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Research on wave regimes at the Cua Dai estuary, Quang Nam

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Abstract
In coastal area of the Cua Dai estuary - Quang Nam province, the processes of erosion-accretion strongly occur. Over this area, the ocean wave is a dynamical factor that directly affects the coastal areas causing erosion-accretion processes. This paper presents an evaluation of the ocean wave regime impacting the areas of Cua Dai estuary by using the model of MIKE21SW. The purpose of this study is to fully interprete the role of dynamical factor, ocean wave in erosion-accretion processes. The results showed a convergence of ocean waves at the estuary of Cua Dai although it is obstructed by the Cu Lao Cham island in front of the Cua Dai estuary. The northeast and north-northeast waves are mainly prevailing with the frequency of more than 60% in the year.

Keywords: Ocean wave, MIKE21-SW, Cua Dai.

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INTRODUCTION

The coastal area of Cua Dai estuary has an irregular diurnal characteristics of tide with the magnitude of lower than 2 m. Consequently, small tidal currents are recorded over this area. Therefore, this area is mainly influenced by waves during the Northeast monsoon period from September to March of the following year. During this period, storms mainly occur in October and December. The combined influence of wind and atmospheric pressure controlled by the monsoon winds causes an increase in water level over the area varying from 0.3 m to 0.5 m. This is an advantageous condition for huge waves to reach and crash the shoreline. The coastal erosion in this area is mainly caused by waves during the Northeast monsoon. In the north of Cua Dai estuary, the coastal sections belonging to the Cam An and Cua Dai wards (Hoi An city), erosion is the strongest, both in intensity and scale. The shoreline tends to be eroded in the Northeast to Southwest direction with an average rate of about 15 m per year. In the south of Cua Dai estuary, during 1965–2010, the strongest erosion is recorded at the river bank of Duy Nghia and Duy Hai communes, Duy Xuyen district. After 2010, these sections are concreted; consequently, only a part of the riverbank section belonging to the An Luong village, Duy Hai commune is still being strongly eroded due to being not concreted. For this area, the strongest horizontal erosion is 1,058 m. This means that the average erosion rate is 23.5 m per year [1].

METHODOLOGY

Description of MIKE21SW

Presently, there are lots of models used to simulate hydrodynamic processes in the estuarine and marine areas such as DELFT (SWAN), MIKE21SW. However, the MIKE software developed by the Institute Hydraulics of Denmark have been widely applied by many countries with the border of the sea. The reason for this is a flexible grid of MIKE for problems with multiple types of terrain with its complexity. The model system is developed and applied in the fields of oceanography, environment in estuarine and coastal areas. In this paper, a state-of-the-art third generation spectral wind-wave model (Mike21SW) is applied to simulate wave propagation [2].

MIKE21SW consists of two different formulas (i.e., fully spectral formulation and directional decoupled parametric formulation). The directionally decoupled parametric formulation is based on a parameterization of the wave action conservation equation. The parameterization is done with frequency domain by introducing zero and first order moments of the wave activity spectrum as independent values (Holtuijsen 1989) [3, 4]. The same approximation is used in the MIKE21-NSW for coastal wind wave module. The total spectral formula is based on the wave conservation equation, described by Komen et al., (1994) [5, 6] and Young (1999) [7], where the wave propagation spectrum of the active wave is the dependent value. Basic equations are developed in both Cartesian coordinate system with small-scale applications and the coordinate system for larger applications.

MIKE21SW includes the following physical phenomena: (i) Waves developed by the wind action, (ii) Nonlinear wave-wave interaction, (iii) Wave dissipation due to the whitecaps, (iv) Wave dissipation due to bottom friction, (v) Dissipating waves due to breaking waves, (vi) Wave refraction and shallow water effects due to changes in depth, (vii) Interaction between wave and flow and (viii) Impact of changes in depth over time.

The basic equation is the wave equilibrium equation developed for both Cartesian and polar coordinates (see Komen et al. (1994) and Young (1999)).

