LONG-TERM VARIATION OF REANALYZED WIND WAVES ON THE SOUTHERN CENTRAL COAST, VIETNAM

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Abstract: *Recently, the southern central coast of Vietnam has suffered from severe coastal erosion. In order to cope with these problems, physical understanding of long-term wave characteristics is essentially important as basic engineering information. Accordingly, this study examines the long-term variation of reanalyzed wind waves in duration 1900-2010 at this area based on the ERA-20C reanalysis data set in order to clarify the long-term tendency as well as the seasonal characteristics of wave properties. On the overall, the seasonal variation in wave height, period and direction are shown to be significant. The monthly-mean wave heights and periods are correlated with 2^nd^ order polynomials very well. The wave heights and periods in the dry season are respectively 3 and 1.5 times higher than that during rainy season. The dominant wave direction in the dry season is the NE, while it is the SW in rainy season. The potential wave energy in the dry season is about ten times higher than that during rainy season. In the two recent decades, wave energy have been considerably increased.*

Keywords: Southern central coast, ERA-20C dataset, reanalysis, long-term waves, seasonal variation.

1. INTRODUCTION

The southern central coast of Vietnam includes approximately 200 km alongshore stretch and has a general NNW-SSE orientation. The coast has experienced serious erosion for a long time under the combined influence of the persistent attack of winter monsoon as well as tropical summer storms and human-related activities. On the northern area, morphology of Cua Dai River mouth and adjacent sandy beaches in Hoi An City has been being eroded severely in recent years (Tanaka et al, 2016). On the southern part of the study area, based on analyzing of past oblique photographs and Google Earth images (Viet et al, 2014) indicated that in recent year the erosion of the Nha Trang coast, which relate to the degeneration of a river mouth sand spit has been getting severe. Around this coastal area, sand mining activity and the presence of hydropower stations on the upstream surrounded rivers also contribute to the acceleration of erosion along this coastline. Furthermore, Vietnam is considered as one of the countries to be severely affected by climate change (IPCC, 2001). Dealing with climate change is essentially important for the country, particularly in coastal areas. In order to cope with these problems, a physical understanding of long-term external forces (tides, waves…) is essentially important as basic engineering information.

In addition, the European Centre for Medium-Range Weather Forecasts (ECMWF), which is a producing and disseminating numerical weather predictions organization, has recently completed the computations of the ERA-20C dataset. 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 the longest and most global dataset, which includes data for several areas along Vietnamese coastline. The continuous 110 year length of the ERA-20C

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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, this study investigates the long-term variation in wave characteristics in duration 1900-2010, which have been retrieved from ERA-20C in order to make a brief outline of wave characteristics along the southern central coast of the country. First, the monthly-mean wave properties averaged over the study duration are examined in order to clarify the characteristics of seasonal variation. The correlation between the wave height and wave period are investigated. 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 southern central coast of Vietnam includes approximately 200 km from Da Nang to Khanh Hoa provinces (**Fig.1**). The averaged data of wind waves from January 1900 to December 2010 have been retrieved from ERA-20C dataset at the area of 12^0N – 16^0N latitude, 110^0E – 112^0E longtitude to reanalyze. 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 bias correction of variation 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

The values of annual- and monthly mean of wave heights, wave periods, and wave directions were retrieved and processed to investigate the seasonal as well as the long-term variation of them. The Mann-Kendall (Kendall, 1938) and Lepage (Lepage, 1971) tests have been conducted in order to detect the significant trend or jump in the long-term variation. In this study, the seasonal characteristics are defined as follows: dry season is from November of the previous year to the next April; rainy season is from May to October.

