Wave Prediction Model To Study On The Wave Height Variation In Terengganu Coast Of Malaysia

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Abstract: In this study, the significant wave height at the Terengganu and the change of wave height at Kuala Terengganu to Merang shoreline were simulated by using the 2D Near-Shore Wave (2D NSW) model. The significant wave height by the 2D NSW model at Kuala Terengganu to Merang shoreline from 2008-2012 were simulated. The model was forced by ECMWF (European Centre for Medium Range Weather Forecast) data. The simulated significant wave height by the 2D NSW model at Airport Kuala Terengganu (AWAC station) was compared with the observed significant wave height. The mean annual significant wave height indicate the higher wave height with average mean value in a range of 1.08-1.10 m in Kuala Terengganu to Batu Rakit area and lower in Merang area with average mean value in a range of 0.74 m. The detailed 5 years simulation period demonstrates that the strong variability of wave height exists during North-East monsoon. The findings of this study could be useful for the erosive calculation, shoreline protection and coastal zone management activities.

Index Terms: Kuala Terengganu, MIKE21 NSW, near-shore wave, ocean wave energy, simulation, wave height, wave period

1 INTRODUCTION

Prediction of the wave characteristics of the surface waves is important for every human activity in coastal areas. In near-shore area, people historically used wave data to provide information for the design of breakwaters and harbors rather than to determine the wave energy resource [1]. Wave prediction also important during the Second World War due to practical need during landing operation [2]. In shoreline erosion study, knowledge of the waves generated by wind is important as the sediment transported by wave height [3]. Studies on the wave characteristics are basically based on directional measurement, satellites or numerical wave model. Wave measurement are expected to have high accuracy [4]. Thus, measurement data is only suitable to verify and calibrate the model. Nonetheless, such detailed information about the wave field is difficult to obtain through directional measurements of buoys and remote sensing even though remote sensing has lately shown great promise to regard [5]. Utilizing the directional measurement of buoy at several points and remote sensing [6, 7] caused a lot of expensive cost involved and subject to theoretical limitation on their resolution [8]. Thus, models are needed to calculate the wave field; especially if the wave climate is of interest since there is insufficient measurement data is available [9]. Numerical wave modelling is therefore one of the most important tools for wave estimation, not only for practical operation used but also for the conceptual and engineering studies. In numerical wave modelling, the process of wave propagating is described in the wave energy balance equation. The wind blowing over the water surface generates tiny wavelets which have two dimensional spectral structures through time and space. The spectral components develop by absorbing the energy transferred from the wind to the wave. Wave spectra are the distribution of energy in wave over frequency. Hence, [11], [12] and [13] introduced spectra models and they believed that spectral model is described based on the basic idea of simple linear waves. So it is related to statistical properties that spectral model is basically a deterministic description of statistical properties of the sea surface. The significant progress in the theory of random functions and mathematical statistics provides powerful mathematical tools for a description of ocean waves as random phenomena. Moreover, a recent development in instrument scheme and data operating has allowed assessing a sample of wave data at large rates and scales. Another important thing that has been improved is the widespread use of high-speed computers. It has provided theoreticians with powerful tools and has made possible great improvement in the analysis of experimental data. Consequently, in the last few decades, numerous fundamental studies were conducted by implementing these developments, combining of data analysis and numerical modelling to assess the present wave climate. Last few decades, third generation wave models were developed and at present, a few of them are widely used in the operational wave forecasting. The operational wave models, such as WAM [2, 13], SWAN [14] and WAVEWATCH III [15] are third generation models. Theoretical explanations about numerical wave modelling and a third generation wave model WAM are described in [2]. Further developments on this model lead to an approximation for the non-linear energy transfer. [16] introduced Discrete Interaction Approximation (DIA) in wave modelling. The efficient computation of the non-linear source term together with more powerful computers made it possible to develop third generation spectral wave prediction models [13]. Third generation wave models are similar in structure and representing the state of the art knowledge of the physics of the wave evolution. For the WAM model, the wind input term, S_m, for the initial formulation was adopted from [17]. Therefore, in order to transform wave propagation from offshore to nearshore area, most of researchers used third generation of
numerical wind wave model as the advanced way to provide general condition of wave climate in specific area. It is because directional measurement and satellite studies cannot explain the situation for each grid point of the input term as in numerical wave model. A number of studies have employed numerical wave model to predict wave climate as demonstrated by [18, 19, 20 and 21]. In this study the numerical model DHI’s MIKE 21 Nearshore Spectral Wind-wave (NSW) was used to simulate waves from offshore to the nearshore. It is a third generation spectral 2D wind-wave numerical model that describes the propagation, growth and decay of short-period and short-crested waves [22]. MIKE 21 NSW takes into account the following physical phenomena, including shoaling, refraction, bottom dissipation, wave blocking, wave breaking, wind generation, frequency spreading and directional spreading. It can therefore show how wave energy change as waves move into shallower water. This type of model assumes that a random sea-state is composed of an infinite number of linear waves where wave height is a function of wave frequency and the direction of propagation of the wave [5]. The model needs a reliable quality of data and is used commercially on the numerous MetOcean worldwide and has been validated in numerous studies such as by [1, 23]. In a recent study conducted in Malaysia, [24] investigated a long term variability of wave climate characteristics by implementing numerical wave WAVEWATCH III spectral model. So, similar to study by [24], this study also produced a model which was forced by the reanalyzed wind and validated against limited available measurement from Acoustic Wave and Current (AWAC) recorder located in Terengganu. This study focused on a local scale while studied by [24] focused on regional scale investigation.

