Tạp chí Khoa học và Công nghệ biển T7 (2007). Số 2. Tr 33 - 48

ESTIMATION OF MAXIMUM WAVE CHARACTERISTICS IN THE VANPHONG BAY AREA, KHANHHOA PROVINCE

LE DINH MAU

Summary *: Estimation of maximum wave characteristics in a particular nearshore area have an important role of economic, tourism developments and environmental protection such as design of marine structures, transportation, fisheries and mari-culture, recreation, etc. for sustainable exploitation of the coastal zone. This paper presents the distribution of calculated wave characteristics in the Vanphong Bay area for typical maximum wind fields, which were taken from Nhatrang Meteorological Station during 1986 to 2000. Typical Tubong wind fields were taken from the investigation report of the Mete-Hydrological Service in Nhatrang. Dolphin and SWAN models estimated wave characteristics in the offshore and nearshore regions, respectively. Study results show that the Vanphong Bay area was strongest affected by wave action in case of maximum incoming winds in the sector from NW to E directions, and slightly affected by the remaining incoming wind directions. Maximum wind field (V = 28 m/s, Direction = NE) generated significant wave height of greater than 2 m which covered the most parts of Vanphong Bay area, the coastline from Honkhoi Cape to Banthang Cape was subjected to wave action with significant wave height of 3 - 6 m. Typical Tubong wind field (V = 20 m/s, Direction = NW) generated significant wave height of 0.5 - 1.5 m in Bengoi and 1.5 - 2.5 m in Vanphong Bay areas.*

I. INTRODUCTION

In recent years, the Vanphong Bay area is become the most attractive area for economic and tourism development such as marine structures, transportation, fisheries, mari-culture, recreation, etc. Knowledge and accurate estimates of the distribution of wave characteristics, especially during typical maximum wind conditions are an important role for sustainable exploitation and development of the study area. Distribution of wave characteristics in the Vanphong Bay area was studied by Le Dinh Mau (2003), but the study considered only the propagation processes of incoming waves from offshore region and not consider the new wave generated processes by local winds. Therefore, necessitating detailed studies on the distribution of wave characteristics in the Vanphong Bay area during typical maximum wind conditions. The present study applied the following wave numerical models :

- Dolphin model to estimate wave characteristics in the offshore region.

- SWAN model to estimate wave characteristics in the nearshore region.

For incoming wind directions, in which Vanphong Bay mouth are exposed to the open sea such as N, NE, E, SE and S. The boundary conditions of SWAN model were wave characteristics in the offshore region which were estimated by Dolphin model and local wind fields. Whereas, in case of incoming wind directions from landmass such as W, NW the boundary conditions of SWAN model were local wind field only.

II. METHODS AND MATERIALS

1. Computation of wave characteristics in offshore region

Numerical wave model - Dolphin (Mandal and Holthuijsen,1985) is used to estimate wave characteristics in the offshore region. The energy balance equation for wind waves from direction (θ) can be expressed as:

$$\frac{dE_1(\theta)}{dt} = S_1(\theta) + \int_0^{\infty} S_2(f,\theta)df \qquad (1.1)$$

Where,

$E_1(\theta)$ = the directional energy density of wind waves propagating in the direction considered (m^2/rad.)

$S_1(\theta)$ = the rate of change of $E_1(\theta)$ induced by wind. If E_1 is less than some upper limit, it represents growth, otherwise decay (m^2/rad/s).

$S_2(f,\theta)$ = the rate of transfer of 2-dimensional swell energy E_2 to the wind wave field at the same frequency (m^2/rad/Hz/s).

θ = direction from which wave component approach the point of forecast (Rad).

f = frequency (Hz).

The energy equation for swell from the direction (θ) is express as:

$$\frac{dE_2}{dt} = -BS_{11}(f,\theta) - S_2(f,\theta) - S_3(f,\theta) \qquad (1.2)$$

Where,

$E_2(f,\theta)$ = the two-dimensional energy density of a swell component with frequency (f), propagating in the direction (θ) (m^2/rad/Hz/s).

$B = 1$ if $S_1 < 0$

$B = 0$ if $S_1 > 0$

S_{11} = the rate of change of E_2 corresponding to S_1 when S_1 is negative

S_2 = the rate of change of transfer of swell energy E_2 to be zero or positive (m^2/rad/Hz/s).

S_3 = the rate of change of swell energy due to swell-bottom interaction, used only for shallow water.

- Input data : Location of calculated point, wind (velocity, duration).

- Output data : Significant wave height (H_s), spectral wave period (T_p), coefficient of spectral directional spreading (DSPR) and wave direction (θ).

2. Computation of wave characteristics in nearshore region

Wave characteristics in the Vanphong Bay area were computed by SWAN (Simulating WAves Nearshore) model which is a third – generation wave model (Booij, et al., 1999) with which realistic estimates of wave parameters in coastal areas, lakes and estuaries from given wind, bottom, and current conditions can be obtained.

a. Action balance equation

The evolution of the wave spectrum is described by the spectral action balance equation, which, for Cartesian coordinate, is (Hasselmann et al., 1973)

$$\frac{\partial}{\partial t}N+\frac{\partial}{\partial x}C_xN+\frac{\partial}{\partial y}C_yN+\frac{\partial}{\partial \sigma}C_\sigma N+\frac{\partial}{\partial \theta}C_\theta N=\frac{S}{\sigma} \tag{2.1}$$

