INTERNATIONAL JOURNAL OF
COASTAL & OFFSHORE ENGINEERING

IJCOE Vol.10/No. 1/Winter 2025 (35-39)

Available online at: www. Ijcoe.org

The prediction of wind-induced waves in Hormuz Strait using the SWAN numerical model

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ARTICLE INFO

Article History:
Received: 5 Dec 2019
Accepted: 15 Jun 2025

Keywords:
wave
predication
swan
Hormuz Strait

ABSTRACT

Nowadays, sea operations require accurate prediction of the characteristics of the waves in the coastal and offshore areas. For modeling wave characteristics, there are various methods such as empirical methods, numerical methods and soft computing methods. In this research, the SWAN numerical model for modeling of wave characteristics in Hormuz Strait area was used. First, a global model for modeling the characteristics of the waves in the Persian Gulf domain was built. Then, the boundary condition obtained from the global model for local modeling with a larger resolution in the area of Hormuz Strait was used. The local model constructed in the Hormuz Strait area was calibrated using the recorded waveforms of the buoy deployed in that area and then was validated. Comparison of the results with the measured data of the Hormuz Strait buoy shows that the modeling has been carried out in this area has very precision results.

1. Introduction

For the design of inshore and offshore structures and for marine operations, prediction of the characteristics of the waves is required. For modeling and prediction of waves' characteristic, empirical, numerical and soft computation methods can be used.

Experimental methods base on coastal engineering manual [1], shore protection manual [2] and SMB [3] are relatively simple and low cost methods that are developed on the basis of specific conditions and in a particular region. Therefore, they are not very accurate in other areas. In comparison with experimental methods, numerical models have a much higher accuracy. Examples of numerical models are: WAVEWATCH III [4], SWAN [5], WAM [6] and Mike 21 [7].

Soft computing tools such as artificial neural network, regression decision tree, genetic algorithm and fuzzy inference system are other ways to predict the characteristics of the waves, but in a specific area.

So far, various studies have been done on the use of numerical models to predict wave characteristics. Moeini [8,9], Rogers [10], Signell [11], Caliskan [12], Rusu [13] and Bolaños-Sanchez [14] are some example of these researchers.

In this study, SWAN's numerical model was used to predict wave characteristics in Hormuz Strait. Became Considering the importance of the Hormuz Strait area, accurate and accurate modeling of wave characteristics is very important.

2. Materials and Methods

2.1. Study area

The Persian Gulf with about 900 km length and 240,000 km^2 is the third largest gulf in the world. It is one of the most important geo-economical and geo-political water body in the world. The Hormuz Strait connected the Persian Gulf to the open seas. In every one hour approximately 10 ships pass through this narrow waterway in which this strait is a rash shipping line [15].

2.2. Required data

The data used in this modeling include the wave information recorded by the Hormuz Strait buoy. This Buoy is deployed Hormuz Strait by the consultant engineering corporation in this area and its information is available in 1-hour time series of wave information. Location of this buoy is at 55.55 degrees east and 26.31 degrees north.

Other data used which are essential as input in SWAN model are the bathymetry data and wind speed. The bathymetry data is a rectangular grid with a resolution of sixtieth degrees.

The wind speed used in this modeling has been modified by the ECMWF database, which has a magnitude of 0.2 degrees and 6 Hour interval. The correction of ECMWF wind data in coastal areas was carried out by the data measured by synoptic stations

2.3. SWAN numerical model

The SWAN model is one of the third-generation numerical models. The SWAN Cycle III version 40.72 was used in this study. It was developed by Delft University of Technology in 2009. This model is an available and freely accessible that is widely used by researchers and engineers for research and consulting.

