STUDY ON THE TROPICAL-STORM-GENERATED WAVE FIELD ON THE SEA AREA AROUND LY SON ISLAND

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Abstract

Ly Son is a frontline island of our country that is often affected by adverse weather conditions such as monsoons or tropical storms. Studying the hydraulic parameters of tropical storms, including the storm's wave field, to determine extreme conditions plays an important role in forecasting, planning and construction of hydraulic works. The author uses the two-dimensional wave propagation model MIKE 21 SW to simulate the wave field of Molave storm 2020 in Ly Son sea. The results show a good agreement between the values obtained from the model and the actual measurements at Ly Son station. Based on the results obtained, the author proposes a method to simulate storm wave fields that is relatively accurate and effective. In particular, current standards based on wind speed and wind fetch still have many limitations. This is valuable in the actual design and planning of hydraulic works.

Keywords: *Molave storm; wave field; MIKE 21 software; Ly Son Island; East Sea.*

1. Introduction

In addition to having a coastline that stretches over 3260 km, our nation also owns a large number of little islands in the East Sea [1] . These are the kinds of areas that are the most vulnerable to natural disasters, diversified, highly sensitive, and ever-changing. One of our nation's typical outpost islands is Ly Son Island, Quang Ngai. On the Ly Son shore, accretion and erosion are occurring at a rate of roughly 5-10 m/year, particularly in the northern coastal section where it has not been strengthened and protected. Images of coastal erosion are shown in Fig. 1 and Fig. 2.

It is clear that waves, particularly waves in rough sea conditions, such as a hurricane, are the primary cause of this devastating phenomena because Ly Son Island is an offshore island with little effect from coastal currents.

Averaging 11 tropical storms and depressions per year [1], half of storms and tropical depressions formed in the Western Pacific Ocean entered the East Sea, of which, approximately 20 percent hit Ly Son coastal area, according to data from 2001 to 2020. The frequency and intensity of heavy storms have grown, especially in the presence of climate change scenario, and they caused the majority of damage to coastal and island structures. Figure 3 displays statistics on the number of storms that have impacted this area.

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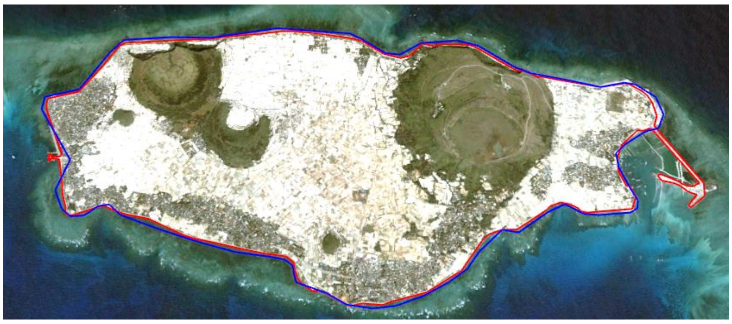


Fig. 1. Shoreline changes on Ly Son Island between 1985 and 2013 (Google Earth)

In 1985, the island coast. *In 2013, the island coast.*

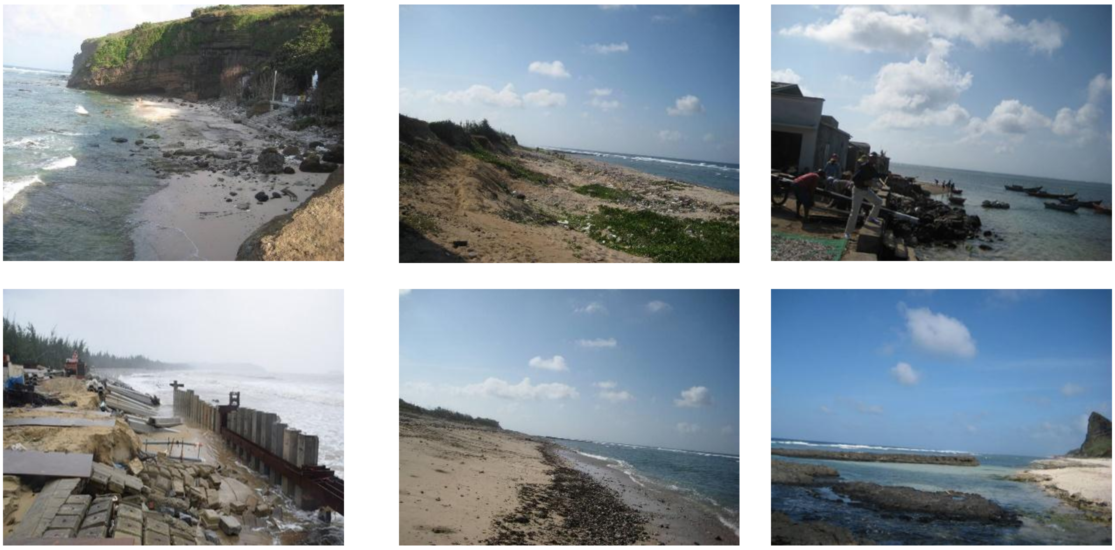


Fig. 2. Erosion in the Ly Son island area is currently in progress.

