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Procedia Engineering 116 (2015) 871 – 879

Procedia Engineering

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8th International Conference on Asian and Pacific Coasts (APAC 2015)

# Potential Assessment of Tidal Stream Energy around Hulu Island, China

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## Abstract

Tidal stream energy is one of most promising resources of marine renewable energy, and it has attracted more and more attention in the recent years. Hulu Island which is located at Zhoushan, China is with a maximal current velocity more than 2.0 m/s, showing a great potential in utilization of tidal stream energy. Meanwhile, a demonstration project for exploiting tidal stream energy, supported by the State Oceanic Administration, People's Republic of China, is planned in this coastal area. This study develops a two-dimensional mathematical model for the simulation of tidal hydrodynamics and potential assessment of tidal stream energy around Hulu Island. The numerical results of tidal elevation and current velocity are compared with those data from field observations (one for water level and two for tidal current), and the good agreement between simulation and measurement indicates a great ability of the model. Distributions of mean and maximal energy densities of tidal stream in the vicinity of Hulu Island are provided, and two possible sites for deploying tidal stream turbines are recommended. At each possible site, velocity profile and power density curve are numerically investigated for a 15-day period for covering the spring-neap tide cycle. The results show the candidate site P1 and P2 hold the mean power density as 0.62 $kW/m^2$ and 1.81 $kW/m^2$, respectively.



*Keywords:* tidal current energy, tidal resource assessment, numerical model, power density, Hulu Island;

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doi:10.1016/j.proeng.2015.08.376

## 1. Introduction

The use of renewable energy technologies has been regarded as the focus of human society, owing to the over-dependence on fossil energies and the serious environmental pollution all around the world today. Tidal stream energy is one of ocean energy and the principle of capture mechanism is similar to wind power generation. Therefore, the technology of wind power generation is treated as a foundation to scientific researches on the development and application of tidal stream energy. Furthermore, tidal current generation has long-time predictability, high load factor derived from the fluid properties (832 times that of wind), large potential resources (0.6 billion kilowatt around the world), less environmental impacts and non-existence of a threat from extreme flow velocities. Hence, the assessment of tidal current energy has a very important significance that many countries have already been working on the relevant domain.

The potential capacity of tidal current energy around Europe is 12.5 MW according to JOULE II Non-Nuclear program. Many test fields and demonstration projects have been built by European Union countries, such as EMEC in England, Galway in Ireland and Nissum Breding in Denmark. In the past decades, many studies were carried out to assess the resource of tidal stream energy around the world, such as UK (Black & Veatch 2005), France (Carballo et al., 2009), Canada (Cornett, 2006), Indonesia (Blunden et al., 2013), Malaysia (Rourke et al., 2010), and China (Li et al., 2010; Chen et al., 2013; Zhang et al., 2013). China holds huge capacity of tidal current energy that has not been exploited on a commercial scale, according to the report *A Comprehensive Survey and Assessment of China's Coastal Sea*, one alleging that the tidal current capacity along Chinese coastline is 8.2 GW.

Considering the commercial scale, most of high current areas are not ideal sites for turbines because of elements such as uneven terrain and shipping lanes. while channels nearby Hulu Island have conditions more ideal than other areas of Zhoushan Islands, so it is accepted that channels nearby Hulu Island are the best candidate sites to set the tidal stream energy demonstration project in China. *Overall Design of Demonstration Project of Tidal Current Generation around Zhoushan Islands* was approved in 2013, and the assessment of tidal current energy distribution around Hulu Island is necessary for this project. Main objective of the study is to imitate the current status of tidal stream energy in Zhoushan Islands through a two-dimensional (2D) numerical model and assess the resource in ideal candidate nearby Hulu Island.