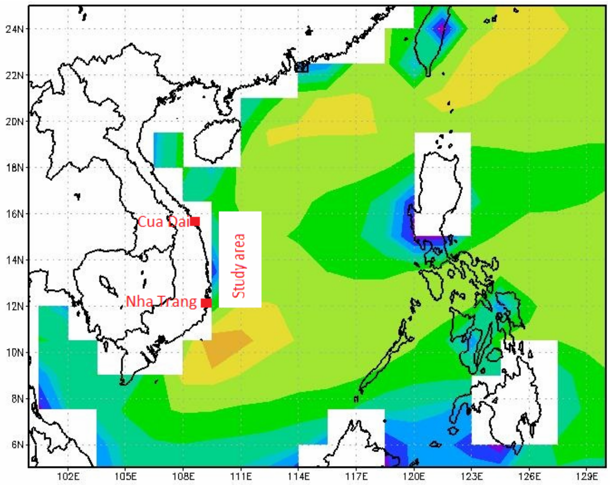


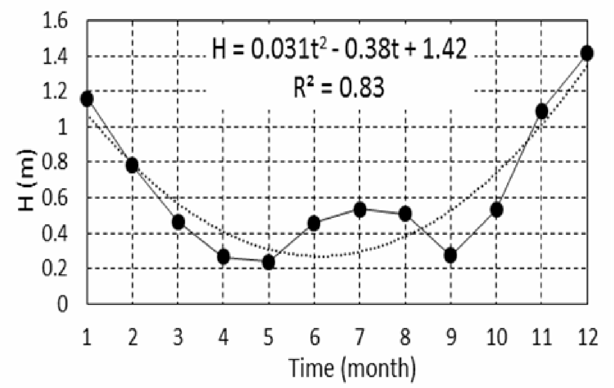
Fig.1 Location of research area

3. SEASONAL VARIATION OF WAVE CHARACTERISTICS

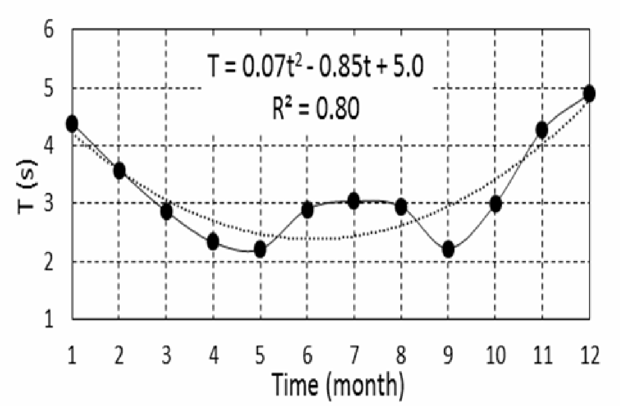
3.1 Wave heights and periods

First, the averaged monthly mean of wave properties averaged over the study area have been retrieved. Then, the averaged values of each month in study duration (1900-2010) have been calculated to clarify the seasonal variation of the waves.

On the overall, the seasonal variation in wave characteristics is significant. Generally, wave conditions are really calm during rainy season. On the contrary, the wave climate becomes violent in the dry season due to the strong East Asian winter monsoon. Figures 2 show the seasonal variation in average monthly-mean wave height and period in duration 1900-2010. The figures clearly illustrate that the wave heights and periods are the highest the dry season and the lowest in rainy season. The averaged mean height of waves in the dry season is around 1.0 m, while it is just approximately 0.35 m in the rainy season. This demonstrates that the averaged value of wave height in dry season is approximately 3 times larger than that in the rainy.



(a) Wave height



(b) Wave period

Fig.2 Seasonal variation in monthly-mean wave properties

The seasonal variation of wave period is quite similar to wave height variation. The waves in dry season have longer periods, the average mean value is around 4.0 s, while waves in rainy season have smaller period with the average value around 2.5 s. The wave periods in dry season are around 1.5 times those of the rainy season. Moreover, these values of monthly-mean wave height and period indicate essentially the same patterns of variation.

In addition, the monthly average wave heights and wave period can be expressed quite well by second order polynomials in relation with progressing time of year as follows:

$H = 0.031t^2 - 0.38t + 1.42$ with $R^2 = 0.83$ (1)

$T = 0.071t^2 - 0.85t + 5.0$ with $R^2 = 0.80$ (2)

Previously, (Hoan et al, 2015) based on a module of coastal area wave (spectral wave FM) of MIKE 21 model examined the wave field in the Nha Trang bay. The result showed that from December to January next year, the average wave height value was about 0.8 - 1.5 m. The average wave height value during the prevailing southwest monsoon period (rainy season) was about 0.3 - 0.5 m. The result is quite the same with that of the reanalysis data in this research (Wang et al, 2014) conducted a wave simulation for period 1976-2005 at South China Sea. The results also indicated that around the southern central coast of Vietnam seasonal variation of average wave heights are quite similar with this analysis result.

Figures 3 show the relationship between the monthly wave height and wave period, for (a) the average and (b) the month by month values during the study period. The regression results are included to examine the correlation between these wave characteristics. It is clearly shown in Fig. 3(a) that the mean values of wave height and period are strongly interdependent. They can be correlated very well with the following 2nd order polynomial with the extremely high correlation coefficient of R^2=0.999:

$H = 0.04T^2 + 0.14T - 0.27$ (3)

The student's t test (Student, 1908) has been performed to judge the significant level of relation between wave height and period. The result illustrates that this relation is judged to be significance at 1% level.