The first term in the left hand side of Eq. 2.1 represents the local rate of change of action density (N) in time, the second and third term represent propagation of action in geographical space (with propagation velocities C_x and C_y in x and y space, respectively). The fourth term represents shifting of the relative frequency due to variations in depths and currents (with propagation velocity C_σ in σ space). The fifth term represents depth-induced and current-induced refraction (with propagation velocity C_θ in θ space). The term $S = S(\sigma,\theta)$ at the right hand side of the action balance equation is the source term in term of energy density representing the effects of generation, dissipation and nonlinear wave-wave interactions.

b. Wind input

Transfer of wind energy to the waves is described with the resonance mechanism and the feedback mechanism. The corresponding source term for these mechanisms is commonly described as the sum of linear and exponential growth:

$$S_{in}(\sigma,\theta) = A + BE(\sigma,\theta) \tag{2.2}$$

In which A (linear growth) and B (exponential growth) depend on wave frequency and direction and wind speed and direction. The effects of currents are accounted by using the apparent local wind speed and direction.

*> Linear growth by wind:

$$A = \frac{1{,}5\times10^{-3}}{g^2 2\pi}\left[U_* \max\left[0, \cos(\theta-\theta_w)\right]\right]^4 H \qquad (2.3)$$

Where

$$H = \exp\left(-\left(\sigma/\sigma^*_{PM}\right)^{-4}\right) \text{ with } \sigma^*_{PM} = \frac{0.13g}{28U_*}2\pi$$

in which,

θ_w = wind direction

H = the filter

σ_{PM}^* = peak frequency of the fully developed sea state.

*> Exponential growth by wind:

$$B = \max\left[0, 0.25\frac{\rho_a}{\rho_w}\left[28\frac{U_*}{C_{ph}}\cos(\theta-\theta_w)-1\right]\right]\sigma \qquad (2.4)$$

in which,

C_{ph} = the phase speed

ρ_a, ρ_w = density of air and water, respectively.

c. ***Wave energy dissipation***

The dissipation term of wave energy is represented by the summation of three different contributions: white capping $S_{ds,w}(\sigma,\theta)$, bottom friction $S_{ds,b}(\sigma,\theta)$, and depth-induced breaking $S_{ds,br}(\sigma,\theta)$.

- White capping is primarily controlled by the steepness of the waves as follow,

$$S_{ds,w}(\sigma,\theta) = -\Gamma\,\tilde{\sigma}\frac{k}{\tilde{k}}E(\sigma,\theta) \qquad (2.5)$$

Where, Γ = steepness dependent coefficient

k = wave number

$\tilde{\sigma}, \tilde{k}$ = mean frequency and mean wave number, respectively.

- Bottom-induced dissipation may be caused by bottom friction, bottom motion, percolation, or backscattering on bottom irregularities. For continental shelf seas with sandy bottoms, the dominant mechanism appears to be bottom friction, which can generally be represented as

$$S_{ds,b}(\sigma,\theta) = -C_{bottom}\frac{\sigma^2}{g^2\sinh^2(kd)}E(\sigma,\theta) \tag{2.6}$$

In which, C_{bottom} = bottom friction coefficient

- Depth-induced wave breaking is still poorly understood and little is known about its spectral modeling

$$S_{ds,br}(\sigma,\theta) = \frac{S_{ds,br,tot}}{E_{tot}}E(\sigma,\theta) \tag{2.7}$$

In which, E_{tot} = total wave energy

Sds,br,tot = the rate of dissipation of Etot due to depth-induced wave breaking.

The value of Sds,br,tot depends critically on the breaking parameter γ = Hmax/d (Hmax is the maximum wave height in the local water depth d), in SWAN a constant value $\gamma = 0.73$.

d. Nonlinear wave-wave interactions

In deep water, quadruplet wave-wave interactions dominate the evolution of the spectrum. They transfer wave energy from the spectral peak to lower frequencies (thus moving the peak frequency to lower values) and to higher frequencies (where the energy is dissipated by white capping). In very shallow water, triad wave-wave interactions transfer energy from lower frequencies to higher frequencies, often resulting in higher harmonics. The discrete triad approximation is used in SWAN in each spectral direction:

$$S_{nl3}(\sigma,\theta) = S_{nl3}^{-}(\sigma,\theta) + S_{nl3}^{+}(\sigma,\theta) \tag{2.8}$$

with

$$S_{nl3}^{+}(\sigma,\theta) = \max\left\{0, \alpha_{EB}2\pi c c_g J^2|\sin(\beta)|\left[E^2(\sigma/2,\theta) - 2E(\sigma/2,\theta)E(\sigma,\theta)\right]\right\} \tag{2.9}$$

$$S_{nl3}^{-}(\sigma,\theta) = -2S_{nl3}^{+}(2\sigma,\theta) \tag{2.10}$$

where, α_{EB} = tunable proportionality coefficient

$$\beta = -\frac{\pi}{2} + \frac{\pi}{2}\tanh\left(\frac{0.2}{Ur}\right) \quad (2.11)$$

where, Ur = Ursell number

$$Ur = \frac{g}{8\sqrt{2}\pi^2}\frac{H_s\overline{T}^2}{d^2} \quad (2.12)$$

where, $\overline{T} = 2\pi / \overline{\sigma}$, J = the interaction coefficient

SWAN model accounts for shoaling, refraction, generation by wind, white-capping, triad and quadruplet wave–wave interactions, bottom friction, and depth – induced wave breaking. The input data for SWAN model was wave boundary conditions, which were taken from the results of Dolphin wave model, and local wind fields. Size of the computational grid was 27.4 x 45.5 km, with resolution of 200 x 200 m, which covers the area from 109.188°E to 109.435°E and from 12.4°N to 12.81°N (Figure 1). The spectral frequency (f) range was 0.052 – 1 Hz with $\Delta f = 0.01$ H_z and range in direction (θ) was 0 to 360° with $\Delta\theta = 10°$. The output data were significant wave height (H_s), wave period (T_p), wave length (L), wave direction (φ).