## 2. Numerical Model

2.1 Governing equations

A two-dimensional hydrodynamic model is developed using Mike 21 package. The model is based on the Reynolds-Averaged Navier-Stokes (RANS), using the assumption of Boussinesq and hydrostatic pressure.

$$\frac{\partial \zeta}{\partial t}+\frac{\partial\left[(h+\zeta)u\right]}{\partial x}+\frac{\partial\left[(h+\zeta)v\right]}{\partial y}=0 \tag{1}$$

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+fv=-g\frac{\partial \zeta}{\partial x}-\frac{\tau_{bx}}{\rho(h+\zeta)}+E_x\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)-\frac{1}{\rho(h)}\left(\frac{\partial S_{xy}}{\partial x}+\frac{\partial S_{xx}}{\partial y}\right) \tag{2}$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+fu=-g\frac{\partial \zeta}{\partial y}-\frac{\tau_{by}}{\rho(h+\zeta)}+E_y\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)-\frac{1}{\rho(h)}\left(\frac{\partial S_{yx}}{\partial x}+\frac{\partial S_{yy}}{\partial y}\right) \tag{3}$$

where t is time, (u, v) are the velocities in the x, y direction, h is the bathymetric depth, $\zeta$ is sea-surface relief, f is Coriolis Parameter, g is accelerationofgravity, $\tau_{bx}$,$\tau_{by}$ are shear force under wave and flow around bottom in the x, y direction, $E_x$, $E_y$ are parameter of turbulence viscosity in the x, y direction, and $S_{xx}$,$S_{xy}$,$S_{yx}$,$S_{yy}$ are components of Radiation stress.

2.2 Boundary conditions

The open boundary is given by *East Chinese Tidal Wave Mathematical Model*, meanwhile zero velocity and no flow flux are defined along the coastal lines. Coriolis force, wind-induced stress and wave radiation are not considered in the model. The starting condition is given as:

$$\zeta(x,y)\big|_{t=0} = \zeta_0(x,y) \tag{4}$$

$$u(x,y)\big|_{t=0} = 0 \tag{5}$$

$$v(x,y)\big|_{t=0} = 0 \tag{6}$$

2.3 Power density equations:

$$P = \frac{1}{2} C_p \rho V^3 \tag{7}$$

Where P is density of tidal current energy within unit area; $C_p$ is turbine efficiency coefficient. According to SeaGen, $C_p$ can reach 0.4; V is magnitude of flow velocity averaged over cross-section; ρ is the density of tidal current which is 1025 kg/m$^3$ here.

2.4 Computational Domain

The computation domain covers Zhoushan Islands (Fig.1) with a distance of about 42.5km in longitude from E122.117° to E122.559° and a distance of about 30km in latitude from N29.889° to N30.160°. As shown in Fig.2, this domain is divided into a series of unstructured triangular grids with 38979 nodes and 75280 elements. A small grid with a size of 20m is used along coastal boundary, while a larger grid with a size of 800m is applied at open-sea boundary.