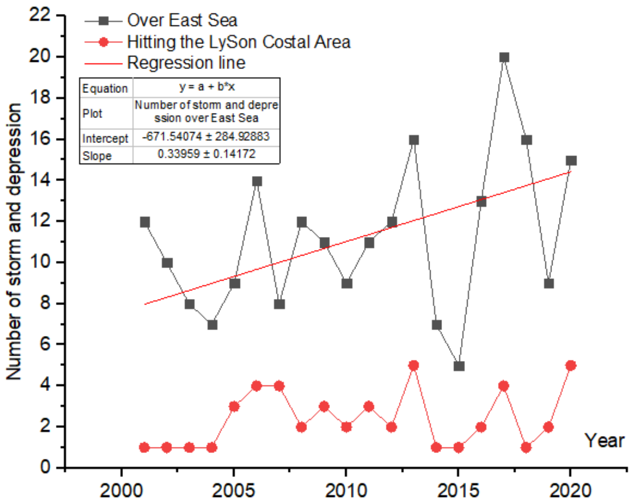


Fig. 3. Statistics on the number of storms and low pressure over East Sea - Joint Typhoon Warning Center (JTWC).

The simulation of a typical storm wave field, which can be used as a basis for the design, planning, exploitation, and use of the island, is an essential demand as a result of the aforementioned analysis, making it possible to immediately decide how to shape the structure and address the issue, technological procedures and building costs.

2. Methodology

2.1. Input data

- Source of wave and wind data:

+ Waves (2015-2020) and water level (2018-2020) data from Ly Son Marine hydrometeorological Station;

+ Wind information from the Ly Son weather station between 1994 and 2020;

+ In the East Sea, covering the Ly Son island region, the European Center for Weather Forecasting (ECMWF) gathered and reanalyzed global wind and wave data.

- Topographic information is mostly derived from three main sources:

+ A map shows the marine area of Vietnam at a scale of 1/10,000;

+ District map of Ly Son island, size 1/25,000; 1/5000.

- Topographic information about the nearby waters gathered from the National Geophysical Data Center's website (NGDC).

2.2. Study scenario (Molave storm 2020)

In order to determine a simulation scenario for Ly Son Island over the period of 20 years (2001-2020), the author conducted research to determine a typical storm in which the unfavorable meteorological conditions result in extreme wave fields [2]. Two presumptions are used by the author:

- In the survey data set, the wind field in the Ly Son sea area is comparatively large.

- Extremely high deep water wave data can be obtained around Ly Son Island, particularly at the East Sea extraction locations D2 and D3. Figure 4 and Table 1 show the survey point locations.

Fig. 4. Location of wave data extraction points.

Table 1. Survey point coordinates

No.	Point	Longitude (degree)	Latitude (degree)	Note
1	D1	108.97	15.47	The side of mainland
2	D2	109.17	15.55	Side of the East Sea
3	D3	109.29	15.31	Side of the East Sea
4	D4	109.08	15.24	The side of mainland

- In the surroundings of Ly Son Island, the findings in demonstrate a strong association between wave height and wind speed. At the same time, tropical storms that have been active close to the island's coast in recent years are what led to the exceptional readings.

- The Molave (10/2020) storm is chosen as the typical storm because, according to NASA, the extreme was 31 m/s on October 28 according to Ly Son meteorological station, and it reached 45.1 m/s according to simulation and 45.8 m/s according to [1]. Through Fig. 5, it is clear that Molave storm also caused the deep water wave height at the survey points to achieve its maximum value.

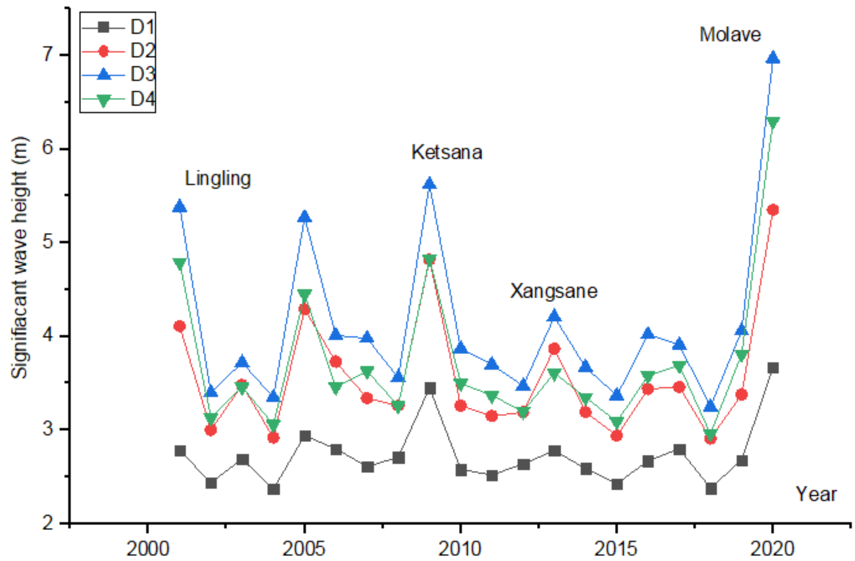


Fig. 5. The maximum significant wave height at the servey points.

