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Wave model predictions in the Black Sea: Sensitivity to wind fields

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ABSTRACT

This paper evaluates the impact of using different wind field products on the performance of the third generation wave model SWAN in the Black Sea and its capability for predicting both normal and extreme wave conditions during 1996. Wind data were obtained from NCEP CFSR, NASA MERRA, JRA-25, ECMWF Operational, ECMWF ERA40, and ECMWF ERA-Interim. Wave data were obtained in 1996 at three locations in the Black Sea within the NATO TU-WAVES project. The quality of wind fields was assessed by comparing them with satellite data. These wind data were used as forcing fields for the generation of wind waves. Time series of predicted significant wave height (H_{mo}), mean wave period (T_{m02}), and mean wave direction (*DIR*) were compared with observations at three offshore buoys in the Black Sea and its performance was quantified in terms of statistical parameters. In addition, wave model performance in terms of significant wave height was also assessed by comparing them against satellite data.

The main scope of this work is the impact of the different available wind field products on the wave hindcast performance. In addition, the sensitivity of wave model forecasts due to variations in spatial and temporal resolutions of the wind field products was investigated. Finally, the impact of using various wind field products on predicting extreme wave events was analyzed by focussing on storm peaks and on an individual storm event in October 1996. The numerical results revealed that the CFSR winds are more suitable in comparison with the others for modelling both normal and extreme events in the Black Sea. The results also show that wave model output is critically sensitive to the choice of the wind field product, such that the quality of the wind fields is reflected in the quality of the wave predictions. A finer wind spatial resolution leads to an improvement of the wave model predictions, while a finer temporal resolution in the wind fields generally does not significantly improve agreement between observed and simulated wave data.

1. Introduction

Wave predictions in deep water 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 good. The predictions, however, are very sensitive to the wind fields used, as has been demonstrated by various authors [1–5]. Nowadays, the wind field's quality over the oceans is generally good, but for enclosed basins, where the surface winds are affected by land's presence the skill of wind models diminishes. In these areas the modelled surface wind speeds are almost always underestimated and the bias depends on the proximity of land. This negative effect appears in various locations of the Mediterranean Sea [4,6–8].

Wave generation models are able to represent complex physical processes involved in the generation and transformation of waves [9,10]. To obtain accurate numerical wave simulations accurate wind fields with adequate temporal and spatial resolution are of prime interest [11]. The parameterisations of the physical processes in the wave model are of secondary importance and numerical aspects come hereafter. Additionally, in small and semi-enclosed seas, wave modelling becomes cumbersome due to a mix of a complex bathymetry, upwind fetch restrictions and orographic effects on the wind fields. It is therefore expected that to first order the quality of wind field will be reflected in the quality of the simulated wave conditions [12,13].

In the last years, various studies [8,13–21] have been performed to analyze the accuracy of different wave and wind models in some seas and the sensitivity of wave predictions to wind fields. For the Black Sea, however, not much information is available on these issues. Rusu [22] only discussed the model performance using two different wind fields which are NCEP NCAR with 1.875° spatial resolution and ECMWF with 2.5° spatial resolution. However, the

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recent new reanalysis sets (the ERA Interim winds from ECMWF, the MERRA winds from NASA, and the CFSR winds from NCEP) are now available, but their performances have not been tested in the Black Sea yet.

In view of the above considerations, the aim of the present study is to assess the quality of different wind field products, the sensitivity of wave model performance on the choice of different wind field products in the Black Sea for both normal and extreme conditions, and the sensitivity to variations in spatial and temporal wind field resolutions. These objectives will be achieved by comparing the wind data with satellite observations of wind speed and wind direction, and running the SWAN wave model driven by each of these wind fields. Further, we will compare the wave model results against satellite observations of significant wave height and against buoy observations of significant wave height, a mean wave period, and mean wave direction at three locations in the Black Sea. In addition, the sensitivity of model performance against variations in spatial and temporal resolution of the wind field is investigated. Further, a statistical analysis is performed to determine the difference in model performance for normal conditions and for extreme conditions. Lastly, an analysis is made of the impact of the various wind fields on the prediction of storm peaks and the highest storm event occurring in the Black Sea in October 1996. We note that this paper is focused on the use of easily available global wind field products, on wave model performance in a semi-enclosed basin. It is also noted that this paper is not aimed at analysing the wind and wave climate in the Black Sea as only one year of wave measurements is available at only three locations.

2. Study area

This study focused on the entire Black Sea, which is located between 40°56′ and 46°33′ north latitudes and 27°27′ and 41°42′ east longitudes and connected to the European Mediterranean Sea (Fig. 1). It is a semi-closed sea connected respectively to the Sea of Marmara and Aegean Sea by the Bosporus and Dardanelles straits and also to the Sea of Azov by the strait of Kerch. It has an area of 461 thousand square kilometres (not including the Sea of Marmara but including the Sea of Azov) and 8350 km of coastline. The maximum depth is 2588 m and its mean depth is about 1300 m. The north-western part of the Black Sea is relatively shallow as it is located on the continental shelf. The longest east–west section is about 1150 km; the narrowest meridional section (between the Crimea Peninsula and the Turkish coast) is 258 km [23,24].

