

ESTIMATION OF WAVE CHARACTERISTICS IN EAST VIETNAM SEA USING WAM MODEL

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ABSTRACT: WAM (WaveModeling) is a third generation wave model developed by WAMDI Group which describes the evolution of a two-dimensional ocean wave spectrum under the effects of winds, currents, bottom and non-linear wave-wave interactions. The model runs for deep and shallow waters and includes depth and current refraction. This study used the WAM cycle 4.5 with model domain which is covered from 99°E to 121°E and 0°N to 25°N with a resolution of $\Delta X = \Delta Y = 0.25^{\circ}$. Bathymetry of East Vietnam Sea (EVS) was taken from 'ETOPOS' data set of National Geophysical Data Center, Colorado, USA with resolution of $5'$ (≈ 9 km). Wind velocities were obtained from 6 hourly NCEP/NCAR reanalysis data, USA with resolution of $\Delta X = \Delta Y = 0.25^{\circ}$. Study results show that during NE monsoon period, the main wave direction in EVS was NE and vice versa during SW monsoon period. Regions of greatest wave height were in the central and northern part of the EVS. Statistic of computed wave characteristics from 1987 to 2011 shows that wave regime in the offshore region of Nhatrang coast has two main wave directions that are NE with 40.82% of occurrence, SSW with 20.15% of occurrence. NE monsoon wave dominated from October to April of the next year, SW monsoon wave dominated from June to August. May and September are transitional periods. Assimilation of wind data with resolution of $\Delta X = \Delta Y = 0.25^{\circ}$ permits the model to be used to simulate the wave field during typhoon activity in EVS.

Key words: WAM cycle 4.5, East Vietnam Sea, Wave field, Typhoon, Monsoons.

INTRODUCTION

The East Vietnam Sea (EVS) is a semienclosed tropical sea located in the southeast of the Asian landmass with a total area of approximately 3,537,000 km² and average depth of 1,140 m, extending from 99°E to 120°E and from 0°N to 25°N . It connects to the East China Sea (through Taiwan Strait), the Pacific Ocean (through Luzon Strait), the Sulu Sea, the Java Sea (through Gasperand Karimata Straits) and the Indian Ocean (through the Strait of Malacca). All of these straits are shallow except Luzon Strait, the maximum depth of which is 1,800 m. The EVS is under the influence of

monsoon winds and synoptic systems such as fronts and tropical cyclones. From November to March, the weather in the sea is dominated by northeasterly winter monsoon wind and from June to August it is dominated by southwesterly summer monsoon wind.

Determination of wind wave characteristics in offshore area has important role for design of marine-structures, social-economical activities and supply of boundary conditions for nearshore wave computation. Processes of formation, development and dissipation of wave corresponding to the varied condition of wind, current and topography are very complicated matters. SWAMP (1985) [1]

domain is covered the area 99°E ÷ 121°E and 0°N ÷ 25°N with resolution of 0.25° × 0.25° which includes 92 × 100 points (fig.1). Measurement of wave characteristics was carried out off Nhatrang coast at water depth of about 15 m by AWAC wave recorder. Wind data at six hourly intervals from 01/7/1987 to 31/12/2011 with resolution of 0.25° × 0.25° were downloaded from website: http://apdrc.soest.hawaii.edu/datadoc/ccmp_6hourly.php which were collected from satellite, Obs.ship, buoys and ECMWF (for 24.5 years with 38,500 data sheets).

Computation methods

WAM Cycle 4.5 model [7] was used to calculate wave characteristics in the EVS. The evolution of the two-dimensional ocean wave spectrum $F(f, \theta, \phi, \lambda, t)$ with respect to frequency f and direction θ (measured clockwise relative to true north) as a function of latitude ϕ and longitude λ on the spherical earth is governed by the transport equation:

$$\frac{\partial F}{\partial t} + (\cos \phi)^{-1} \frac{\partial}{\partial \phi} (\phi \cos \phi F) + \frac{\partial}{\partial \lambda} (\lambda F) + \frac{\partial}{\partial \theta} (\theta F) = S \quad (1)$$

Where S is the net source function describing the change of energy of a propagating wave group and :

$$\phi = \frac{d\phi}{dt} = vR^{-1} \cos \theta \quad (2)$$

$$\lambda = \frac{d\lambda}{dt} = v \sin \theta (R \cos \phi)^{-1} \quad (3)$$

$$\theta = \frac{d\theta}{dt} = v \sin \theta \tan \phi R^{-1} \quad (4)$$

represent the rates of change of the position and propagation direction of a wave packet traveling along a great circle path. Here, $v = g/4\pi f$ denotes the group velocity.