2.3. About Molave storm

Molave storm, one of the most powerful storms to operate in the East Sea recently, originated in the area late in October 2020 and was known as a storm during the 2020

Pacific hurricane season. The storm intensified over the next four days before attacking Quang Ngai's coast. Table 2 and Fig. 6 show the storm's path in detail.With wind speeds of level 14 and above gusting close to Ly Son Island, the storm eye caused enomous damage to the island residents' homes and other property [2].

Table 2. The path of the center of Molave storm (JTWC-UTC+7)

No.	Time (hour)	Longitude (degree)	Lattitude (degree)	Rmax (km)	Vmax (m/s)	Pc (hPa)	Pn (hPa)
1	*0-2020102201*	137.400	8.700	55	7.7	1009	1013
2	48	132.000	11.800	55	10.3	1007	1013
3	96	121.900	13.100	55	38.6	980	1013
4	144	111.300	14.200	55	51.4	955	1013
5	174	105.400	15.500	55	7.7	1010	1013

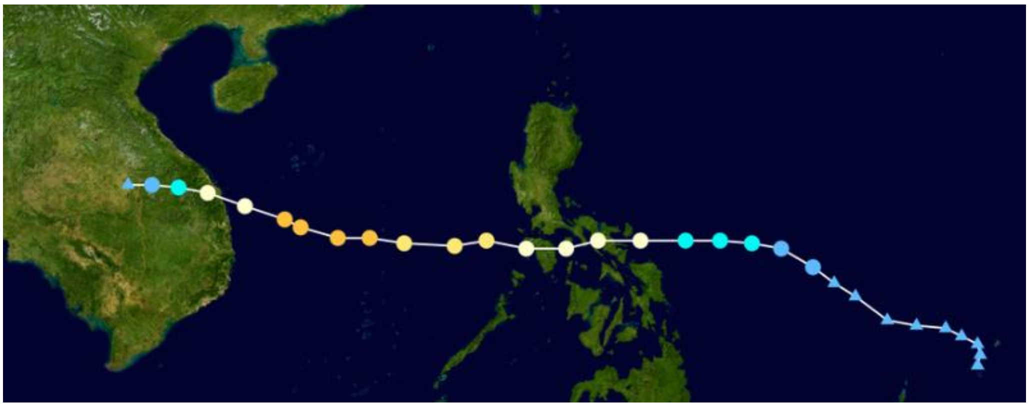


Fig. 6. The path of Molave storm 2020 [3].

2.4. Model description

Based on the outcomes of the mathematical model, the study used a module of the specialized software MIKE 21 created by the Danish Hydraulic Institute is called MIKE 21 SW. When designing and building coastal structures, MIKE 21 SW is used to anticipate waves in offshore and coastal areas, assess wave conditions (wave height, wave period, and wave direction), and evaluate wave conditions, protection of the port and shore work.

A system of equations for wave momentum conservation expressed in Cartesian or spherical coordinates serves as the program's fundamental set of equations. Details are provided in Young (1999) and Komen et al. (1994) [3].

The equation to balance the wave's action in the Cartesian coordinate system is as follows:

$$\frac{\partial N}{\partial t}+\nabla\left(\vec{v}N\right)=\frac{S}{\sigma} \tag{1}$$

where $N=\left(\vec{x},\sigma,\theta,t\right)$ is the active energy density, t is the time, $\vec{x}=\left(x,y\right)$ is the Cartesian coordinate system, $\vec{v}=\left(c_x,c_y,c_\sigma,c_\theta\right)$ is the propagation velocity of the wave group in space, S is the source component in the energy balance equation, ∇ is the dimensional differential operator in space $\vec{x},\sigma,\theta$. The characteristics of the transmission speed are determined by the formula:

$$\begin{aligned}
&\left(c_x,c_y\right)=\frac{d\vec{x}}{dt}=\overrightarrow{c_g}+\vec{U}\\
&c_\sigma=\frac{d\sigma}{dt}=\frac{\partial\sigma}{\partial d}\left[\frac{\partial d}{\partial t}+\vec{U}\nabla_{\vec{x}}d\right]-c_g\vec{k}\frac{\partial\vec{U}}{\partial s}\\
&c_\theta=\frac{d\theta}{dt}=\frac{1}{k}\left[\frac{\partial\sigma}{\partial d}.\frac{\partial d}{\partial m}+\vec{k}\frac{\partial\vec{U}}{\partial m}\right]
\end{aligned} \tag{2}$$

where s is the spatial coordinate in the wave direction θ, m are coordinates perpendicular to s, $\nabla_{\vec{x}}$ is a two-dimensional differential operator in space $\vec{x}$.

