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Review

Assessment of wind models around the Balearic Islands for operational wave forecast

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ABSTRACT

A wave hindcast in the Western Mediterranean Sea is carried out in order to assess the performance of three atmospheric models in providing the forcing for a third generation wave model. The wind models have been used as forcing fields for the generation of waves and the resulting significant wave height time history compared with four buoys around the Balearic Islands. Two different wave-model grid resolutions are used to get the wave field in the entire Mediterranean and around the Balearic Islands. The present application was performed for three months: November 2008 and for July and August 2009. Results indicate that all data sources provide good forcing for operational wave forecast at large scales (wind forecast with grid resolution of 30 and 25 km). Near the coast or at the lee of islands, resolving small scale topographical features result in a better forecast of wave fields. However, for the area studied, the atmospheric model that better represents summer and winter conditions is hourly WRF at 1.5 km resolution.

Contents

1. Introduction

A proper assessment of wave climate is a requirement for scientific and engineering activities in the coastal zone. Beach nourishment, port design and operability, dispersion and diffusion of pollutants are some examples that require a proper estimation of significant wave heights fields (diagnostic) as well as their evolution (prognostic) forward in time. The diagnostic of waves has traditionally been obtained using scalar and directional wave buoys moored at specific locations. Moored instruments are the most reliable systems used to obtain wave conditions but they are expensive providing only records at specific locations. In the last

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decade, satellites and more recently High Frequency Radar systems have overcome to some degree the problem of the spatial lack of data. However these platforms only provide information at limited spatial and temporal coverage.

By contrast, numerical models provide on a regular basis, wave conditions at different spatial and temporal resolutions by integrating physical principles forward in time. Wave generation models are able to reproduce complex physical processes involved in the generation and transformation of waves [1,2]. To obtain reliable numerical simulations accurate wind fields with the adequate temporal and spatial resolution are mandatory since realistic forcing terms will provide accurate wave predictions.

Despite the diversity of wave generation models as well as in atmospheric models, numerical predictions of wave fields in a particular region still fail mainly due to an inadequate representation of the physical processes involved in the wave generation or due to errors associated to the spatial and/or temporal wind field resolutions. Wave models are very sensitive to wind field variations, which results in one of the main source of errors in wave predictions [3–5]. Additionally, in small and semi-enclosed seas, wave modelling becomes cumbersome due to the complex bathymetry and the limited fetch. Surface waves are generated by the wind blowing over the sea surface and any error in the input wind field will be reflected in the computation of wave conditions [3].

For instance, wave climate over the Balearic Sea has in general, a complex pattern as a result of the complex orography of the surrounding area. In the last years, some studies have attempted to analyse the accuracy of different wave and wind models in the NW Mediterranean Sea. Signell [6] analysed the surface wind quality in the Adriatic Sea concluding that for a period of two months the limited area models LAMI-Limited Area Model Italy [7] and COAMPS-Coupled Ocean/Atmosphere Mesoscale Prediction System [8] provide better amplitude response than the coarser ECMWF (European Center for Medium-range Weather Forecasts). Ardhuin [9] analysed the accuracy of four atmospheric models and three wind-wave models concluding that quality of the wind fields degrades in the coastal areas. Ponce de León and Guedes Soares [10], compared wave hindcast in the Western Mediterranean Sea using the reanalysis wind fields from HIPOCAS and ERA-40 finding systematic negative biases of significant wave height using ERA-40 fields and positive biases for the HIPOCAS data.

In addition, there are several works pointing out the necessity of further improvement on the wind field quality as well as in the increase of wind field spatial resolution especially in enclosed basins such as the Mediterranean Sea. Cavaleri and Bertotti [11] found that large errors in wave height estimation were obtained at short fetches (∼100 km); Bertotti and Cavaleri [12] pointed that the reliability of forecasts may decrease when dealing with meteorological situations characterized by strong temporal and spatial gradients. In spite of these advances, to our knowledge, the effects of local meteorological events around archipelagos in the Mediterranean Sea have not been treated in detail.

The aim of this work is to further study the accuracy of a third generation wave model forced by three different atmospheric wind fields with different spatial resolutions (30, 25, 16, 6, 5 and 1.5 km) around the Balearic Islands (NW Mediterranean Sea) prior to the development of a real time operational system for wave prediction in the area. The present application was performed for November 2008 and July and August 2009 as these months are representative of the different wave climates of the area during winter and summer seasons. Moreover, during the summer the local sea breeze needs to be properly reproduced since it can drive an important part of wave variability.

The paper is structured as follows: Section 2 presents the singularities of the study area. Section 3 provides a description of the atmospheric models, in situ measurements as well as wave model set-up. Section 4 presents the results and provides the discussion and finally Section 5 concludes the work.

2. Study area

The Western Mediterranean (WM) has a complex structure with numerous peninsulas and islands that difficult numerical modelling. Moreover, the WM is an important cyclogenetic area where the main hydrodynamics is conditioned by the severe atmospheric-climatic forcing during winters [13]. Most of the strong winds observed in the Mediterranean belong to the category of local winds and are originated as down slope flows by air-flow/mountain interaction or due to channelling effects [14]. The WM area is forced by northerly and north-westerly winds during most of the year, while less intense cyclogenetic activity is observed during the rest of the year [15,16]. The mountains range in the vicinity is a key factor in its climatic characteristics [17]. The role of the Pyrenees in the western area and the Alps in the north-eastern area are decisive boundaries for the pressure and wind distribution over the WM basin. Wind speeds for a 100-year return period shows a maximum located in the Gulf of Lion with winds up to 30 m/s [16]. The low-pressure systems entering to the Mediterranean Sea from the Atlantic Ocean tend to dissipate moving east, with the major storms taking place in the WM [10].

The Balearic Archipelago, near the eastern Mediterranean coast of Spain is formed by four major islands that may lead to a reduction of the wave energy in the basin during winter period due to the shadowing effect of the islands [18].

The present work has been centered in the southern coast of Mallorca Island for operational purposes where a high resolution wave model (1500 m) has been implemented and nested to the general wave model covering the entire Mediterranean. Resulting wave fields are compared with in situ data from deep and shallow water wave buoys.

3. Data and methods

3.1. Atmospheric models

Three different sources of atmospheric models are used to test the accuracy of wave fields within this work: HIRLAM-High Resolution Limited Area Model [19], ECMWF [20] and WRF-Weather Research and Forecasting [21]. HIRLAM was chosen because it is the atmospheric model that runs daily four times in the Spanish Meteorological Agency (AEMET); the WRF because it presents the highest spatial resolution and the ECMWF because it is provided operationally by the European Center for Medium-range Weather Forecasts.

To assess the sensitivity of wave fields to the wind, data sets have been divided into two groups according to their spatial resolution. The first group consists of atmospheric models with a relatively coarse resolution HIRLAM(16), WRF(30) and ECMWF(25) with 16, 30 and 25 km resolution, respectively. The second group includes the atmospheric models with higher resolution HIRLAM(5) with 5 km and two WRF(6/1.5) configurations with 6 km and 1.5 km.

The HIRLAM is a hydrostatic, primitive-equation model, which uses a three dimensional variational (3D-VAR) data assimilation scheme [22]. In the WM, HIRLAM is operated by AEMET providing wind fields every 3 h at 16 km (low resolution) and 5 km (high resolution) twice a day cycle with a 72 h horizon [23]. In this configuration, HIRLAM takes the boundary conditions from the ECMWF atmospheric global model.

The ECMWF is a spectral model which incorporates a four dimensional variational (4D-VAR) data assimilation procedure [24].