Ocean Engineering 75 (2014) 81–89

Contents lists available at ScienceDirect

Ocean Engineering

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

Error distribution and correction of the predicted wave characteristics over the Persian Gulf

Mohammad Hadi Moeini [a,1], Amir Etemad-Shahidi [b,*], Vahid Chegini [c], Iraj Rahmani [d], Mona Moghaddam [d]

[a] School of Civil Engineering, Iran University of Science and Technology, Tehran, Iran
[b] Griffith School of Engineering, Gold Coast Campus, Griffith University, Gold Caost, QLD 4222, Australia
[c] Iranian National Institute for Oceanography, Tehran, Iran
[d] Transportation Research Institute, Tehran, Iran

ARTICLE INFO

Article history:
Received 20 April 2013
Accepted 6 November 2013
Available online 30 November 2013

Keywords:
Persian Gulf
Wave hindcasting
SWAN
Error distribution
Wave modeling

ABSTRACT

Wind-waves are the most important environmental parameter for the design of coastal and offshore structures, sediment transport, coastal erosion etc. Therefore, an accurate evaluation of the wave climate is of great importance. Due to the lack of long term measurements, nowadays numerically modeled wave data are widely used for determining the wave climate. The numerically simulated wave data are continuous in time and space, but generally inaccurate in enclosed and semi-enclosed basins mainly due to the inaccurate wind input data. The main goal of this study is to develop a new and efficient approach to improve the hindcasted wave parameters in the Persian Gulf. Hence, the third generation SWAN model was employed for the wave modeling forced by the 6-hourly ECMWF wind data with a resolution of 0.5°. A new methodology was introduced for the distribution of wave prediction errors from discrete observation points to the other points of interest. It was found that the proposed method which considers the wave generation physics, leads to a significant improvement in the predicted wave parameters. In addition, it was revealed that the improvements in prediction of waves with higher wave heights and longer periods are more than those of others. This was shown to be due to the higher correlation between high values of output parameters which contain larger errors. The influence radius in the error distribution procedure was found to be near 2° (~200 km).

1. Introduction

Wind generated waves are the most important parameter in the design of coastal and offshore structures in the marine environment. The wave climate can be determined using long term wave data from instrumental measurement such as buoys, observation by satellites or numerical models (e.g. Goda, 2000). Each of these data sources has its advantages and disadvantages. The buoys present more accurate and frequent data but their locations are very sparse and mostly close to coasts. In addition, the long term buoy data may not be available in many regions. The altimetry data are continuous and accurate, but very intermittent and inaccurate near the coast (Krogstad and Barstow, 1999). The numerically modeled wave data are continuous in time and space, but generally inaccurate (mainly underestimated) in enclosed and semi-enclosed basins (Cavaleri and Sclavo, 2006). The most important reason for the underestimation of modeled data is inaccurate wind input data (Cavaleri and Sclavo, 2006; Komen et al., 1994). The wind data in the wave models are generally produced by numerical weather prediction models such as those operated at the ECMWF (European Center of Medium-range Weather Forecast). These simulated wind data are inevitably inaccurate and lead to inaccurate prediction of wind waves (Ardhuin et al., 2007; Cavaleri and Bertotti, 2004; Signell et al., 2005). Nevertheless, due to some irrecoverable drawbacks of buoys and altimetry data, nowadays numerically modeled data are widely used for determining the wave climate in different regions. To reduce the model errors, data assimilation techniques are employed to combine the modeled data with measurements at various points in the domain and produce the best possible estimation of the sea state over the entire domain (Kantha and Clayson, 2000).

Data assimilation techniques can be classified into four main groups namely updating of input parameters, updating of state variables, updating of model parameters and updating of output variables (UOV) (Babovic et al., 2005; Refsgaard, 1997). In these methods buoy and altimetry data are used to improve the accuracy

* Corresponding author. Tel.: +61 7 5552 9267; fax: +61 7 5552 8065.
E-mail addresses: mhmoeini@iust.ac.ir (M.H. Moeini), a.etemadshahidi@griffith.edu.au, etemadshahidi@yahoo.com (A. Etemad-Shahidi), v_chegini@inio.ac.ir (V. Chegini), rahmani@rahiran.ir (I. Rahmani), moghadam@rahiran.ir (M. Moghaddam).
[1] Tel.: +9821 7724 0399; fax: +9821 7745 4053.

0029-8018/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.oceaneng.2013.11.012

