coasts.

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