In the spherical coordinate system, the wave action balance equation is as follows:

$$\frac{\partial\hat{N}}{\partial t}+\frac{\partial}{\partial\phi}c_\phi\hat{N}+\frac{\partial}{\partial\lambda}c_\lambda\hat{N}+\frac{\partial}{\partial\theta}c_\theta\hat{N}+\hat{N}\frac{\partial}{\partial\sigma}c_\sigma\hat{N}=\frac{\hat{S}}{\sigma} \tag{3}$$

where $\hat{N}=NR^2\cos\phi=\left(\mathrm{ER}^2\cos\phi\right)/\sigma,\vec{x}=\left(\phi,\lambda\right)$ are the spherical coordinates, ϕ is the latitude, λ is the longitude, R is the radius of the earth, $S=\left(\vec{x},\sigma,\theta,t\right)=SR^2\cos\phi$ is the total source function. The transmission speed characteristics are determined by the formula:

$$c_\phi=\frac{d\phi}{dt}=\frac{c_g\cos\theta+u_\phi}{R} \tag{4}$$

$$c_\lambda=\frac{d\lambda}{dt}=\frac{c_g\sin\theta+u_\lambda}{R\cos\phi} \tag{5}$$

$$c_\sigma = \frac{d\sigma}{dt} = \frac{\partial\sigma}{\partial d}\left[\frac{\partial d}{\partial t} - \frac{d}{R}\left(\frac{1}{\cos\phi}\frac{du_\lambda}{\partial\lambda} + \frac{du_\phi}{\partial\phi} - u_\phi \tan\phi\right)\right]$$
$$-\frac{kc_g}{R}\left[\begin{array}{l}\cos\theta\left(\sin\theta\frac{du_\lambda}{\partial\phi} + \cos\theta\frac{du_\phi}{\partial\phi}\right) + \frac{\sin\theta}{\cos\phi}\left(\sin\theta\frac{du_\lambda}{d\lambda} + \cos\theta\frac{du_\phi}{d\lambda}\right) \\ -\cos\theta\tan\phi\left(u_\lambda\sin\phi + u_\phi\cos\theta\right)\end{array}\right] \quad (6)$$

$$c_\theta = \frac{d\theta}{dt} = \frac{c_g \sin\theta\tan\phi}{R} + \frac{1}{Rk}\frac{\partial\sigma}{\partial d}\left(\sin\theta\frac{\partial d}{\partial\theta}\right) +$$
$$\frac{\sin\theta}{R}\left(\sin\theta\frac{\partial u_\lambda}{\partial\phi} + \cos\theta\frac{du_\phi}{\partial\phi}\right) - \frac{\cos\theta}{R\cos\phi}\left(\sin\theta\frac{du_\lambda}{d\lambda} + \cos\theta\frac{du_\phi}{d\lambda}\right) \quad (7)$$

where $\left(u_\phi, u_\lambda\right)$ are the components of the average hydraulic velocity $\vec{U}, \theta$ is the angle of the wave direction (positive clockwise from north).

2.5. Model setup

The author combined two models to replicate the storm wave field on the Ly Son Island coastline region:

- Regional model: A wave propagation model is used to calculate the boundary values for the research model over the East Sea region.

- Local model: A 33 × 46 km model of wave propagation in the vicinity of Ly Son Island in Quang Ngai, with all edges being in the deep water wave region as shown in Fig. 7 and Table 3.

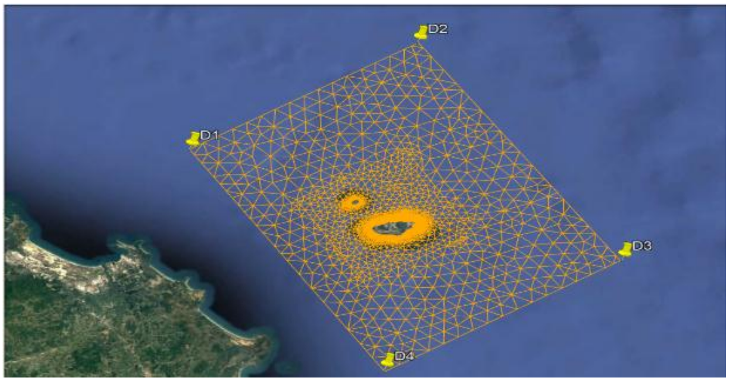


Fig. 7. Domain and mesh calculation model of Ly Son island.

There are 5 sections on the grid, each with a distinct mesh size. As the mesh moves farther offshore and gets closer to the domain's edge, its resolution becomes more coarse. A fine triangular grid is visible around the island's shoreline, especially in the area where the Ly Son wave monitoring station is located. The smallest grid size is around twenty meters. The largest grid cells, measuring roughly 1500 m, are found in the offshore and border regions. On the other hand, distributing coarse mesh to offshore regions is a useful method of lowering the total number of grid cells.

