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22-Year wave energy hindcast for the China East Adjacent Seas

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ABSTRACT

In order to investigate the wave energy resource, the third-generation wave model SWAN is utilised to simulate wave parameters of the China East Adjacent Seas (CEAS) including Bohai, Yellow and East China Sea for the 22 years period ranging from 1990.1 to 2011.12. The wind parameters used to simulate waves are obtained by the Weather Research & Forecasting Model (WRF). The results are validated by observed wave heights of 7 stations. The spatial distributions of wave energy density in the CEAS are analysed under the 22-year largest envelop, mean annual and season averaged wave conditions. Along China east coastal, the largest nearshore wave energy flux occurs along the nearshore zones between Zhoushan Island and south bound of CEAS area. The wave energy resources at Liaodong Peninsula Headland and East Zhoushan Island where economy develops rapidly are also studied in detail. For the two sites, the monthly averaged wave energy features of every year for the 22 years are investigated. The wave energy resources of the two potential sites are characterised in terms of wave state parameters. The largest monthly averaged density for the two sites occurs at Zhoushan Island adjacent sea and amounts to 29 kW/m.

1. Introduction

The world's growing energy consumption and traditional methods of energy production have led to serious environmental problems. Renewable energy sources may play a key role in meeting the growing demand for energy. Solar, wind and ocean (i.e., waves, tides and currents) energy are among the sources that can be a good alternative to fossil energy [1]. Among the novel renewable energy sources, wave energy is one of the most promising marine energy sources [2]. Wave energy is regarded as an enormous source of renewable energy with limited negative environmental impacts, which needs to account for economic interests in terms of features of wave energy resource before utilizing the wave energy [3,4].

In the present work, the wave energy resources of the China East Adjacent Seas (CEAS), shown in Fig. 1(a, b), are studied to look for which sites are reasonable to deploy wave energy converters (WECs). The energy demand along the CEAS is rising rapidly due to fast development of the local economy. To meet this demand, many plans to utilise or study technologies of wave energy utilization have been initiated by China governments recently.

Usually, economics dictate the site selection for wave farms, taking into account the differences in the resources and costs of WECs and the submarine connection to the land network [1,5,6]. Technologies for transforming wave energy into electricity are still in the development stage [7]. Every technology has different efficiencies under different sea states. It is known that the characteristics of the wave energy resource, in terms of wave parameters, are important for choosing the most appropriate WECs for an area and tuning the design parameters of the wave energy converter [6]. Before installing WECs, the wave energy resource should be investigated and characterised in terms of wave parameters. Therefore, up to now, the wave energy resources of some regions in the world have been reported [1,2,5,8–36].

These former studies regarding wave energy resources have contributed to the discovery of the wave energy features in different zones of the world greatly. Among the former studies, 16 year wave energy in nearshore of Shandong peninsula being inside CEAS is given [30]. Effects of the currents and bathymetry resolution on the wave energy resources are discussed in detail [35,36]. Recently, to develop utilizing technology of marine renewable energy has been paid more and more attentions by governments. However, the determination for marine energy utilizing or testing sites is significantly dependent on energy abundance and other

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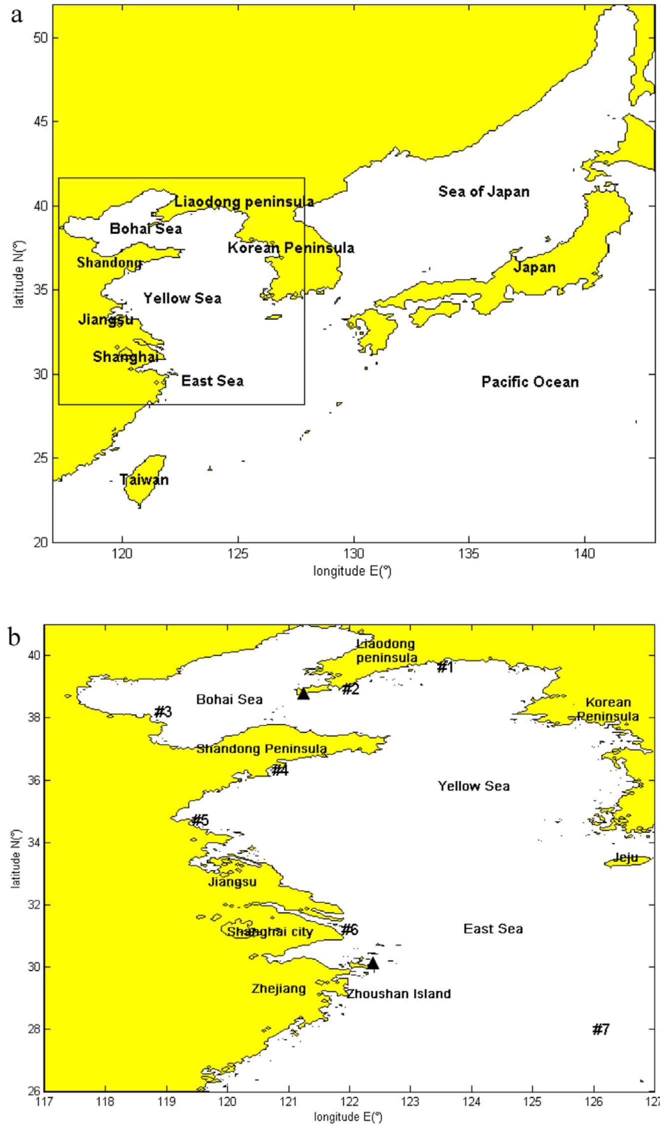