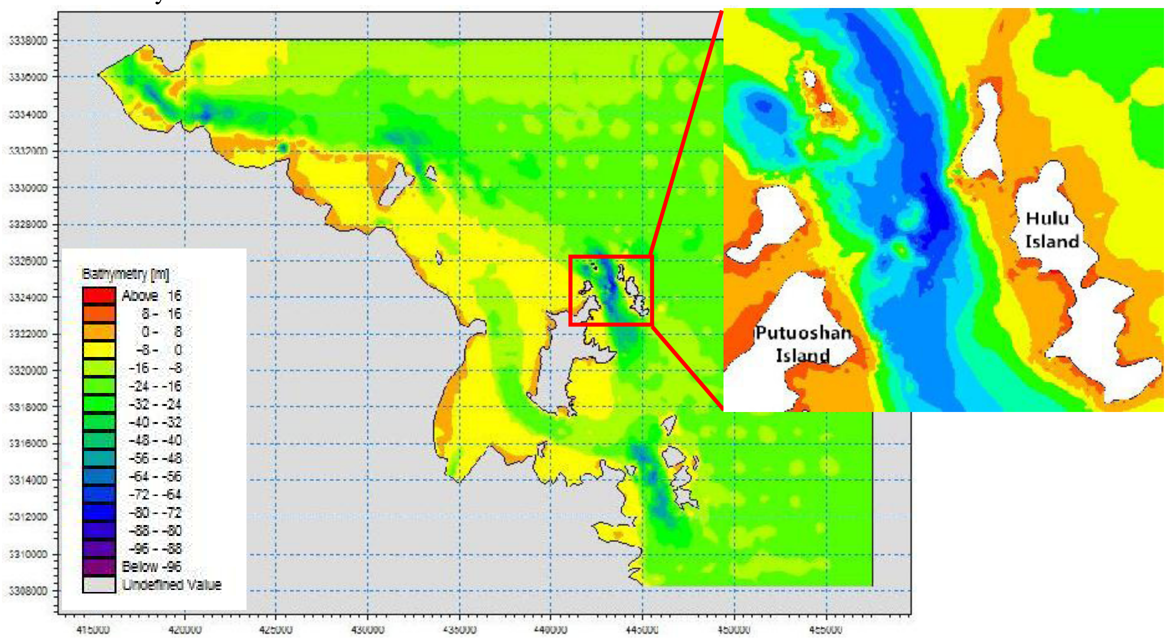



Fig.1 Bathymetry of numerical domain and partial enlarged detail

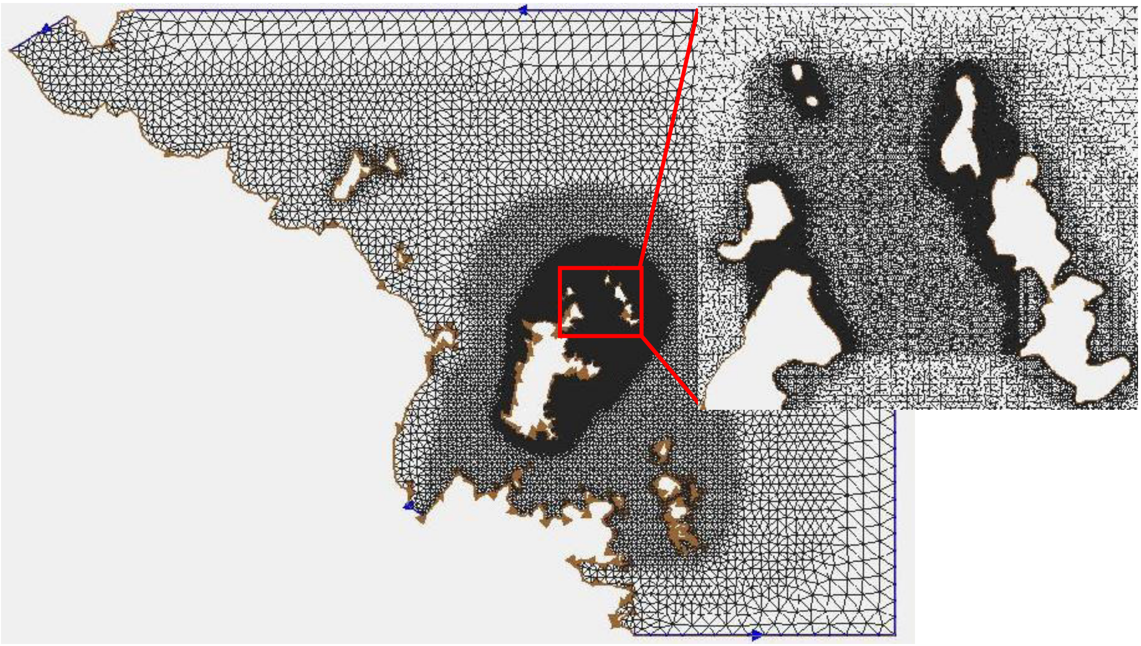


Fig. 2 Numerical model grids and partial refined details

## 3. Model Validation

The locations for field measurement are shown in Fig.3. B1 and B2 are the measurement points of tidal current velocity, while S1 is measurement point of water level. The coordinate of these measurement points are given in Table.1. Fig.4 shows the comparison of water level between simulated and measured data with the time series at S1 from the 14/August/2013 to 24/August/2013, indicating a reasonable agreement between numerical model and field measurement. The values of mean absolute error (MAE) and root mean square error are 0.08m and 0.21m. Fig.5 and Fig.6 show the comparison between measured data and simulated of surface tidal current. In general, this model has a good ability in simulating the hydrodynamics around Hulu Island.