Table 3. Parameters of the model calculation grid

Parameters	Ly Son
Coordinates	WGS_1984_UTM_Zone_49N
Number of node points	5328
Number of triangle elements	10324
Marginal number	04
Highest resolution	20 m
Lowest resolution	1500 m

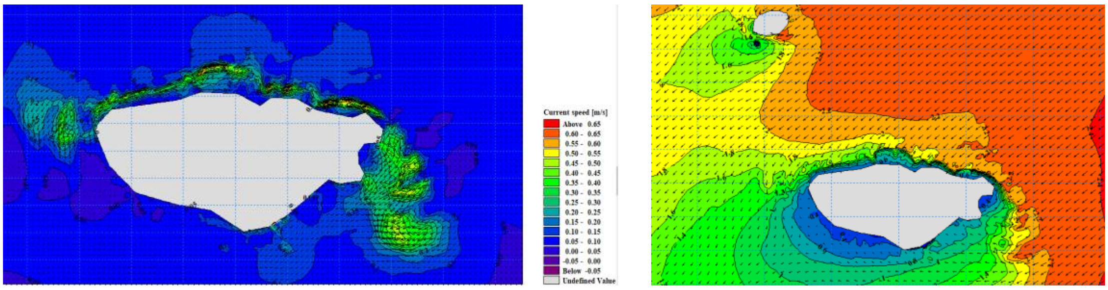
2.6. Model calibration

The model's accuracy is primarily influenced by topography, boundary conditions, and bottom roughness. On the basis of wind data at the Ly Son meteorological station, water level, flow (velocity and direction), and wave (height and period) measurements at the from Ly Son Marine hydrometeorological station, the model is calibrated and confirmed. The metrics used to contrast the model-generated data with the actual measured data are crucial and very essential. The comparative indexes are the basis for the optimal model comments, evaluations and conclusions. Where OBSi is the i^{th} observed (measured) value in the series of statistics. SIM i is the i^{th} value according to the equivalence model. $\overline{OBS}$, $\overline{SIM}$, respectively, is the average value of the real value chain measured and the value chain calculated according to the equivalent model, $i = 1,\ldots, N$. From there, the comparative indexes are calculated as in Table 4 below.

Table 4. Comparative indicators to evaluate model data with real data

Comparative index	Formula
Absolute Difference Mean (*ADM*)	$ADM = \frac{1}{N}\sum_{i=1}^{N}\left\|OBS_i - SIM_i\right\|$
Correlation coefficients	$R^2 = 1 - \frac{ESS}{TSS}$

The mathematical model was calibrated during a period of roughly 15 days, from November 22, 2020 to December 7, 2020 as seen in Fig. 8. Over the Ly Son sea region, a strong northeast monsoon is currently present.



Flow field *Wave field*

Fig. 8. Simulation results in model calibrating.

The maximum wave height (3 data points per day, 7h - 13h - 19h, manual monitoring), wave direction, and maximum wind have all been measured with accuracy by the Ly Son meteorological and marine station for the author. The analysis of the model is based on that.

Through Fig. 9 and Fig. 10, it is evident that the simulated findings and actual values exhibit a fair amount of agreement, and the Jonswap frequency spectrum and the Rayleigh height spectrum are appropriate for the East Sea region. The simulation of the subsequent phases can therefore be performed using the model with perfect confidence.

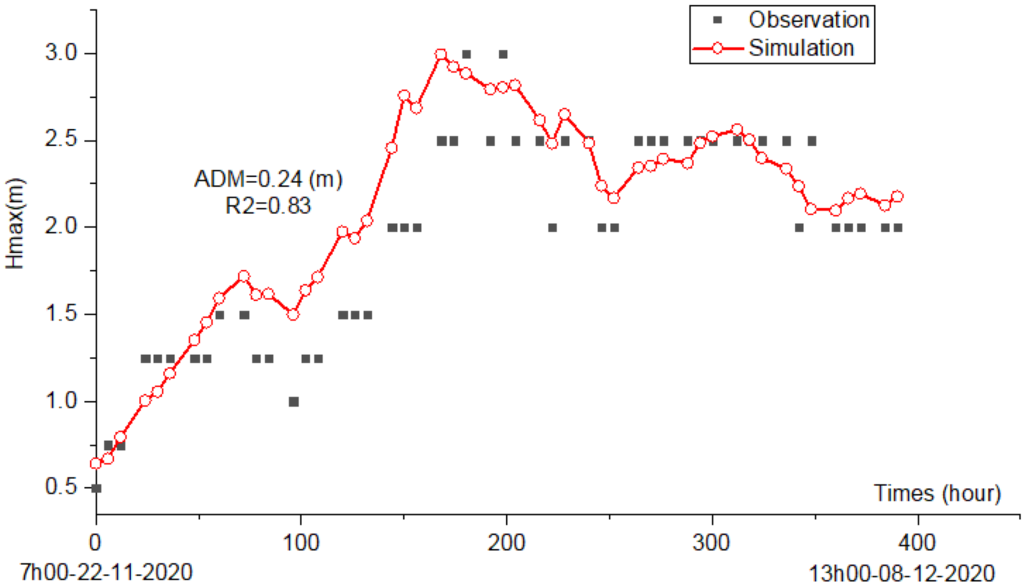


Fig. 9. Hmax correction results (observation and simulation).

