LONG-TERM VARIATION OF REANALYZED WIND WAVES ON THE CAPE OF CA MAU COAST, VIETNAM

Nguyen Trinh Chung[1]

Abstract: *This study investigated the long-term variation of reanalyzed wind waves in duration 1900-2010 at the cape of Ca Mau coast, Viet Nam based on ERA-20C dataset in order to clarify basic engineering information about the long-term trend as well as the seasonal characteristics of wind wave properties around study area. On the overall, the seasonal variation of wave height, period and direction were shown to be significant. The monthly-mean wave height and period were correlated with 2nd order polynomials very well. The wave height in dry season was about 2 times higher than that in rainy season, while the seasonal discrepancy of wave period between these two seasons was approximately 1.5 time. The student's t test indicated that the relations between wave height and period are significant at 1% level. The dominant wave direction in dry and rainy season was the ENE and WSW, respectively. The potential wave energy in dry season is about 7 times higher than that in rainy season. Recent five decades, average mean of potential wave energy flux were much higher than that of previous decadal values.*

Keywords: Cape of Ca Mau coast; ERA-20C dataset; reanalysis; wind waves; seasonal, long-term variation.

1. INTRODUCTION

Ca Mau is surrounded by the South China Sea on the east and west sides, the Gulf of Thailand on the west side with approximately 180 km of the coastline. The cape of Ca Mau locates at the end of the south side, where is characterized by significant mangrove squeeze and high erosion rates in the last decades. Recently, many devastating coastal problems which are strongly influenced by local wave characteristics around the region have been revealed occurring at this area. For example, the severed erosion occurred along the coastline from Ganh Hao river mouth to Khai Long beach (Nguyen Van Lap, Ta Thi Kim Oanh, 2012); the land cover changes during the period 1953 to 2011 in the cape of Ca Mau have been determined (T.T. Van et al, 2015); the reduction of mangrove area relating to the erosion of coastline also have been revealed (V. Tran Thi et al, 2014). Moreover, coast waves play an extremely vital role in the mechanism of sediment transport especially within the mangroves area (Massel, S.R et al, 1999). In addition, a report by the Southern institute for Water Resources Planning, Viet Nam indicated that until 2013 in the south of Ca Mau there are no sea dykes, the coastal area is only protected by mangroves. In order to cope with these problems, a physical understanding of long-term wave characteristics is essentially important as basic engineering information.

Recently, the computations of the ERA-20C dataset has been conducted by the European Centre for Medium-Range Weather Forecasts (ECMWF). This is an atmospheric reanalysis, including the spatial-temporal evolution of the atmosphere and ocean surface wind waves, from January 1900 to December 2010. Its final result has covered data for several areas along the coastline of Viet Nam. The continuous 110 year length of the ERA-20C datasets makes it available for investigating long-term trend of its features. Moreover, in Vietnam, observed wave data of many coastal areas is not available. Accordingly,

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this study investigates the long-term variation in wave characteristics in duration 1900-2010 base on ERA-20C dataset in order to make a brief outline of wave characteristics at the coastline of the cape of Ca Mau. First, the characteristics of seasonal variation are clarified by the investigation of monthly-mean averaged over the study duration of wave properties. The correlation between the wave height and wave period are investigated. Second, the long-term variations in annual- and monthly-mean wave properties are then examined. Finally, the monthly and decadal mean values of potential wave energy flux are investigated.

2. DATASETS AND METHODS

2.1 Field site and datasets

The wave data from January 1900 to December 2010 have been retrieved from ERA-20C dataset at the area of 6^0N – 8^0N latitude, 104^0E – 108^0E longtitude to reanalyze (Fig 1). Since the record comprises of 110 years, it is sufficiently long for the inspection of long-term changes. In the retrieved dataset, the assimilation methodology is 24-hour, 4D-Var analysis, with variational bias correction of surface pressure observations. The available raw data can be retrieved from the Website of ECMWF (http://www.ecmwf.int/en/research/climate-reanalysis/era-interim).

