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Statistical analysis and numerical modeling of the coastal waves at the South of the Caspian Sea (coasts of Amir Abad Port)

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Abstract

In this study, the coastal waves of Amir Abad Port are simulated using Mike21-SW Model. The data in this research including the bathymetry and fetch were obtained from the Iranian National Institute for Oceanography. Moreover, the wind data was acquired from Babolsar synoptic station, and the wave data were obtained from Amir Abad and Neka buoys. First, semi-analytical wave prediction methods such as SPM and CEM were used to determine the wave characteristics on offshore. Following that, the wave characteristics in the study area were simulated by Mike21 using unstructured meshes with approximate netting of 0.005 geographical degree and initial and boundary conditions. The results of the semi-analytical methods and the simulations were compared with the data from Amir Abad and Neka buoys, and they were calibrated based on the buoys' data. The results showed that Mike21 is more appropriate than the semi-analytical methods for predicting the coastal waves in the study area. Considering the wave-roses obtained from the numerical modeling, the direction of the prevailing wave was determined to be toward the west, and given the model output, the prevailing wave height was predicted about 0.485 m.

Keywords: Amir Abad Port; Mike21-SW Model; Semi-analytical methods; Wave prediction; Extreme value analysis.

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1. Introduction

Wind climate refers to wind parameters changes (magnitude and direction) derived from meteorological patterns over a specific area .Wave climate refers to wave parameters changes derived from meteorological characteristics and hydrodynamic relations in a specific area . In other words, long-term averages of variable wave parameters are included. This concept is not only used for average state, but also for all wave parameters such as maximums, minimums. Ecological factors controlling the wave climate include geographical coordinates, elevation above the water surface, bottom topography, as well as wind blowing over the mean sea level.

Waves have great importance in coastal engineering. Waves are also very important in specifying geometry and shape of the shore. They also have major effect on the design of harbored entrance projections and ports, bars and beach preservation as well as coastal structures projections and coastal works. Wave characteristics extremely change in time and space. For a suitable assessment of wave characteristics in an area, long-time measurements (about 10 years and more) are required in short-time interval (about 1 hour and less) at many points of the study area. In America, Japan, and Netherlands, coastal engineering and physical oceanography has improved extremely over the last five decades. Developments of these countries in coastal structure design and fishing, trading and army bars, oil rig building as well as coastal engineering actions is salience.

Iranian coastal provinces are important from the economic point of view and in the southern provinces; the existence of oil increases this importance. Performing the oil industry projections in the sea, fishing, tourism and beach preservation play a major role in the economic growth of the country.

Performance of this projection requires the accurate knowledge of wave and wind climate as well as physical oceanography and coastal engineering (Chegini, 2007).

Siegle *et al*. (2002) simulated the water level changes by Mike21 (NSW) model and investigated the coastal morphology in Tiegmouth, UK gulf. The results were compared to the remote pictures taken from five cameras that covered this zone. The headland length in the gulf was about 2 km. They implemented the model in different tides. The tides data were extracted from European Coast Project. Then, Mike21 (NSW) output data was used as Mike21 (HD) input data. The coastal morphology was studied along with the wave current plotting in different wave heights. Then, the significant wave height affecting the coastal morphology was investigated. They found out that there is a direct relationship between the coastal topography and tide range and sea level ahead of the gulf change between 0.2 and 0.4 m.

Lin *et al*. (2002) compared two different wave models, the second generation model GLERL (Great Lakes Environmental Research Laboratory) and the SWAN wave model with measurements in Chesapeake Bay. Simulations have been made without including the effects of current and water level variations. Wave breaking and triad wave-wave interaction were activated in SWAN model. Comparisons of time series showed that both models over-predicted the wave heights and under-predicted the peak period.

Derakhshan (2003) in her research analyzed about 5600 weather data including wind speed and direction, duration-averaged windspeed, air-sea temperature difference, fetch length and buoy data in Bushehr marine area. Then using the SMB, SPM, JONSWAP, Donelan, Krylov semi-analytical methods, and the wave climate was studied in Bushehr marine area. The results showed that SMB method is the best method for wave forecasting.

Seyfan Ahari (2004) investigated offshore wind waves in Bushehr port using the SMB method and OSW module from Mike21 package software. The results showed that the maximum wave height derived from SMB method was 3.99m and the wave period was 9.39s. The correlation coefficient (CC) between SMB and OSW model was 59 percent.

The second phase of Iranian Sea Wave Modeling Project was performed in Iranian Natural Center of Oceanography and waves were simulated in the Caspian Sea for 12 years from 1992 to 2003. Ports and Maritime Organization defined this project and the Iranian Natural Center of Oceanography and Danish Hydraulic Institute performed it. Prior to the enactment of the second phase of the Iranian Sea Wave Modeling Project, the required data for numerical modeling such as wind data (from remote sensed, synoptic station and weather prediction models), topography, tides, sea level changes, freezing, etc. were collected and analyzed. Then the wind-induced waves over the Caspian Sea were calculated by Mike21-SW, which is a new generation wind wave model. Calibration and verification were conducted by comparison of the measured wind and wave data. The Iranian Natural Center of Oceanography performed the third phase of the Iranian Sea Wave Modeling project, and the south waves of Iran were simulated during 12 years from 1992 to 2003 (Golshani, 2004).

Siadatmousavi (2005) simulated wind wave in Chabahar Gulf using the SWAN model, SPM method, and Mike21-SW. Then, the results of the above-mentioned methods were compared with the buoy data and the affecting process in wave-spectrum energy, and wave growth were investigated in numerical models. The results indicated that triad wave-wave interactions in shallow waters do not change the wave parameters, and Mike21-SW is applicable with an insignificant error.

Chegini (2007) acquired wave climate using the semi-analytical methods (SMB, SPM, CEM and Jonswap).The study results were compared to Amir Abad buoy data and the SPM was recognized as the best model correlating with the buoy data.

Neelamani *et al*. (2007) performed extreme value analysis in 12, 25, 50, 100, 200 years return period in 38 different points of Persian Gulf. The input data was extracted from WAM model during 12 years from 1993 to 2004. One-meter threshold level in the studied area was chosen for EVA analysis. They found that Weibull probability distribution had the best function in the extreme value analysis. Based on this function in 100 years return period, the wave height ranged from 9 to 16m and the depth changed between 3 m to 4.5 m.

2. Material and methods

Geographic coordination of the Amir Abad port are $36^{0}\ 47^{'}$ N and $53^{0}\ 15^{'}$ E. Amir Abad port that is located in the south-west edge of the Caspian Sea will be developed and converted to most important economic port in the future (Chegini, 2007).

2.1. Equations in Semi-Analytical Methods

Semi-analytical methods are of the wave forecasting methods, which are used when there are defective long-term data, or in primary studies like probability of projection. These methods are simpler, faster and widely used. They rely on the equations between the non-dimensional parameters of waves.
In these methods according to fluid mechanics and dimensional analysis, non-dimensional parameters are defined and the experimental coefficients between them are determined from observations and measurements. These methods are based on the assumption of uniform and steady wind blowing over the ocean, that is, wind velocity and direction are constant in wind blowing duration and in fetch.

2.2. SMB Method

SMB is one of the semi-analytical methods. Sverdrup and Munk (1947) applied a combined empirical-analytical procedure in the first widely used wave prediction system. Bretschneider (1952; 1958) revised the Sverdrup-Munk prediction curves using empirical data. This prediction system is the SMB method. The significant wave height and wave period are calculated by the following equations:

$$H_S = 0.283 \frac{U^2}{g} \tanh\left[0.0125 \left(\frac{gX}{U^2}\right)^{0.42}\right] \quad (1)$$

$$H_S = 0.283 \frac{U^2}{g} \tanh\left[0.0125 \left(\frac{gX}{U^2}\right)^{0.42}\right] \quad (2)$$

In the equation above, U represents the wind speed in m/s, X represents the fetch length in m and g is the acceleration of gravity (Chegini, 2007).

2.3. SPM Method

SPM is one of the semi-analytical methods given in Shore Protection Manual by Bishop *et al.* (1992). Using this method requires the adjustments of wind speed, duration-averaged wind speed, stability correction, location effect and coefficient of drag. Significant wave height and period in deep water are given in the following equation:

$$H_{m_o} = 2.433 \times 10^{-1} \left(\frac{U_A^2}{g}\right) \quad (3)$$

$$T_P = 8.134 \left(\frac{U_A}{g}\right) \quad (4)$$

In the equation above, U_A represents the wind-stress factor in m/s and g represents the gravity acceleration.