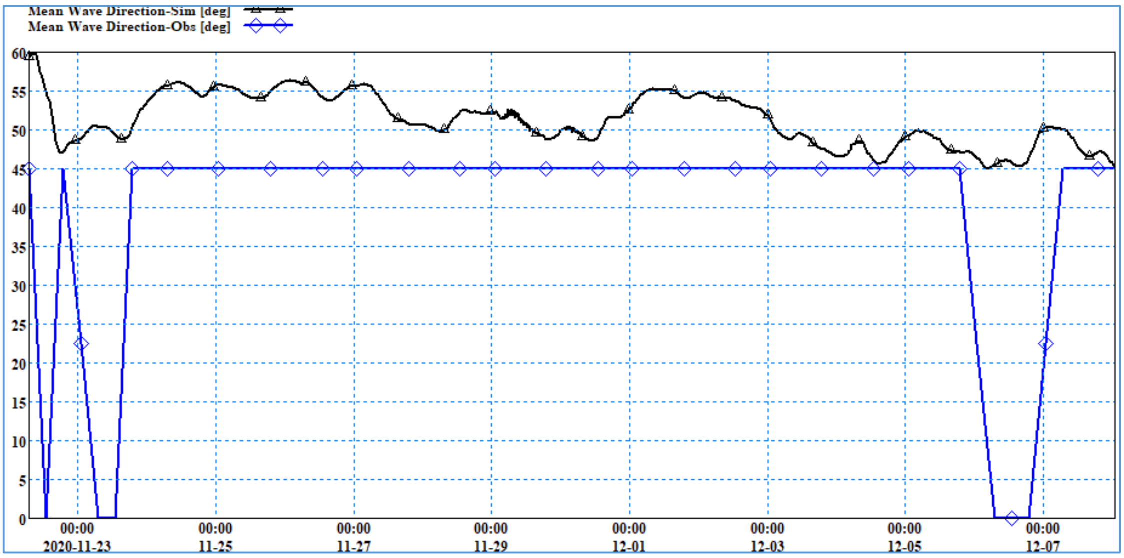


Fig. 10. Wave direction correction results (observation and simulation).

3. Results and discussion

3.1. Generating the wind field of Molave storm

The wind field is one of the most important inputs that determine the accuracy of the model results.

In this study, the storm wind field is built based on the storm data set combined with the storm wind field calculation model proposed by Young and Sobey to build a storm wind database for the calculated domain.

The eddy wind speed V_g at the storm eye r is given by the following formula [4, 5]:

$$\begin{cases} V_g(r) = V_{\max}\left(\dfrac{r}{R_{mv}}\right)^7 \exp\left(7\left(1-\dfrac{r}{R_{mv}}\right)\right) & \text{when } r < R_{mv} \\ V_g(r) = V_{\max}\exp\left(\left(0.0025R_{mv}+0.05\right)\left(1-\dfrac{r}{R_{mv}}\right)\right) & \text{when } r > R_{mv} \end{cases} \quad (8)$$

where R_{mw} is the radius of the maximum wind speed (km), $V_{\max}$ is the maximum wind speed (m/s). According to the Shore Protection Manual [6] the air pressure p is given by the formula:

$$p_r = p_c + (p_n - p_c)\exp\left(-\frac{R_{mv}}{r}\right) \quad (9)$$

where P_c is the air pressure at the storm eye, P_n is the natural atmospheric pressure (1013 hPa). Thereby, Molave storm is simulated as shown in Fig. 11.

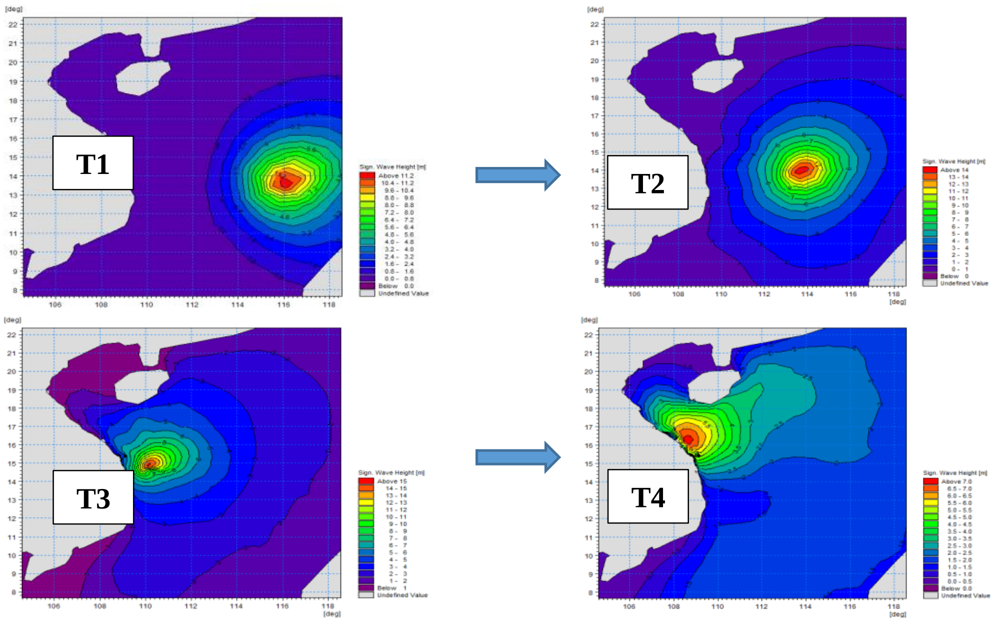


Fig. 11. Molave storm wind field simulation
(T1, T2,T3,T4: timeline following the storm path).