3. Materials

- Bathymetry of Vanphong Bay area was taken from the hydrographic map with scale 1 : 50,000 published in 1967 by USA Navy. Bathymetry and features of study area are shown in Figure 1.

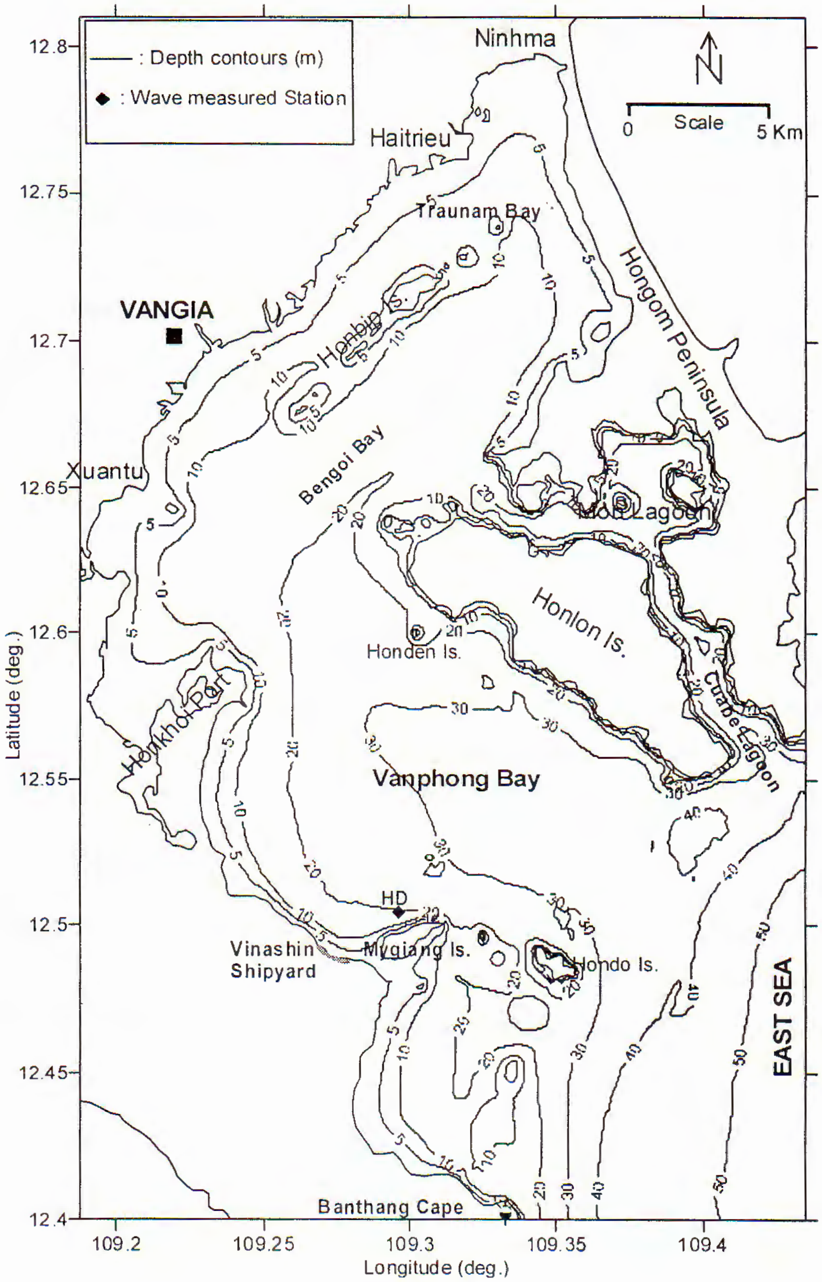

Figure 1. Study area

- Typical maximum wind velocity for incoming wind directions from the offshore region such as : N, NE, E, SE were taken from Nhatrang Meteorological Station (1986 – 2000). Typical Tubong wind fields were taken from the investigation report of the Mete-Hydrological Service in Nhatrang (Center for Mete-Hydrology in Southern Vietnam, 1995). Table 1 shows the typical maximum wind fields used to estimate the maximum wave conditions in the Vanphong Bay area.

Table 1. Typical maximum wind velocity used to estimate the maximum wave conditions in the Vanphong Bay area.

Serial No.	Directions	Maximum wind speed V_{max} (m/s)	Remarks
1	N	24	From Nhatrang Station
2	NE	28	From Nhatrang Station
3	E	16	From Nhatrang Station
4	SE	8	From Nhatrang Station
5	NW	20	From Vangia Station

III. RESULTS

1. Verification of wave models

To verification the accuracy of wave models, we are carried out the comparison between measured wave characteristics at Location HD which located at : $\lambda = 109.29925^{o}$ E; $\varphi = 12.4995^{o}$ N, and Depth $\approx$ 20 m (Figure 1). Measured wind data at chosen times and the results of comparation are shown in Table 2. Data in Table 2 shows that average relative difference between measured and computed significant wave heights was around 12 %, average relative difference between measured and computed wave periods was less than 10 %. Comparation results indicated that the computed results were reasonable good agreement with the measured ones.