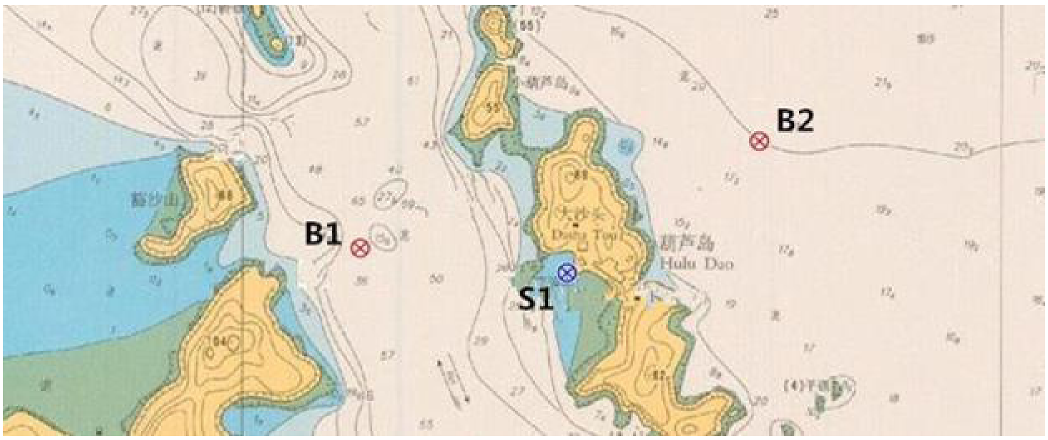



Fig.3 The measurement points of tidal velocity (B1 and B2) and water level (S1).

Table.1 Coordinate of three measurement points.

| Measurement Point | | S1 | B1 | B2 |
|---|---|---|---|---|
| Coordinate（Beijing54）（° ′ ″） | Latitude（E） | 122°25′17.0″ | 122°24′28.0″ | 122°26′02.6″ |
| | Longitude（N） | 30°02′03.5″ | 30°02′08.4″ | 30°02′30.6″ |

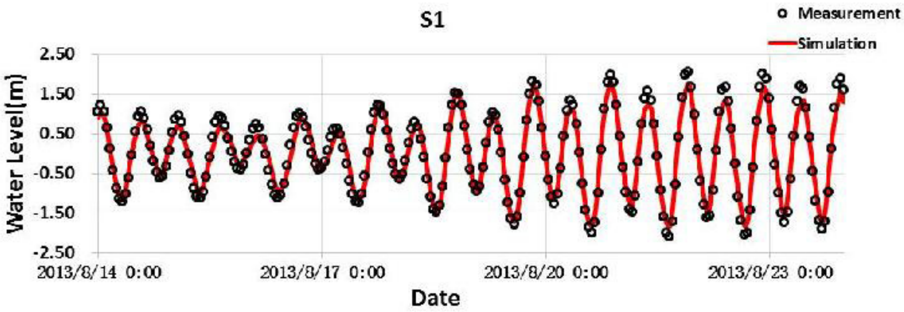



Fig.4 Comparison of water level between simulated and measured data at S1

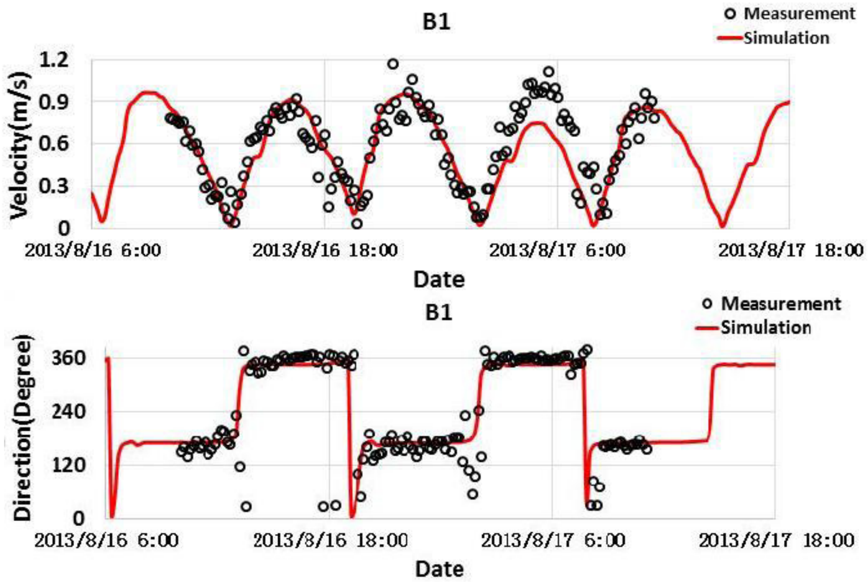
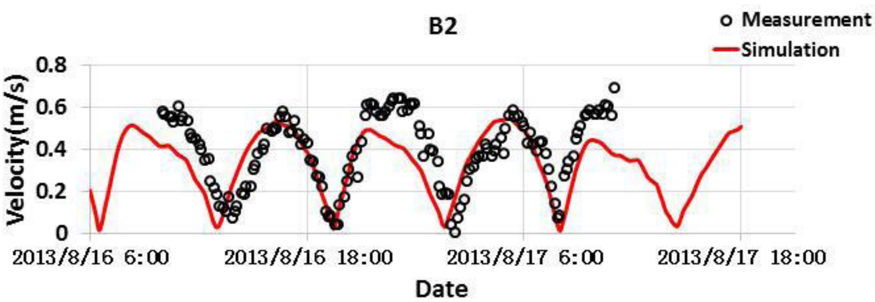