The governing equation in MIKE21SW is the wave action balance equation formulated in either Cartesian or spherical coordinates. In horizontal Cartesian coordinates, the conservation equation for wave action is expressed as follows:

$$\frac{\partial N}{\partial t} + \nabla.\left(\vec{v}.N\right) = \frac{S}{\sigma}$$

Where: $N\left(\vec{x},\sigma,\theta,t\right)$ is the action density; t is the time; $\vec{x} = \vec{x}\left(x,y\right)$ is in the Cartesian coordinates and $\vec{x} = \vec{x}(\varphi, \lambda)$ is in polar coordinates, bridged with ϕ as latitude and λ as longitude; $\vec{v} = \vec{v}(c_x, c_y, c_\sigma, c_\theta)$ is the propagation velocity of a wave group in the four-dimensional phase space $\bar{x}$, σ and θ and S is the source term for energy balance equation; ∇ is the four-dimensional differential operator in the $\bar{x}$, σ and θ space . The velocity of the wave group transmitting in four dimensions is calculated by the following equations:

$$\left(c_x, c_y\right) = \frac{d\vec{x}}{dt} = \vec{c}_g + \vec{U}$$

$$c_\sigma = \frac{d\sigma}{dt} = \frac{\partial\sigma}{\partial d}\left[\frac{\partial d}{\partial t} + U.\vec{\nabla}_{\vec{x}} d\right] - c_g \vec{k}.\frac{\partial\vec{U}}{\partial s}$$

$$c_\theta = \frac{d\theta}{dt} = -\frac{1}{k}\left[\frac{\partial\sigma}{\partial d}\frac{\partial d}{\partial m} + \vec{k}.\frac{\partial\vec{U}}{\partial m}\right]$$

Boundary conditions are closed and open boundaries.

Fig. 1. Study area

Setup of the MIKE21SW model

(i) Topography data: Bottom bathymetry is based on survey results conducted by the Institute of Geography on a scale of 1:5,000 for the study area and a 1:50,000 topographic map of the sea floor for the offshore area is produced by the Center for Sea Survey and Mapping.

(ii) Data for boundary conditions: Waves in offshore area are collected from a series of wave, reanalysis winds of NOAA from 1979 to 2018 (fig. 2) [8, 9].

(iii) Computing grid covers an area of 6,000 elements with the variation of resolution from 20 m to 1,000 m for the river mouth and islands (fig. 3).

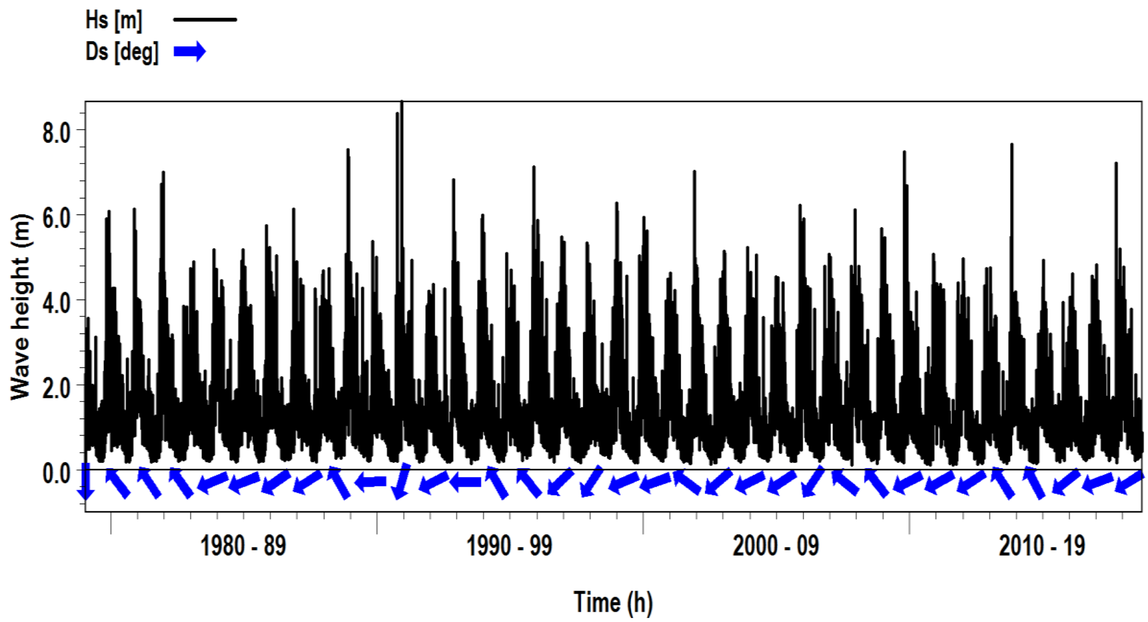

Fig. 2. NOAA wave data at the offshore area of Quang Nam (1979–2018)