The SWAN model solves the spectral action balance equation without any predetermined condition on the spectrum for the evolution of wave growth. In the SWAN model, waves are described by the two-dimensional spectrum of the wave-action density, in which the growth of the action density, N, is determined by the time-dependent wave action balance equation that in the Cartesian coordinates as follows:

$$\frac{\partial N}{\partial t}+(\overrightarrow{C_g}+\vec{U}).\nabla N+\frac{\partial C_\sigma N}{\partial \sigma}+\frac{\partial C_\theta N}{\partial \theta}=\frac{S_{tot}}{\sigma} \quad (1)$$

The first sentence in the equation 1 shows the rate of change in the action density. The second term indicates the wave energy propagation in a two-dimensional geographic space where C_g Wave group speed and U is the lateral limited current. This statement can be restored in the Cartesian, spherical or curvilinear coordinate. The third sentence shows the relative frequency shifting effect due to variations in depth and currents. The fourth expression reflects the refraction from the depth or current. The quantities C_σ and C_Θ are the propagation speeds in the spectral space (σ, θ), which σ shows the relative frequency and θ for propagation direction. The S_{tot} parameter is the source term in terms of energy shown in the Eq.(2):

$$S_{tot}=S_{wind}+S_{nl3}+S_{nl4}+S_{wc}+S_{bot}+S_{db} \quad (2)$$

The right parameters of the above equation are, respectively, the energy input by the wind (linear or exponential growth by wind), the nonlinear energy transfer of the wave under triple and Quadruple interactions, wave deformation due to white capping, bottom friction, and depth-induced wave breaking.

The specification of the model used includes a uniform and rectangular computational spatial grid which magnification for the overall model is 0.1 degrees (about 10 Km) and for the local model is 0.01 degrees. The grid spectrum is divided into an angular grid and a frequency grid.

An angular grid is considered as a full circle with 18 sectors, and the frequency grid is composed of a frequency of 0.8 to 1 and includes 20 parts with logarithmic distribution is divided. Figure 1 shows the position of global and local models for modeling the waves profile in the Hormuz Strait.

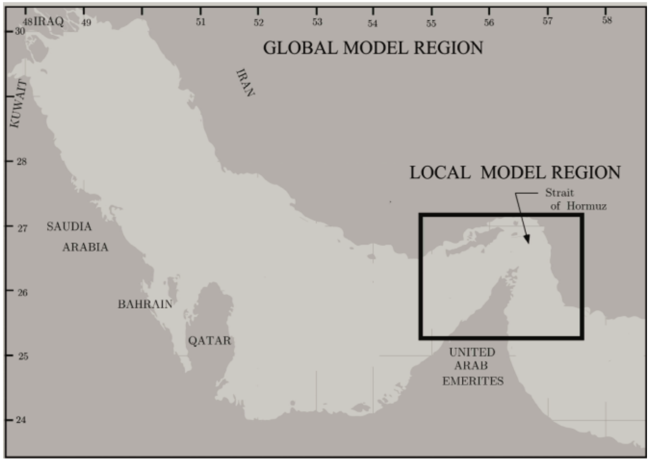

Figure 1. Global and local model domain

Local modeling was carried out after global modeling and the local model boundary conditions were extracted from global model, which was given in the next step.

3. Results and Discussion

The model should be calibrated for a period of time to reduce the difference in results with measured values. Calibration and validation durations in Hormuz Strait, from July 17 to August 17and August 20-31, 2018 was considered, respectively. The time series of wind and wave data is shown in figures 2 to 11.