Fig.5 Comparison of current speed and direction between simulation and measured data at B1



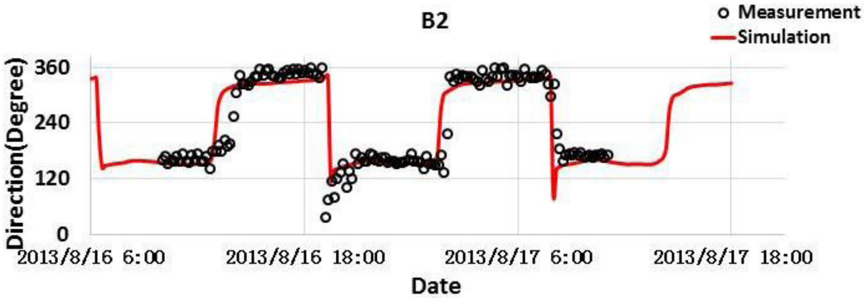



Fig.6 Comparison of current speed and direction between simulation and measured data at B2

## 4. Assessment of Tidal Stream Energy Resources

4.1 Distributions of power density and mean power density

The simulation time is set from 6/August/2013 to 5/September/2014. Fig.7 presents maximal speed and maximal power density around Hulu Island. The maximal depth-average velocity is greater than 1.7 m/s between Putuoshan Island and Hulu Island, meanwhile the maximal power density is over 2517 W/m$^2$. Fig.8 presents mean speed and mean power density around Hulu Island. The mean depth-average velocity is between 0.6 m/s~1.0 m/s, with somewhere reaching 2.1 m/s. The distribution of mean power density is between 110 W/m$^2$~512 W/m$^2$, with somewhere reaching 4746 W/m$^2$. A distribution of annual cumulative number of hours with depth-averaged flow velocity larger than 2.0 m/s is shown in Fig.9. It can be seen that some locations with values over 2000 can be regarded as ideal site for tidal current generation.

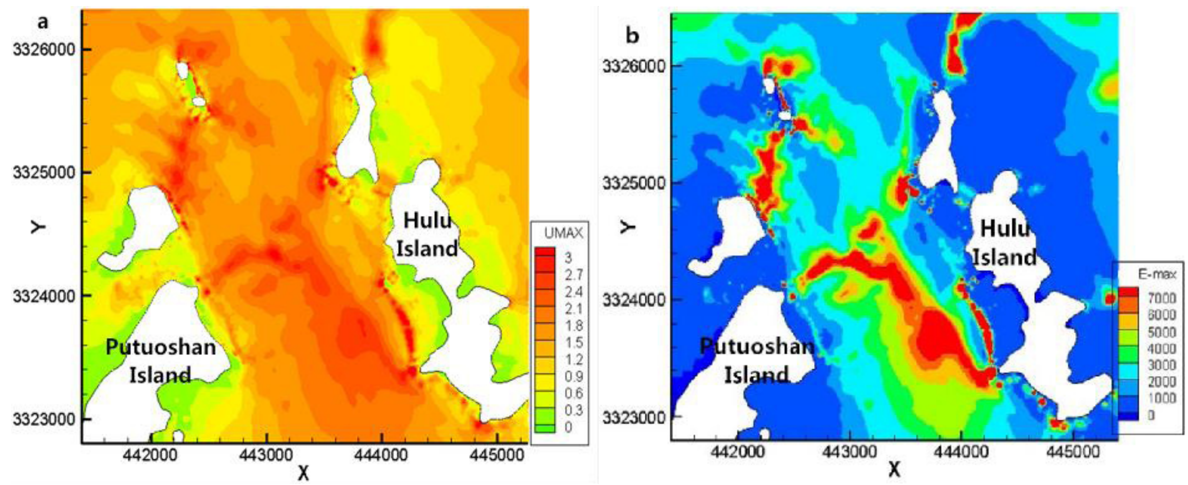



Fig.7 The distribution of maximal speed (a) and maximal power density (b) of tidal current around Hulu Island