2.4. CEM Method

CEM is one of the semi-analytical methods given in Coastal Engineering Manual (2003). In this method, adjustments must be made for the measured wind data inclusive level, duration, and stability. Significant wave height and period in deep water for fully developed wave growth are given in the following equation:

$$H_{m_0} = 1.115 \times 10^{2} \left(\frac{u_*^2}{g}\right) \quad (5)$$

$$T_P = 2.398 \times 10^{2} \left(\frac{u_*}{g}\right) \quad (6)$$

In the Equations (5) and (6), u_* represents the friction velocity in m/s according to CEM guide in 2003.

2.5. JONSWAP Method

Hasselmann *et al.* (1973) derived Jonswap spectrum from an analytical research on 2000 spectrum that were extracted from the North Sea Wave Project. From 200 spectrums, 121 spectrums were suitable for fetch limited wave growth condition.

Significant wave height (H_{m_0}) can be obtained by wave energy density and zero-order moment of the wave spectrum:

$$H_{m0} = 4\sqrt{m_0} \tag{7}$$

T_{m01} which represents the wave period corresponding to the mean frequency of the spectrum is given in SPM guide in 1984 by the following equation:

$$H_{m0} = 4\sqrt{m_0} \tag{8}$$

2.6. Equations in SW Model

Calculation of the significant wave height in the numerical wave forecasting model is based on solving the wave action conservation equation using discretization in temporal, directional and frequency domain.

$$\frac{\partial E}{\partial t} + \frac{\cos\theta}{C}\frac{\partial(ECC_g)}{\partial x} + \frac{\sin\theta}{C}\frac{\partial(ECC_g)}{\partial y} + \frac{C}{C_g}(\sin\theta\frac{\partial C}{\partial x} - \cos\theta\frac{\partial C}{\partial y})\frac{\partial E}{\partial\theta} = S \tag{9}$$

In Equation (9), the terms in the left hand indicate wave transformation and this part include the effect of shoaling, refraction, and diffraction. On the right hand, the terms indicate source and sinks of energy such as input energy from wind, nonlinear interaction between wave components and energy loss due to wave breaking. In fact, this equation indicates the mechanisms of wave generation, wave growth, and wave transport (EVA, 2008).

2.7. Extreme Value Analysis

A measured wave record never is repeated exactly, due to the random appearance of the sea surface. However, if the sea state is stationary, the statistical properties of the distribution of periods and heights will be similar from one record to another. The most appropriate parameters to describe the sea state from a measured wave record are therefore statistical. Hence, the following terms are frequently used in physical oceanography: average wave height, maximum wave height, significant wave height, Wave height return period.

Structural engineers need an estimate of the likely severest conditions to be experienced by the structures. The usual parameter chosen to describe such conditions is *N* year return value of the wave height. Return value is a statistical parameter, and the engineer in his design has to allow the possible occurrence of waves greater than the *n*-year return value, or even several waves like this within a few years.

The concept of return value as a design criterion has proved useful, and the extreme wave condition, which a coastal or offshore structure is designed to survive are called design wave conditions. These conditions are usually expressed in terms of wave characteristics as a function of occurrence probability. The method usually employed to estimate the *n* years return value of the significant wave height is to fit some specified probability distribution to the few years' data and to extrapolate the probability of occurrence of once in *n* years.

2.8. Equations in Extreme Value Analysis

For evaluating the risk of extreme events, a parametric frequency analysis is used formulated based on the fitting of a theoretical probability distribution to the observed extreme value series. Two different extreme value models are provided in EVA, the annual maximum series (AMS) method and the partial duration series (PDS) method, also known as the peak over threshold (POT) method.

The defined extreme value population is described by a stochastic variable *X*. The cumulative distribution function *F(x)* is the probability that *X* is less than or equal to *x*:

$$F(x) = P\{X \leq x\} \tag{10}$$

The probability density function *f(x)* for a continuous random variable is defined as the derivative of the cumulative distribution function:

$$f(x) = \frac{dF(x)}{dx} \tag{11}$$

The quantile of the distribution is defined as:

$$x_p = F^{-1}(p) \tag{12}$$

where p = P{X ≤ x}. The quantile x_p exceeds with probability (1-p), and hence, it is often referred to as the (1-p)-exceedance event. Often the return period of the event is specified rather than the exceedance probability. If (1-p) denotes the exceedance probability in a year, the return period T is defined as follows (EVA, 2008):

$$T = \frac{1}{1-P} \tag{13}$$

In AMS method, there is not enough data for fitting to probability density function. On the other hand, if two or more big events occur in one year, the maximum event is used in extreme the value analysis. Then, the PDS method is used.

2.9. Data Requirement for Semi-Analytical Methods

The wind data, fetch length, and shape of the studied area are required in the semi-analytical methods.

2.9.1 Topographic data

Caspian Sea topographic file data was obtained from Iranian Natural Center of Oceanography, which has been used in the Iranian Sea Waves Modeling Project.

2.9.2 Fetch length data

Fetch length in this study was obtained from the Iranian Natural Center of Oceanography with 3 degrees directional resolution.

2.9.3 Wind data

In this study, Babolsar synoptic station data was used. Geographic coordinates of Babolsar synoptic station are $36^0\ 43^{'}$ N and $52^0\ 39^{'}$ E. This station was established in 1951. The measured wind characteristics are wind speed and direction at 10 m level with 3- hours recording interval. Constant wind definition is used for duration-averaged wind speed. In this study, constant wind is defined as the wind with a magnitude difference less than 4 m/s and direction difference less than 20 degrees. Wind data was used during 1991-2005.

Amir Abad buoy is located on the latitude of $36^0\ 55^{'}$, longitude of $53\ ^0\ 24^{'}$ and depth of 17 m. Buoy recording was made from 19/2/2002 to 19/3/2003 with 2-hours discontinuous recording intervals. Neka buoy is located on the latitude of 53.3 and longitude of 37.1. Its wave recording was continuous and the time interval for the recording was 0.5-hours from 1/1/1992 to 31/10/1992.

3. Results

3.1. Local SW Model Setup

In this study, an unstructured application of the mesh file SW model was constructed covering 53.2 to 53.6 E and 36.8 to 37.2 N with the mesh size of 0.005 degree (500m) in the area (which are uniform. Boundaries in the north, east and west were open and in the south, there was closed boundary. In Figure 1 indicates the bathymetry and meshes used in the local model. Using a high-performance computer, the model setup and its implementation were conducted in the data processing laboratory of Tarbiat Modares University.

In general, wind-induced wave growth is very important as the first step in the calculation of wave characteristic. In this case, at first, the wind energy is transported to the sea surface and then the wave energy is transported between the wave components until the wave reaches the fully developed case and the energy transport by wind is stopped. In this condition, the model solves equations as fully spectral formulations. This means that all the phenomena associated with the energy transportation, and all the frequencies and directions are completely included, and any presuppose is excluded. Hence, such solutions need a long-time period. The local model setup requires suitable boundary conditions. Because the local model is part of the global model, it is discrete in the boundary position. The boundary condition of local SW model was extracted as parametric from the Iranian Sea Waves Modeling Project (ISWM) during 12 years from 1992 to 2004. These parameters are significant wave height, peak wave period, mean wave direction

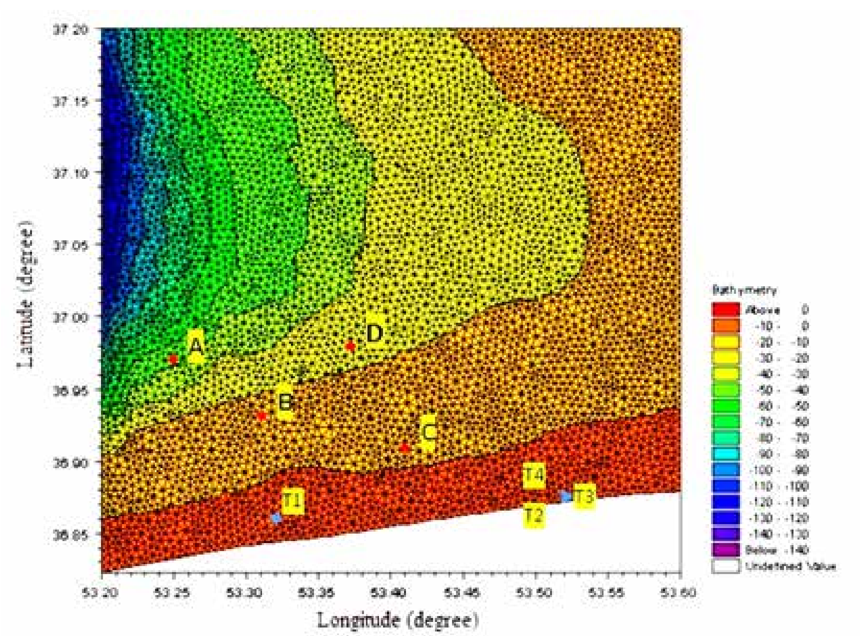

Figure 1. Computational mesh and bathymetry around Amir Abad in local model

and spreading directional index. The local model solves balance energy equations as directionally decoupled. This model was verified and calibrated using the Iranian Sea Waves Modeling Project results and Amir Abad buoy data and correlation coefficient of 80 % was acquired between buoy data and local model results.