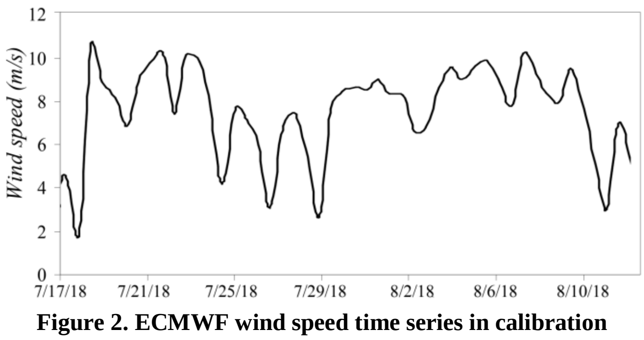

Figure 2. ECMWF wind speed time series in calibration period

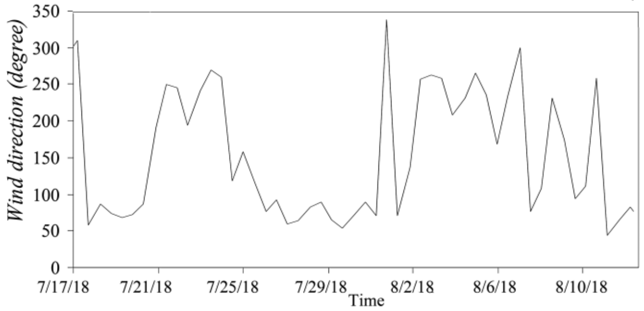

Figure 3. ECMWF wind direction time series in calibration period

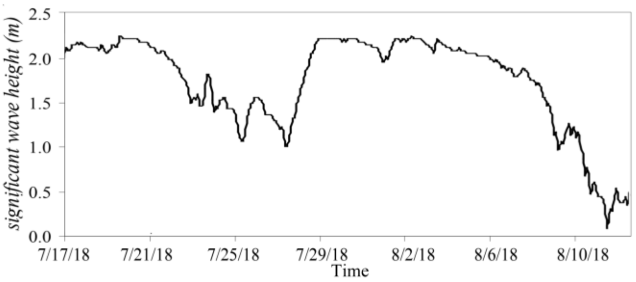

Figure 4. significant wave height time series in calibration period

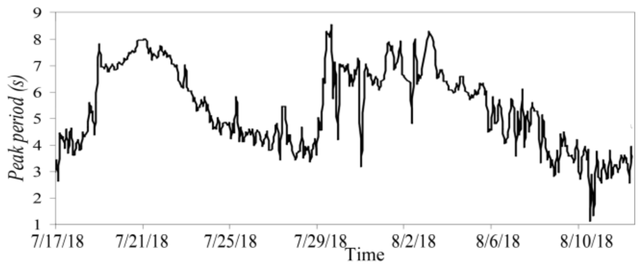

Figure 5. peak period time series in calibration period

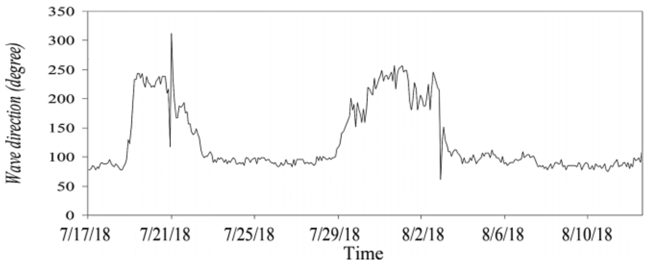

Figure 6. wave direction time series in calibration period

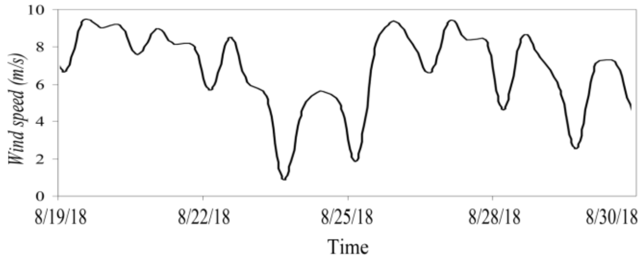

Figure 7. ECMWF wind speed time series in verification period

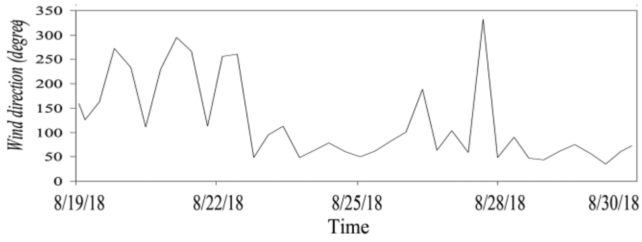

Figure 8. ECMWF wind direction time series in calibration period

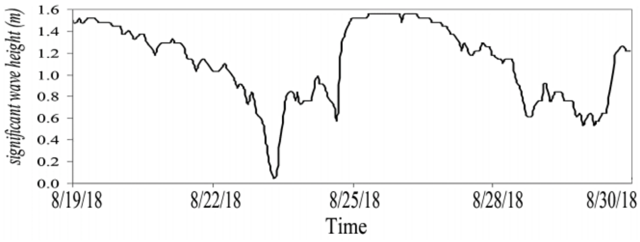

Figure 9. significant wave height time series in verification period

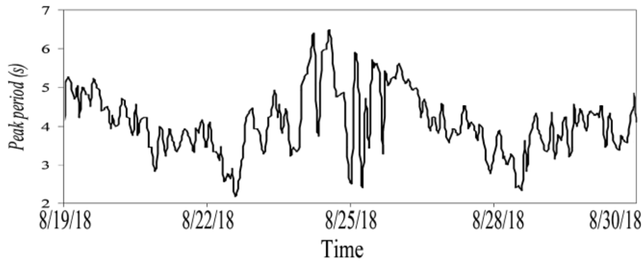

Figure 10. peak period time series in verification period

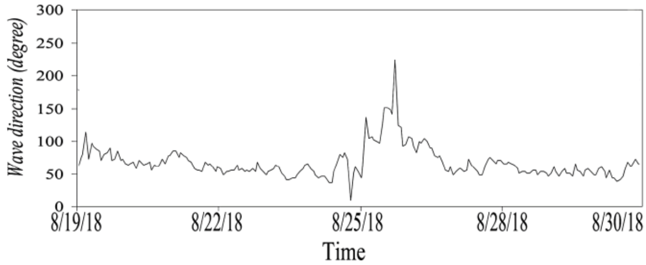

Figure 11. wave direction time series in verification period

Figures 2, 4 and 5 show that the trend of wind speed variations, significant wave height and wave peak period are roughly the same. Figure 3 shows the dominant wind direction is between 50 to 320 degrees and figure 6 shows a dominant wind of about 80 degrees.

