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An assessment of the wind re-analyses in the modelling of an extreme sea state in the Black Sea

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ABSTRACT

This study aims at an assessment of wind re-analyses for modelling storms in the Black Sea. A wind-wave modelling system (Simulating WAve Nearshore, SWAN) is applied to the Black Sea basin and calibrated with buoy data for three recent re-analysis wind sources, namely the European Centre for Medium-Range Weather Forecasts Reanalysis-Interim (ERA-Interim), Climate Forecast System Reanalysis (CFSR), and Modern Era Retrospective Analysis for Research and Applications (MERRA) during an extreme wave condition that occurred in the north eastern part of the Black Sea. The SWAN model simulations are carried out for default and tuning settings for deep water source terms, especially whitecapping. Performances of the best model configurations based on calibration with buoy data are discussed using data from the JASON2, TOPEX-Poseidon, ENVISAT and GFO satellites. The SWAN model calibration shows that the best configuration is obtained with Janssen and Komen formulations with whitecapping coefficient (C_{ds}) equal to 1.8e−5 for wave generation by wind and whitecapping dissipation using ERA-Interim. In addition, from the collocated SWAN results against the satellite records, the best configuration is determined to be the SWAN using the CFSR winds. Numerical results, thus show that the accuracy of a wave forecast will depend on the quality of the wind field and the ability of the SWAN model to simulate the waves under extreme wind conditions in fetch limited wave conditions.

1. Introduction

Natural hazards continue to be one of the major causes for the loss of human lives and economic damages, damages to the ecosystems and infrastructure with the associated decrease in the quality of life of the population in the areas affected by those hazards (Galabov and Kortcheva, 2013). The extreme waves have become an important issue in recent years because of the increased potential for severe damage to human activities and societal infrastructure. Intense storms can exhibit rapidly varying winds that can produce large complex ocean waves that can propagate thousands of kilometers away from the storm center, resulting in dramatic variations of the wave field in space and time (Barber and Ursell, 1948). In recent years, numerical modelling has made impressive steps in forecasting waves on global and regional scales, and considerable efforts were made to measure the directional spectra of storm generated waves and to investigate their spectral characteristics

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(Padilla-Hernandez et al., 2007). It is evident that, the spectral wave models are still being a powerful tool to study or reproduce the very extreme sea state as defined in Cardone et al. (2011). Especially, in enclosed seas such the Black Sea high-resolution applications of the SWAN model are a good alternative to study extreme events.

Previous works using the SWAN model in the Black Sea deserve attention. Rusu (2009) assessed wave energy resources by focusing on the western part of the Black Sea. Later, an evaluation of oil spills propagation in the coastal environment of the Black Sea was presented in Rusu (2010a). In addition, Rusu (2010b) modelled wave-current interactions at the mouth of the Danube Delta in the Black Sea. Akpınar and Kömürcü (2012) presented wave energy potential in the south-eastern coastal areas. Existence and variability of wave energy resource potential of the Black Sea based on 15-year hindcast data were described in Akpınar and Kömürcü (2013). Arkhipkin et al. (2014) presented spatio-temporal patterns of the wind wave fields in the Black Sea. Rusu et al. (2014) evaluated the performance of a wind-wave modelling system applied to the Black Sea basin. Despite the fact that the Black Sea is not the best scenario for a spectral wave model because of its short limited conditions and the physics implemented in the third generation wave models that still present some shortcomings, but it can be a good scenario to develop these models. The recent work of Akpinar et al. (2012) for the Black Sea has shown that when the SWAN model is applied in non-stationary mode, numerical problems arise, on the cases of variable wind conditions. Therefore, a proper time step is crucial for SWAN to be able to catch the effect of fast wind speed temporal changes on the wave field. Additionally, they pointed out inaccuracies in source term-balance for short fetches in the Black Sea.

It is also well known that the performance of such wave models depends strongly on the accuracy of the forcing wind fields. In the last years, some studies have attempted to analyze the performance of different wind re-analyses in wave modelling studies for other seas. For instance, Feng et al. (2006) presented an assessment of an operational wave model, focusing upon the model sensitivity to four different wind-forcing products. They suggested that model output is critically sensitive to the choice of the wind field product and that higher spatial resolution in the wind fields does lead to improved agreement for higher-order wave statistics. Ponce de León and Guedes Soares (2008) compared wave hindcast in the Western Mediterranean Sea using the reanalysis wind fields from HIPOCAS and ERA-40 for November 2001 concluding that the inconsistencies in the comparisons of modelled waves against measurements seem to be associated with the quality of the wind fields. They reported that in the case of the ERA-40 data set, biases (varied between −0.38 m and −1.3 m) for significant wave height (H_s) were constantly negative values indicating the underestimation of the H_s values, whereas biases (the range of −0.29 m to 0.73 m) obtained when using the HIPOCAS data are positive values except one indicating a persistent overestimation of the H_s values. Ponce de León et al. (2012) carried out a wave hindcast in the Western Mediterranean Sea in order to assess the performance of three atmospheric models, which are High Resolution Limited Area Model with 16 km resolution, Weather Research and Forecasting model with 30 km resolution, and European Centre for Medium-Range Weather Forecasts (ECMWF) with 25 km resolution in providing the forcing for a third generation wave model for three months. Their 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). In the Black Sea, which is the area of interest of our study, Rusu (2009) discussed the model performances using two different wind fields namely National Center for Atmospheric Research with 1.875° spatial resolution from the National Center for Environmental Prediction (NCEP) and ECMWF with 2.5° spatial resolution. Van Vledder and Akpınar (2015) evaluated 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 waves during 1996. However, the recent new reanalysis sets (the ERA-Interim winds from ECMWF, the MERRA winds from National Aeronautics and Space Administration, NASA, and the CFSR winds from NCEP) are now available and their performances have not been tested for storm cases in the Black Sea yet. Therefore, this study focuses on the assessment of different forcing re-analyses products for modelling storms in the Black Sea.

The most notable storm for the Western Black Sea coast in terms of impact on the coast is the storm of February 1979. It lasted for more than a week with the maximum sea level rise on February 19 of more than 1.5 m. The storm caused massive damages around the Bulgarian coast. There are no wave registrations for this period and maximum wind wave height of 5.8 m for 15 m depth was estimated using spectral analysis (Palazov et al., 2007). Galabov and Kortcheva (2013) examined three case studies of severe storms in the Black Sea including the above mentioned storm. They obtained wave parameters by using SWAN model forced by two different wind input data. It has been found that the use of ERA-Interim coarse resolution wind data leads to a significant underestimation of the waves. The availability of measurements of wave parameters in the North Eastern part of the Black Sea provided an opportunity to compare wave simulations by SWAN model forcing with different wind re-analyses. And, a maximum wave was observed in February 2003 off-shore Gelendzhik as the measurements available. The storm was short, but the H_s reached the extreme value of nearly 7 m. Therefore, this study focused on simulation of this storm to assess quality of the wind re-analyses and capability of the SWAN model for modelling storms.

The purpose of this paper is to examine the performance of a wind-wave modelling system, which will become a part of the Black Sea operational wave prediction system after the necessary adjustment, during an extreme condition occurred on February 1, 2003. In Section 2, the description of general properties of the study area is presented. The setup of the SWAN model is summarized in Section 3. In Section 4, data used in the wind/wave modelling and determination of performances of the wave model configurations is summarized. In this section, the quality of wind re-analyses are determined by using the ASCAT (Verhoef and Stoffelen, 2012) and the GLOBWAVE data set (Ash et al., 2012). The evolution and description of the storm focused in this study are presented in Section 5. SWAN model results against buoy and satellite data are discussed