The source includes wind input - S_{in} , nonlinear transfer - S_{nl} , and white capping dissipation source function - S_{dis} :

$$S = S_{in} + S_{nl} + S_{dis} \quad (5)$$

The model contains 25 frequency bands on a logarithmic scale, with $\Delta f / f = 0.1$, spanning a frequency range $f_{max} / f_{min} = 9.8$ and 12 directional bands (30° resolutions). The frequency units can be selected arbitrarily. In all hind cast studies the frequency interval extended from 0.042 to 0.41 Hz.

Output data with six hourly intervals from 01/7/1987 to 31/12/2011 with resolution of 0.25° × 0.25° was carried out.

Verification of modeled results

Field measurement of wave characteristic to verify the modeled results was carried out off Nhatrang coast ($\phi = 12^{\circ}07.125'N$, $\lambda = 109^{\circ}14.600'E$, depth ≈ 15 m) from 9h30'/11/8/2012 to 16h00/12/8/2012 by AWAC wave recorder (fig. 1). Comparison between measured and modeled data is shown in fig. 2a, b.

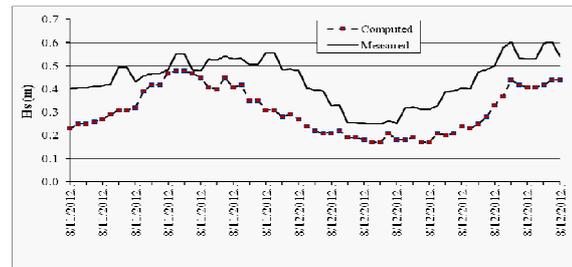


Fig. 2a. Comparison of measured and computed wave heights at Nhatrang station

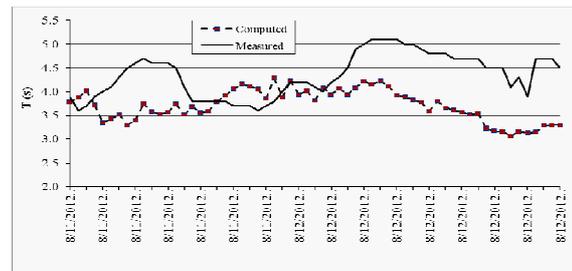


Fig. 2b. Comparison of measured and computed wave periods at Nhatrang station

The period of verification is southwest monsoon. In general the wave heights and wave periods from modeled results are larger than those of measured ones. Relative

difference between measured and modeled is 13% for wave heights and 20% for wave periods. The measured station was located in nearshore and shallow region where conditions affected verified results. Nevertheless, based on the verified results, WAM model can be used to calculate wave characteristics in the EVS.

STUDY RESULTS

Wave height pattern in EVS during monsoons

At 0h 7/1/2011 wind field over the EVS was strong, mostly of $V \geq 10$ m/s especially in the northeast area (Luzon strait) with $V > 16$ m/s and wind direction was dominated in NE direction. This wind field resulted in wave height field being characteristic of NE monsoon with relatively stable wave direction from NE. The central region of EVS was prevailed by wind wave with $H_s \approx 4 \div 5$ m, $T \approx 8.5 \div 9.0$ s. The wave height contour of $H_s \approx 3$ m was close to central Vietnamese coast and $T \approx 7.5 \div 8.5$ s. The gulf of Tonkin has $H_s \approx 1 \div 3$ m, $T \approx 5 \div 7$ s, the gulf of Thailand has $H_s \approx 1 \div 2$ m, $T \approx 4 \div 6$ s (fig. 3).