Figures 7, 9, and 10 show similar trends for wind speed, significant wave height, and peak period. Figure 8 shows the dominant wind direction blowing is between 50 and 250 degrees and figure 11 shows a dominant wave of about 50 degrees (similar to the calibration period).

Tables 1 and 2 also show wind and wave statistics in calibration and validation periods, respectively.

Table 1. wind and wave characters in calibration period

Parameter	Min	Mean	Max	SD[1]
significant wave height	0.03	0.65	2.1	0.58
peak period	1.52	3.8	8.28	1.13
Wave direction	150	250	300	28.12
Wind speed	2	4	10	3.11
Wind direction	100	270	320	85.3

Table 1. wind and wave characters in verification period

Parameter	Min	Mean	Max	SD
significant wave height	0.03	0.45	1.8	0.49
peak period	1.62	3.2	7.88	1.01
Wave direction	200	250	300	19.23
Wind speed	2	4	10	2.57
Wind direction	50	200	300	78.9

3.1. Model Calibration

To calibrate the model, the variations of the coefficients of the whitecapping, wave breaking and sea bottom friction are used. In this modeling, sensitivity analysis indicates that the changing in whitecapping coefficient has the most effect on the accuracy of the results. Therefore, this coefficient was used for model calibration. The model was calibrated for the corresponding time period and the calibration results of the model are shown in figures 12 and 13.

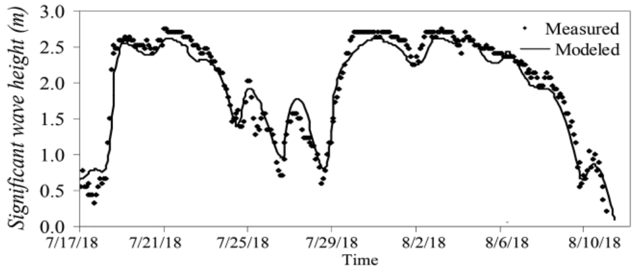

Figure 12. model and measurements significant wave height time series in calibration period