of the simulated wave data in the hindcast or forecast databases (Babovic et al., 2005; Mínguez et al., 2011; Moeini et al., 2012). The UOV technique is an appropriate method to reduce the error of the numerical models (Babovic et al., 2001). This method can be employed to modify different wave characteristics noting that the numerical model errors are not the same for different outputs (e.g. Moeini and Etemad-Shahidi, 2007). Some researchers have studied the correction of the simulated wave data based on the information taken from the measurements. Caires and Sterl (2005) presented a nonparametric approach to correct model outputs. They applied their approach to the significant wave height dataset of the 45 years European Centre for Medium-Range Weather Forecasts Re-Analysis (ERA-40). Their results showed clear improvements in bias, scatter, and quantiles of the corrected data in the whole range of significant wave height. Cavaleri and Sclavo (2006) used information taken from buoy, altimetry and model data to calibrate decadal time series at a large number of points, distributed at 0.5° intervals in the Mediterranean sea. They derived single calibration coefficients for wind speed and wave height at the various grid points. They showed that the model captures well the structure of the wave fields, i.e. wave direction; and applied no correction to the wave direction. In the above-mentioned studies, the calibration process was conducted on a point-to-point basis, without considering the spatial correlation between adjacent points or taking into account the effect of wave climate. Tomas et al. (2008) developed a methodology for the spatial calibration of wave hindcast data sources based on an empirical orthogonal function and a non-linear transformation of the spatial-time modes. They applied their method to monthly long-term distribution of significant wave height in the Western Mediterranean. This approach may not be applicable for the correction of hourly hindcast data bases. In addition, since they assume a prior distribution function of the data in their study area, their method may not be generalized. Sannasiraj and Goldstein (2009) presented an assimilation model based on an optimal interpolation scheme. They formulated the gain matrix (weighting matrix) according to the model physics (by which the waves are generated by winds). They evaluated the efficiency of their method by using buoy observations in the Arabian Sea. Their assimilation approach led to a 30–50 percent reduction of root mean square error of wave height at the validation stations. In their method, the gain matrix was formulated without considering the difference between wave climate in each season e.g. south-west monsoon, north-east monsoon, and non-monsoon. Mínguez et al. (2011) proposed a calibration procedure for wave hindcast databases based on a nonlinear regression method. In their method, the correction parameters were formulated based on the wave propagation direction and varied smoothly along the possible wave directions by means of cubic splines. They showed the performance of their method using buoy and satellite data from different locations around Spain.

Limited researches have been conducted on wave modeling and data assimilation in the Persian Gulf. Al-Salem et al. (2005) employed the third-generation spectral WAM model to simulate the wind waves in the Persian Gulf with focus on Kuwait territorial waters. They used wind data with a spatial resolution of 0.5° obtained from the ECMWF to force the model. The model was validated using measurements at several locations near Kuwait waters. They showed that the WAM model successfully simulates the wave conditions except for some storm events where the wave heights were underestimated. This underestimation was due to the underestimation of the storms' intensity by ECMWF. Similar results were echoed by Rakha et al. (2007). Moeini et al. (2010) evaluated the quality of two wind data sources, i.e. numerically modeled winds and the measured data, for wave hindcasting in the Persian Gulf using the SWAN model. They found that the SWAN model overestimates the low wave heights and underestimates the higher ones because of the smoothing of wind field by ECMWF. They also noted that the calibration of the model parameters cannot lead to a comprehensive improvement of the model results. Moeini et al. (2012) developed an approach based on the point to point correction of the hindcasted wave parameters in the Persian Gulf. They showed that calibration of model parameters does not result in simultaneous and wide-ranging improvement of wave heights and periods. They proposed an error prediction approach using artificial neural networks (ANN) to correct wave heights and periods, separately. In addition, they showed that combination of the ANN estimated error with numerically modeled wave parameters leads to better results showing the importance of numerical wave modeling in the assimilation procedure.

The main goal of this study is to develop an efficient approach for improvement of the simulated wave parameters over the entire domain based on the error distribution. Two approaches are investigated for the error distribution and their results are compared with each other. In the first approach, the errors at the desired grid point are estimated based on the linear combination of the predicted errors at the observation points. In the second one, it is assumed that the error ratios at the different grid points are the same as the ratio of the wave heights at these points.

2. Study area and data

The Persian Gulf, located in the southwest of the Asian continent is a shallow, semi-enclosed basin in a typical arid zone and is an arm of the Indian Ocean. It is located between the longitude of 48–57°E and the latitude of 24–30°N (Fig. 1). This Gulf is connected to the deep Gulf of Oman through the narrow Strait of Hormuz. The Persian Gulf covers an area of approximately 226,000 km^2 with a length of 990 km. Its width varies from 56 to 338 km, separating Iran from the Arabian Peninsula where the shortest distance is about 56 km in the Strait of Hormuz. This basin has an average depth of about 35 m and the deepest water depth is approximately 107 m (Purser and Seibold, 1973; Emery, 1956).

Generally, the input wind data for wind-wave simulation are generated by the meteorological models. Many different organizations run global atmospheric model producing 2-D gridded wind data all over the world. In this study, the wave model was forced by

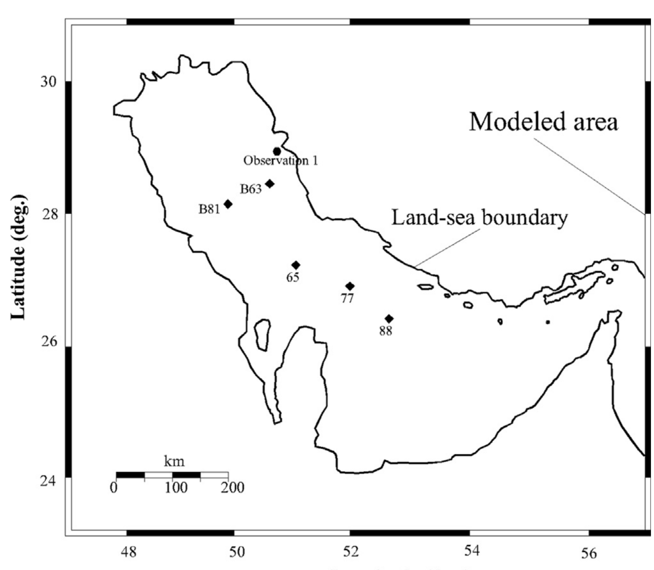

Fig. 1. The Persian Gulf, modeled area and the location of the observation and grid points used for assessment of the error distribution results.