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Long-term wind and wave energy resource assessment in the South China sea based on 30-year hindcast data

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ABSTRACT

The long-term wind and wave characteristics, and their associated stored power, are investigated in the South China Sea (SCS) from 1986 to 2015. The Weather Research and Forecasting model (WRF) and WAVEWATCH-III (WW III) are continuously performed to simulate a 30-year wind and wave hindcasts in the entire domain. Comparisons between the simulated and observed wind and wave data show good agreement under extreme typhoon conditions as well. The spatio-temporal patterns of annual, seasonal and monthly averaged wind fields and wind power density, significant wave heights, and wave potential are presented using the 30-year simulated results. Our results show that offshore winds and waves, with mean annual energy densities reaching up to 1100 W/m^2 and 65 kW/m, respectively, are relatively stronger than they are nearshore or inland. The most abundant power occurs in December and the least abundant appears in May. Furthermore, wind and wave energy roses of average power potential at 15 typical points across the SCS are calculated at length. The dominant directions for both the wind and waves are consistently NNE, NE, and ENE. Additionally, the wave energy is mainly the result of energy periods (between 6 and 11 s) and significant wave heights (between 1 and 6 m).

1. Introduction

As a result of climate warming, the limited storage of fossil fuels and the continuous soaring oil expenses, the development of renewable energy becomes more and more important than before. Many alternatives, such as solar, wind and ocean energy, can be selected in the future (Ueckerdt et al., 2015). Wind and wave energy are enormous sources of renewable energy, due to their limited negative environmental impacts. Previous valuation of wind and wave energy potential so far have been conducted, based on reanalysis datasets and numerical models, at a global scale (e.g., Arinaga and Cheung, 2012; Zheng and Pan, 2014) or across various regions (e.g., Kamranzad et al., 2013; Akpınar et al., 2016). Meanwhile, offshore wave energy converters and wind turbines are being continually designed and optimized by different companies and researchers (e.g., Muliawan et al., 2013; Wan et al., 2016).

Wind and wave power are abundantly renewable in China. For offshore wind exploitation, the newly installed capacity of generation has reached 51,473 MW in the world; in particular, the top country is China, which contributes 45.1% to the total newly generation. The rapid investments of the new installed capacity of wind power are the direct results of the Chinese government's policy (Liao, 2016). In addition, wave energy has also become a hot focus in some domestic research literature (Liang et al., 2013, 2014; Zheng et al., 2013; Wang et al., 2014, 2016).

In the north-western Pacific, the largest semi-enclosed marginal sea is the South China Sea (SCS). As is shown in Fig. 1, the SCS has a topographical advantage for renewable energy development. The SCS is connected to the surrounding seas, such as through the Strait of Malacca to the Indian Ocean, through the Gasper to the Sulu Sea, through the Karimata Straits to the Java Sea, through the Luzon Strait to the Pacific Ocean, and through the Taiwan Strait to the East China Sea. Wind and wave power potential is of great significance to oil and gas development, the fishing industry, Army garrisons, islander living, and tourism construction.

To our knowledge, a few existing investigations on surface winds and waves have been conducted in the SCS or other regions of the China Sea. Based on the long time series of daily averaged wind dataset, Jiang et al. (2013) estimated that the total 10 m wind power in China's offshore regions can up to be about 660 GW. Based on 23-year (1990–2012) historical wind fields, the offshore wind potential in Bohai was comprehensively analyzed and assessed (Wang et al., 2014). The