2.2 Method of analysis

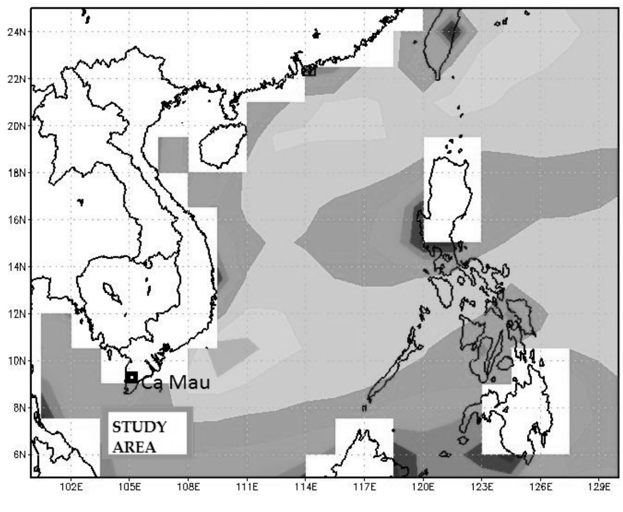


Fig 1. Location of research area

The values of annual- and monthly mean of significant wave heights, wave periods, and wave directions were retrieved and processed to investigate the seasonal as well as annuallong-term variation of them. The student's t test were conducted to judge the significant levels of relations between wave height and period. In this study, the seasonal characteristics are defined as follows: the dry season is from November of previous year to next April that is strongly impacted by the winter monsoon with the ENE dominant wind direction; the rainy season is from May to November that is influenced by summer monsoon with the WSW dominant wind direction.

3. SEASONAL VARIATION OF WAVE CHARACTERISTICS

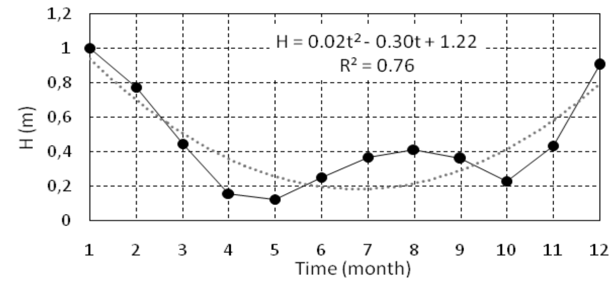
3.1 Wave heights and periods

The regional climate of Ca Mau is tropical monsoon with two distinguishing seasons, in which the variations of seasonal wave characteristics are considerable. On the overall, waves are the smallest during rainy season and the largest in dry seasons. Figures 2 show the seasonal variation in monthly-mean of reanalyzed wave characteristics at Ca Mau in duration 1900-2010. Accordingly, the averaged mean of wave heights in dry and rainy season are about 0.6 m and 0.3 m, respectively. This illustrates that the averaged wave height in dry season is approximately 2 times larger than that in the rainy season. Similar to the wave heights, the variation of seasonal wave periods is also significant. The monthly-mean wave height and period indicate essentially the same patterns of variation. The waves in dry season have longer periods in which the average mean value is around 3.0 s, while waves in rainy season have smaller periods with the average value around 2.0 s. The wave periods in dry season are around 1.5 times those of the rainy season. Moreover, the monthly average values of wave heights and wave period can be expressed quite well by second order polynomials as follows:

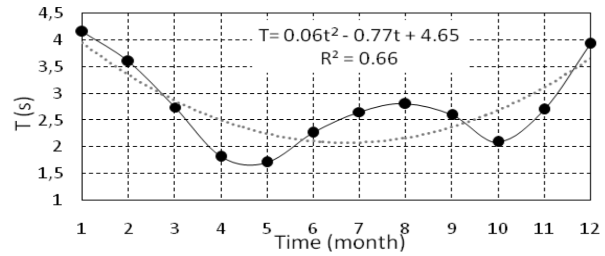
$$H = 0.02t^2 - 0.30t + 1.22 \text{ with } R^2 = 0.76 \quad (1)$$

$$T = 0.06t^2 - 0.77t + 4.65 \text{ with } R^2 = 0.66 \quad (2)$$

In which, H is averaged mean of wave heights; T is averaged mean of wave periods; t is time value; and R is mean square root value.