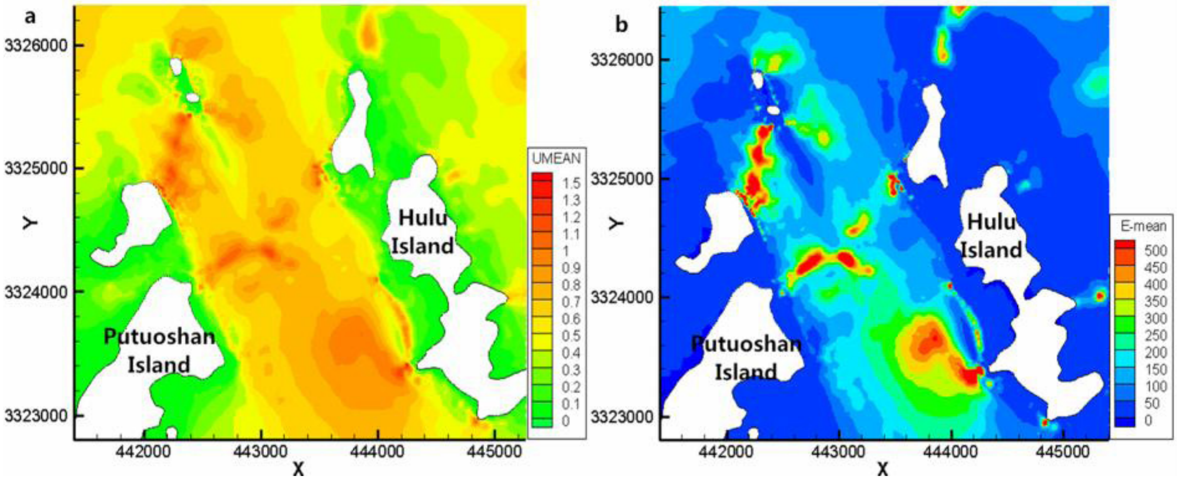



Fig.8 The distribution of mean speed (a) and mean power density (b) of tidal current around Hulu Island

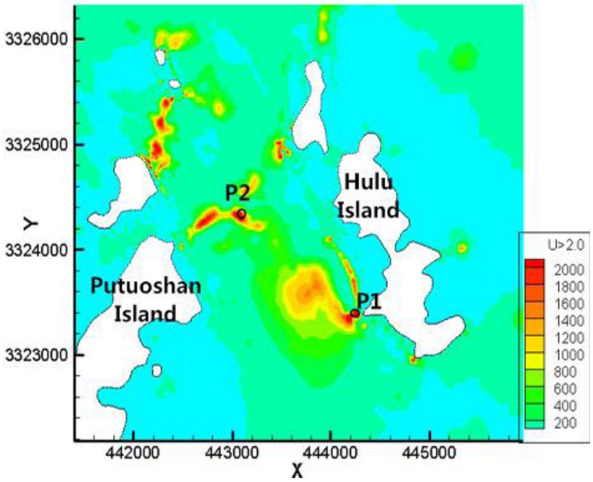



Fig.9 Distribution of annual cumulative number of hours with a depth-averaged flow velocity larger than 2.0 m/s

