INTER AND INTRA-ANNUAL VARIATION OF WAVE ENERGY IN SOUTHEAST ASIA

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ABSTRACT

In this study, the inter and intra-annual variation of wave energy in Southeast Asia is evaluated using 55 years of simulated wave dataset using JRA-55 wind field as forcing to SWAN numerical model with the boundary condition provided by a global wave model. The model was validated against the satellite data for monthly averages of significant wave height. After validation, the wave characteristics generated by the model for 55 years were used to calculate the wave power parameter, and time series of wave power in each output grid point were utilized to evaluate the inter and intra-annual variability of wave resources, as well as its decadal changes and its spatial distribution. The results of this study reveal novel information about the sustainability of available resources in long-term taking into account the decadal changes for the first time, and specifies the areas with higher stability for wave downscaling in order to determine the potential locations for wave energy extraction.

Keywords: Wave Enegry, Southeast Asia, Decadal Change

1. INTRODUCTION

Ocean renewable energies and specifically the wave energy, due to its advantages, are proper alternative to fossil fuels for mitigating the negative impacts of climate change in the areas adjacent to the water bodies. Traditionally, areas with higher energy were considered for wave energy extraction. However, the stability of available resources is vital for future sustainable development. Southeast Asia and especially, South China Sea has been a topic of interest for wave energy assessment due to its potential and also relatively wide continental shelf. For instance, Zheng et al. (2013) have assessed the wave energy in China Sea based on a 22-yearly data in annual, seasonal and monthly scales. Mirzaei et al. (2015) investigated the wave energy potential in the central and southern regions of the South China Sea based on 31 years of numerical simulation and discussed the annual and seasonal variations. Lin et al. (2019) evaluated the wave energy potential and its intra-annual variation in the China adjacent seas using 20 year of modeled waves. Wang et al. (2018) utilized a 30-yearly wave dataset obtained by numerical modeling to assess the long-term wind and wave energy resources in the South China sea. Wan et al. (2018) used the ERA-Interim dataset for 38-years to evaluated the annual and seasonal variation of wave energy in the South China Sea.

The above-mentioned studies have focused on intra-annual variability of wave resources. However, long-term variation of the wave energy potential in terms of decadal changes has not been investigated, yet. Hence, in this study, the inter and intra-annual variation of wave energy is evaluated based on a 55 yearly simulated wave dataset to investigate the decadal and long-term change, as well.

2. METHOD

Wave dataset for a 55-yearly period (1958-2012) has been generated in the study area using SWAN (Simulating WAves Nearshore) (Booij et al., 1999). For this purpose, a computational domain covering southeast Asia was considered, in which, the boundary condition is provided by a global wave model. The Southeast Asia model covers the longitudes of 95°E-128°E and latitudes of 8°N-32°N (Figure 1) with computational spatial resolution of 0.25° × 0.25° and temporal resolution of 30 min. The outputs have been generated with the same spatial resolution and time step of 6 hrs in a domain covering the longitudes of 98°E-122°E and latitudes of 8°N-32°N.

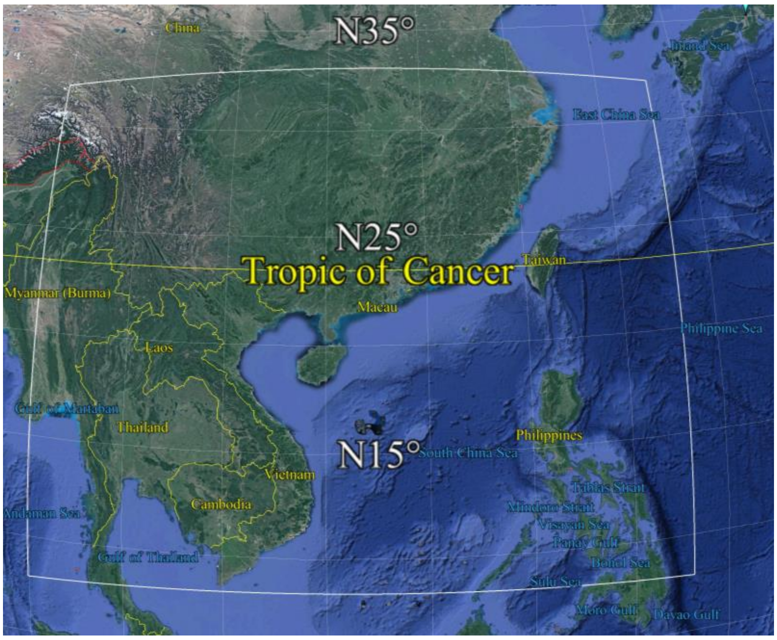

Figure 1. Computational domain in the study area.