3.2. Comparison between Local Model Results and Global Model Results in Different Points of the Studied Area

After verifying and calibrating the local model, and ensuring that the local model results are accurate, their results were compared to the global model in different areas as time series and accordingly, the accuracy of the Iranian Sea Waves Modeling Project or the global model in shallow waters were estimated. Simulation duration was 4 months from February 2002 to June 2002. Note that the goal of simulation was the assessment of the accuracy scale in the global model domain and acquiring a reliable domain for the global model in nearshore zone. Comparison of the local model and global model results as time series helped to reach the goal. Considering the global model meshes, this model provided accurate and reliable results in offshore elements (to about 5 km). To compare the significant wave height, peak wave period and mean wave direction obtained in the local and global models in elements placed at the distance of 5 km from the near shore zone, points A, B, C, and D were selected as presented in Figure 1. To compare the significant wave height, peak wave period and mean wave direction obtained in the local and global models in shallow waters elements, points T1, T2, T3, and T4 were selected as shown in Figure 1.

Figure 2 compares the significant wave height, peak wave period and mean wave direction in the global and local models at point C.

Furthermore, Figure 3 compares significant wave height, wave period peak, and mean wave direction in the global and local models at point T4.

In element meshes placed at a distance of 5 km outside of the shore, there is negligible difference in the significant wave height, peak wave period and mean wave direction between the local and global models. As shown in Figure 3, there is a great difference between the wave parameters at shallow waters element meshes and element meshes, which are placed at a distance of 1-2 km in the global model and elements that are too close to the land. Due to the fine-meshes of the local model, this model forecasts the wave parameters more accurately than the global model. At point T4, which is the nearest point to the shore, there is great difference in mean wave direction due to refraction.

The wave height and wave period were determined by the semi-analytical methods, and the results were compared with Amir Abad buoy data. In general, wave growth cases are classified into three categories: duration limited, fetch limited, and fully developed conditions. In SPM and CEM methods, equations are exhibited for wave parameters forecasting in all the three cases. Furthermore, in SMB method, the equations are represented for the first two cases. The percentage occurrence of each of the above-mentioned conditions in Amir Abad deep waters are calculated and shown in Table 1.

Table 1 shows that wave growth in Amir Abad marine area is in a duration-limited condition, and approximately, in few cases it occurs in a fully developed condition.

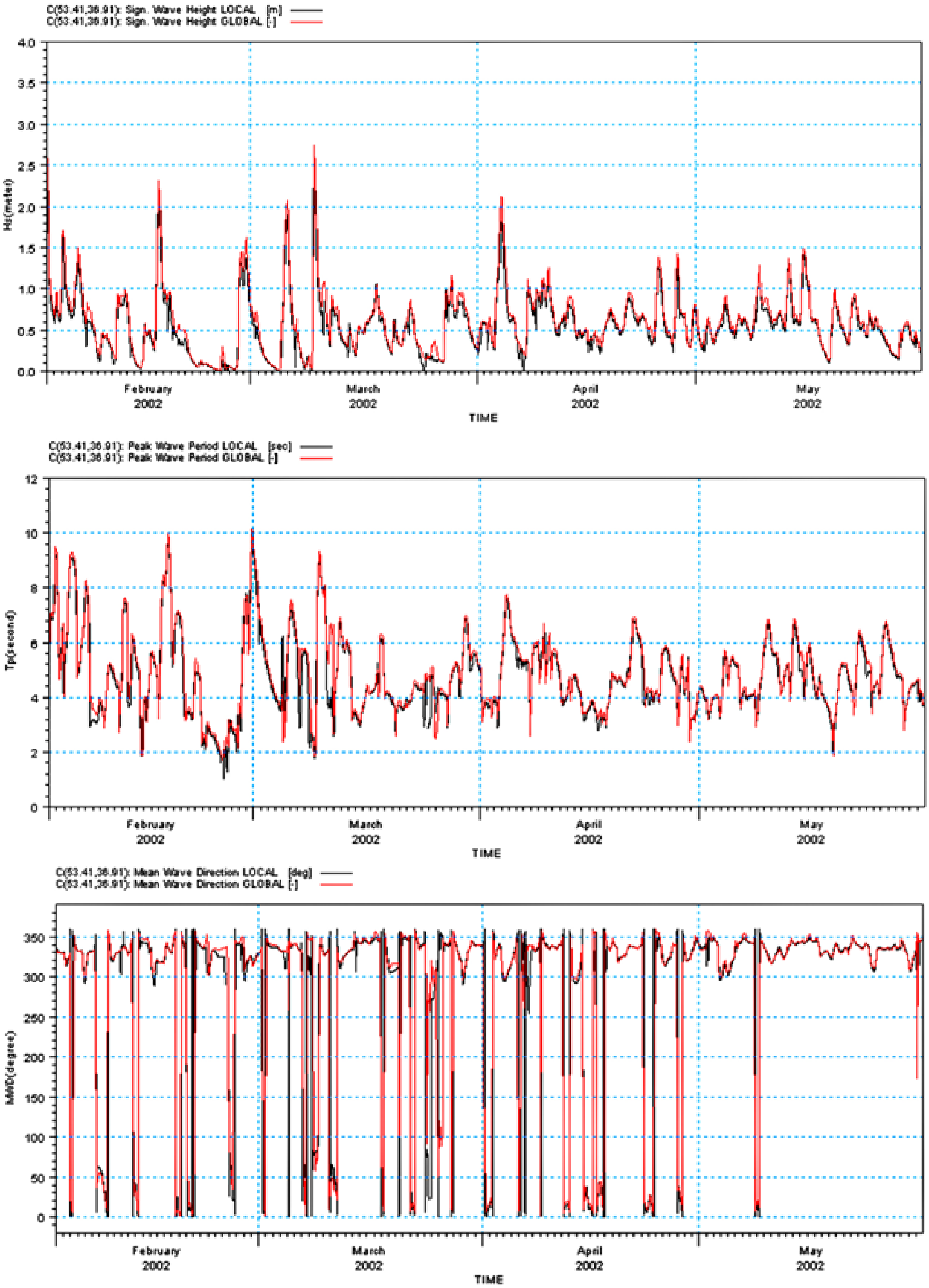

Figure 2. Comparison of the significant wave height, peak wave period and mean wave direction in the global and local models at point C