2 METHODS

2.1 Study Domain and Data Collection

In order to simulate waves in the Terengganu water, a domain range from 5° 0’N to 5° 25’N and 102° 25’E to 103° 45’E was selected. The bathymetry data for the wave transformation for the site is taken from bathymetric surveys near to the shores of Pangkalan Maras, Batu Rakit, Tok Jembat, Kuala Terengganu Airport and Terengganu River. The bathymetry data however was not available outside the bathymetric survey areas. Therefore, for grid points outside the bathymetry survey area, the data were taken from the General Bathymetric Chart (GECBO) data. Another important input is a high resolution image. It is rectified into MIKE ZERO and exported as the background image to create the bathymetry. The simulation model was forced by the offshore boundary wave records obtained from the European Centre for Medium Range Weather Forecast’s (ECMWF). The data set obtained is approximately 70 km from the nearest shoreline area with coordinate 5.77° N and 103.61° E. Meanwhile, the wind is extracted from the ERA-interim model at the same point as the wave data. Time series of wind data contain the wind speed and wind direction.

2.2 Wave Model Setup

The Danish Hydraulic Institute (DHI) produced a software package named MIKE-21 Near-shore Spectral Wind-wave (NSW) and have been tested against analytically [27]. In this study the numerical model DHI’s MIKE 21 NSW is used to transform waves from offshore to the shoreline. It is a third generation spectral 2D wind-wave numerical model that describes the propagation, growth and decay of short-period and short-crested waves [22]. MIKE 21 NSW take into account the following physical phenomena includes shoaling, refraction, bottom dissipation, wave blocking, wave breaking, wind generation, frequency spreading and directional spreading. It can therefore show how wave energy change as waves move into shallower water. Wave data applied at the offshore boundary of the NSW model grid must propagate into the model area within an angle of less than ±30° to the x-axis, which points towards the coast. As every offshore boundary wave data have their own direction, and then they are transformed separately. The five years’ time series of offshore boundary conditions was split up into several parts according to the wave direction. In addition, the directional spreading of the waves on the offshore boundary of the model is also defined. MIKE-21 NSW model assumes that \( \cos^2 \)-type directional spreading function and the directional wave properties are specified by the power, \( n \), and the maximum allowed deviation from the specified mean wave direction (DMWD) [22]. Hence in this study, the power \( n = 5 \) and DMWD=30’ is chosen since we assume that the conditions of waves is wind generated sea [1]. However the north (\( \gamma = \gamma_{max} \)) and south (\( \gamma = 0 \)) boundary conditions of the incoming waves are unknown. Therefore, symmetrical boundary conditions are applied. Symmetrical boundary condition assumed that the contours are locally straight and parallel near the boundary.