Fig. 1. a EAS computational area. b The CEAS computational area (#1, #2, #3, #4, #5, #6 and #7 are wave observation stations; ▲ stands for potential station to be investigated in the present work).

features such as period, direction et al. In order to find other and more reasonable potential sites in larger areas, based on the above features of wave energy, the 22-year nearshore wave energy of CEAS covering most of the East China continental shelf is assessed by wave numerical modelling with high space resolution in the present work. The numerical simulation is carried out through the wave generation model SWAN [37]. The method involves implementing a numerical model to simulate the wave climate during the period 1991–2011 in CEAS. To enhance the spatial resolution, the nested method is adopted to simulate the wave climate of CEAS. The nested method means there are two computational areas. One computational area is larger and the other one is smaller. The smaller area is inside of the larger area. So the model of smaller area can get boundary conditions from the model of larger area. The wave modelling is validated based on in situ measurements from 7 stations. After validation, the model can predict the variation of the wave energy both in space and time confidently. That is why wave modelling is adopted to investigate wave energy resources in the world widely.

This article is structured as follows:

First, theories for estimating wave energy are described. The wave numerical model, with its governing equations and the theories, is also presented. The model setting and the validation with in situ measurements are introduced.

Second, the results of the wave energy in CEAS are discussed. The candidate sites with the large wave energy potential for a wave farm or huge energy demands are analyzed. The wave state parameters and wave energy features of the candidate locations for developing wave farms are characterised in detail.

Finally, conclusions and summaries are given.

2. Theory description

2.1. Methods of estimating wave energy

Real sea waves are described as random waves, which are composed of many waves of different frequencies, amplitudes and directions. It is possible to describe these wave parameters in terms of the directional wave energy spectrum $E(\sigma,\theta)$. The wave power level in terms of the wave spectrum is:

$$J=\rho g\int_0^{2\pi}\int_0^{\infty} C_g E(\sigma,\theta)d\sigma d\theta \tag{1}$$

The unit of J is W/m. Where ρ is the mass density of the sea water (1025 kg/m^3), g is the gravitational acceleration, C_g is the group velocity, θ is the wave direction and σ is relative frequency.

The wave powers in the x and y directions are:

$$J_x=\rho g\int_0^{2\pi}\int_0^{\infty} C_{gx} E(\sigma,\theta)d\sigma d\theta \tag{2a}$$

$$J_y=\rho g\int_0^{2\pi}\int_0^{\infty} C_{gy} E(\sigma,\theta)d\sigma d\theta \tag{2b}$$

J_x and J_y can be outputted by SWAN [37]. Thus, it is easy to calculate J (wave power magnitude per unit length of the wave front) by $J=\sqrt{J_x^2+J_y^2}$. C_{gx} and C_{gy} are propagation velocities of wave energy in the geographical space.

The energy period (T_e) of the sea state and the significant wave height (H_s) are respectively given by:

$$T_e=2\pi\frac{\int_0^{2\pi}\int_0^{\infty}\omega^{-1}E(\omega,\theta)d\omega d\theta}{\int_0^{2\pi}\int_0^{\infty}E(\omega,\theta)d\omega d\theta} \tag{3}$$

$$H_s=4\sqrt{\int_0^{2\pi}\int_0^{\infty}E(\omega,\theta)d\omega d\theta} \tag{4}$$

Where $E(\omega,\theta)$ is the variance density spectrum and ω the absolute radian frequency determined by the Doppler-shifted dispersion relation.

In deep water areas, the wave energy flux per unit width of the progressing wave front in terms of the energy period and significant wave height can also be simplified by Refs. [1,12,14,15,27,38]:

$$J=\frac{\rho g^2}{64\pi}T_e H_s^2 \tag{5}$$