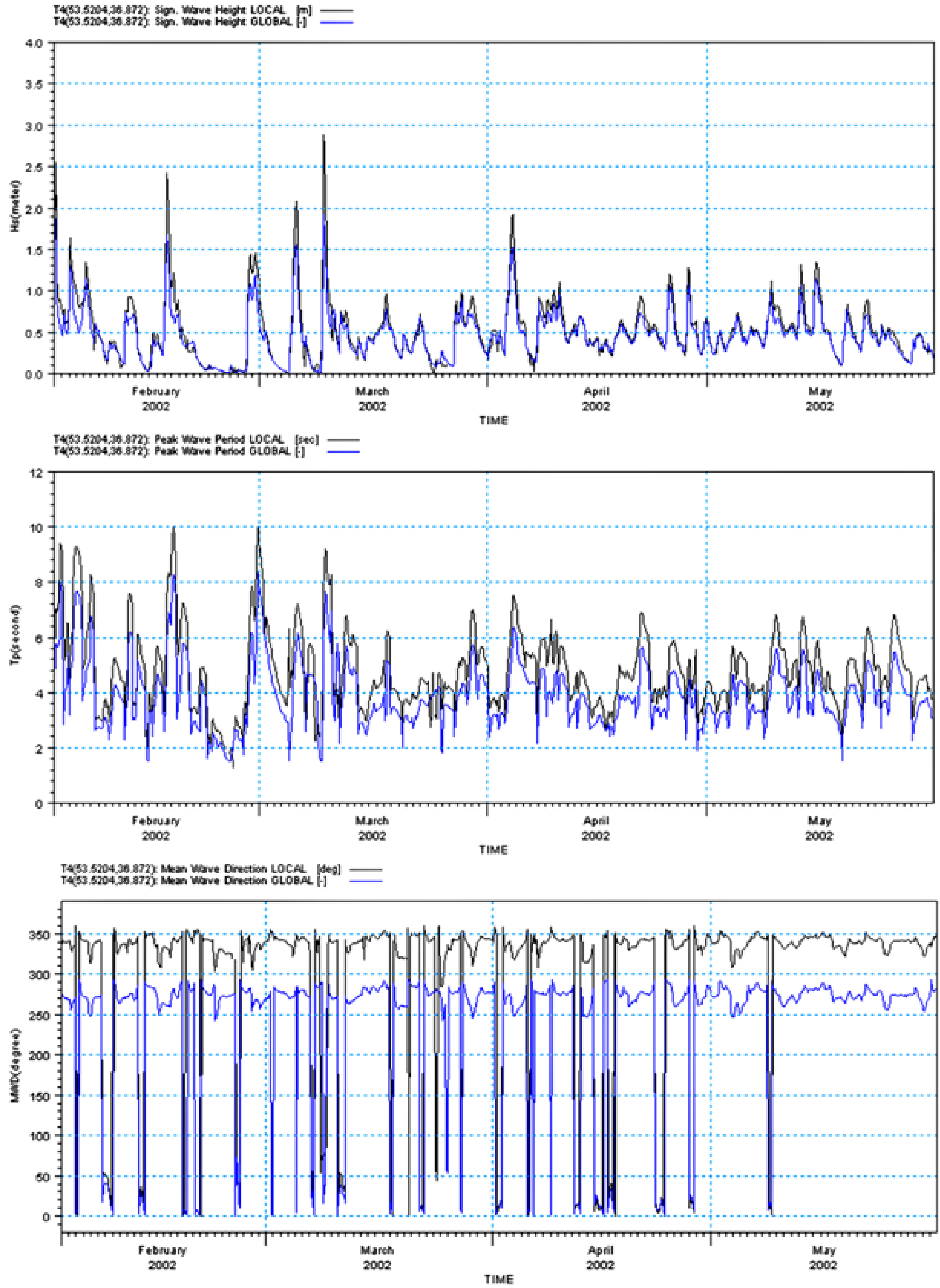

Figure 3. Comparison of the significant wave height, peak wave period and mean wave direction in the global and local models at point T4

Table1. Percentage occurrence of wave growth condition in Amir Abad area

CEM	SPM	SMB	Condition
39.62	39.62	31.05	Percentage occurrence of calm condition(wave height is zero)
57.22	55.90	60.91	Percentage occurrence of duration limited condition
3.09	4.05	8.04	Percentage occurrence of fetch limited condition
0.07	0.43	0	Percentage occurrence of fully developed condition

3.3. Comparison of Semi-Analytical Methods Results with Buoy

Considering the accessible data, the results of semi-analytical methods are controlled by Amir Abad and Neka buoy data. There are statistic parameters that are used as scales of correlation between two data series. One of these parameters is correlation coefficient. Correlation coefficient (*CC*) changes between 1 and - 1. If *CC* =1, then there is an absolute and direct correlation between the data series and if *CC* = -1, there is an absolute but opposite correlation between the data series. If *CC* =0, there is no correlation between the data series nowise. The CC is given by the following formulation:

$$CC = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2 (y_i - \bar{y})^2}} \tag{15}$$

In the equation above, x represents measured data, y represents the simulated data and $\bar{x}$ and $\bar{y}$ represent the average of the related data. In Figures 4 and 5, the correlation coefficients of the semi-analytical methods, local SW model and Amir Abad buoy data are compared together (Chegini, 2007).

In addition, the results of different analyzes with the methods described in this study were compared together (Figures 6 to 14).

The results show that the local SW model is the best method for wave condition prediction as expected. This concept is common, since in the local SW model, all phenomena associated with energy transport and all frequencies and directions are included completely and every presupposition is excluded. The local SW model gives a suitable pattern for wave forecasting. The SMB correlation coefficient is greater than the other semi-analytical methods. However, by comparison of the wave height in several peaks, it was found that the SPM method is in best agreement with the buoy data.

In general, as a result, there is not good agreement between the semi-analytical methods and buoy data and using these methods may be significantly problematic. The semi-analytical methods predicted the values typically less than the observations. The correlation coefficient between the SPM method and buoy was 22%. The wave period acquired by the CEM method is less than the SPM method obviously. This is one of the problems of the semi-analytical methods. Because when the wind speed is zero, the wave characteristics forecasted by the semi-analytical methods are zero. However, it is rare to have a flat sea affected by wind or swell waves.

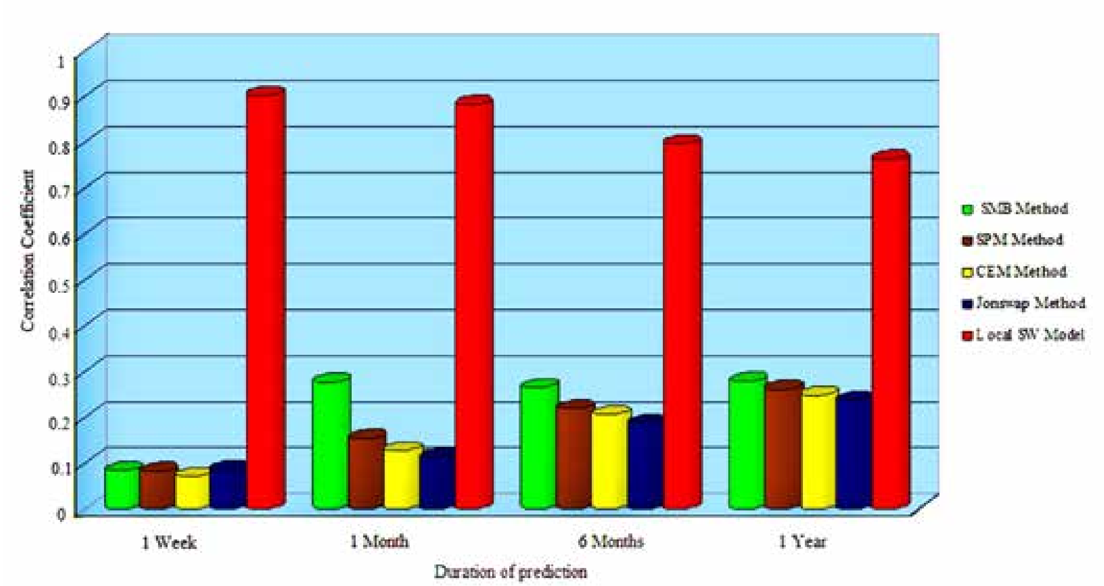

Figure 4. Correlation Coefficient, comparison between predicted wave heights derived from different methods and buoy

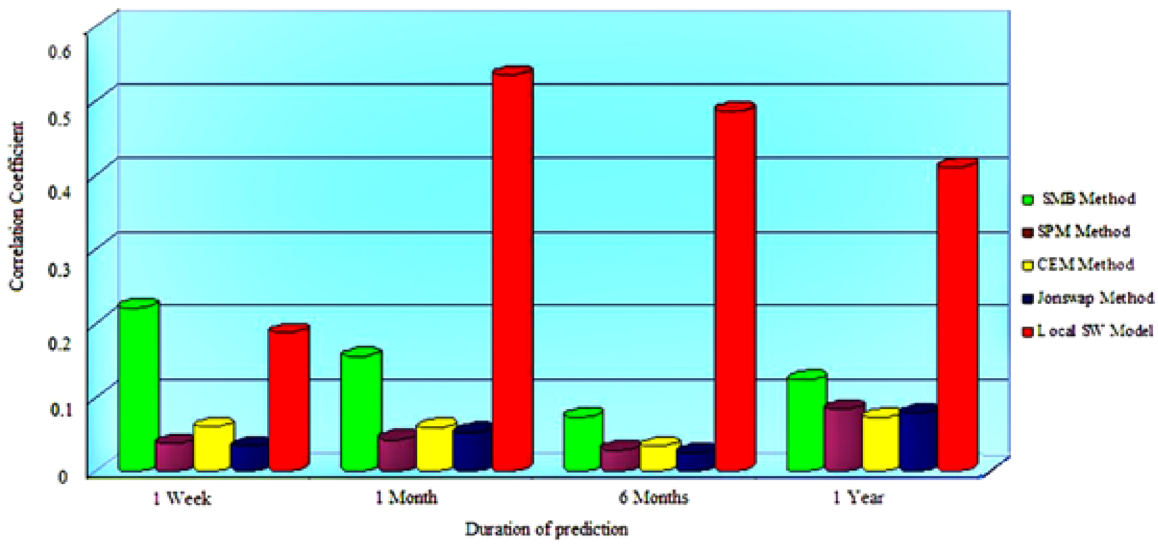

Figure 5. Correlation Coefficient, comparison between predicted wave periods derived from different methods and buoy

