Ocean Engineering 165 (2018) 450–464

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Setup and evaluation of a SWAN wind wave model for the Sea of Marmara

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ARTICLE INFO

Keywords:
Wave modeling
Whitecapping
ERA-Interim
CFSR
SWAN
The Sea of Marmara

ABSTRACT

A high-resolution SWAN wind wave hindcast model was implemented for the Sea of Marmara. For this, we focused firstly on the quality of two data sources for the wind forcing, viz., the ERA-Interim winds from the ECMWF and CFSR winds from the NOAA/NCEP. These were compared against wind measurements for 2013 collected at the Silivri offshore buoy in the north of the Sea of Marmara. A sensitivity analysis was performed to find the optimal numerical settings and wind source. This analysis showed that the CFSR winds are most suited for wave modeling in the Sea of Marmara. As the Sea of Marmara can practically be considered as deep water, we calibrated the SWAN model for different combinations of wind input and whitecapping source terms. The calibration was performed by varying the whitecapping coefficient for different combinations. The model setting giving the lowest errors and highest correlation via sensitivity analysis was determined as the calibrated model. Thirdly, the calibrated model was validated against measurements at the Silivri buoy for the years 2014, 2015 and 2016. This validation confirmed that the calibrated SWAN model with CFSR wind forcing performed better than the default settings. Lastly, the performance of the calibrated SWAN model was assessed for different wave height ranges, wind sources, annually and per season, their directional properties using wind and wave roses, their distribution function and Quantile – Quantile plots along with extreme waves. The calibrated model offers almost the same extreme waves with different recurrent periods as the measurements.

1. Introduction

Determination of wind-induced wave conditions is important in coastal areas in view of their economic, societal and marine activities. The modeling of wind waves in enclosed seas like the Sea of Marmara is a difficult process because of the proximity of boundaries, varying upwind fetch restrictions and the large number of influencing parameters. Ardhuin and Roland (2013) indicates that the primary input that affects the model's accuracy in an enclosed water body is wind forcing and the secondary factor is parameterization of the physical processes, i.e. the source terms. Therefore, the focus in this study concerns the wind forcing and the physical processes. Since waves are generated by surface winds, the winds are easily affected by the orography of the surrounding environment. Any change in the wind input will therefore influence the computational results (Ponce de León and Orfila, 2013; Komen et al., 1994). For these reasons, in this study, performances of two wind fields (CFSR and ERA-Interim) with different temporal and spatial resolutions were assessed following Van Vledder and Akpinar (2015). Hereafter, a sensitivity analysis was carried out to determine the impact of using different wind data sources on model performance in combination with finding the optimal physical and numerical settings of the SWAN model.

The wind and wave climate of the Sea of Marmara has been studied by various authors. Özhan and Abdalla (1999) produced a wind and wave atlas covering all the Turkish coasts using ECMWF (The European Centre for Medium-Range Weather Forecasts) wind fields and TSMS (Turkish State Meteorological Service)'s synoptic maps. They reported that data obtained from the ECMWF wind fields is good enough for use in wind and wave climate calculations for large water bodies such as the Mediterranean and the Black Sea. On the other hand, they realized that the ECMWF wind fields give poor results in small water bodies such as the Sea of Marmara as the spatial resolution is insufficient to represent effect of sudden changes in land-sea roughness, orography and sea breeze effects. Examples of such effects are presented by e.g. Ponce de León and Orfila (2013). In order to resolve this challenge, a new wind model was developed by Erkal (1997) taking into account the conditions of the Sea of Marmara. The model was later revised by Özhan et al. (1998) who brought it to a more practical state. In the wave calculations made for the Black Sea and the Mediterranean, the dimensions of the grids constituting to a rectangular grid were 0.3°

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https://doi.org/10.1016/j.oceaneng.2018.07.053
Received 21 January 2018; Received in revised form 20 June 2018; Accepted 21 July 2018
Available online 01 August 2018

longitude and 0.25° latitude. The time step was set to 15 min and the calculated sea state parameters were accumulated at 3 h intervals. In the Sea of Marmara, the spatial resolution (rectangular dimensions) was chosen as 0.12° longitude and 0.09° latitude (approximately 10 km × 10 km). The time step was set to 5 min and the sea state parameters were stored at 1 h intervals. Due to the lack of available wave measurements, no calibration or verification was done for their wave model results (Özhan et al., 1998). They gave annual and seasonal roses of observed wave heights and surface wind velocities for each point determined in the sea areas studied. In addition, significant wave height and mean wave period relationships, long-term extreme values of wind and waves, and monthly maximum wind and wave distributions were presented.

Saraçoğlu (2011) obtained the wind and deep sea wave climate for the Black Sea and the Sea of Marmara using the 3rd generation wave model Mike 21 SW. ERA reanalysis data by ECMWF was used as the wind input in the model. Using this wind data, modeling was performed for both seas. For the calibration of the models, Gelendzhik, Hopa, Sinop, Filyos and Karaburun buoy data were used on the Black Sea coasts and only wave parameters obtained from the Ambarlı measurement station for a short two-month time period were used on the coast of the Sea of Marmara. Following the calibration operations for both seas, model simulations were carried out for a period of 12 years (1996–2008). For some stations determined by model results; wave roses, graphs of relation between mean wave period and significant wave height, cumulative probability plots of exceedance distribution, and deep sea maximum wave height statistics were obtained. These results were presented comparatively with the Wind and Deep Sea Wave Atlas for the Turkish Coasts (Özhan and Abdalla, 1999). Saraçoğlu (2011) concluded that his results for the Black Sea are agreeable with those of Özhan and Abdalla (1999), but the results for the Sea of Marmara are not sufficiently agreeable with those of Özhan and Abdalla (1999).