The model has been validated by comparing to buoy measurements (in one point inside the computational domain). Table 2 shows the error indices (including Bias, Scatter Index (SI) and Room Mean Square Error (RMSE) for three periods of validation (period-1:1996/3/7-1996/5/26, period-2:1997/9/18-1997/10/17 and period-3: 1999/01/25-1999-1999/02/28) for wave power parameter. Wave power (P) was calculated based on the deep water formula ($P \approx 0.49\ H_s{}^2 T_e$) (Abbaspour and Rahimi, 2011), in which, H_s and T_e are the significant wave height and the wave energy period, respectively.

Table 1. Error indices for three periods of validation.

	Bias (kW/m)	SI	RMSE (kW/m)
Period-1	-0.02	42%	2.08
Period-2	0.49	41%	1.37
Period-3	0.11	33%	1.57

3. RESULTS AND DISCUSSION

Figure 2 shows the annual averages of various parameters as well as the Monthly Variability Index (MVI). MVI is calculated based on the ratio of the difference between maximum and minimum monthly mean to the mean annual values (e.g. Kamranzad et al., 2017) and lower amounts represent more stable conditions. Figure 2 indicates that the highest wave height and period, and consequently, wave power can be found in the north of Philipines, the South China Sea and southeast of Vietnam reaching 30 kW/m and 15 kW/m, consequently (Figure 2a). Interestingly, however, the monthly variability is high for the wind speed in those areas, it is low for wave parameters and South China Sea has the lowest monthly variation for wave power (Figure 2b). The south of Vietnam experiences the highest monthly variability in wave power parameter.