The Black Sea, one of the world's largest semi-enclosed basins, is an elliptical basin with a complex surrounding orography (Fig. 1). The western coastal region is relatively low as being part of the Black Sea lowlands. In general, the coastline of the entire basin is not very deeply indented. The area of the Black Sea shelf is about 24% of the total basin area and its outer edge can be traced along the 100–150 m depth contour [25]. The flat abyssal plain (depth > 2000 m) of the Black Sea occupies more than 60% of the total area. The continental shelf in the remaining part of the Black Sea rarely exceeds a width of 20 km and occurs as narrow stretches along the coasts of Anatolia, Caucasus and Kerch, often separated by canyons or steep slopes adjoining the land [26].

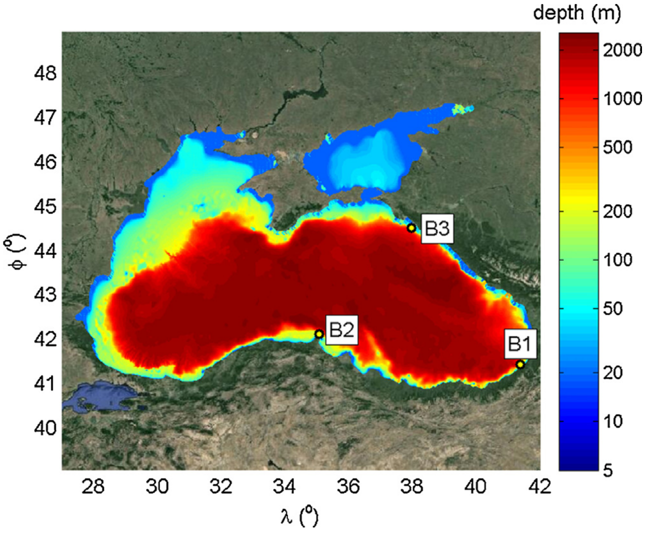

Fig. 1. Bathymetry of Black Sea and location of measurement locations; Hopa (B1), Sinop (B2) and Gelendzhik (B3).

3. Materials and methods

3.1. Description of atmospheric wind field datasets

In this study we used six different wind field products (five reanalyses and an operational dataset) to determine their performances, and their impact on wave model performance using satellite and buoy data. These wind field products are NCEP CFSR – Climate Forecast System Reanalysis from the American reanalysis of National Centre for Environmental Prediction (NCEP), ERA40 and ERA Interim from European reanalysis of European Centre for Medium-Range Weather Forecast (ECMWF), JRA-25 from Japanese 25-year reanalysis, and NASA MERRA from NASA Goddard Space Flight Center reanalysis. The operational wind field product is from the ECMWF. Among these, NCEP CFSR, ERA Interim, and NASA MERRA are the recent reanalysis products. The Japan Meteorological Agency (JMA) started the second Japanese global atmospheric reanalysis project named the Japanese 55-year reanalysis (JRA-55), but it was not yet available when this study was performed.

The new NCEP Climate Forecast System Reanalysis, CFSR (Saha et al. [27]), has recently been developed and entails a coupled reanalysis of the atmospheric, oceanic (only circulation), sea-ice and land data from 1979 to 2010. This reanalysis has much finer spatial and temporal resolutions than previous NCEP reanalyzes, and thus provides a valuable resource to develop a long-term hindcast database for wind waves [28]. Recently, Hulst and Van Vledder [29] presented a global calibration of the CFSR wind fields using satellite data. We therefore included the calibrated CFSR wind fields (denoted as CFSRC in this study) to our analysis.

Recently, NASA released the MERRA reanalysis (Rienecker et al. [30]), using a version 5 of the Goddard Earth Observing System Data Assimilation System. The MERRA time period covers the modern era of remotely sensed data, from 1979 to the present. MERRA output data resemble other global reanalyzes, with several key advances, including output at smaller time intervals than the 6-hourly analyses. Two-dimensional diagnostics (surface fluxes, single level meteorology, vertical integrals and land states) are produced at 1-hour intervals. The spatial resolution of these data product are 1/2° and 2/3° at both latitude and longitude.

The Japan Meteorological Agency (JMA) conducted the Japanese 25-year ReAnalysis (JRA-25), the first long-term reanalysis undertaken in Asia, in collaboration with the Central Research Institute of Electric Power Industry (CRIEPI) and produced high quality meteorological datasets for seasonal prediction models and climate research use. The analysis covers the period from 1979 to the present. Six-hourly data assimilation cycles were performed, producing 6-hourly atmospheric analysis and forecast fields of various physical variables. The global model used in JRA-25 has a spectral resolution of T106 (equivalent to a horizontal grid size of around 120 km). Onogi et al. [31] and [32] present the details of JRA-25 reanalysis project.