(a) Wave height



(b) Wave period

Fig 2. Seasonal variation in monthly-mean wave properties

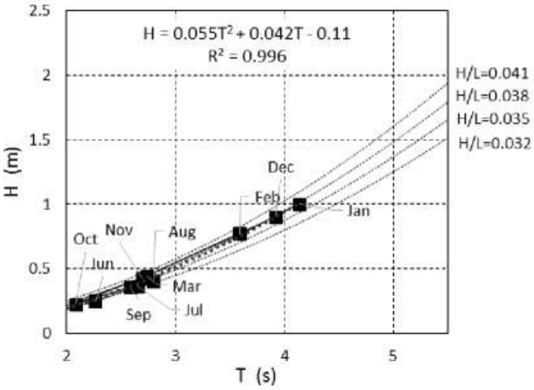
Figures 3 show the relationships between monthly wave heights and wave periods during the study duration. The regression results are included to examine the correlation between these wave characteristics. According to Figure 3(a), the averaged mean values of wave heights and periods are strongly interdependent. They can be correlated very well with the a 2nd order polynomial (equation (3)) with a high correlation coefficient of R^2=0.996. The student's t test has been performed to judge the significant level of relation between wave heights and periods. The result illustrates that this relation is judged to be significant at 1% level.

$$H = 0.055T^2 + 0.042T - 0.11 \quad (3)$$

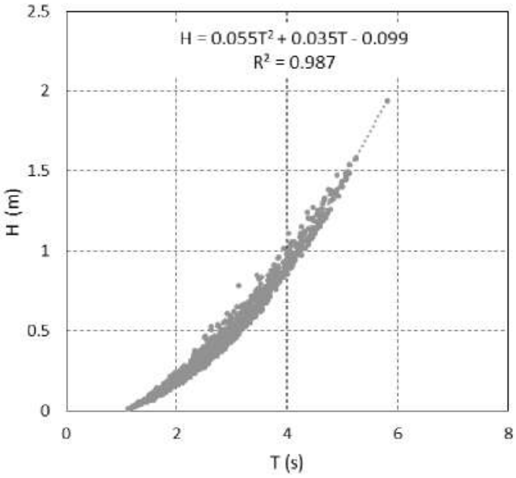
In the figure, several curves corresponding to typical wave steepness (*H*/*L*) are included to clarify the discrepancy between waves in dry- and rainy season. The figure illustrates that the waves in dry seasons are steeper than that of rainy season. The wave steepness in dry season asymptotic to 0.038, while they are 0.035 in rainy season.

The month by month values of wave heights and periods also have a close correlation (Fig.3(b)). The represent second order polynomial, in which the correlation coefficients is also high (R^2=0.987) is described by equation (4). The student's t test also indicates the 1% significant level for the month by month relation of wave heights and periods.

$$H = 0.055T^2 + 0.035T - 0.099 \quad (4)$$



(a) Average values



(b) Month by month values

Fig 3. Relationship between monthly-mean wave characteristics during 1900-2010

3.2 Wave direction

Figure 4 shows the average incoming wave direction relating to wave period from January to December, respectively. In general, waves in dry season have longer wave period and approach the coast mainly from the ENE direction. In May, the transition from dry to rainy season, waves are small periods and approach shoreline from three side of the coast. In major duration of rainy season (June to September) waves approach the coast mainly from the SWS direction. The wave periods are the small. In October, the transition from rainy to dry season incoming waves are also from three side of the coastline with short periods.