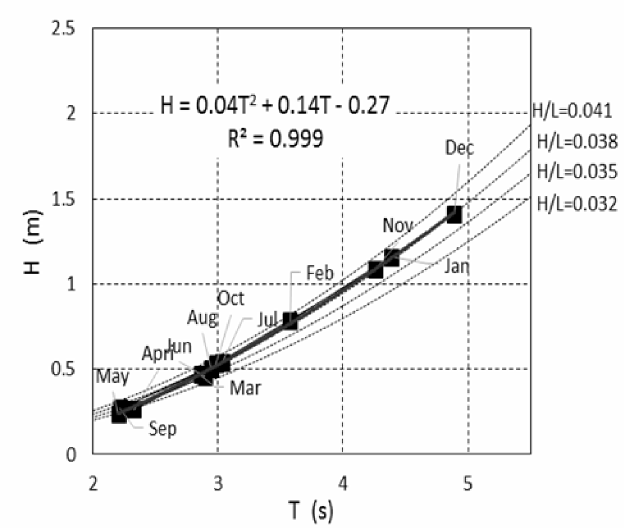
In the figure, several curves corresponding to typical wave slope (*H*/*L*) are also included. Accordingly, the wave slopes in both seasons are similar. For the mean values, the wave slopes in these seasons are asymptotic to 0.038

Similarly, the month by month values of wave height and period are closely correlated (Fig.3(b)). The represent second order polynomial in which the correlation coefficients is also extremely high (R^2=0.992) is as following:

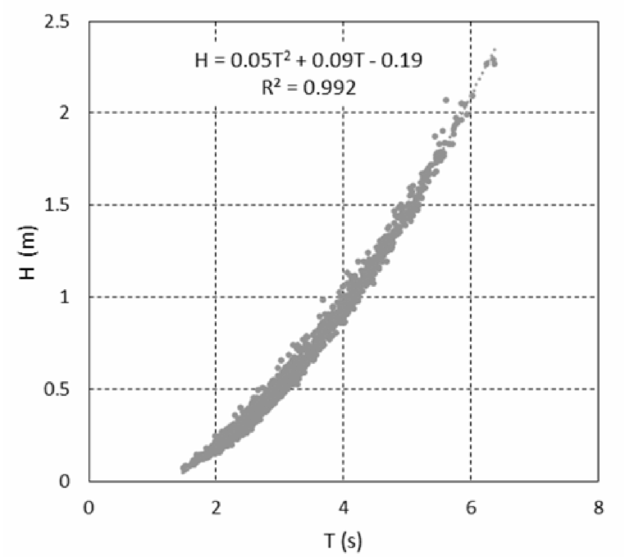
$H = 0.05T^2 + 0.09T - 0.19$ (4)

The student's t test also indicates the 1% significant level for the month by month relation of wave height and period.

The relations between wave height and period vary from location to location therefore these regression equations are limited around study area. They should not to be used in design of shoreline protected construction.



(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 periods and approach the coast mainly from the NNE, NE and ENE direction. In rainy season except for May, waves approach the coast mainly from the S, SSW and SW direction. The wave periods in this season are the shortest in comparison with that of other seasons. In May, the transition from dry to rainy season, incoming waves are from the SE direction. The wave periods in this month are also short.