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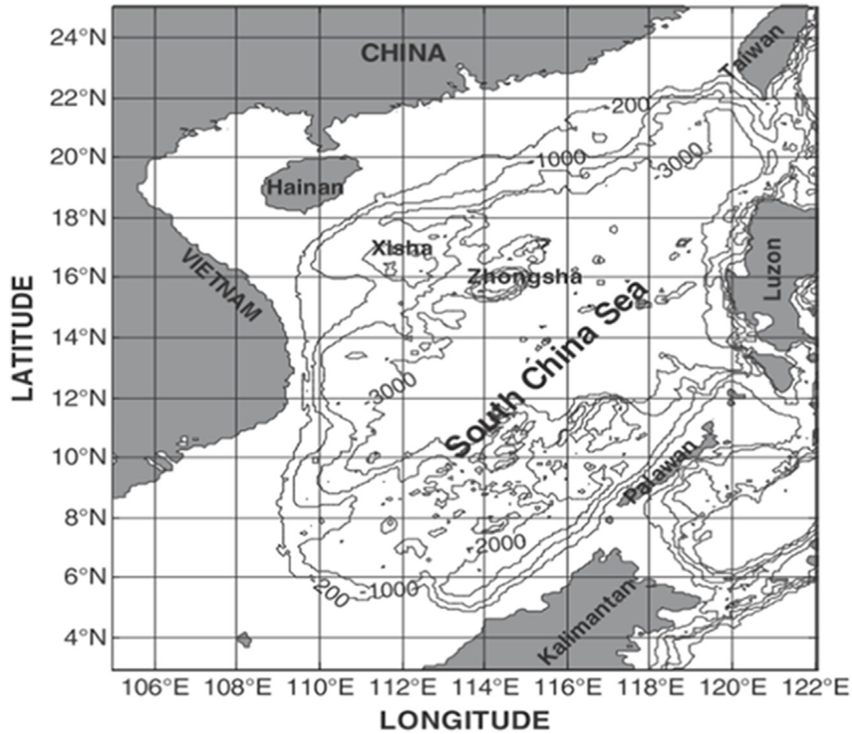

Fig. 1. The study domain in this paper: topography and depth of water in the South China Sea (m).

Table 1
Model set-up of the WRF.

Physical Process	Reference
Boundary	YSU (Hong et al., 2006)
Cloud	Kain-Fritsch (Kain and Fritsch, 1990)
Rad	Long: RRTMG (Mlawer et al., 1997)
	Short: RRTMG (Dudhia, 1989)
Land	Noah (Decharme, 2007)

assessment showed that the research domain had high-density wind power available. Chang et al. (2015) calculated the wind power density characteristics in the strait based on the double-parameter Weibull distribution function. The analysis indicates that the wind energy potential will be slightly larger in the eastern part of the Taiwan Strait in future climate periods, while they decrease by about 3% relative to the previous climate periods. Besides, there are relatively more wave climate and energy analyses than wind investigations in the SCS. The

Table 3
Comparisons of H_s between the simulation and observations when the typhoons passed through the region.

Typhoon	Observation time	Lon (E)	Lat (N)	Obs. (m)	Sim. (m)
Wayne	06:00 Sep 05, 1986	112°07.6′	19°32.8′	8.6	8.9
Brian	12:00 Sep 30, 1989	112°07.6′	19°32.8′	8.7	9.0

wave model was utilized to achieve the wave hindcast during the period when two cold fronts and two typhoons passed Hong Kong in the northern SCS (Wang et al., 1992). Kohei et al. (1998) analyzed the wave characteristics in a port near the Vietnam's central coastline in the SCS by utilizing real measurements from April 1997 to February 1998. Zhu et al. (2003) constructed a coupled numerical system of currents, tides, as well as waves in the costal regions of the SCS under the extreme weather conditions such as the tropical cyclones. Similarly, Chu and Cheng (2008) analyzed the wave states when the typhoon Muifa crossed the SCS during the winter months in 2004. In addition, based on

Table 2
Validations of the reanalysis wind data at the three stations.

Month	Errors in wind speed (m/s)			Errors in wind direction (°)			Number of records		
	Dongsha	Xisha	Nansha	Dongsha	Xisha	Nansha	Dongsha	Xisha	Nansha
1	2.85	4.65	1.86	20.6	20.5	22.5	532	558	338
2	2.64	4.10	1.66	19.2	25.7	21.2	572	650	441
3	2.60	3.45	1.84	24.5	23.8	27.7	649	712	471
4	1.87	2.34	1.80	34.0	27.0	27.9	663	701	427
5	2.00	1.90	1.76	34.3	31.5	34.3	663	721	456
6	2.66	2.20	1.94	29.3	23.9	31.2	654	703	449
7	2.60	2.17	1.80	27.9	29.8	25.6	664	728	482
8	2.67	2.12	2.05	27.9	29.1	22.3	578	627	406
9	2.84	2.38	1.71	31.7	36.7	30.6	622	668	473
10	3.13	4.06	2.06	16.1	25.2	22.5	666	705	702
11	3.34	5.35	2.58	16.6	21.8	27.5	610	674	348
12	3.68	6.32	2.68	16.6	21.8	29.2	648	726	389
Average	2.73	3.40	1.96	25.1	26.4	29.6	7521	8173	5168