2.3 Model Calibration and Validation

The performance of MIKE-21 NSW based on the default value recommended by model developers and suggested by most of previous researchers was carried out. In calibration, a number of runs were performed using the coefficient corresponding to different formulas. The combination of adjustable parameters leading to the best agreement between the measured and calculated data sets. It assists on reproducing the most significant wave events as accurately as possible. Also, they are expected to contribute towards the most accurate wave power potential. In order to carry out the calibration process, the following calibration parameters were used and the results produced were compared. Several simulations were carried out in order to investigate the following; influence of wave growth formula used in the source function, influence of bottom friction and it leads to wave breaking. It was shown that the combination of adjustable parameters leading to the best agreement between the measured and calculated data sets. Bottom dissipation gives no significant effect on the wave height and wave period since the AWAC measurement point located in deep water. Hence, this section showed the final verification result between measured and calculated model for a one year period by tuning the wave growth coefficient formula. Simulations for all one year wave events for wave coming from 322.5°-142.5° were carried out. Figure 1 (a) and (b) shows the comparisons between measured data at the AWAC measurement station and the model results for wave height and wave period respectively. The overall comparison in Figure 1 (a) and (b) shows a close matches between measured and modelled result. However, the root mean squared value calculated is larger for wave height (RMSE=0.29) and wave period (RMSE=2.06). It was found that the model slightly underestimated the mean wave height.
and period in the end of November to January 2012. This is due to the influence of the wind data resolution during strong NE monsoon, which is not sufficient for wave model. Nevertheless, the model slightly overestimated the mean wave height and mean wave period in January to March 2012. Therefore, the implementation of high-resolution bathymetry models in the area of interest seems to be important.

![Fig.1. Comparison between measured and modeled wave parameters at AWAC measurement point: (a) Significant wave height and (b) Mean wave period.](image)

4 RESULTS AND DISCUSSIONS

After validation, an analysis of the wave height distribution during 5 years was performed. It can be conducted for any of the grid points in study domain. Figure 2 shows the spatial map distribution of annual mean of significant wave height. Wave reduced its height and loses its energy due to friction at the sea bed and wave breaking occurred. The same trends of significant wave height are shown in each annual and monthly spatial map (Figures 2 and 3) as the wave propagates 25 km away from offshore boundary. The wave propagates to near shore area and hence a bulk of wave energy generated at the offshore boundary gradually reduces its height. This is due to the gradual change of water depth and the existence of several islands which may obstruct, refract and reduce the wave height and consequently wave energy. Based on mean annual spatial map of significant wave height (Figure 2), the most of the significant wave height value reduced to 0.75 m after wave propagated and reached at several islands. The mean significant wave height distribution was relatively same for each grid point in 2008 and 2009. The trends were different in 2010 and 2011 when there was some maximum distribution of mean significant wave height at certain grid point in the middle of study domain. This is because the highest magnitude of wind speed occurred during 2011, affected the dominant waves to generate higher wave height during 2011.