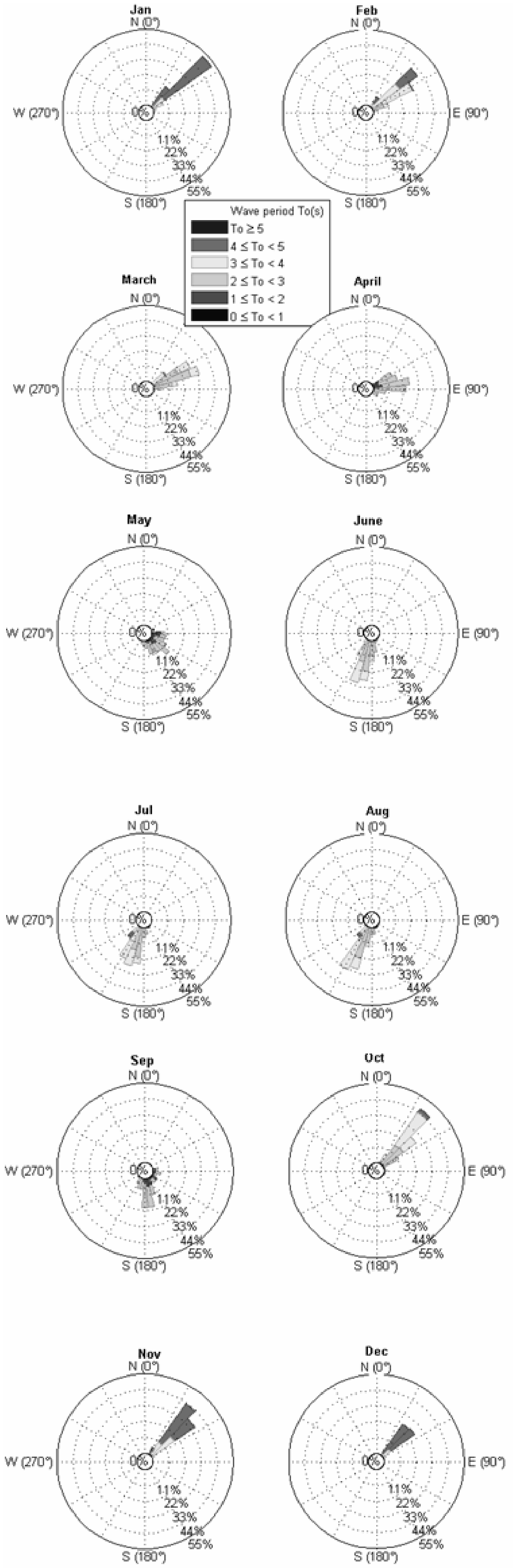
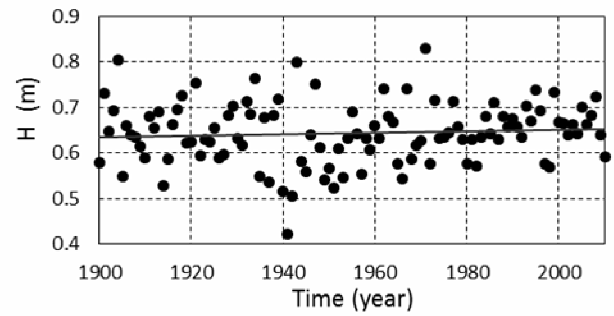


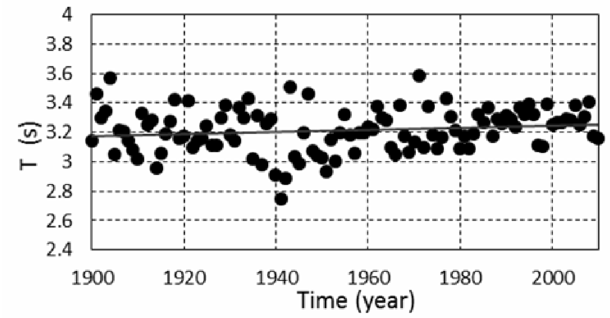
Fig.4. Incoming wave directions and periods.

4. LONG-TERM VARIATION OF WAVE CHARACTERISTICS

Next, the long-term variation in wave properties have been analyzed in duration 1900-2010. Figure 5(a) shows the variation in annual-mean of wave height. The figure illustrates that wave heights fluctuate between 0.4 and 0.8 m. The statistical tests demonstrated that neither a trend nor a jump exists in the long-term variation. A close inspection of Fig. 5(a) indicates that the data is more scattered previously: the standard deviation in the last 55 years (0.06 m) has substantially decreased compared with that in the first 55 years (0.08 m). According to Fig. 5(b), the annual-mean of wave period showed an increasing trend. However, the Mann-Kendall and Lepage tests indicated that the trend is not significant. The wave periods fluctuate between 2.8 and 3.6 s, and the standard deviations in the first 55 years and last 55 years have a noticeable discrepancy as well, in which the values are 0.17 s and 0.11 s, respectively.



(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

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

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

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

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

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

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

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

If the used time interval is 1 hour (3,600s), 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. Accordingly, the wave energy in dry season is about ten times higher than that of the rainy season. Especially, the potential wave energy flux in January, November, and December are about 10,000 kWh/m, 9,000 kWh/m, and 17,000 kWh/m, respectively. In contrast, the monthly values of wave energy flux in rainy season are always lower than 2,000 kWh/m.