Table 2. Comparison between measured and computed wave characteristics at Location – HD

Times	**07h/28/12/2006** Wind: V = 6 m/s; $\alpha = 20^{0}$			**10h/28/12/2006** Wind: V = 6.3 m/s; $\alpha = 30^{0}$			**18h/28/12/2006** Wind: V = 7 m/s; $\alpha = 20^{0}$		
Wave characteristics	Hs (m)	Tp (s)	α (Deg.)	Hs (m)	Tp (s)	α (Deg.)	Hs (m)	Tp (s)	α (Deg.)
Measured	*0.42*	*4.6*	*40*	*0.43*	*4.6*	*46*	*0.44*	*5.8*	*43*
Computed	0.44	4.6	37	0.49	4.6	48	0.52	5.2	39
Absolute difference	*0.02*	*0*	*3*	*0.06*	*0*	*2*	*0.08*	*0.6*	*4*
Relative difference (%)	*5*	*0*	''	*14*	*0*	''	*18*	*10*	''

2. Estimation of maximum wave characteristics in the offshore region of Vanphong Bay for typical conditions

Maximum wave characteristics off Vanphong Bay were estimated by Dolphin wave model corresponding to the incoming wind directions from offshore region. These estimated data will be used as boundary conditions of SWAN model. The calculated results are shown in Table 3.

Table 3. Estimated wave characteristics in the offshore region of Vanphong Bay corresponding to maximum wind velocity for typical conditions

Serial No.	Directions	Maximum wind speed (m/s)	Offshore wave characteristics		
			H_s (m)	T_p (s)	DSPR (deg.)
1	N	24	6.1	10.1	27.0
2	NE	28	7.4	11.1	26.9
3	E	16	3.5	8.4	27.2
4	SE	8	1.3	5.2	27.6

3. Distribution of maximum significant wave height in the Vanphong Bay area for typical maximum wind fields

Computed maximum significant wave height patterns in the Vanphong Bay area (Fig. 2 to Fig. 6) shows that :

- **For maximum wind field (V = 24 m/s, Direction = N)** : in the Vanphong Bay mouth area significant wave height was $H_s \approx 3 - 5$ m, major wave direction was NE. The area between Honkhoi Cape and Hondo Island significant wave height was $H_s \approx 2 - 3$ m, major wave direction was NW to N. In the Bengoi Bay area significant wave height was $H_s \approx 1 - 2$ m, major wave direction was NE. The areas of Traudam Bay, Mon and Cuabe Lagoons significant wave height was $H_s \approx 1.0 - 1.5$ m, major wave direction was N. In general, the area along the coastline from Vinashin Shipyard to Banthang Cape was strongest affected by wave action (Fig. 2).