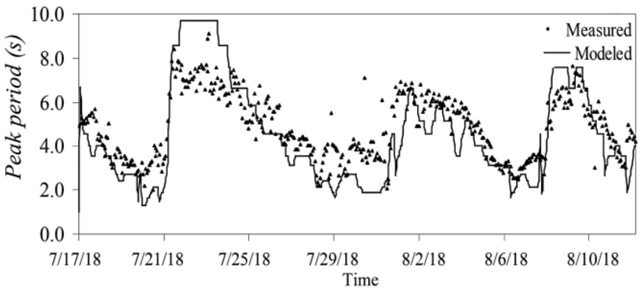

Figure 13. model and measurements peak period time series in calibration period

As shown in figures 12 and 13, the time series of the wave characteristics of the model is well suited to the time series of the measured wave specification.

To investigate the accuracy of the results, the bias, correlation coefficient(CC), root mean square error(RMSE) and the Scatter Index (SI) are calculated in accordance with relations 3 to 6 and are shown in table 3.

$$Bias = \bar{x} - \bar{y} \quad (3)$$

$$CC = \frac{\sum_i (x_i - \bar{x}) \times (y_i - \bar{y})}{\sqrt{\sum_i (x_i - \bar{x})^2 \times \sum_i (y_i - \bar{y})^2}} \quad (4)$$

$$RMSE = \sqrt{\frac{\sum_i (x_i - y_i)^2}{n}} \quad (5)$$

$$SI = \frac{\sqrt{\frac{1}{n} \sum_i (x_i - y_i)^2}}{\bar{x}} \quad (6)$$

Table 2. Error index in calibration period

Error index	Significant wave height	Peak period
Bias	-0.05	-0.26
CC	0.8	0.65
RMSE	0.13	1.10
SI	28	22

Low bias, root mean square error and dispersion index and good correlation coefficient also shows the high accuracy of modeling done in the Hormuz Strait region.

3.2. Model verification

The results of the model validation for the respective period are shown in figures 14 and 15.

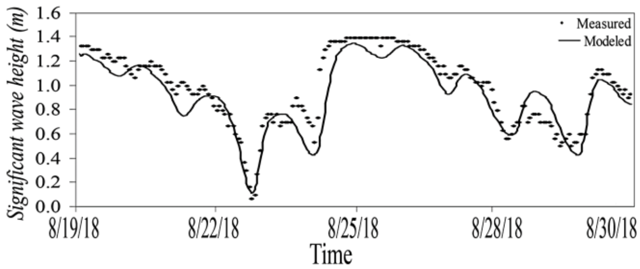

Figure 14. model and measurements significant wave height time series in verification period

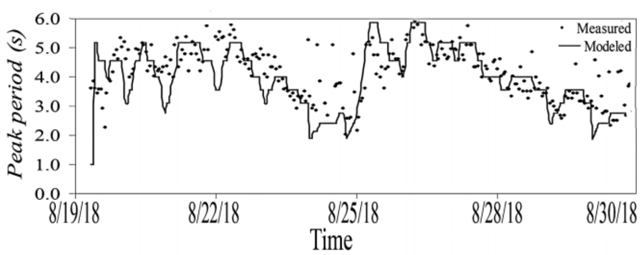

Figure 15. model and measurements peak period time series in verification period

Figures 14 and 15 show the time series matching of modeling and measured wave characteristics.

[1] Standard Deviation

Calculated error indicators for the verification period are shown in table 4.

Table 3. Error index in verification period

Error index	Significant wave height	Peak period
Bias	-0.015	-0.25
CC	0.83	0.88
RMSE	0.11	1.20
SI	18.55	25.13

The calculated error indices in the verification period also show the acceptable accuracy of modeling in the Hormuz Strait by the SWAN model.

Therefore, the constructed model can be used to predict the significant wave height and the peak period in the Hormuz Strait.

4. Conclusions

In this research, the prediction of wave characteristics in the Hormuz Strait was carried out using the SWAN numerical model. Model inputs include ECMWF wind field data and bathymetry. The model was first calibrated for a 19-day period, and then verified for the 13-day period. The verification results of the model showed that the results of the calibrated model have good precision.

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