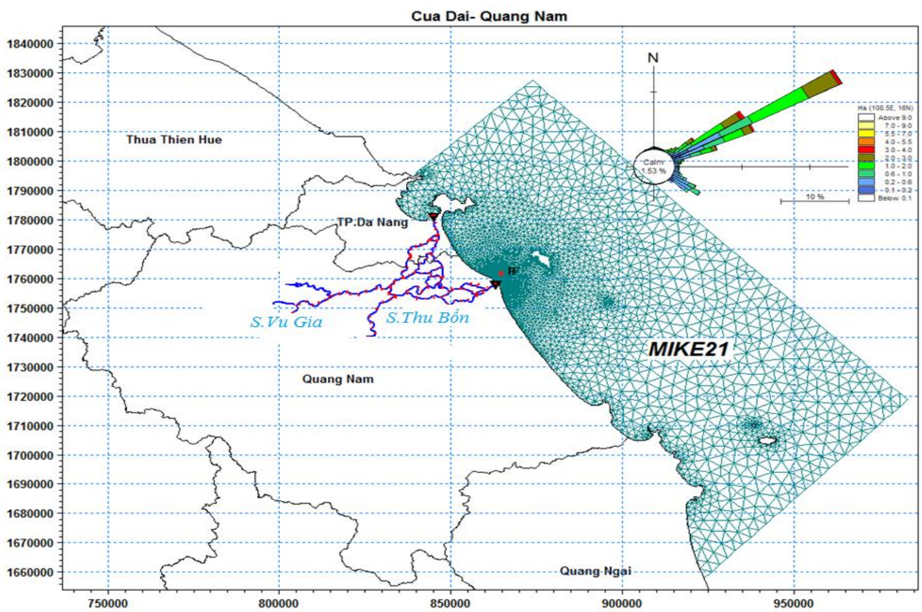

Fig. 3. Setup of MIKE21 model

Calibration of the model

In order to ensure the good agreement of simulations, the model is calibrated using the measured data at the Cua Dai estuary in March 2017. The paper used the Nash-Sutcliffe (1970) [10] indicator to evaluate the agreement between the calculated data against the measured data of the MIKE21SW model. The results of the comparison between measurements and calculations show that the Nash coefficient is quite good: $N = 0.88$. This illustrates that the model simulations are well fitted with the measured data (fig. 4).

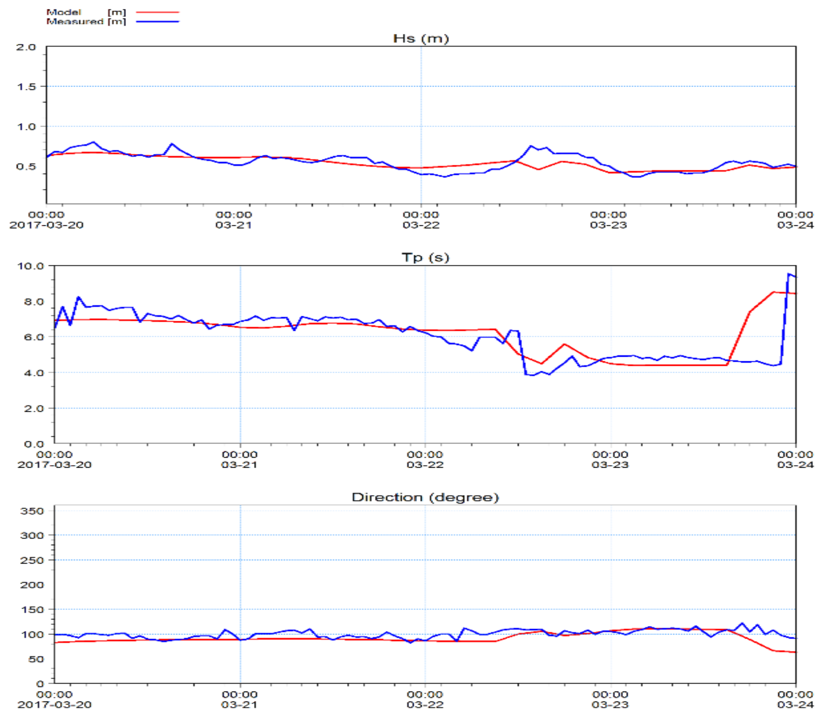

Fig. 4. Measured and calculated wave heights, wave periods and wave directions at AWAC station

$$N^2 = \frac{\sum_{i=1}^{n}\left(X_i - \bar{X}\right)^2 - \sum_{i=1}^{n}\left(X_i^{'} - X_i\right)^2}{\sum_{i=1}^{n}\left(X_i - \bar{X}\right)^2}$$

Where: N^2: Efficiency ratio of the model (Nash); i: Indicator; X_i: Measurement value; $X_i^{'}$: Value calculated by model; $\bar{X}$: Average measured value.