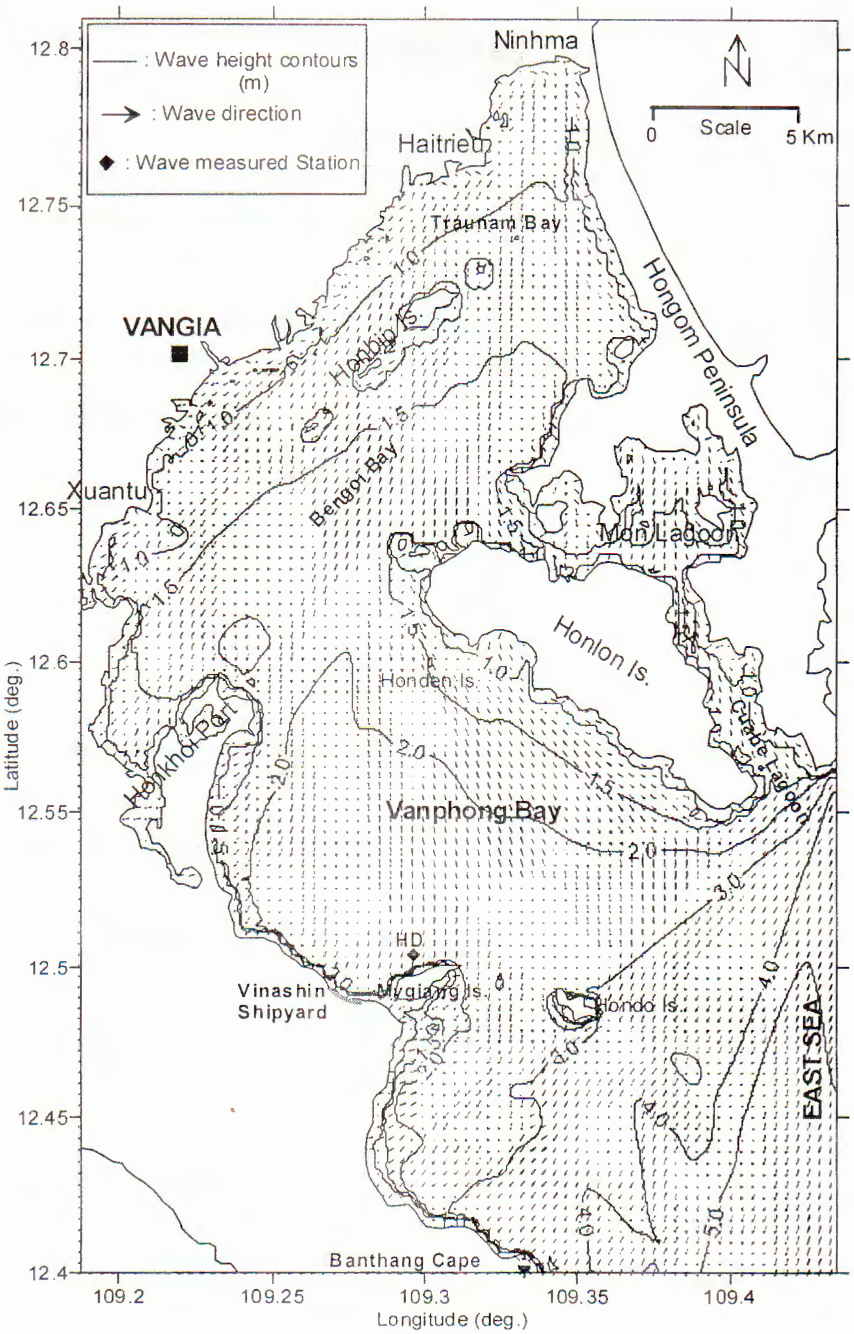

Figure 2. Computed significant wave height pattern in the Vanphong Bay area (Wind condition : V = 24 m/s, Direction = N)

- **For maximum wind field (V = 28 m/s, Direction = NE)** : in the Vanphong Bay mouth area significant wave height was $H_s \approx 5 - 7$ m, major wave direction was NE. The area between Honkhoi Cape and Mygiang Island significant wave height was $H_s \approx 3 - 5$ m, major wave direction was NE to E. Bengoi Bay area significant wave height was $H_s \approx 2 - 3$ m, major wave direction was NE. The areas of Traudam Bay, Mon and Cuabe Lagoons significant wave height was $H_s \approx 1 - 2$ m and major wave direction was NE. In general, the areas along the coastline from Honkhoi Cape to Banthang Cape was strongest affected by wave action (Fig. 3).

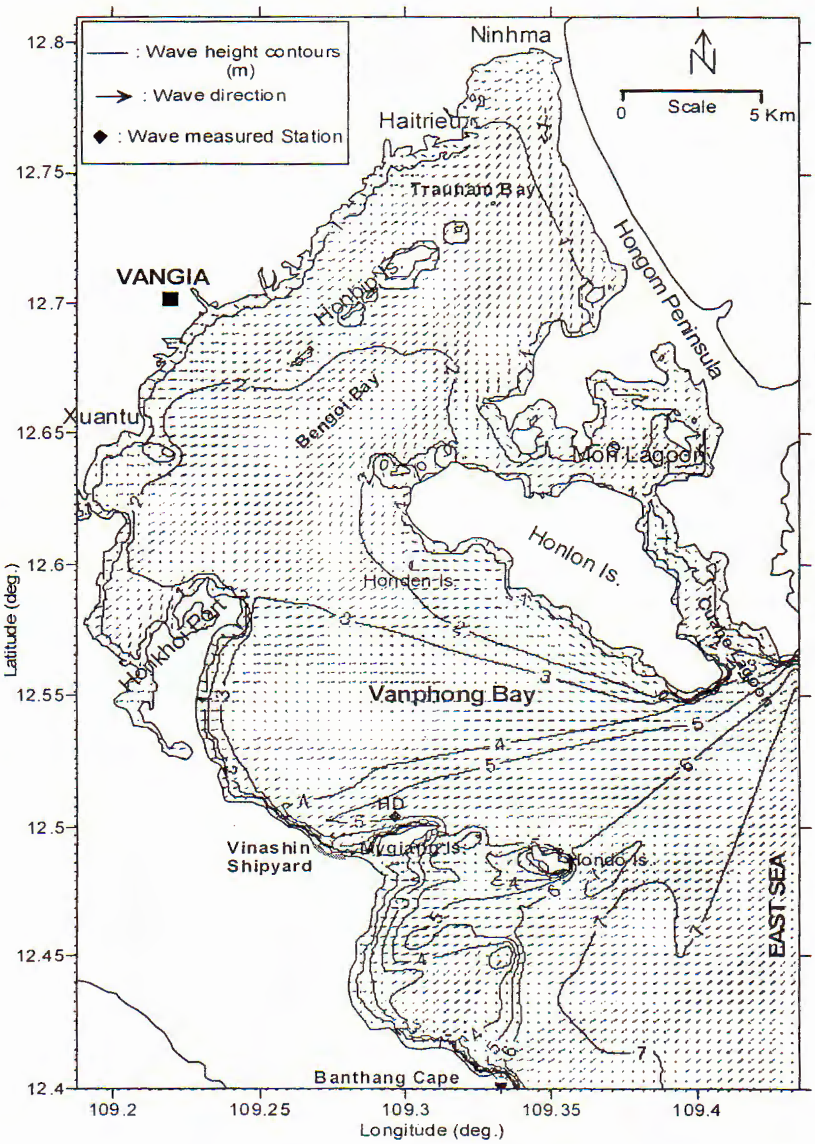

Figure 3. Computed significant wave height pattern in the Vanphong Bay area (Wind condition : V = 28 m/s, Direction = NE)

- For maximum wind field (V = 16 m/s, Direction = E) : in the area of Vanphong Bay mouth significant wave height was $H_s \approx 3$ m, major wave direction was E. The area between Honkhoi Cape and Mygiang Island significant wave height was $H_s \approx 2 - 3$ m, major wave direction was E. Bengoi Bay area significant wave height was $H_s \approx 1 - 2$ m, major wave direction was SE. The areas of Traudam Bay, Mon Lagoons significant wave height was $H_s \approx 1$ m, major wave direction was E. In general, the areas along the coastline from Honkhoi Cape to Banthang Cape and Xuantu was strongest affected by wave action (Fig. 4).