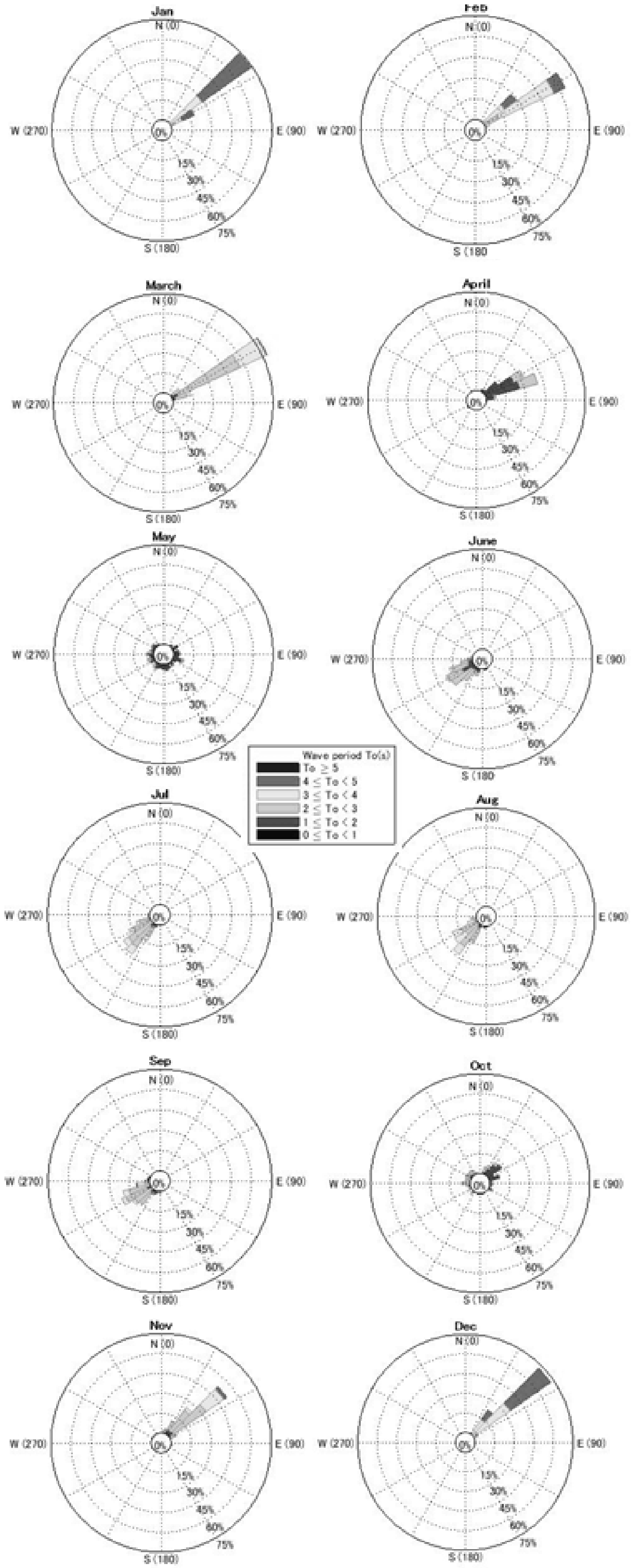
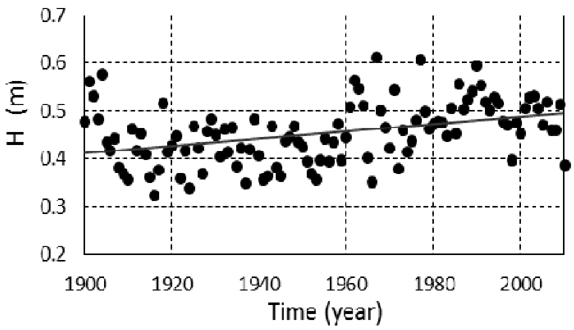


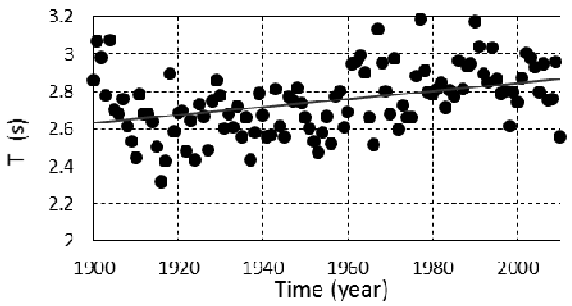
Fig 4. Incoming wave directions and periods