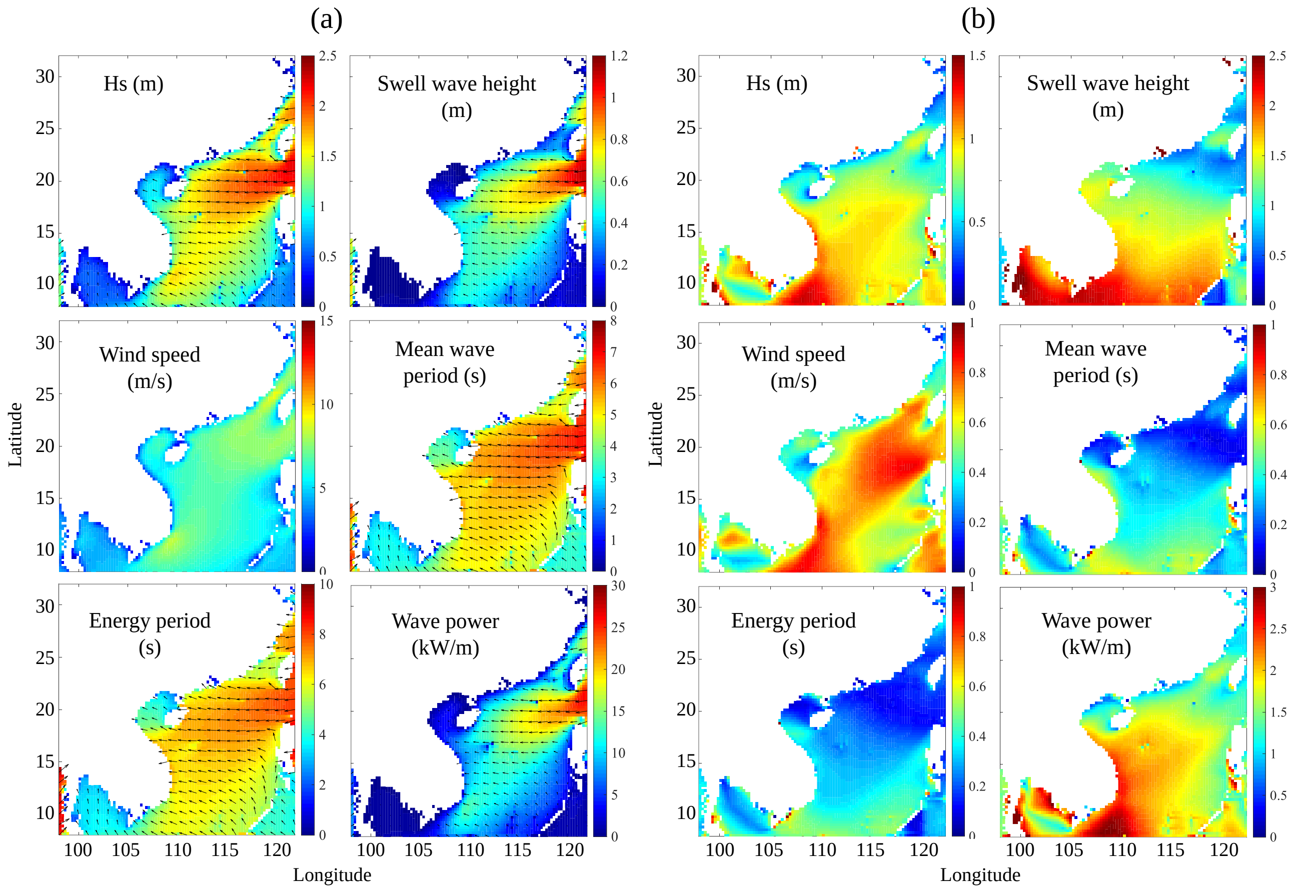

Figure 2. (a) Annual averages based on 55 years of simulation and (b) MVI values for different parameters.

In order to investigate the stability of wave power in long-term, the annual rate of change was calculated based on the slope of the best fitting line to the mean annual values for 55 years (1958-2012) and shown in Figure 3. This figure shows that all the areas have experienced almost no change during the 55-yearly period, except for north of Philipines.

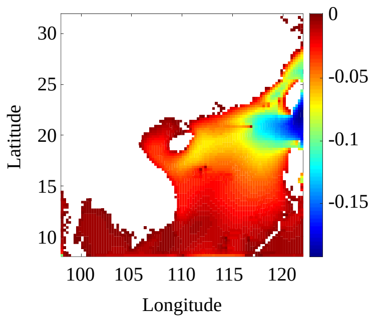

Figure 3. Annual rate of change (based on 55-yearly analysis).

4. CONCLUSIONS

The wave energy potential and the stability of wind and wave parameter was evaluated based on a 55-yearly dataset and in terms of both short-term variation (MVI) and long-term change (rate of change). The spatial distribution of the wave power represented that north and northwest of Philipines, Chinese coasts of the South China Sea and southeast of Vietnam have the highest potential. The short-term variation showed that the wave power is more stable in Chinese coasts of the South China Sea and north of Philipines, while long-term change indicated that the wave power has been stable for 55 years in the whole region, except for the north of Philipines. Hence, it can be concluded that Chinese nearshore areas of South China Sea are the most suitable area for wave energy extraction in the region and further assessment and downscaling is required in order to locate the most appropriate location in Chinese nearshore areas of South China Sea as a potential site for wave energy exploitation.

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REFERENCES

Abbaspour, M. and Rahimi, R. (2011). Iran atlas of offshore renewable energies. *Renewable Energy*, 36:388-398.

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: Oceans*, 104:7649-7666.

Kamranzad, B., Etemad-Shahidi, A. and Chegini, V. (2017). Developing an optimum hotspot identifier for wave energy extracting in the northern Persian Gulf. *Renewable Energy*, 114:59-71.

Lin, Y., Dong, S., Wang, Z. and Guedes Soares, C. (2019). Wave energy assessment in the China adjacent seas on the basis of a 20-year SWAN simulation with unstructured grids. *Renewable Energy*, 136, 275–295.

Mirzaei, A., Tangang, F. and Juneng, L. (2015). Wave energy potential assessment in the central and southern regions of the South China Sea. *Renewable Energy*, 80, 454-470.

Wan, Y., Fan, C., Dai, Y., Li, L., Sun, W., Zhou, P. and Qu, X. (2018). Assessment of the Joint Development Potential of Wave and Wind Energy in the South China Sea. *Energies*, 11:398.

Wang, Z., Duan, C. and Dong, S. (2018). Long-term wind and wave energy resource assessment in the South China sea based on 30-year hindcast data. *Ocean Engingeering*, 163:58-75.

Zheng, C., Pan, J. and Li, J. (2013). Assessing the China Sea wind energy and wave energy resources from 1988 to 2009. *Ocean Engineering*, 65:39-48.