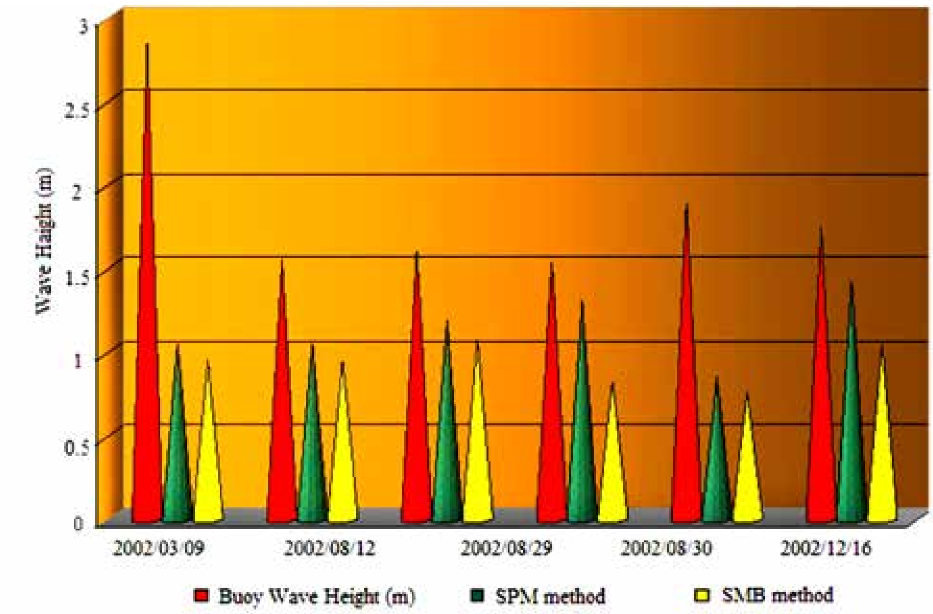

Figure 6. Wave height comparison between SPM, SMB and buoy data in different wave peaks

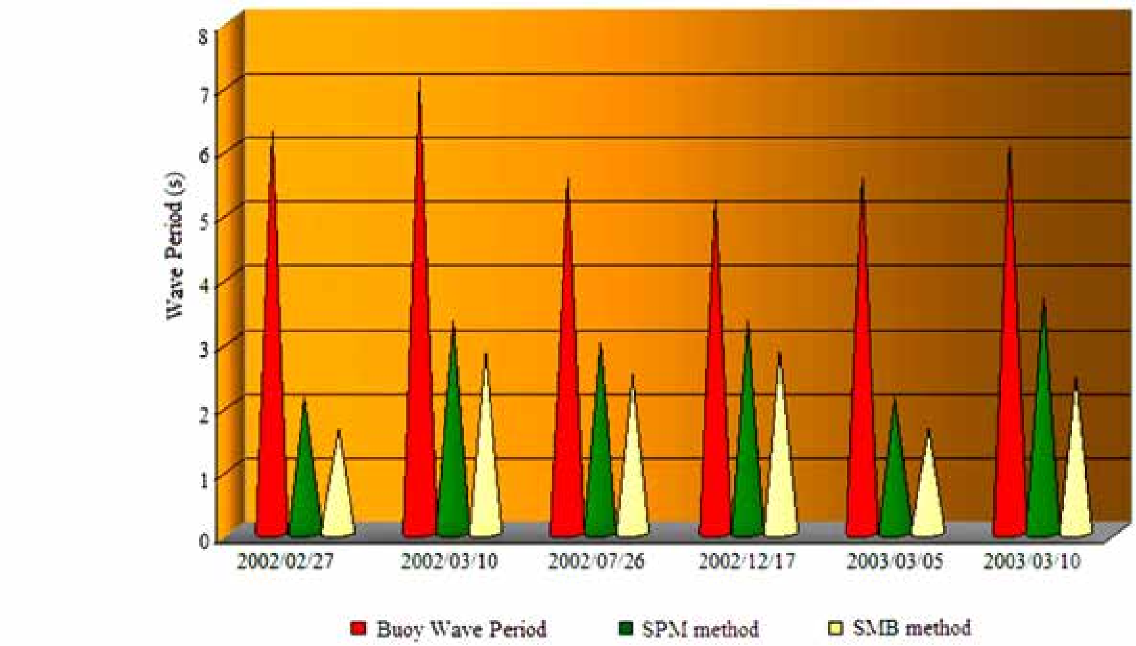

Figure 7. Wave period comparison between SPM, SMB and buoy data in different wave peaks

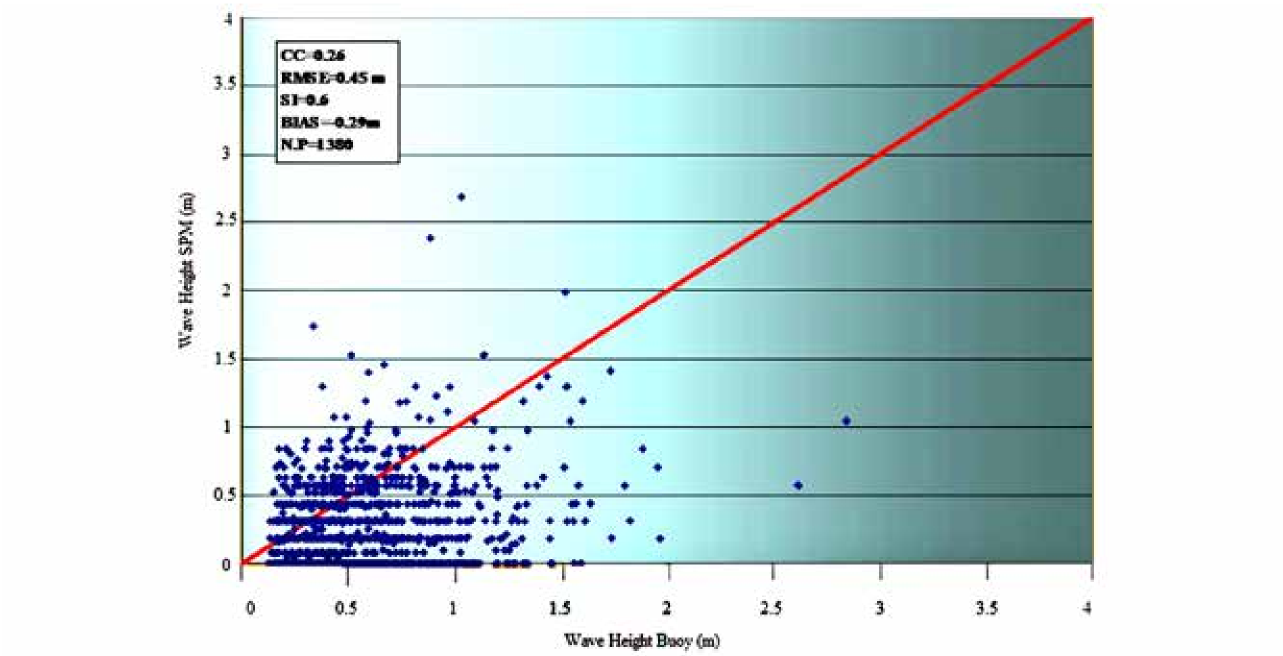

Figure 8. Wave height comparison between SPM method and local model

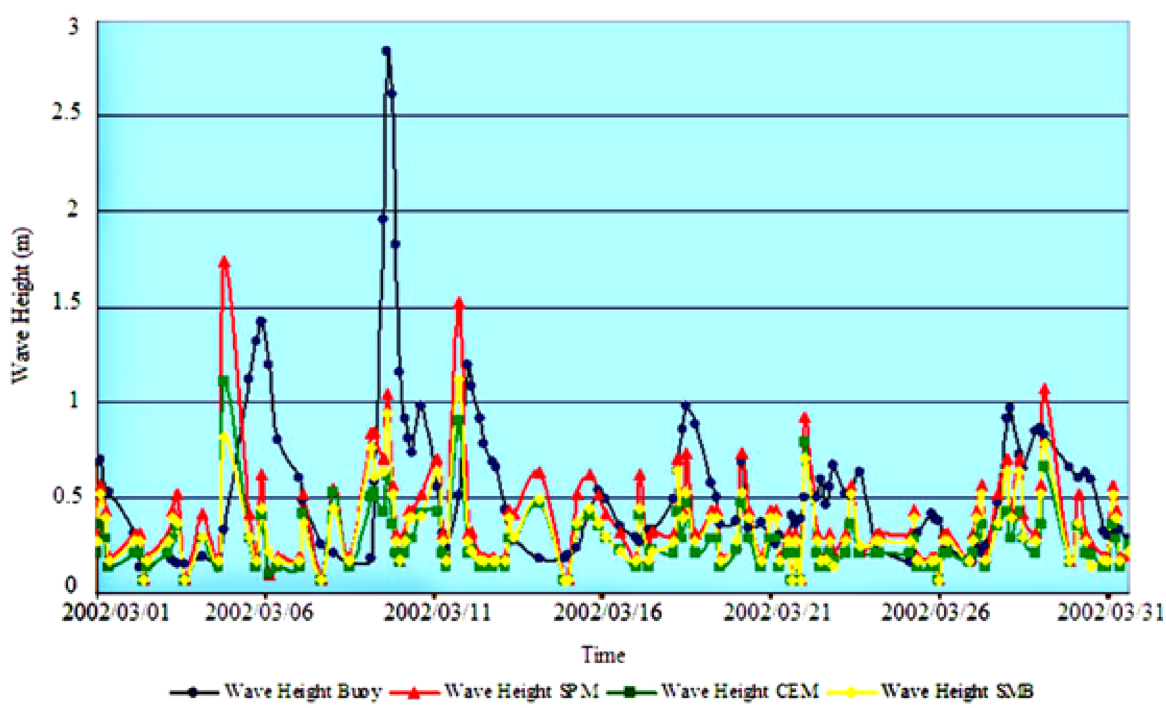

Figure 9. Wave height time series, comparison between semi-analytical methods and buoy in March 2002