![Fig. 2. Mean annually spatial significant wave height (m) for each year (2008-2012).](image)

In order to give a detail assessment of spatial significant wave height potential, the variability of spatial map could be presented monthly. The mean monthly spatial distribution of average significant wave height is presented. There are only several months involved for comparison purpose due to the non-occurrence of wave events with dominant direction during the unselected months (May, June, July, August and September). Figure 3 display the mean monthly spatial mapping of significant wave height. Some observations can be found including the averaged mean significant wave height occurrence with respect to each grid point (from offshore boundary to the coastline) ranging from 0-1.6 m in January, 0-1.2m in February, 0-1.2m in March, 0-0.9m in April, 0-1m in October, 0-1.2m in November and 0-1.6m in December. Therefore, it can be noticed that the months that significantly contributed to the higher wave height are January and December, which comes in the Northeast (NE) monsoon season. Basically, the monsoon involved with South China Sea (SCS) is Southwest (SW) monsoon and the NE monsoon, SW monsoon is influenced by low level southwesterly winds (April-August). Meanwhile, NE monsoon is influenced by northeasterly winds that cross the SCS (November-March) [28].
Therefore, the change of wind effect during each particular month impacts the wave height distribution. Accordingly, the highest wave height occurs during December and January is due to the dominant waves with higher magnitude of wind during NE monsoon. In addition, during February, March and November, the significant wave height are relatively lower (5.03-5.69 m/s) as compared to January and December (>6.87 m/s). The wave height are excessively lower in April (< 3.86 m/s) due to much weaker wind condition. It can be observed that there are some variations of wave height distribution occurred in January, November and December (See Figure 3). This situation happened due to the existence of a local wind generation with higher magnitude in the specific area that leads to fluctuation in waves. Therefore, there are some areas containing a high distribution of wave height. The months of January and December consistently generate the highest wave height as compared to other months. Having observed the spatial estimate of wave height, an analysis of wave parameters and wave height distribution can be conducted for any grid points in study domain. For this purpose, there are 4 locations selected and then the extracted results were compared corresponding to time (temporal analysis).

<table>
<thead>
<tr>
<th>Location</th>
<th>Mean H</th>
<th>Variance H²</th>
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<tbody>
<tr>
<td>P1</td>
<td>1.0</td>
<td>6.3</td>
</tr>
<tr>
<td>P2</td>
<td>0.9</td>
<td>6.3</td>
</tr>
<tr>
<td>P3</td>
<td>1.0</td>
<td>6.3</td>
</tr>
<tr>
<td>P4</td>
<td>0.5</td>
<td>6.3</td>
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In addition, as the location of P1, P2 and P3 are on the same...
contour line, same depth and exposing from the same coming wave, the wave climate distributions are also relatively same for each particular year. Based on Table 1, the mean, $\bar{x}$ and variance, $s^2$ of wave parameters at each point with respect to each year are described. Comparison between each year shows that the mean values of significant wave height are higher in 2011 ($H_s=0.65-1.10$ m, $T_m=6.20-6.50$ s). It was followed by 2009 ($H_s=0.71-1.06$ m, $T_m=6.03-6.23$ s), 2008 ($H_s=0.70-1.03$ m, $T_m=6.00-6.63$ s), 2012 ($H_s=0.64-1.10$ m, $T_m=5.87-6.05$ s) and lastly 2010 ($H_s=0.61-0.87$ m, $T_m=5.68-5.93$ s).

5 CONCLUSION
In this study, we investigated the wave height potential around Kuala Terengganu coastal area by using near-shore wave modeling, MIKE 21 NSW. MIKE 21 NSW model is used to model the wave transformation from deep water to a near-shore site. Near-shore wave modeling was carried out with the boundary conditions obtained from the AWAC measurement station. The study was based on data collected covering the period from June 2011 to January 2012. These investigation shows that wave height in the near-shore along Terengganu is significantly smaller than wave height in the offshore area. Furthermore, detailed assessment by each month for each particular year was presented. The highest total monthly wave height was shown in December 2011. Hence, it can be concluded that the wave height distribution is mostly contributed by the dominant wave direction in January, February, March, April, October, November and December. Therefore, the findings of this study could be useful for the erosive calculation, shoreline protection, coastal zone management activities and renewable wave energy around Terengganu coastal area.

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