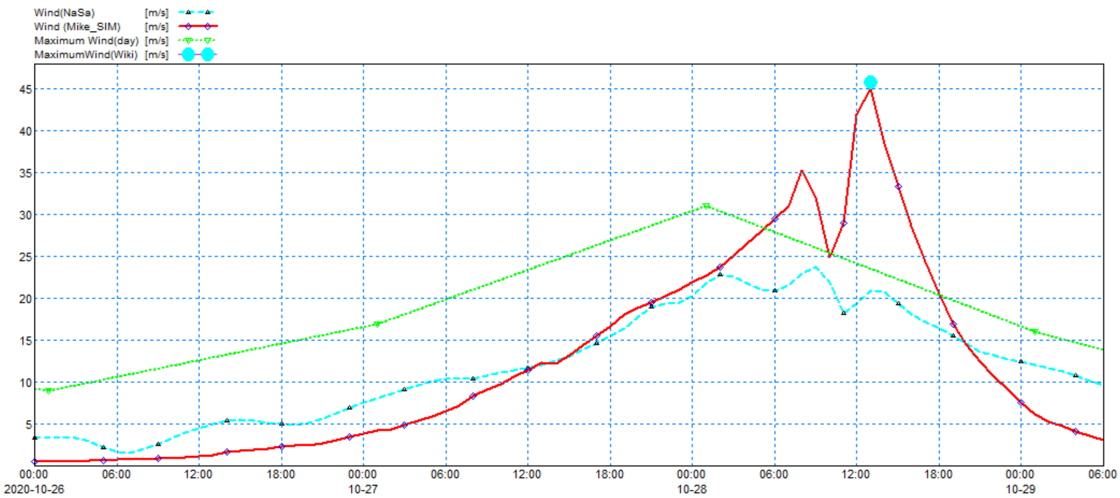


Fig. 12. Simulated wind field at Ly Son station.

Based on the comparison graph between the actual measured value and the simulated wind field derived at the Ly Son wind measuring station as Fig. 12 above, it is clear that with a maximum wind speed of 45.1 m/s, which is close to the maximum wind level of

45.8 m/s reported at the Ly Son Meteorological station, the model MIKE 21 has quite accurately recreated the storm wind field in the Ly Son sea area.

3.2. Simulating the wave field of Molave storm

Based on the comparison graph between the actual measured value and the simulated wind field derived at the Ly Son wind measuring station:

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From Fig. 13, it can be seen that despite the fact that Cu Lao Bo Bai and Ly Son island are 4.6 km away, the diffraction phenomena through Cu Lao Bo Bai island has a significant impact on the local wave field. As a result, it is determined that in comparable situations, this phenomenon should be taken into account in design practice.

The greatest wave field occurs in the NE direction, despite the storm's route being in the south direction approaching Ly Son Island (direction 180°). This demonstrates that, in reality, storm waves can arise in any direction and have a very significant value despite having a modest amount of fetch. As a result, in accordance with existing regulations, the design based on wind momentum and wind speed will appear to favor the safe direction.

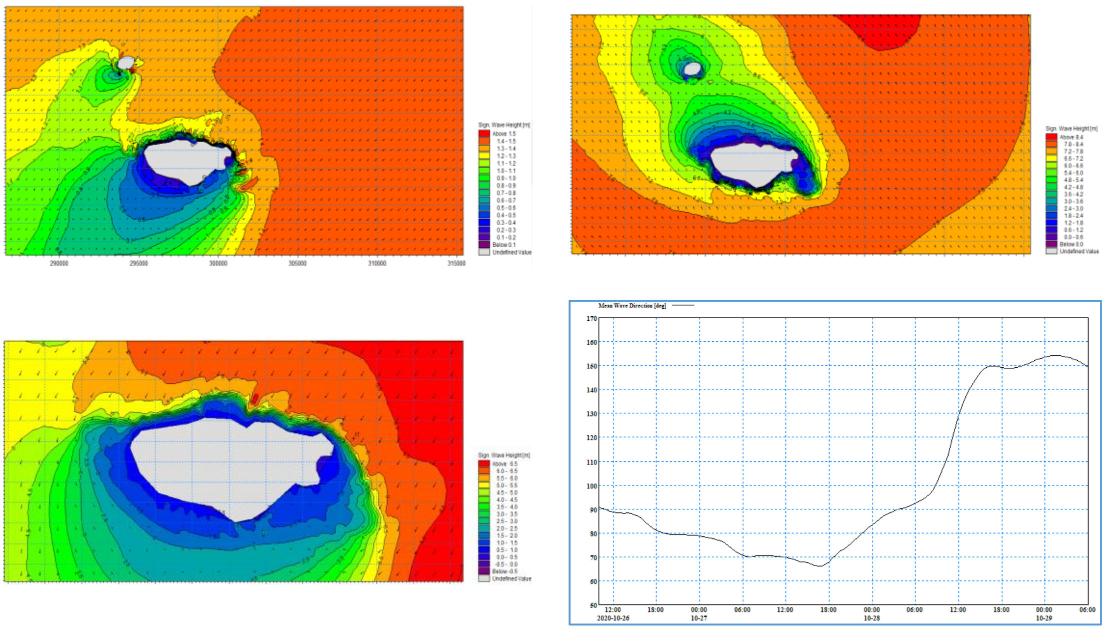

Fig. 13. Simulation results of significant wave field, wave direction.