Using MIKE 21, a 3rd generation Spectral Wave Model, Abdollahzadehmoradi et al. (2014) estimated the potential of wave energy that the Sea of Marmara possesses. The model was run with ECMWF wind input and its calibration was carried out based on two months of measurements from Ambarlı station. They also compared their results with those of Saraçoğlu (2011). They claimed that their work had improvements compared to the previous work performed by Saraçoğlu (2011) in a sense that they created a new and finer computational mesh and also, they were able to predict wave characteristics for 2012. They claimed that, overall, the previous model was outperformed by their new model. It is seen, however, that they did not compare model performances based on any statistical error indicators. It cannot, therefore, be concluded that the model of Abdollahzadehmoradi et al. (2014) is superior to the previous study by Saraçoğlu (2011).

To this day, there are only three studies available on wind-wave modeling in the Sea of Marmara. These have, however, been carried out using wave measurements that are too short (about 2 months) for consistent model development, calibration or validation (Özhan and Abdalla, 1999; Saraçoğlu, 2011; Abdollahzadehmoradi et al., 2014). To improve on this situation, we use a much longer period of four years of wind and wave measurements to implement an accurate SWAN wave model for the Sea of Marmara. A key element of this development is choosing the best model wind field data source for driving the wave model. Innovative components of our study are the use of CFSR wind data and the use of measured wave data for calibration and validation purposes. Preliminary results were presented in Kutupoğlu et al. (2016) and now we present more comprehensive results of the setup, calibration and validation of an accurate SWAN wave model for the Sea of Marmara.

The structure of this paper is as follows. The characteristics of our study area are presented in Chapter 2. The materials used, comprising of wind data, the wind and wave measurement data, bathymetry of the study area, the methodology to develop an accurate wave model for the Sea of Marmara, a description of the SWAN model setup and the statistical techniques used to quantify model performance are presented in Chapter 3. Chapter 4 presents results of determining qualities of wind data sources, the sensitivity analysis, the model calibration, and the validation of the calibrated model. In concluding, we summarize the important results obtained in this study on wave modeling of the Sea of Marmara and recommendations for future studies in Chapter 5.

2. The study area

The Marmara Region including the Sea of Marmara forms a passage between the Balkan Peninsula and Anatolia, and connects Europe and Asia. As a result of being on the edge of Europe, connecting the Bosphorus and Dardanelles Straits as a passage from the Black Sea to the Aegean Sea, and lying close to sea ports in the Black and Aegean Seas, this region is highly developed in industry, commerce, tourism, and transportation. Located on its coasts are the cities of İzmit, Çanakkale, Yalova, Tekirdağ, Balıkesir as well as some of Turkey's biggest cities Istanbul, Kocaeli and Bursa. The Marmara region is also the most industrialized region in Turkey and one third of the country's industry is situated in this region (Sertel et al., 2010).

The study area and location of wind and wave measurement station considered in this study, are presented on the bathymetry of the Sea of Marmara in Fig. 1. It is an inner sea of Turkey lying between 40° - 41.25° North and 26° - 30° East. As can be seen from this figure, the Sea of Marmara is a relatively small and narrow basin with islands in which fetch-limited conditions are dominant, i.e. when the dimensionless

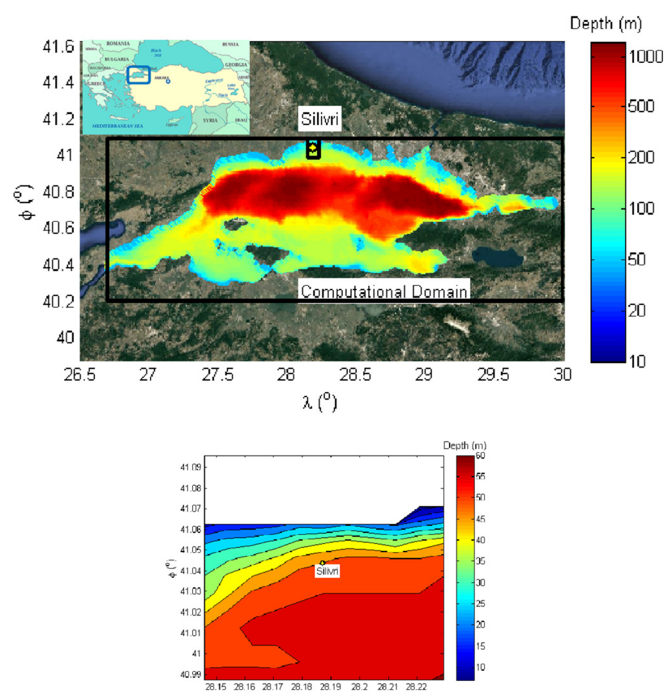

Fig. 1. Study area, bathymetry of the Sea of Marmara and location of the measurements, the outer square in the plot in the middle presents the computational domain, and the lower plot shows the high-resolution bathymetry near Silivri buoy.