RESULTS AND DISCUSSION

The results indicate that the waves in offshore area of the Cua Dai estuary, Quang Nam province have several characteristics as follows: (i) Prevailing waves of Northeast and East-Northeast directions account for 11.5% and 52.85%, respectively. (ii) Height of wave ranging from 1–3 m and higher than 4 m accounts for 29.8% and 9%, respectively. (iii) The Southeast monsoon period accounts for a frequency of 19.2% with the height of wave lower than 2 m. In offshore area of the Cua Dai estuary, so, huge waves mainly occur in the period of Northeast winds as shown in table 1.

Table 1. Frequency of wave height from 1979–2018

Wave height (m)	Wave direction (degree)																Total
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	
0–0.2	0.00	0.00	0.01	0.13	0.01	0.01	0.01	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
0.2–0.6	0.15	0.12	0.84	6.70	1.10	1.35	4.20	3.39	0.09	0.06	0.09	0.15	0.12	0.13	0.20	0.20	18.89
0.6–1	0.19	0.28	2.35	9.54	1.23	1.53	9.03	2.08	0.03	0.01	0.03	0.06	0.04	0.07	0.27	0.36	27.10
1–2	0.17	0.31	4.57	17.79	0.46	0.48	5.89	0.43	0.00	0.00	0.00	0.00	0.01	0.01	0.23	0.50	30.86
2–3	0.05	0.11	2.12	11.01	0.08	0.04	0.05	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.10	13.59
3–4	0.02	0.04	1.16	5.59	0.03	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	6.91
4–5.5	0.00	0.01	0.42	1.81	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	2.27
5.5–7	0.00	0.00	0.03	0.13	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17
7–9	0.00	0.00	0.01	0.13	0.01	0.01	0.01	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
Total	0.58	0.88	11.50	52.85	2.94	3.43	19.20	5.96	0.12	0.07	0.12	0.21	0.17	0.21	0.72	1.22	100