4.2 Flow velocity and power densities at the two potential locations

In order to characterize the tidal stream resource with more precision in the area, two locations are chosen for analysis. As shown in Fig.9, a higher value of annual cumulative hour for Points P1 (444210, 3323400) and P2 (443150, 3324230) can be identified. The velocity magnitude at both points are shown in Fig.10, during a 15-day (2013/8/15-2013/8/31) period, so as to cover the spring-neap variation. Peak values in spring are 2.18 m/s and 2.98 m/s, while average values are 0.83 m/s and 1.15 m/s, at point P1 and P2, respectively. Fig.11 shows the time-dependent distribution of the power density at both points. The peak power densities at point P1 and point P2 are 5.31 kW/m$^2$ and 13.56 kW/m$^2$, while the mean value are 0.62 kW/m$^2$ and 1.81 kW/m$^2$. A numerical integration yields 222.84 kWh/m$^2$ and 649.44 kWh/m$^2$ for P1 and P2. The annual values are 5348.16 kWh/m$^2$ and 15586.56 kWh/m$^2$. Assuming a power coefficient $C_p$=0.3, the annual energy output is 1604.45 kWh and 4675.97 kWh per square meter of turbine aperture at P1 and P2, respectively.

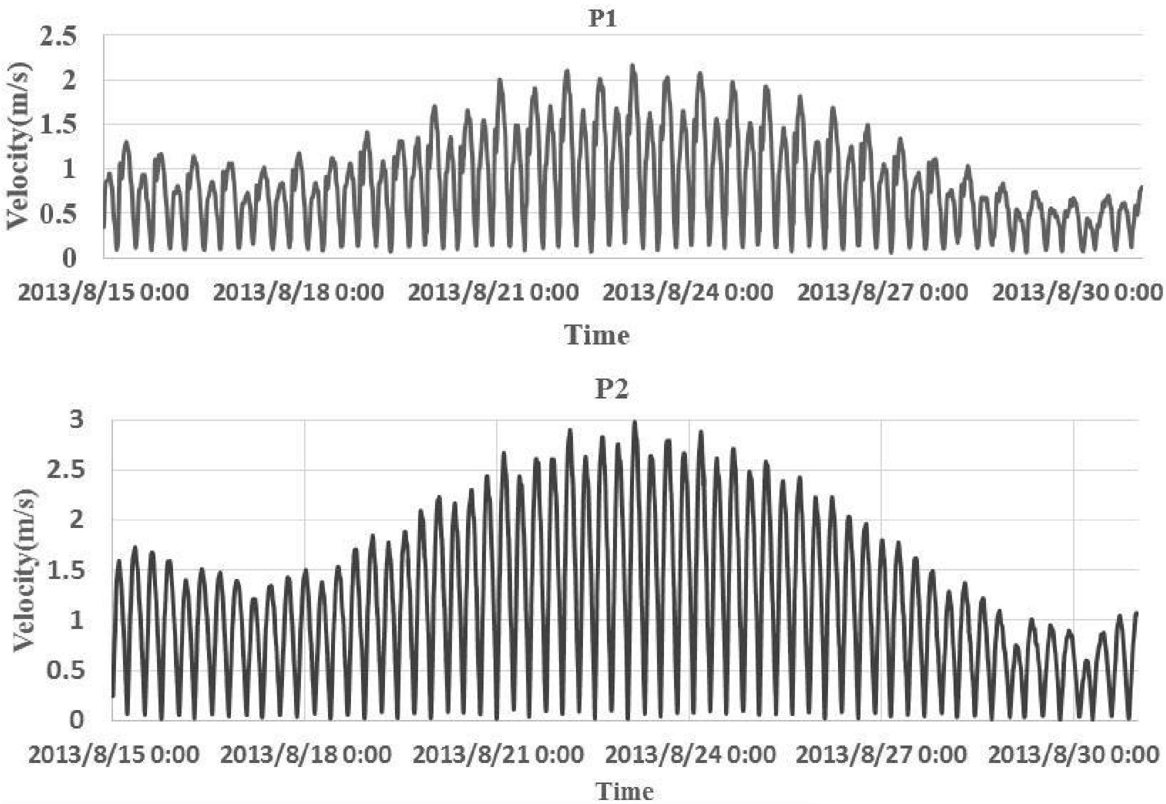
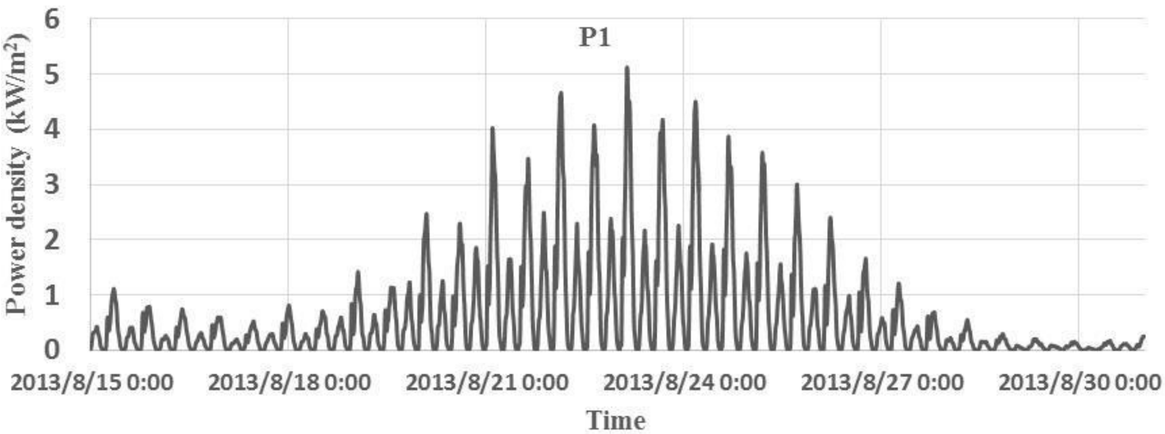