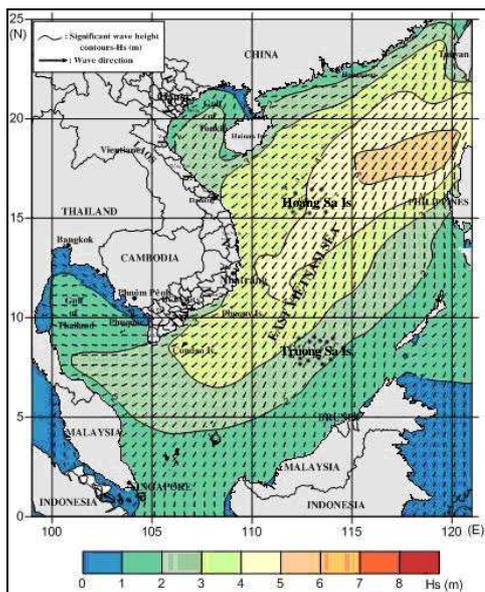


Fig. 3. Wave height pattern in EVS during NE monsoon (at 0h 7/1/2011)

At 0h 16/7/2011 wind field over EVS was mostly of $V \geq 6$ m/s, maximum value of 10.8 m/s and wind direction was dominated from SE. This wind field resulted in wave height

field being characteristic of SW monsoon with relatively stable wave direction from SW. In general EVS was prevailed by wind wave with $H_s \approx 0.5 \div 1.5$ m, $T \approx 4.5 \div 6.0$ s. Northeast region of EVS has $H_s \approx 1.5 \div 2.5$ m, $T \approx 6$ s (fig. 4)

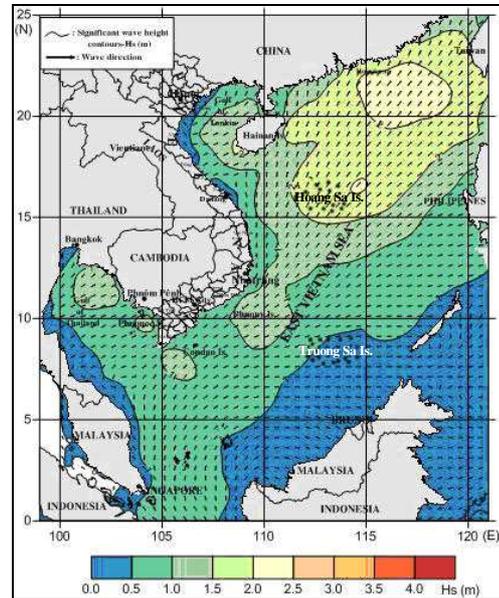


Fig. 4. Wave height pattern in EVS during SW monsoon (at 0h 16/7/2011)

Wave height pattern in EVS during typhoons

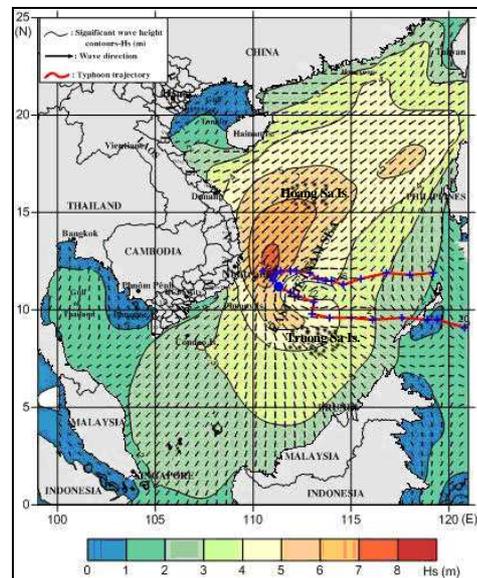


Fig. 5. Wave height pattern induced by typhoon Hagibis (at 18h 22/11/2007)

