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A hybrid approach to estimate the nearshore wave characteristics in the Persian Gulf

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ABSTRACT

Since ocean waves are mainly wind induced, carrying out coastal engineering projects and investigating environmental issues call for determination of wind-generated wave characteristics, especially in nearshore areas. In this study, a nested grid SWAN model and a hybrid approach combining artificial neural network (ANN) and coarse grid SWAN modeling results are used to hindcast the significant wave height in two nearshore locations in the Persian Gulf. However, the results are only valid in the regions where they are trained and tested. The models were calibrated in order to minimize the scatter index and the performances were compared, and the results show that the scatter index for significant wave height for both nearshore locations is less using the hybrid model rather than the nested one and there is no significant difference for the other error indices using both approaches. Regarding that the nesting approach is costly and consumes much more time in comparison to the hybrid one, and also taking into account that the nested model is unable to correctly calibrate wave height and other wave parameters, simultaneously and additional calibration may be required, the alternative hybrid approach is suggested to be used in wave simulation in nearshore areas. It is because the proposed hybrid model takes advantage of both SWAN and ANN merits while trying to avoid their limitations.

1. Introduction

Waves are among the major and determinative phenomena in coastal areas that play a significant role in design of nearshore and offshore structures, fisheries industry, port planning and management, maritime transportation, oil-related activities, sediment transportation, air–water interaction, etc. Considering that the most important factor in wave generation is the wind; the irregular nature of the wind causes irregularity in wave heights and periods, as well. The wave characteristics can be obtained from buoy or satellite measurements, or can be simulated using different approaches such as empirical methods, numerical models, soft computing approaches.

Empirical methods, including CEM [1], SPM [2], Donelan [3], JONSWAP [4] and SMB [5] are of proven easiness and quickness to determine the wave characteristics. However, they do not yield sufficient accuracy and also their application is limited and is developed for specific areas. Therefore, numerical models were developed to achieve the higher accuracy and extensive applicability. Consequently, a number of so-called third generation models such as SWAN [6], MIKE-SW [7], WAM [8] and WAVEWATCH III [9] have been developed and utilized in different regions for wave simulation.

Rusu [10] studied various strategies in using numerical wave models, including WAM, WAVEWATCH and SWAN, in which six different case studies were considered and showed that SWAN model is very flexible and can be applied for a wide range of coastal applications. In addition, Rogers et al. [11] conducted a research on numerical modeling of wind waves in the Southern California Bight, using SWAN. Although numerical modeling is efficient up to some level, it is quite expensive and time consuming, especially in the nearshore regions where model grids are needed to be finer in order to simulate the nearshore processes, accurately.

Soft computing approaches such as artificial neural networks (ANNs), decision trees, genetic programming, etc. are widely used in coastal and ocean engineering applications, including wave modeling (e.g. [12–20]). However, the soft computing method is reliable in a point where there is enough and long-term dataset for training the model. Hence, the results of soft computing modeling are only valid in the regions where they are trained and tested.

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An accurate estimation of nearshore wave characteristics is of great importance for design purposes or for nearshore activities. As mentioned before, numerical models and soft computing methods are appropriate to estimate the wave characteristics, accurately. Due to the complexity of nearshore processes, the numerical models are required to be nested in a finer grid so that the calculations of a higher resolution computational grid can be carried out. However, it leads to more computational time. Soft computing methods are another alternative to estimate the wave characteristics with high accuracy in nearshore areas.

Hybrid approaches can be a good solution to compensate the shortcoming of soft computing and numerical modeling and meanwhile maintain their advantages. For example, Sannasiraj et al. [21] and Zhang et al. [22] incorporated ANN and data assimilation techniques into the WAM model for wave forecasting. Furthermore, Breivik et al. [23] forecasted and hindcasted nearshore wave characteristics in Norwegian Sea by dynamical and statistical downscalings using WAM coarse model outputs as the boundary conditions of SWAN fine model.

This study aims to utilize a new hybrid method for simulation of wave characteristics in two nearshore locations in the Persian Gulf. The previous studies in the region used a high resolution numerical modeling to produce the wave characteristics in the whole area or some parts of the Persian Gulf [24–26] or used the soft computing methods to forecast or hindcast the wave characteristics using soft computing method in specific locations for a limited time span [19]. Hence, in this study, the nearshore wave characteristics are obtained from a coarse modeling (for saving the time) and are modified using soft computing, instead of utilizing a nested numerical modeling in nearshore locations. For this purpose, SWAN numerical model and ANN were used to evaluate the reliability of the proposed hybrid method, comparing to the nested numerical modeling. Moreover, the long term hindcast results can be used for long-term wave climate analysis, extreme value analysis for design of marine structures, etc.