4. LONG-TERM VARIATION OF WAVE CHARACTERISTICS

The long-term variation in wave properties in duration 1900-2010 have been examined. Figure 5(a) shows the variation in annual-mean of wave height. The figure illustrates that the wave height fluctuates between 0.30 m and 0.62 m. The regression trend line expresses positive relation. Fig. 5(b) illustrates that similar to wave height, the annual-mean of wave period showed an increasing trend. The range value of wave period fluctuates between 2.3 s and 3.2 s.



(a) Annually-mean wave height



(b) Annual- mean wave period

Fig 5. Long-term variation of wave heights and periods

5. WAVE ENERGY

The wave energy flux of ocean irregular waves is given by the following equation

$$W=\frac{\rho g^2}{32\pi}H_{rms}^2T \quad (5)$$

where W the wave energy flux per unit length of wave-crest (W/m), ρ the water density (1025 kg/m^3), g the acceleration by gravity (m/s^2), T the wave period (s), and H_{rms} the root-mean-square wave height (m).

If the Rayleigh distribution is assumed, the relation between H_{rms} with significant wave height ($H_{1/3}$) are as following

$$H^2_{rms} \approx \frac{1}{2}(H_{1/3})^2 \quad (6)$$

In combination of equations (5) and (6), the wave energy flux is elucidated as

$$W=\frac{\rho g^2}{64\pi}(H_{1/3})^2T \quad (7)$$

The total energy flux in a given time duration is calculated as follows:

$$P=\sum Wdt=\frac{\rho g^2}{64\pi}dt\sum(H_{1/3})^2T \quad (8)$$

If the used time interval is 1 hour (3,600 s), the parameter for P will be Wh/m. Using equation (8), the potential energy fluxes of waves at the study area are calculated.

Figure 6 shows the average monthly mean of potential wave energy flux in duration 1900-2010 around the study area. The figure demonstrates that the wave energy in dry season is about seven times higher than that of the rainy season. Especially, the potential wave energy flux in December, January, and February are about 5,500 kWh/m, 7,200 kWh/m, and 3,800kWh/m, respectively. In contrast, the monthly values of wave energy flux in rainy season are always low. The lowest potential wave energy flux in this season is 45 kWh/m, occurring in May.

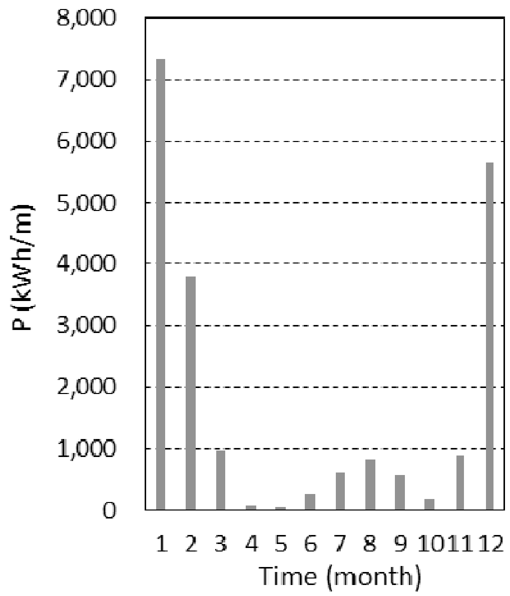


Fig 6. Monthly mean of potential wave energy

Figure 7 shows the analysis of decadal potential energy flux of waves around study area. The figure illustrates that in the first decade of the 20th century the average mean of potential wave energy is around 1,000kWh/m. In the next five decades the average values of potential wave energy are similar with about 800 kWh/m. In recent five decades the energy are extremely high with the average values around 1,200 kWh/m.