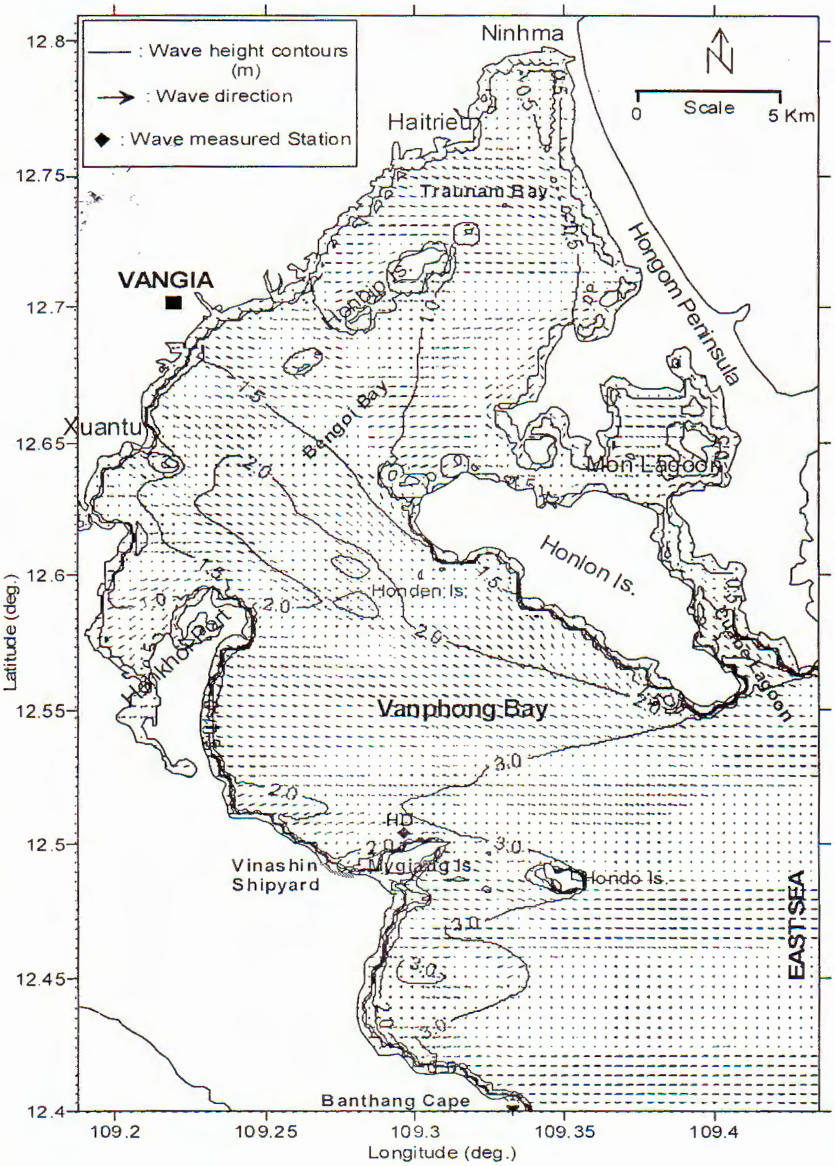

Figure 4. Computed significant wave height pattern in the Vanphong Bay area (Wind condition : V = 16 m/s, Direction = E)

- **For maximum wind field (V = 8 m/s, Direction = SE)** : in the area of Vanphong Bay mouth significant wave height was $H_s \approx 1$ m, major wave direction was SE. The area between Mygiang Island and Xuantu significant wave height was $H_s \approx 0.7 - 1.0$ m, major wave direction was SE. The remaining parts of Vanphong Bay area significant wave height was $H_s \leq 0.5$ m, major wave direction was SE. In general, Vanphong Bay area was not seriously affected from wave action by incident wind direction from SE (Fig. 5).