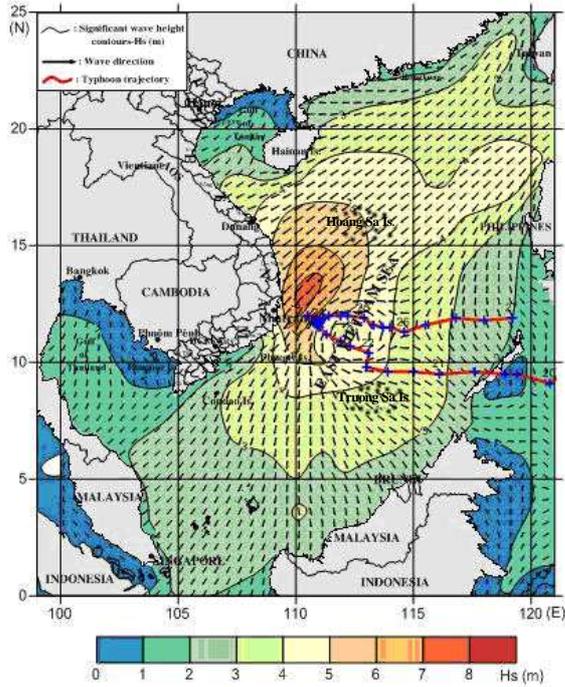


Fig. 6. Wave height pattern induced by typhoon Hagibis (at 06h 23/11/2007)

Typhoon Hagibis occurring in the EVS from 18/11 to 27/11/2007 induced maximum wave height in the offshore region of Nhatrang coast (at location: 12.125°N, 109.375°E). Track of Hagibis is shown in fig. 5, 6. At 18h 22/11/2007 maximum wind velocity was 23.6 m/s, maximum wave height was 7.3 m, wave period was 10.8 s. In offshore region of Nhatrang coast maximum wave height was 5.6 m, wave period was 11.1 s. At 6h 23/11/2007 Hagibis moved closer to Nhatrang coast and wind velocity reduced, but wave height and period are increased with $H_s = 6.3$ m, $T = 11.1$ s. Wave height patterns induced by Hagibis at 18h 22/11/2007 and 6h 23/11/2007 are shown in fig. 5, 6 respectively.

Long term distribution features of wave characteristics in EVS

Frequency distribution (%) of $H_s > 1.0$ m during 1/7/1987 - 31/12/2011 greater than 50% occurred in northeast, central region of EVS and central Vietnamese coast. The gulf of Thailand and Tonkin have frequency < 20% (fig.7).

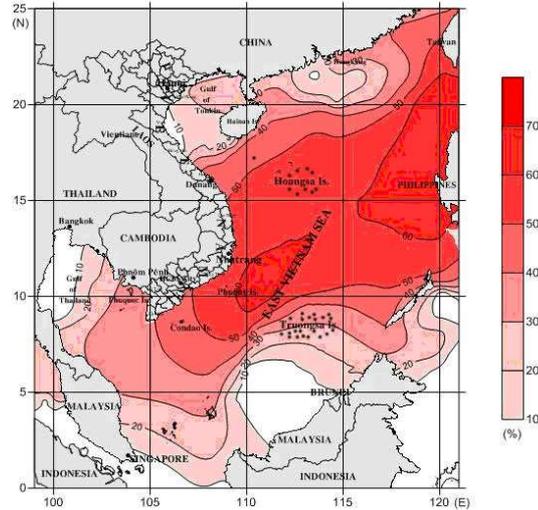


Fig. 7. Frequency distribution (%) of occurrence in case of $H_s > 1.0$ m from 1/7/1987 to 31/12/2011