Assuming that the wave height follows the Rayleigh distribution, MIKE 21 calculates the maximum wave height, H_{max} (m) [7, 8].

$$H_{\max} = H_{mo}\sqrt{\frac{1}{2}\ln N} \qquad (10)$$

where N is the number of waves defined: N = Time Step/T01. Time step, up to 3 h (10800s), H_{mo} is the significant wave height, T01 is wave period.

Figure 14 shows that, in comparison to the wave monitoring value at Ly Son station, the simulation findings are fairly accurate.

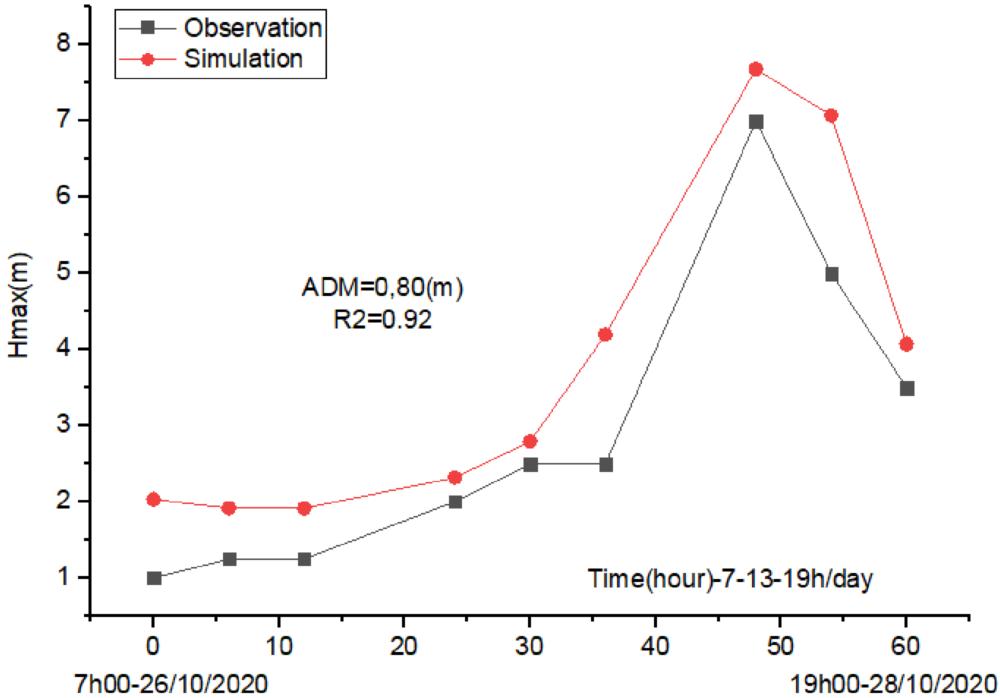

Fig. 14. Simulate Max wave height (7h, 13h, 19h).

4. Conclusions

On the basis of the extensive record for the Ly Son sea area, the typical tropical storm is chosen for this study. Based on the storm's actual parameters, the Molave storm wave field is simulated by using MIKE 21. High concordance between simulation results and monitoring data from the Ly Son coastal hydrographic station demonstrates that the simulation method entirely provides dependability and is applicable to construction.

The Jonswap spectrum's frequency and the Rayleigh spectrum's height distribution criteria are appropriate for Vietnamese waters and are fairly compliant with current Vietnamese standards.

The storm wave field rotates with the storm, making it feasible for huge wave heights in wave directions with low fetch. As a result, when designing, the largest wave that might possibly originate from any direction must be taken into account.

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NGHIÊN CỨU TRƯỜNG SÓNG BÃO TRÊN KHU VỰC ĐẢO LÝ SƠN

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Tóm tắt: Lý Sơn là đảo tiền tiêu của tổ quốc thường xuyên chịu ảnh hưởng của các điều kiện tự nhiên bất lợi như đới gió mùa hay bão nhiệt đới. Nghiên cứu các thông số thủy lực của bão nhiệt đới, trong đó có trường sóng của bão để xác định các điều kiện cực trị có vai trò quan trọng trong công tác dự báo, quy hoạch và xây dựng công trình thủy công. Tác giả sử dụng mô hình truyền sóng hai chiều MIKE 21 SW để mô phỏng trường sóng của bão nhiệt đới Molave 2020 trên vùng biển Lý Sơn. Kết quả cho thấy sự phù hợp cao giữa giá trị thu được của mô hình và thực tế đo đạc tại trạm Lý Sơn. Dựa trên các kết quả thu được, tác giả đề xuất một phương pháp mô phỏng trường sóng bão tương đối chính xác và hiệu quả. Đặc biệt, các tiêu chuẩn hiện hành dựa trên đà gió và tốc độ gió còn có nhiều hạn chế. Điều này có giá trị lớn trong thực tế thiết kế và quy hoạch các công trình thủy công.

Từ khóa: *Bão nhiệt đới Molave; trường sóng; phần mềm MIKE 21; đảo Lý Sơn; Biển Đông.*

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