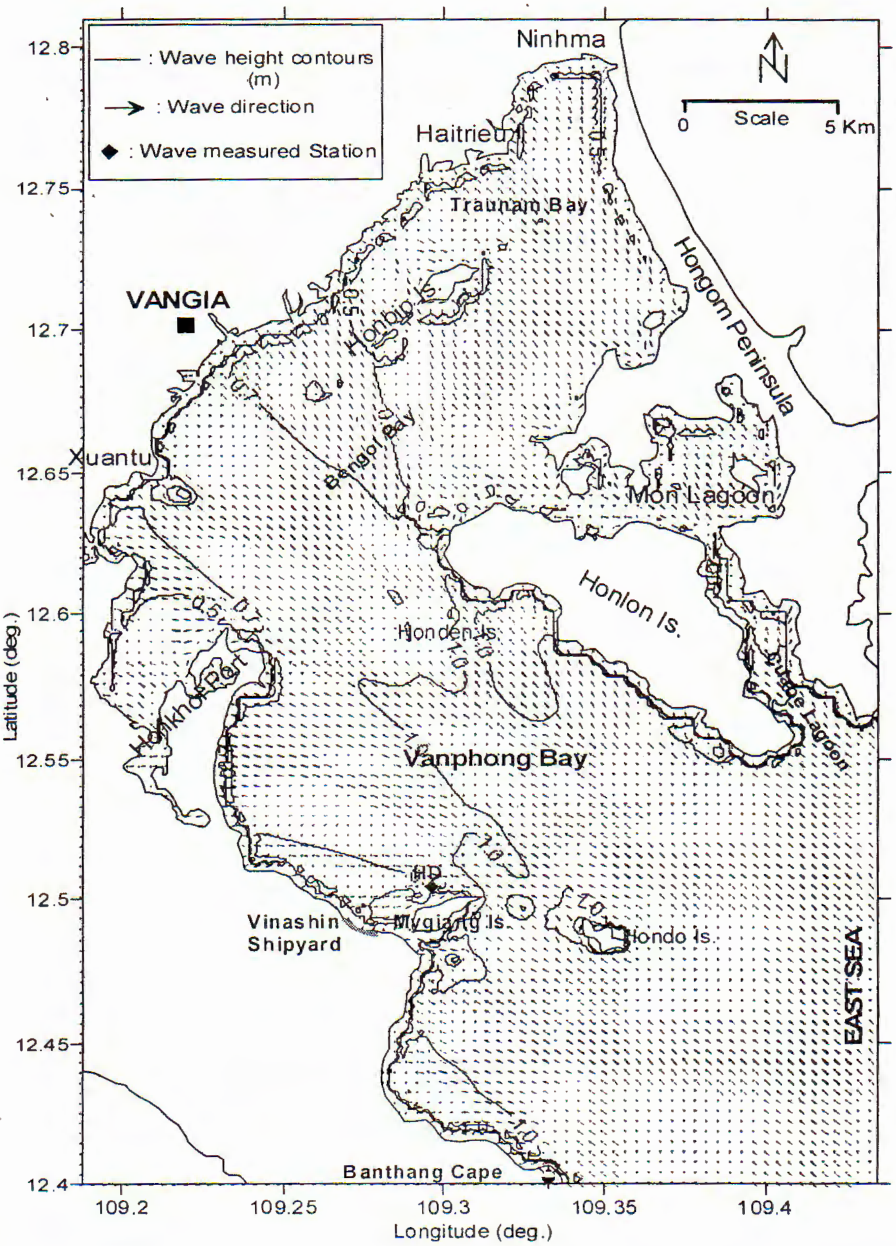

Figure 5. Computed significant wave height pattern in the Vanphong Bay area
(Wind condition : V = 8 m/s, Direction = SE)

- **For maximum Tubong wind field (V = 20 m/s, Direction = NW)** : in general, major wave direction was NW. In the Bengoi Bay area significant wave height was $H_s \approx$ 0.5 - 1.5 m, Vanphong Bay area significant wave height was $H_s \approx$ 1.5 - 2.5 m. In general, Vanphong Bay area was significant affected from wave action by incident wind direction from NW (Fig. 6).

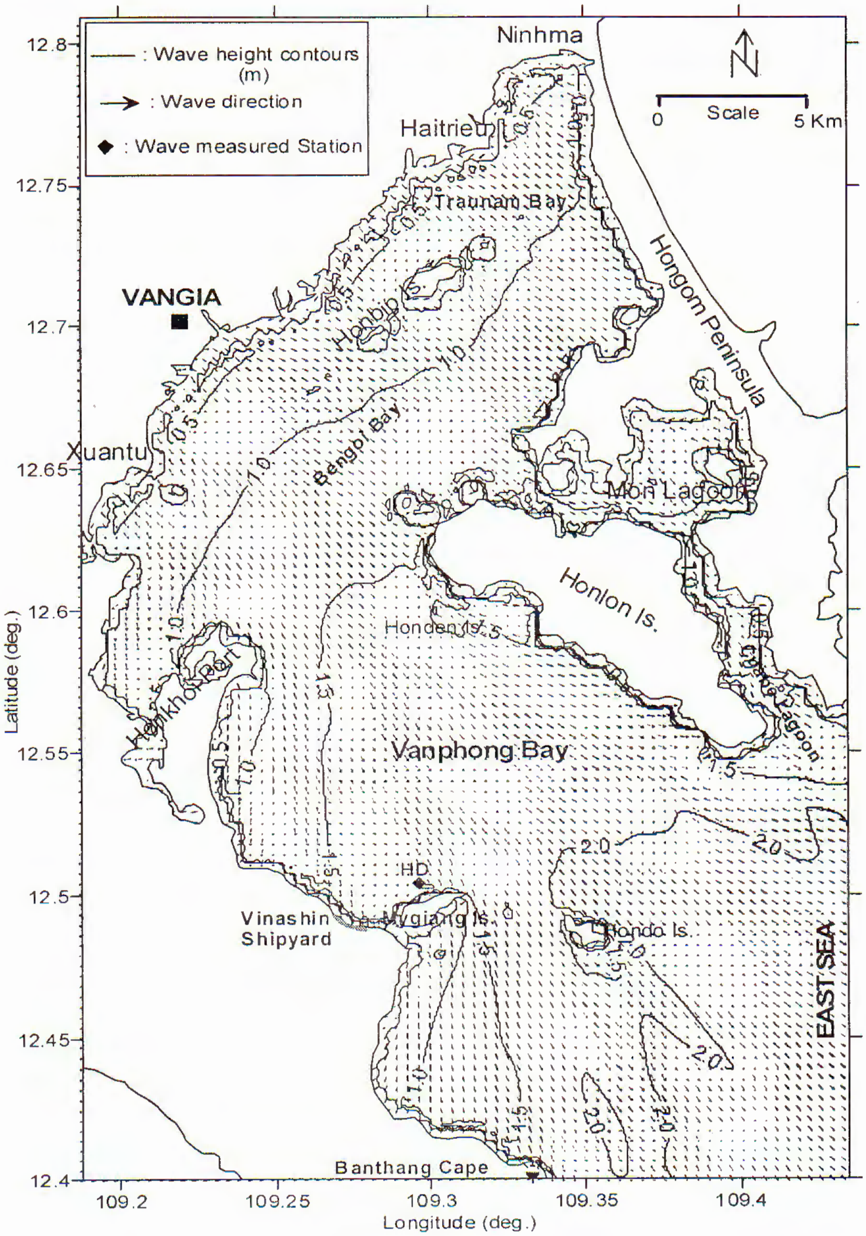

Figure 6. Computed significant wave height pattern in the Vanphong Bay area (Wind condition : V = 20 m/s, Direction = NW)