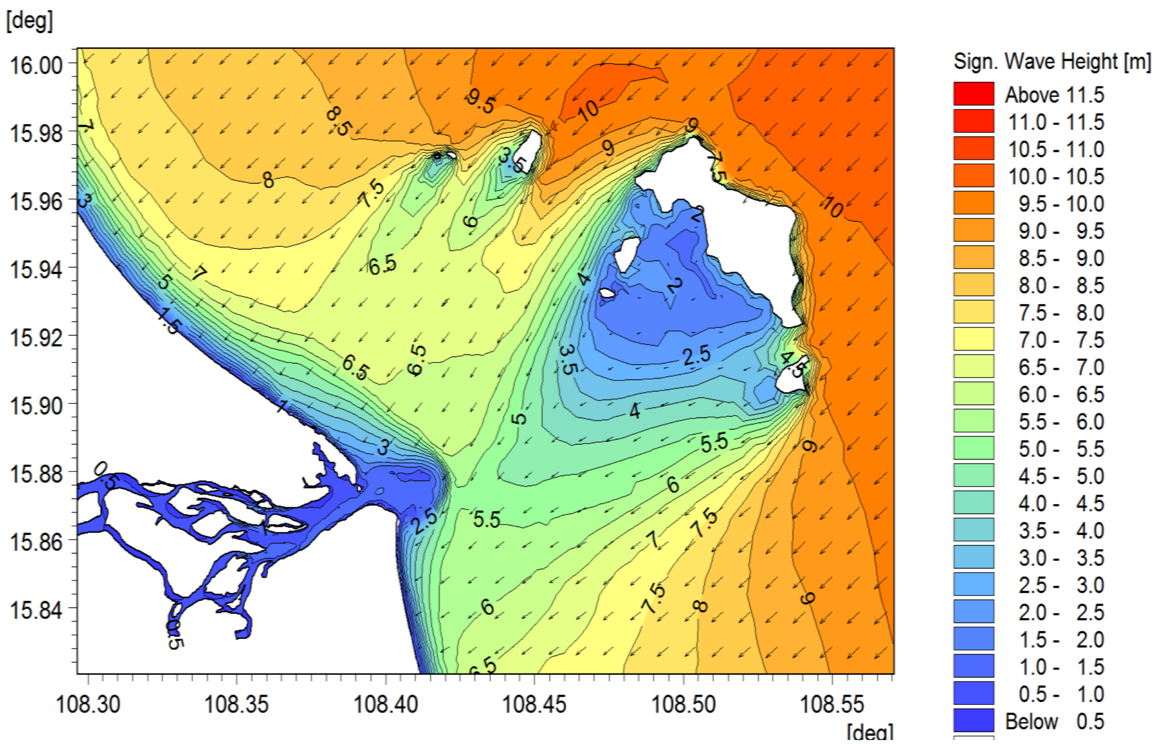

Fig. 5. Wave field in the Cua Dai area in the period of Northeast monsoon

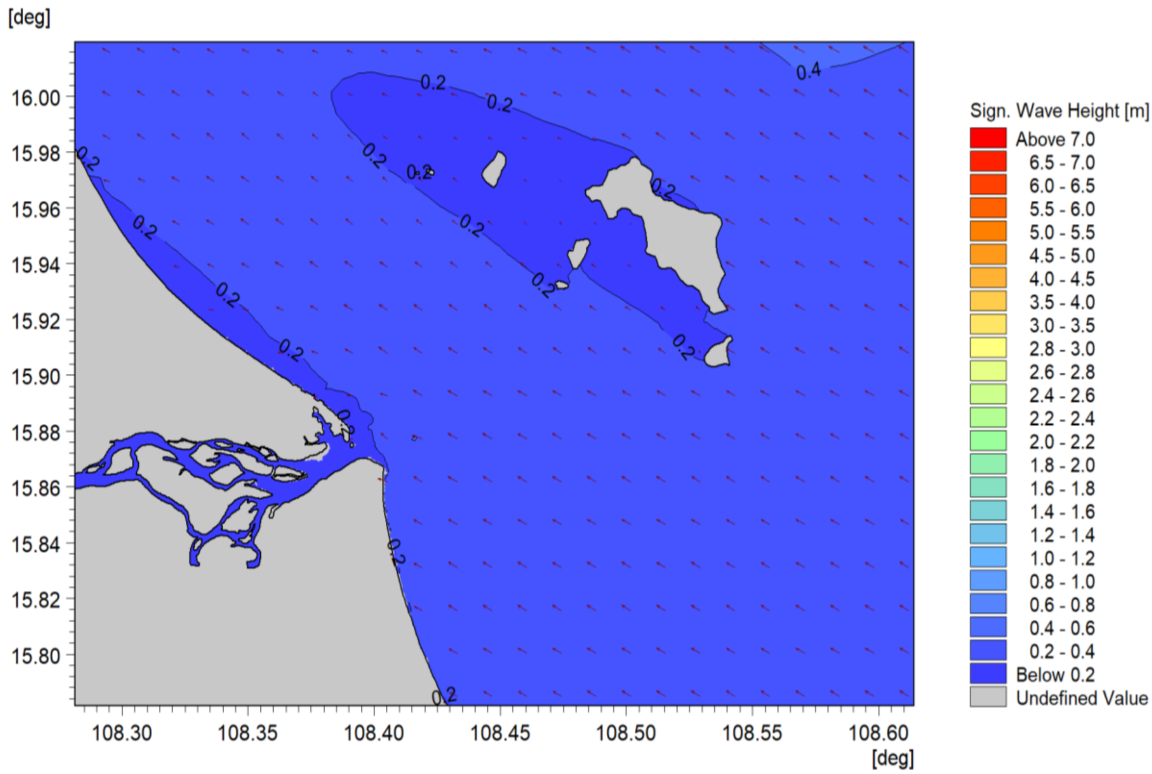

Fig. 6. Wave field in the Cua Dai area in the period of Southwest monsoon

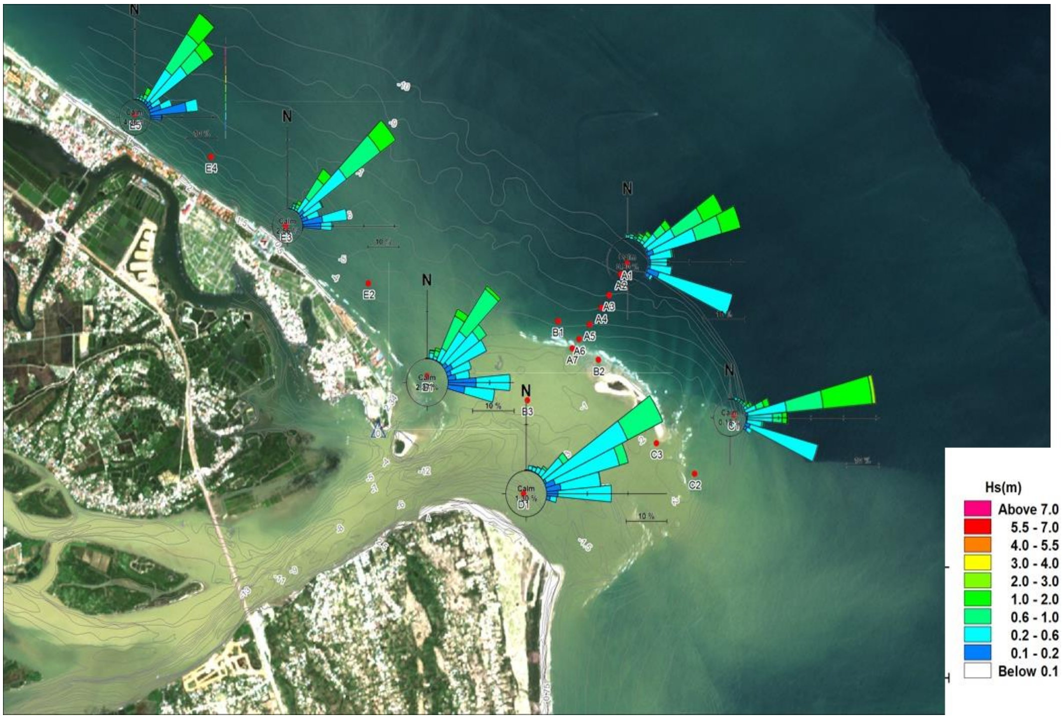

Fig. 7. Wave rose at the Cua Dai area

The simulations of wave field with small wave height are observed behind the Cu Lao Cham island. The reason for this is due to the Cu Lao Cham island that is considered to be the shield causing the reduction of wave energy. However, there is an increase in wave height when the wave catch up to the Cua Dai estuary. A far distance between the Cu Lao Cham island and Cua Dai mouth (about 16 kilometers toward the east of Cua Dai mouth) is likely to be an advantage to the increase in wave height around the sand dunes in front of the river mouth (fig. 5). Due to the topography, there is a convergence of waves at the Cua Dai estuary. This causes accretion processes when flood events are recorded. Especially, the period of the Northeast monsoon coincides with the flood season in the Thu Bon river. During this period, the combined effects of water surges by the Northeast monsoon and storms with the range of 0.3 m to 0.5 m and higher than 1 m respectively have strong impacts on the shoreline with the huge waves. On the contrary, wave height is small during the Southeast monsoon from April to August. (fig. 6).

The estuarine area is mainly affected by the prevailing wave roses of the Northeast direction. At the north side, wave roses having the wave height of 0.2 m to 2 m with the Northeast direction account for more than 70%. Meanwhile, the wave with the height lower than 0.6 m is in Southeast direction. The erosion processes at the north side of the Cua Dai estuary are mainly from the effects of waves in the period of Northeast monsoon.

CONCLUSIONS

Study of wave regime in coastal and river estuary areas has a great value in science and practice. This is fundamental to evaluate the factors and processes that affect the coastal areas. This will help to protect the coastline, minimize the accretion of river mouth and erosion of coast. The wave factor is quantified for the Cua Dai estuary. The simulations are well fitted with the actual conditions for this area.

Using the MIKE21SW, the wave conditions are defined for the Cua Dai estuary. The huge waves are mainly from September to March of the following year. This period coincides with the Northeast monsoon. A difference of wave fields over this area compared to the others is a convergence of waves at the estuary even though it is shielded by the Cu Lao Cham island. This study shows an overview of changes in wave fields in the Cua Dai estuary.

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