Fig.10 Flow velocity at points P1 and P2 throughout a 15-day spring-neap cycle



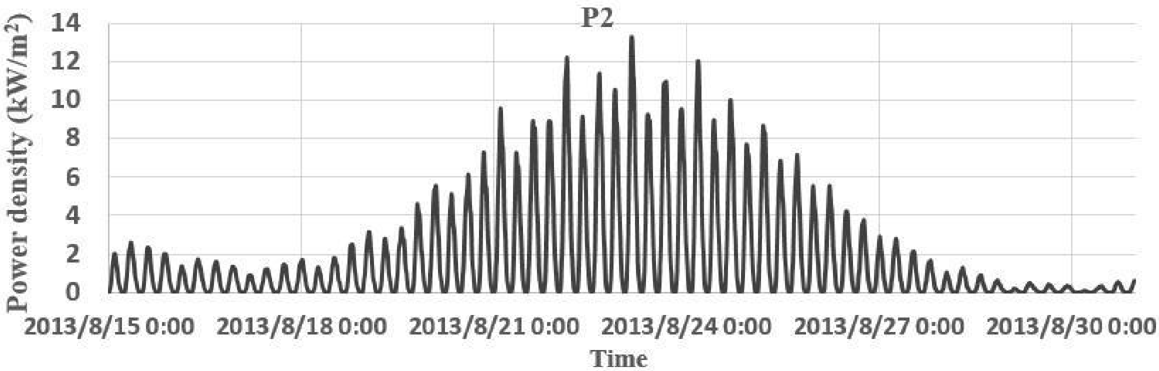



Fig.11 Power density at points P1 and P2 throughout a 15-day spring-neap cycle

## 5. Conclusions

Zhoushan Islands is a large coastal embayment in east China, where many channels hold peak flow velocity over 2 m/s. Aiming at quantifying the tidal stream resource and assessing the viability of a tidal stream plant, a numerical model of Zhoushan Islands hydrodynamics has been implemented. The maximal and mean depth-average velocity around Hulu Island are greater than 1.7 m/s and between 0.6 m/s~1.0 m/s, respectively. The maximal and mean power density are 2517 W/m$^2$ and between 110 W/m$^2$~512 W/m$^2$. However, the mean velocity can reach 2.1 m/s somewhere and the corresponding mean power density of 4746 W/m$^2$. Two points in this tidal channel were chosen for a detailed examination. The peak power densities at point P1 and point P2 are 5.31 kW/m$^2$ and 13.56 kW/m$^2$, while the mean value are 0.62 kW/m$^2$ and 1.81 kW/m$^2$. A numerical integration yields 222.84 kWh/m$^2$ and 649.44 kWh/m$^2$ for P1 and P2, and the annual values are 5348.16 kWh/m$^2$ and 15586.56 kWh/m$^2$.

## Acknowledgments

The authors are grateful to financial supports from the marine renewable energy research project of State Oceanic Administration (GHME2013GC03) and the Fundamental Research Funds for the Central University, China (2014B05114),

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