2. Study area and dataset

The study area is the Persian Gulf (Fig. 1), an extension of the Indian Ocean which is located in the middle-east. Persian Gulf is a crescent-shaped water body with 990 km length, and its width varies between 56 and 338 km. The surface area of the Persian Gulf is approximately 226,000 km^2 with the mean depth of about 35 m that reaches up to 107 m in the deepest point which permits the easily extraction of its great resources of oil and gas [27,28]. In addition, other marine activities such as fisheries and transportation are very important in this area. Hence, the accurate wave characteristics, especially in nearshore areas are required for many usages.

In this study, two different locations are selected as study areas in the Persian Gulf, including Boushehr and Asalouyeh, which are located in the northern coasts of the Persian Gulf (Fig. 1). It should be taken into consideration that the two sites are selected regarding their close proximity to the tremendous oil and gas reserves and marine transportation as well as the availability of a highly valuable measured data.

The wind data used for numerical modeling of the wave characteristics using SWAN was the ECMWF wind field consisting of both operational and re-analysis series which is modified in the Persian Gulf to imply higher accuracy comparing to the measured data [29]. This dataset includes wind components with the temporal and spatial resolutions of 6 h and 0.5°, respectively. The high resolution bathymetry data is necessary for accurate modeling of the waves, especially in shallow areas. Therefore, GEBCO data which are globally available with a resolution of −30 arc-seconds were used for this simulation.

Table 1
MVI index for the significant wave height and wind speed in Boushehr and Asalouyeh.

Parameter	Year			
	2007		2008	
	Asalouyeh	Boushehr	Asalouyeh	Boushehr
Significant wave height	0.88	0.77	0.96	0.67
Wind speed	0.57	0.47	0.58	0.41

To calibrate and verify the coarse numerical model as well as training and testing the soft computing method, the wave measurement is required. In this study, for the training period, time series of continuous significant wave height for the time periods of 4 and 1 months with 1-hourly intervals near Boushehr and Asalouyeh were employed for training and testing, respectively. Wave data were recorded by two buoys, which were deployed in 28 m depth near Boushehr port (50.5 N, 28.58 W) and 50 m depth near Asalouyeh port (52.55 N, 27.51 W) with 1-hourly intervals.

In order to ensure that the monthly variation of the wind system and significant wave height in the Persian Gulf are not significant to affect the accuracy of calibration and verification, Monthly Variability Index (MVI) was calculated for two years, separately [30,31] and presented in Table 1. The MVI is the ratio of the difference between the maximum and minimum monthly mean wave height/wind speed and the annual mean wave height/wind speed [32] and the lowest values imply the lowest seasonality and more stable conditions.

According to Table 1, monthly variations of the significant wave height and wind speed are totally less than 1 and are not significant and hence, the selected periods for trainings and verifications can be appropriate representatives for the other periods.

3. Method

3.1. Numerical nested modeling

SWAN (Booij et al. [6]) is a third generation numerical wave model that simulates the evolution of the wave spectrum, $E(\sigma, \theta)$, according to:

$$\frac{\partial}{\partial t}N + \frac{\partial}{\partial x}c_xN + \frac{\partial}{\partial y}c_yN + \frac{\partial}{\partial \sigma}c_\sigma N + \frac{\partial}{\partial \theta}c_\theta N = \frac{S}{\sigma} \tag{1}$$

where N is wave action density, equal to energy density divided by relative frequency ($N = E/\sigma$), σ is the wave frequency measured from a frame of reference moving with a current, in case a current exists, t is time, θ is wave direction, c_x, c_y, c_σ, and c_θ are the wave group velocities in x, y, σ, and θ space, respectively, and $S \approx S_{in} + S_{nl} + S_{ds}$ is the sum of source terms. The quantity $S_{in}(f,\theta)$ represents wave, growth by wind and $S_{nl}(f,\theta)$ represents nonlinear wave–wave interactions including both quadruplet and triad interactions and $S_{ds}(f,\theta)$ represents the dissipation through whitecapping, bottom friction, and depth induced breaking.

SWAN has the ability of nested modeling, which means generating the boundary conditions on a fine grid by a previous run on a coarse grid (dynamical downscaling). In this study, coarse and fine grid resolutions of 0.2 and 0.01° are used, respectively. The coarse grid covers the whole Persian Gulf, while the fine grids are designed to cover the Boushehr and Asalouyeh with a 0.5° × 0.5° rectangle, starting from 50.245° E and 28.45° N, and 52.2° E and 27.05° N, respectively (Fig. 1).

In order to obtain the accurate results, parameters such as bottom friction, wave breaking and whitecapping coefficients were subjected to several modifications. Sensitivity analysis indicated that changing the whitecapping dissipation has the highest impact