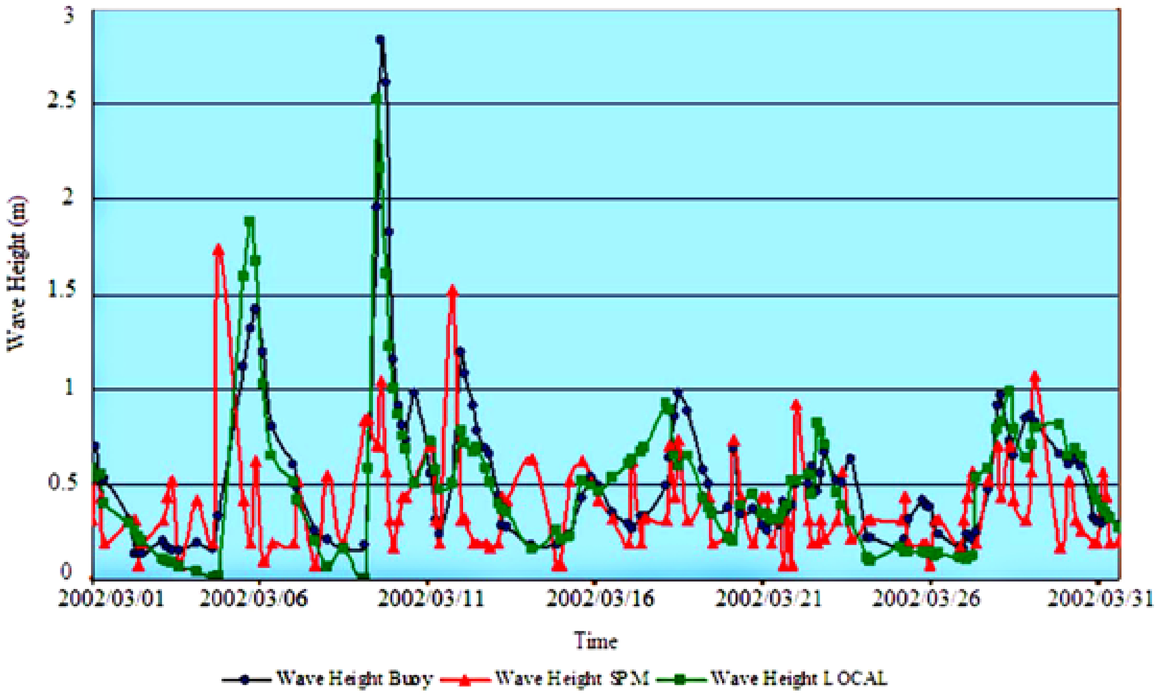

Figure 10. Wave height time series, comparison between SPM method and buoy in March 2002

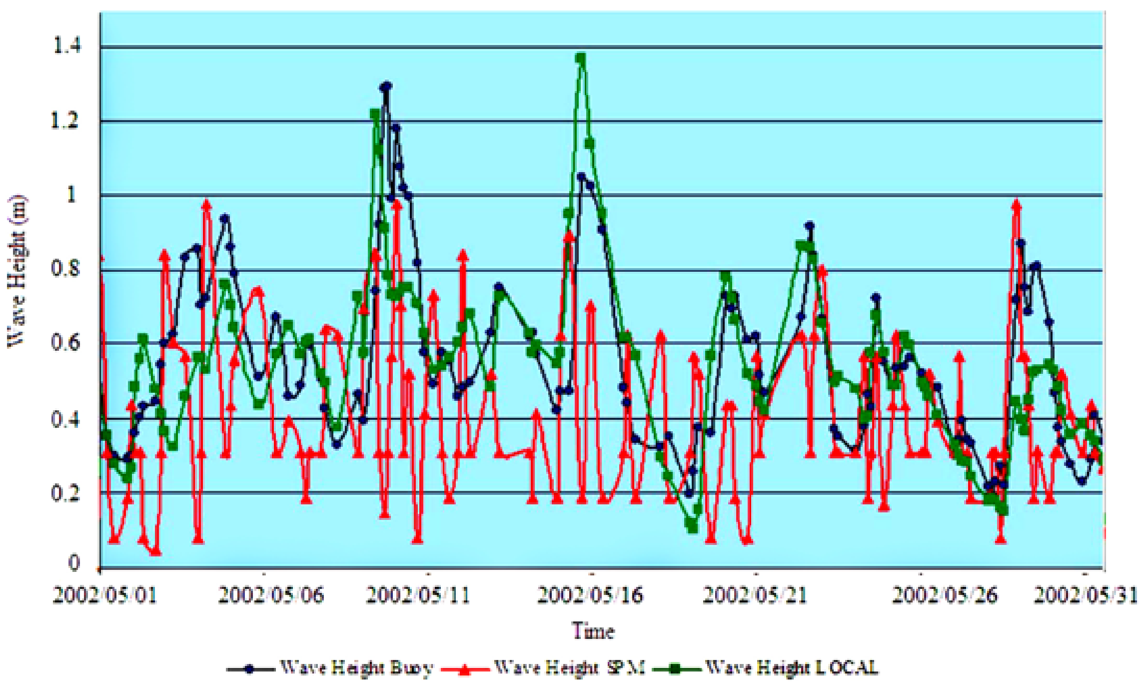

Figure 11. Wave height time series, comparison between semi-analytical methods and buoy in may 2003

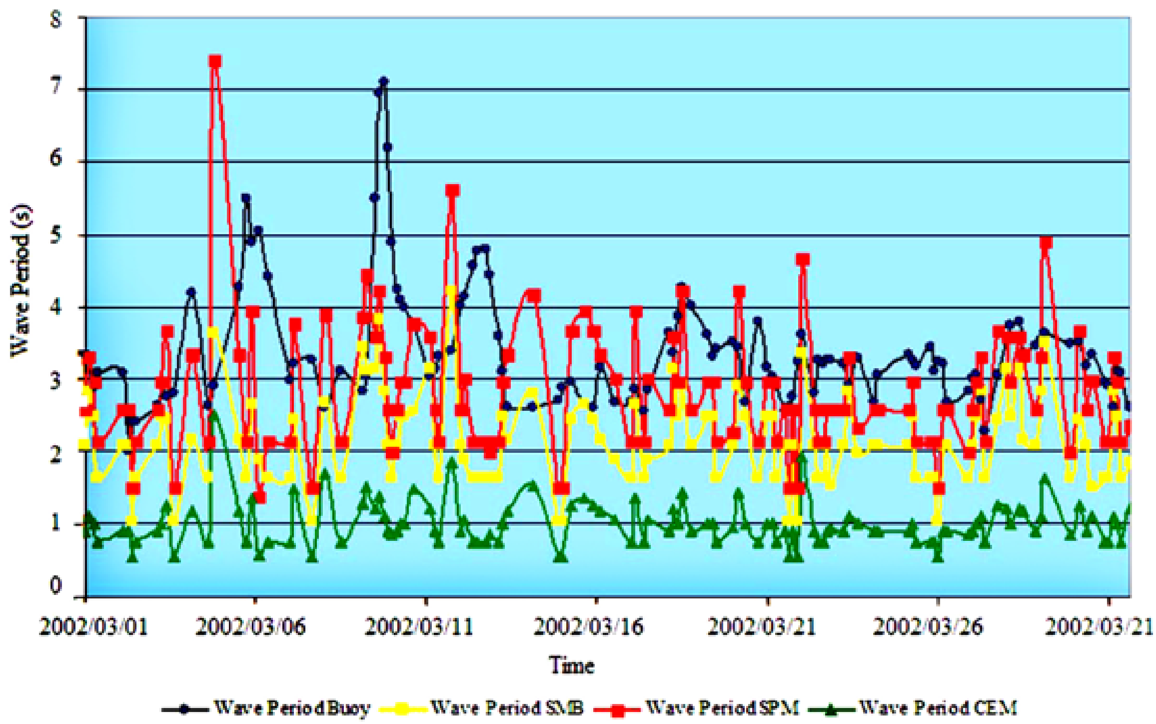

Figure 12. Wave period time series, comparison between semi-analytical methods and buoy in March 2002