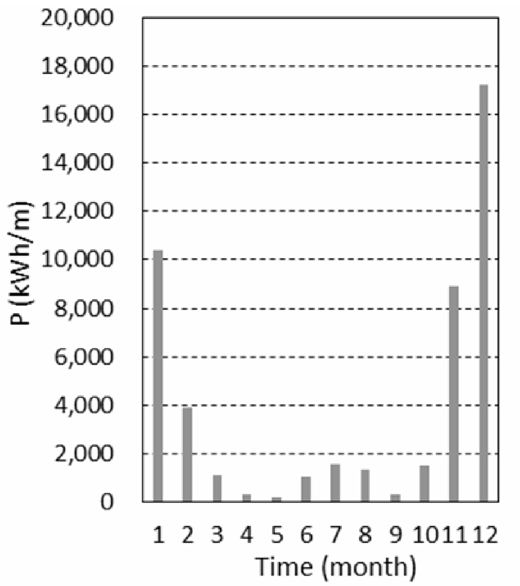


Fig.6. Monthly mean of potential wave energy

Next, the decadal potential energy flux of waves are examined in Figure 7. The figure illustrates that in the fifth decade of the 20th century the potential wave energy is lowest with less than 2,000 kWh/m. In both recent two decades the energy are higher than 2,500 kWh/m.

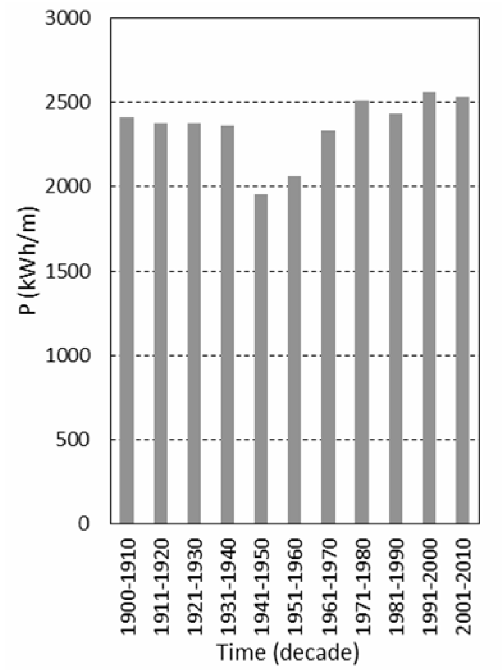


Fig.7. Decadal mean of potential wave energy

6. SUMMARY REMARKS

This study examined the long-term wave data at the southern central coast of Vietnam in duration 1900-2010, which had been retrieved from ERA-20C reanalysis 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 significant. The wave heights in dry season were about 3 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 dominant wave direction in dry season was the NE. The dominant direction in rainy season was the SW. The monthly-mean wave height and period were correlated with 2nd order polynomials very well. The long-term trends of wave heights and periods were not clarified, while the data was more scattered in the last 55 years. The potential wave energy in dry season was about ten times higher than that in rainy season. Recent two 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 NAM TRUNG BỘ, VIỆT NAM

Gần đây, bờ biển Nam Trung Bộ của Việt Nam đang bị xói lở nghiêm trọng. Nhằm đối phó với vấn đề này, việc tìm hiểu đặc điểm biến đổi dài hạn của sóng là rất quan trọng, đóng vai trò làm kiến thức cở sở cho ngành kỹ thuật biển. Do đó, nghiên cứu này dựa trên các số liệu tái phân tích ERA-20C xem xét sự biến đổi của sóng gây ra do gió trong thời đoạn 1900-2010 tại khu vực này để làm rõ khuynh hướng biến đổi dài hạn cũng như các đặc tính theo mùa của sóng. Nhìn chung, biến đổi theo mùa của chiều cao và chu kỳ sóng là tương đối rõ ràng. Chiều cao và chu kỳ sóng hàng tháng có tương quan với đa thức bậc 2 rất tốt. Chiều cao và chu kỳ sóng trong mùa khô cao hơn trong mùa mưa lần lượt là 3 và 1,5 lần. Hướng sóng chiếm ưu thế trong mùa khô là hướng Đông Bắc, trong khi Tây Nam là hướng chính của sóng trong mùa mưa. Năng lượng sóng trong mùa khô cao hơn so với mùa mưa khoảng mười lần. Hai thập kỷ gần đây, năng lượng sóng có xu hướng tăng đáng chú ý.

Từ khóa: Bờ biển Nam Trung Bộ, số liệu ERA-20C, tái phân tích, sóng dài hạn, biến đổi theo mùa.

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