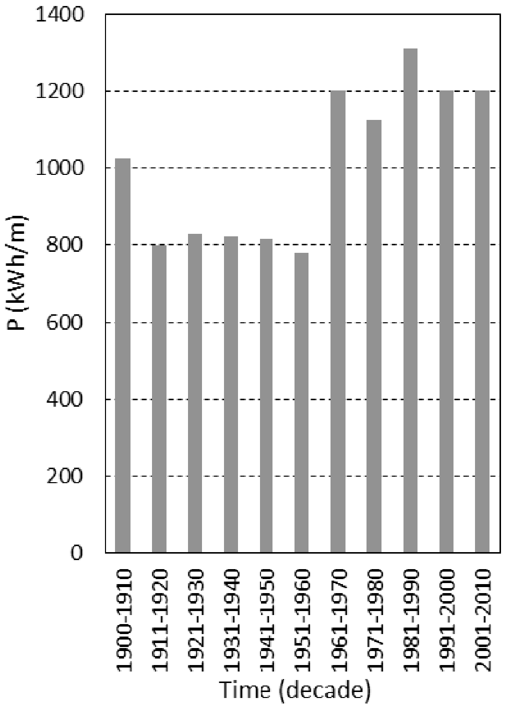


Fig 7. Decadal mean of potential wave energy

6. SUMMARY REMARKS

This study examined the long-term reanalyzed wave data at the cape of Ca Mau coast, Viet Nam in duration 1900-2010, which have been retrieved from ERA-20C of the European Centre for Medium-Range Weather Forecasts, in order to clarify the long-term as well as the seasonal characteristics in wave heights and wave periods. On the overall, the seasonal variation in wave height, period, and direction were shown to be signifi-cant. The wave heights in dry season were about 2 times higher than that in rainy season. The wave periods in dry season were approximately 1.5 times larger than that in the other. The monthly-mean wave height and period were correlated with 2nd order polynomials quite well. The student's test had been performed to judge the significant level of relations between wave height and period. The result indicated that these relations were significance at 1% level. The dominant wave direction in dry and rainy season were ENE and SWS, respectively. The long-term annual mean of wave heights and periods indicate noticeable increasing trends. The potential wave energy in dry season was about 7 times higher than that in rainy season. Recent five decades, wave energy have been considerably increased.

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Tóm tắt:

BIẾN ĐỔI DÀI HẠN CỦA SÓNG GIÓ TÁI PHÂN TÍCH TẠI VÙNG BIỂN MŨI CÀ MAU, VIỆT NAM

Nghiên cứu này khảo sát sự biến đổi dài hạn của sóng gió tái phân tích trong thời đoạn 1900-2010 tại bờ biển mũi Cà Mau, Việt Nam dựa trên cơ sở dữ liệu ERA-20C nhằm đưa ra các thông tin kỹ thuật cơ bản về khuynh hướng dài hạn cũng như các đặc tính theo mùa của sóng biển gây ra do gió trong khu vực. Nhìn chung, biến đổi theo mùa của chiều cao, chu kỳ và hướng sóng là tương đối rõ rệt. Trung bình tháng của chiều cao và chu kỳ sóng có tương quan với đa thức bậc hai rất tốt. Chiều cao sóng trong mùa khô cao hơn trong mùa mưa khoảng 2 lần, trong khi sự khác biệt của chu kỳ sóng giữa hai mùa này là khoảng 1,5 lần. Kiểm nghiệm Student's t cho thấy tương quan giữa chiều cao và chu kỳ sóng có mức ý nghĩa 1%. Hướng sóng chiếm ưu thế trong mùa khô và mùa mưa lần lượt là đông đông bắc và tây tây nam. Tiềm năng năng lượng sóng trong mùa khô cao hơn trong mùa mưa khoảng 7 lần. Năm thập kỷ gần đây, trung bình tiềm năng thông lượng năng lượng sóng cao hơn nhiều so với các thập kỷ trước.

Từ khóa: Bờ biển mũi Cà Mau, số liệu ERA-20C, tái phân tích, sóng gió, biến đổi theo mùa, dài hạn.

Ngày nhận bài: 05/8/2019

Ngày chấp nhận đăng: 28/10/2019