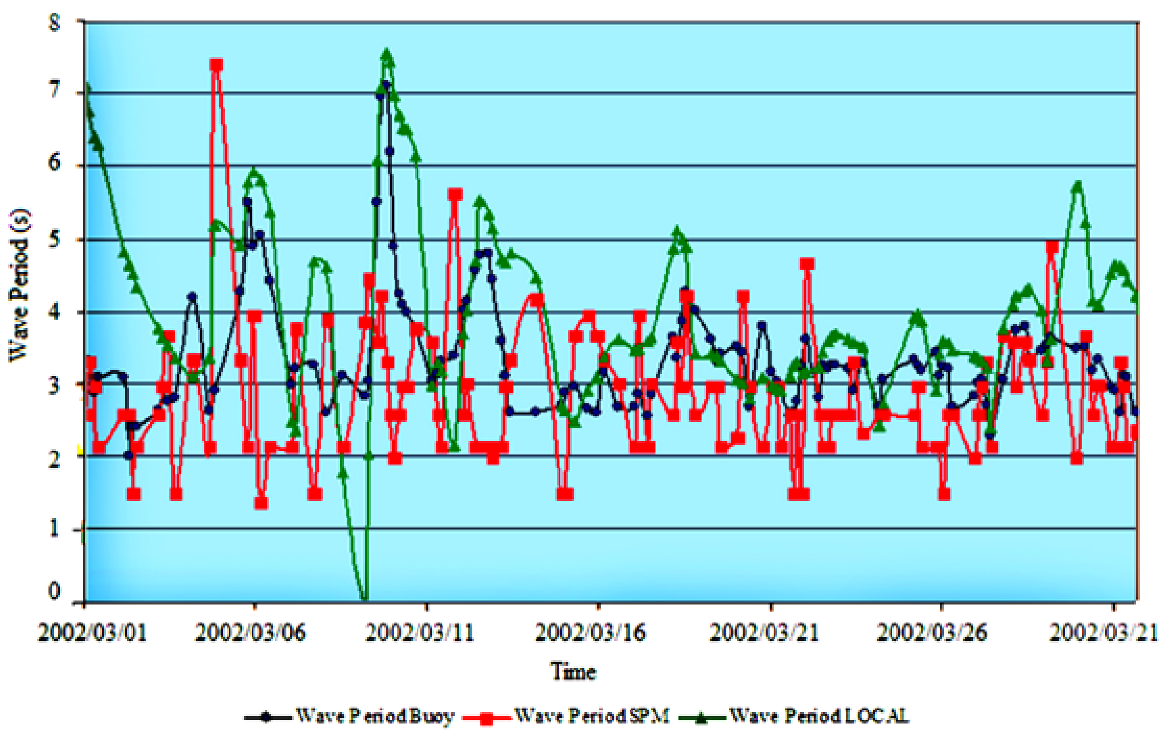

Figure 13. Wave period time series comparison between SPM method and buoy in March 2002

3.4. *Rose wave comparison between the SPM Method, the Local SW Model and Neka Buoy Data*

The local SW model was run during 12 years (from 1992 to 2004). In this period, the wave climate in the specified area was calculated. Figures 14 to 16 compare the rose wave obtained from the local model, the SPM method and Neka buoy data.

These figures indicate strong correlation between the local model results and buoy data. In general, there was not a proper correlation between the rose wave derived from the SPM method and Neka buoy data. The fundamental dominate wave direction was toward North West that included 47 % of all waves in Neka buoy rose wave and 30% of the SPM rose wave and 56% of the local SW model rose wave. The other dominate directions were toward west and north. There was a great difference between the three rose waves in the percentage of calm state. Since the chosen threshold limit for the calm state was 0.25m, by decreasing this value, the percentage of the calm state increased. Semi-analytical methods are related to wind speed, if wind speed is zero then wave characteristics predicted are zero and therefore, the calm state percent increases. Dominate wave height calculated was 0.285 m by buoy data and 0.185 m by the SPM method and 0.485 m by the local SW model.