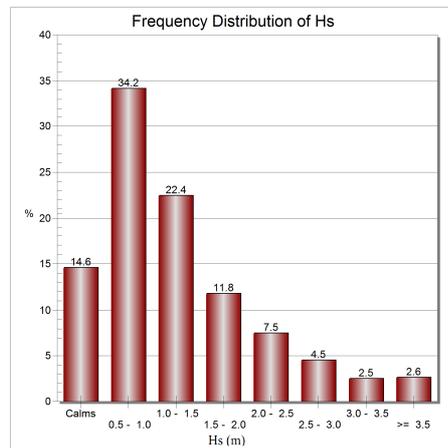
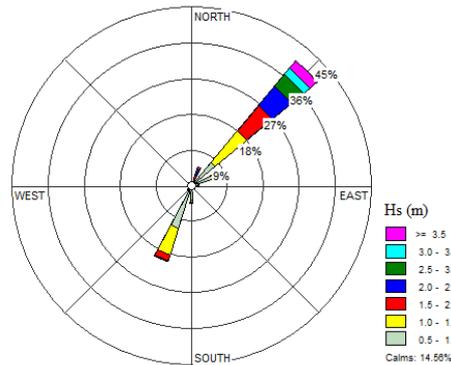


Fig. 8. Wave rose diagram and frequency distribution of occurrence of wave height off Nhatrang coast during 1/7/1987 - 31/12/2011

Offshore region of Nhatrang coast is a region of narrow continent the depth contour of 200 m is close to the coastline. Therefore, this coast is most affected by wave action especially during NE monsoon period. Statistic of computed wave characteristics data for offshore region of Nhatrang coast (at point: 12.125°N, 109.375°E) from 1/7/1987 to 31/12/2011 shows that wave regime off Nhatrang coast has two main directions NE with 40.82% of occurrence, SSW with 20.15% of occurrence. $H_s \approx 0.5 \div 1.0$ m occurred 34.16%, $H_s \approx 1.0 \div 1.5$ m occurred 22.43%, and $H_s > 1.5$ m occurred 28.84% (fig. 8).

CONCLUSIONS

Frequency distribution (%) of $H_s > 1.0$ m during 1/7/1987 - 31/12/2011 greater than 50% occurred in northeast, central region of EVS and central Vietnamese coast. The gulf of Thailand and Tonkin have frequency of occurrence < 20%;

Wave regime in the offshore region of Nhatrang coast from 1/7/1987 to 31/12/2011 indicates two main wave directions that are NE with 40.82% of occurrence, SSW with 20.15% of occurrence. $H_s \approx 0.5 \div 1.0$ m occurred 34.16%, $H_s \approx 1.0 \div 1.5$ m occurred 22.43%, and $H_s > 1.5$ m occurred 28.84%. NE monsoon wave affected from October to April of the next year, SW monsoon wave affected from June to August. May and September are transitional periods.

With the assimilation of wind data of high resolution $\Delta X = \Delta Y = 0.25^0$, the model can be used to simulate wave fields during typhoon activity in East Vietnam Sea

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REFERENCES

1. *WAMDI Group, 1988.* The WAM model - A third generation ocean wave prediction model, *Journal of Physical Oceanography*, **18**(12): 1,775-1,810.
2. *Young, I. R., 1988.* Parametric hurricane wave prediction model. *Journal of Waterways Port Coastal and Ocean Engineering*, **114**(5): 637-652.
3. *Londhe, S. N., Vijay Panchang, 2006.* One-day wave forecasts based on artificial neural networks. *Journal of Atmospheric and Oceanic Technology*, **23**(11): 1,593-1,603. Online publication date: 1-Nov-2006.
4. *Mandal, S., and Prabakaran, N., 2003.* An overview of the numerical and neural network Accosts of ocean wave prediction, COPEDEC VI, 2003. Colombo, Sri Lanka.
5. *Mau, L. D., Sanil Kumar, V., Nayak, G. N., Mandal, S., 2004.* Estimation of wave characteristics during hurricane in the Hoian area, Central Vietnam. *Proceeding of the Third Indian National Conference on Harbour and Ocean Engineering*, 1, 105-113.
6. *Guenther, H., Hasselmann, S., Janssen, P. A. E. M., 1992.* The WAM Model Cycle 4.0. User Manual. Technical Report No.4, Deutsches Klimarechenzentrum, Hamburg, Germany, 102 p.
7. *Guenther, H., 2002.* WAM Cycle 4.5. User Manual. Technical Report. Institute for Coastal Research GKSS Research Centre Geesthacht. Germany, 40 p.
8. *Tolman, H. L., 1991.* A third-generation model for wind waves on slowly varying, unsteady and inhomogeneous depths and currents. *Journal of Physical Oceanography*, **21**, 782-797.
9. *Chu, Peter C., Kuo-Feng Cheng, 2008.* South China Sea wave characteristics during typhoon Muifa passage in winter 2004. *Journal of Oceanography* **64**(1): 1-21. Online publication date: 1-Feb-2008.
10. *Ali Mirzaei, Fredolin Tangang, Liew Juneng, Muzneena Ahmad Mustapha, Mohd Lokman Husain, Mohd Fadzil Akhir, 2013.* Wave climate simulation for southern region of the South China Sea. *Ocean Dynamics*, **63**(8): 961-977. Online publication date: 9-Jul-2013.