IV. CONCLUSIONS

Distribution of maximum wave characteristics in the Vanphong Bay area for typical maximum wind fields can be reported as follows :

- Distribution of wave characteristics depends on the geographical location and incoming wind directions.

- Vanphong Bay area was strongest affected by wave action in case of maximum incoming winds in the sector from NW to E directions and slightly affected by maximum incoming winds in the sector from SE to W directions.

- Maximum wind field (V = 28 m/s, Direction = NE) generated significant wave height of greater than 2 m which covered the most parts of the Vanphong Bay area, the coastline from Honkhoi Cape to Banthang Cape was subjected to wave action with significant wave height of 3 - 6 m.

- Maximum wind fields (V = 24 m/s, Direction = N) and (V = 16 m/s, Direction = E) generated significant wave height of greater than 1.0 m which covered the most parts of the Vanphong Bay area, the coastline from Honkhoi Cape to Banthang Cape was also serious affected by wave action with significant wave height of 2 - 3 m.

- Maximum Tubong wind field (V = 20 m/s, Direction = NW) generated significant wave height of 0.5 - 1.5 m in Bengoi Bay area, and of 1.5 - 2.5 m in Vanphong Bay area.

REFERENCES

1. **Booij, N., Ris, R. C., and Holthuijsen, L. H., 1999.** A third-generation wave model for coastal regions. 1- Model description and validation, Journal of Geophysical Research, 104 (C4), 7649-7666.
2. **Hasselmann, K., Bernett, T.P., Bouws, E., Carlson, H., Cartwright, D.E., Enke, K., Ewing, J.A., Gineapp, H., Hasselmann, D.E., Kruseman, P., Meerburg, A., Muller, P., Olbers, D.J., Richer, K., Sell, W., and Walden, H., 1973.** Measurements of wind wave growth and swell decay during the Joint North Sea Wave Project, JONSWAP. Supplement Report No. A8 (12), Dutch, Hydrogr Z.
3. **Le Dinh Mau, 2003.** Distribution of wave characteristics in Khanh Hoa coastal zone. Collection of Marine Research Works, Vol. XIII, 55-63.

4. **Mandal, S., and Holthuijsen, L.H., 1985.** A numerical wave prediction model DOLPHIN: Theory and test results, Report No. 3-85, Delft University of Technology, Department of Civil Engineering, Group of Fluid Mechanics.
5. **Center for Mete-Hydrology in Southern Vietnam, 1995.** Features of climate and hydrogy in Khanhhoa Province. Department of Science and Environment, Khanhhoa Province, p. 190.

TÍNH TOÁN CÁC ĐẶC TRƯNG SÓNG CỰC ĐẠI TẠI VỊNH VÂN PHONG, TỈNH KHÁNH HÒA

LÊ ĐÌNH MẦU

Tóm tắt : *Tính toán các đặc trưng sóng cực đại tại một khu vực ven biển có vai trò rất quan trọng đối với việc phát triển kinh tế, du lịch và bảo vệ môi trường như thiết kế các thủy công trình, giao thông vận tải, đánh bắt và nuôi trồng thủy sản, các hoạt động vui chơi giải trí trên biển... phục vụ việc qui hoạch, phát triển bền vững vùng biển ven bờ. Bài báo trình bày sự phân bố các đặc trưng sóng tính toán tại Vịnh Vân Phong ứng với các điều kiện gió cực đại điển hình được thống kê từ số liệu gió đo đạc tại trạm Nha Trang từ năm 1986 đến 2000. Trường gió Tu Bông điển hình được thu thập từ báo cáo chuyên đề của Đài Khí tượng – Thủy văn Nam Trung bộ. Các đặc trưng sóng vùng khơi được tính toán bằng mô hình số trị Dolphin, các đặc trưng sóng vùng nước nông ven bờ được tính toán bằng mô hình số trị SWAN. Kết quả nghiên cứu cho thấy rằng Vịnh Vân Phong bị tác động mạnh nhất bởi sóng ứng với các trường gió cực đại có hướng từ NW đến E và ít bị sóng tác động ứng với các trường gió cực đại có hướng từ SE đến W. Trường gió cực đại (V = 28 m/s, Hướng = NE) gây ra độ cao sóng hữu hiệu lớn hơn 2 m bao trùm phần lớn diện tích của vịnh, dải ven bờ từ mũi Hòn Khói đến mũi Bàn Thang bị sóng tác động mạnh nhất với độ cao sóng hữu hiệu từ 3 - 6 m. Gió Tu Bông điển hình (V = 20 m/s, Hướng = NW) gây ra độ cao sóng từ 0.5 – 1.5 m tại Vịnh Bến Gỏi và 1.5 – 2.5 m tại Vịnh Vân Phong.*

Ngày nhận bài: 26 - 3 - 2007
Người nhận xét: TS. Lê Đình Mầu

Địa chỉ: Viện Hải dương học