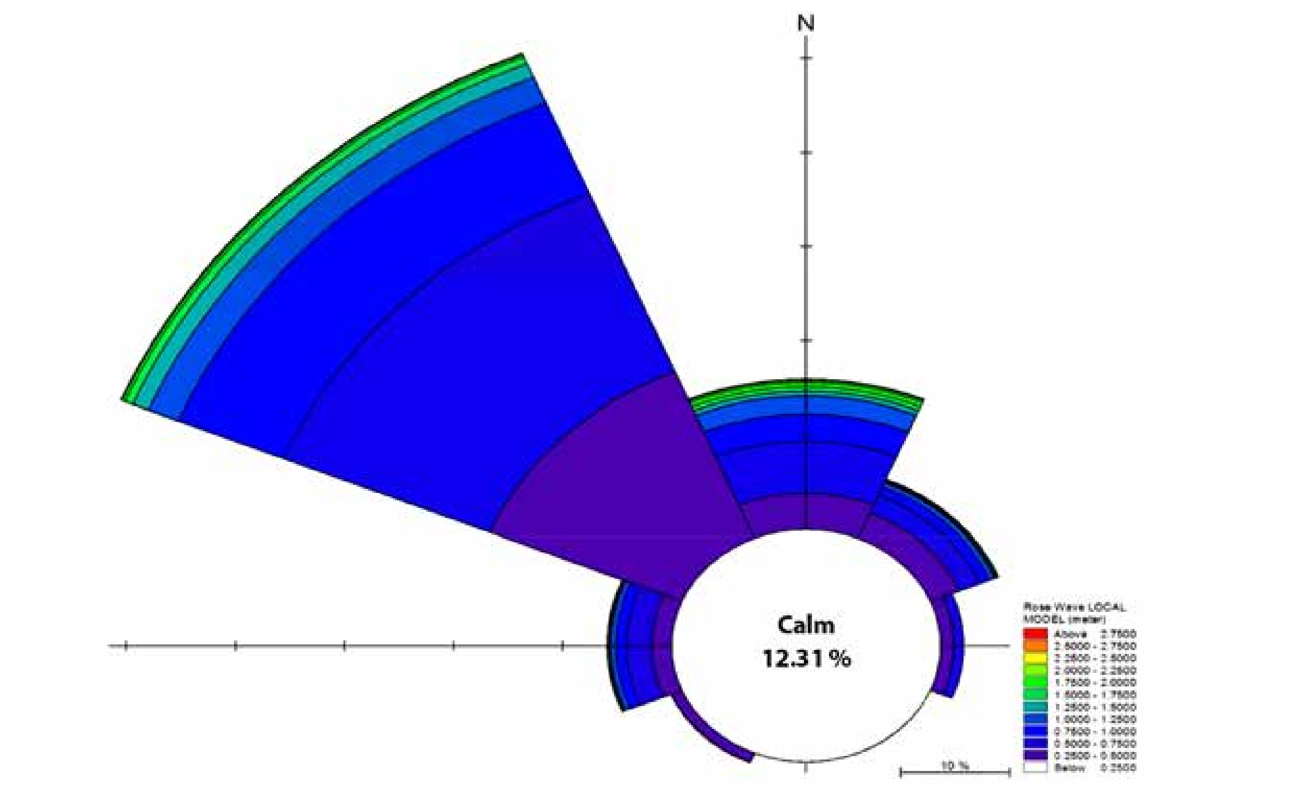

Figure 14. One-year rose wave acquired the local by Neka buoy data

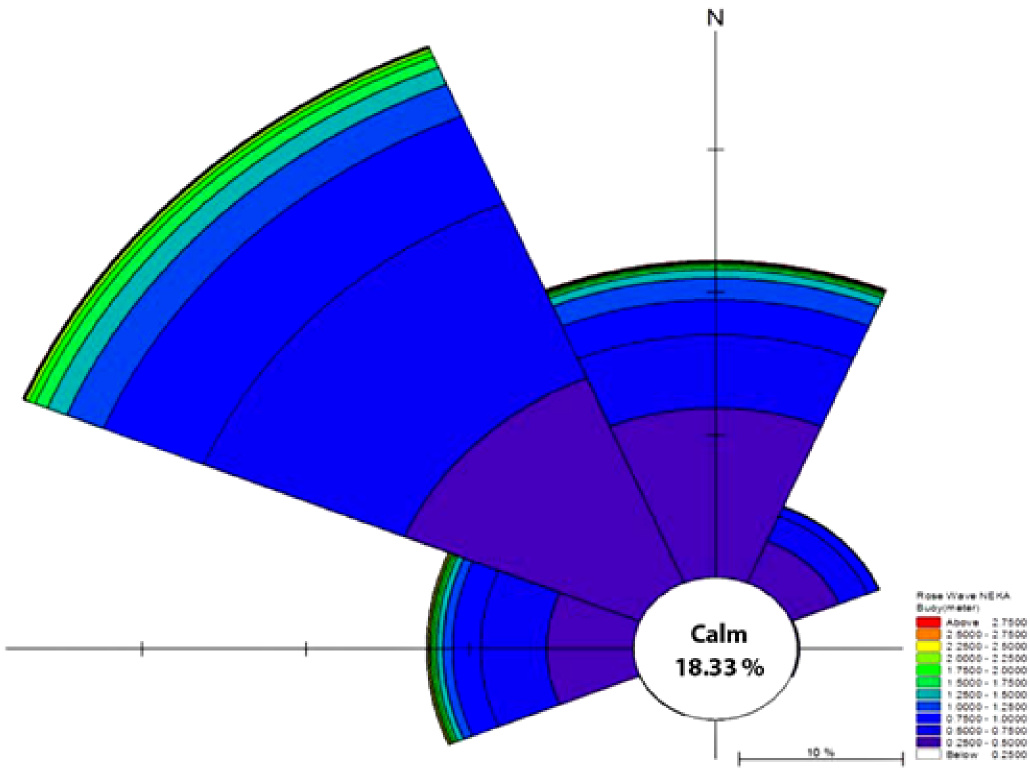

Figure 15. One-year rose wave acquired by model

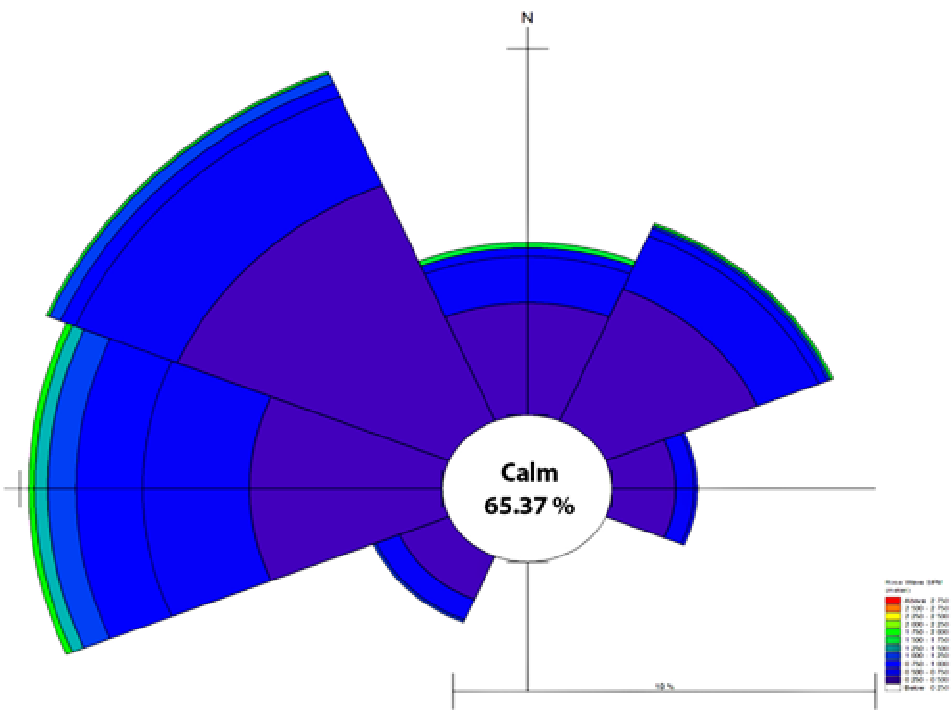

Figure 16. One-year rose wave acquired by the SPM method

3.5. Comparison between the Extreme Value Analyses Determined by the Local Model and the Semi-Analytical Methods Results

Using EVA model of MIKEZero software, extreme value analysis was performed on the wave height results calculated by the local model and the semi-analytical methods. To perform the extreme value analysis, the wave height was extracted from the related time series. It was in homogeneous time intervals and then fitted to the statistic functions.

Based on the different statistic tests made in the Iranian Sea Waves Modelling Project studies, Trunched Gumble was recognized as the best statistic function for calculating the wave height in different return periods. Thus, in this study, the Trunched Gumble function was used and two largest annual events for PDS method were chosen. In Figure 17, the wave height derived from the semi-analytical methods in different return periods were compared to each other. As shown in the figure, the extreme value analysis calculated by the SPM method was in best agreement with the buoy data with the return period of 5 years.

3.6. Extreme Value Analysis in Directional Categorization

The west wind was great and consequently, the wave characteristics forecasted by the semi-analytical methods was large in this direction. Therefore, to assess the wave climate properly, the extreme value analysis was performed in directional categorization. Extreme value analysis was not performed in south, west, south and east south directions because in these directions, the fetch length was low and the wave heights were small. Table 2 shows the 5 and 2 years return period for the buoy and the local model.

The dominate wave direction is NW and in this direction, the local SW model results is in good agreement with the buoy results. Other dominant wave directions are N and E and in these directions, the local SW model simulated the wave characteristics well.

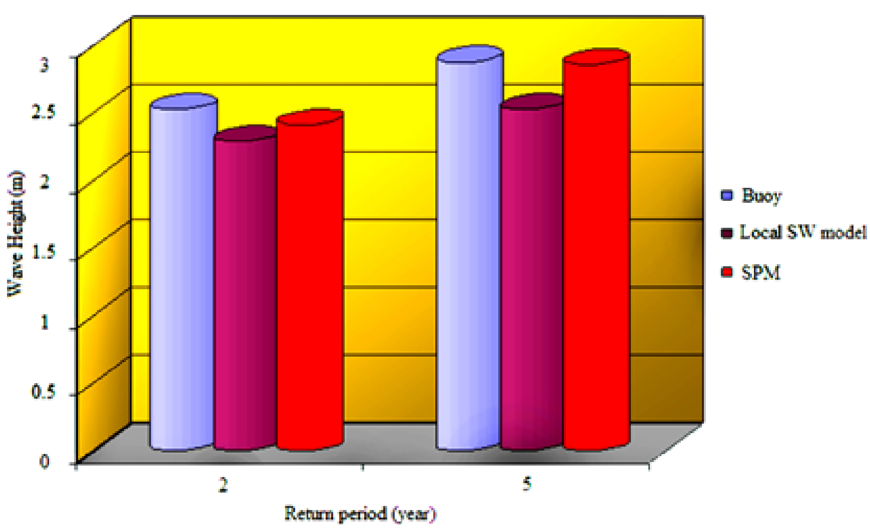

Figure 17. Comparison between the extreme value analyses of wave height calculated by the semi-analytical methods and local models results

Table 2. Extreme Value Analysis in Directional Severance

Direction	W		NW		E		NE		N	
Return Period	5	2	5	2	5	2	5	2	5	2
Buoy	2.12	1.97	2.55	2.26	0.88	0.71	1.67	1.46	2.41	2.18
Local Model	2.6	2.17	2.09	1.98	0.75	0.687	1.99	1.64	3.26	2.83

Conclusion

- In semi-analytical methods, the result of CEM method was in the best agreement with the forecasted wave parameters.
- In semi-analytical methods, the result of SPM method showed the best agreement with the buoy data.
- The rose wave acquired by the local model indicated that the dominant wave direction in Amir Abad Port was NW and another dominant wave direction was N.
- The numerical models forecasted the wave direction more accurately than the semi-analytical methods and the rose wave acquired by the local model have had a strong agreement with the buoy data.
- The maximum difference between the local and global model results in 1-2 elements of the global model at the distance of 2-5 km offshore was 14.5 %.
- The difference between the local and global model results in 1 element of the global model was high. In this domain, the local model forecast of the wave height was 13.5 % higher than the global model due to shoaling phenomena.
- The wave breaking depth and distance of wave breaking line to beach was forecasted to be 3.8 m and 30 m.
- Due to great difference in mean wave direction between local and global model, dominant phenomenon in study area is suggested refraction.
- The accuracy scale of the global model was at the distance of 1.6 km outside of the shore.
- Correlation coefficient between the SPM method and the buoy data in wave height forecasting was 26 percent.
- The correlation coefficient between the SPM method and the buoy data in wave period forecasting was 8 percent.
- In general, the use of local SW model is recommended for wave condition forecasting.
- By comparing the local SW model results and buoy data during 2/2/2002 to 15/3/2002, the CC was acquired about of 0.906.

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