11. Liangming Zhou, Zhanbin Li, Lin Mou, Aifang Wang, 2014. Numerical simulation of wave field in the South China Sea using WAVEWATCH III. Chinese Journal of Oceanology and Limnology, 1-9. Online publication date: 24-Jan-2014.
12. Lê Đình Mậu, 2006. Tính toán các đặc trưng sóng biển khơi bằng mô hình số trị WAM. Tạp chí Khoa học và Công nghệ biển. Hà Nội, Việt Nam, Tập 6, Số 3. Tr. 26-39.

TÍNH TOÁN CÁC ĐẶC TRƯNG SÓNG TRÊN BIỂN ĐÔNG BẰNG MÔ HÌNH WAM

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TÓM TẮT: WAM (WaveModeling) là mô hình tính sóng thế hệ thứ 3 được xây dựng và phát triển bởi tập thể các nhà khoa học nghiên cứu sóng trên thế giới (WAMDI Group), mô hình mô tả sự phát triển của phổ sóng hai chiều dưới tác động của gió, dòng chảy, địa hình đáy và tương tác phi tuyến sóng - sóng. Mô hình tính toán các đặc trưng sóng biển sâu, biển nông bao hàm hiệu ứng khúc xạ sóng bởi nước nông và dòng chảy. Mô hình WAM phiên bản 4.5 (WAM cycle 4.5) đã được áp dụng với khu vực tính toán là toàn bộ Biển Đông từ $99^{\circ}E$ đến $121^{\circ}E$ và $0^{\circ}N$ đến $25^{\circ}N$ với kích thước lưới tính là $\Delta X = \Delta Y = 0,25^{\circ}$. Độ sâu Biển Đông lấy từ cơ sở dữ liệu 'ETOPO5' của Trung tâm dữ liệu Địa vật lý quốc gia Colorado, Hoa Kỳ với độ phân giải $5'$ (≈ 9 km). Số liệu gió 6h/lần lấy từ cơ sở dữ liệu NCEP/NCAR, Hoa Kỳ với độ phân giải $\Delta X = \Delta Y = 0,25^{\circ}$. Kết quả tính toán cho thấy thời kỳ gió mùa Đông Bắc (NE Monsoon) trên toàn Biển Đông sóng có hướng chủ đạo là Đông Bắc (NE) và có hướng ngược lại trong thời kỳ gió mùa Tây Nam (SW monsoon). Khu vực trung tâm và Đông Bắc của Biển Đông có độ cao sóng lớn nhất. Thống kê kết quả tính toán các đặc trưng sóng từ 1987 đến 2011 cho thấy chế độ sóng ngoài khơi Nha Trang có hai hướng chính là NE chiếm 40,82%, SSW chiếm 20,15%. Sóng hướng NE tác động từ tháng 10 đến tháng 4 năm sau, sóng SSW tác động từ tháng 6 đến tháng 8, tháng 5 và 9 là các thời kỳ chuyển tiếp. Tập dữ liệu gió với độ phân giải $\Delta X = \Delta Y = 0,25^{\circ}$ cho phép mô phỏng trường sóng trong bão trên Biển Đông.

Từ khóa: WAM cycle 4.5, Biển Đông, trường sóng, bão, gió mùa.