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EVALUATION OF OFFSHORE WIND ENERGY RESOURCE IN CHINESE COASTAL SEA USING QUIKSCAT DATA

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ABSTRACT

The development of offshore wind energy resources becomes a trend to meet the demand of clean renewable energy. Distributions of offshore wind speeds and associated energy density with high accuracy need to be estimated. Offshore wind energy resources of Chinese coastal seas are estimated with the wind speed data from scatterometer SeaWinds onboard QuikSCAT satellite with 12.5km spatial resolution. Annual mean wind speed of the period from 2006 to 2008 is evaluated at the height of 10m and 80m (turbine hub height) respectively. Considering the effects of stability of marine atmospheric boundary layer, the stability dependent wind speeds are calculated based on Monin-Obukhov similarity theory using QuikSCAT wind speed data and National Center for Environmental Prediction Final Analysis data (NCEP FNL).The stability dependent wind speed is 0.5m/s smaller than equivalent neutral wind speed (which is QuikSCAT-derived wind speed) in Chinese coastal seas. Furthermore the wind energy potentials are discussed by using the Weibull probability density function with its two parameters namely scale and shape. The energy density distribution map based on Weibull's shape and scale parameters characterizes the offshore wind energy resources of Chinese coastal seas. From the result, the Taiwan Strait is relatively high in energy density which is more than 1000W/m^2 and most of Chinese coastal seas have the wind speed of over 7m/s at 80m height. Moreover validation of stability dependent wind speed against in situ data will be discussed.

Keywords: offshore wind, wind energy, QuikSCAT, China

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1. INTRODUCTION

The study reported by IPCC shows the risk of anthropogenic greenhouse gases to global climate change and ecosystems, and many countries concerned about the renewable energy instead of fossil fuels (IPCC, 2007). Wind energy could be a good selection for large resource potential, proven commercial technology and very low CO_2 emissions. In general offshore wind has higher wind speed than onshore wind. Offshore wind development started from Europe in the early 1990s. As of 30 June 2011, there are 1,247 offshore wind turbines fully grid-connected with a total capacity of 3,294 MW in 49 wind farms spread between nine European countries, and offshore wind power will avoid the emission of 10Mt of CO_2 (EWEA, 2011). The development of the offshore wind power is quite slow in other countries because of the complexity of offshore wind power technologies, high cost of the construction and difficulties of operation and maintenance.

In order to reduce the greenhouse gas emission from fossil fuels, China has started to develop the offshore wind energy. Since China is rich in wind resource but lack of experience and own technology, the accurate offshore wind energy assessment and further research are needed.

For these reasons, the purpose of this paper is to assess the offshore wind energy resource of Chinese coastal sea using QuikSCAT data.

2. DATA

2.1 QuikSCAT data

For the large-scale assessment of offshore wind resources, QuikSCAT is appropriate than SAR (Synthetic Aperture Radar) with high temporal and spatial resolution. QuikSCAT is a SeaWinds scatterometer onboard earth-observing satellite. It was launched in 1999 by NASA and stopped working in 2009; it has been operating 10 years beyond its design life. It observes 10m-height wind speed twice a day and it passes at local sun time 6 A.M., 18 P.M. QuikSCAT derived-wind speeds are defined as equivalent neutral wind (ENW) speeds assuming the neutral stability in the atmospheric stability condition. (JPL, 2006).

QuikSCAT Level-2B data at 12.5km spatial resolution are obtained from the PO.DAAC of NASA. Wind speed data from the 2006 to 2008 are used in this paper. Outline of QuikSCAT and the Level 2B data are shown in Table 1.

Table 1 Outline of QuikSCAT/SeaWinds

QuikSCAT Satellite	
Launch	June 20, 1999
Orbit	Sun-synchronous polar orbit
Recurrent period	4 days (57 orbits)
Orbital Period	101 minutes (14.25 orbits/day)
Altitude	803 km
Inclination	98.616
SeaWinds	
Microwave	13.4GHz (Ku-band)
Spatial resolution	25 km
Coverage	90% of ice-free ocean every day
Wind speed	RMSE 2 m/s (3-20 m/s) 10% (20-30 m/s)
Wind direction	RMSE 20 (3-30m)

2.2 NCEP FNL data

The National Centers for Environmental Prediction Final Analysis (NCEP FNL) data are on 1.0x1.0 degree grids prepared operationally every six hours. This product is from the Global Data Assimilation System (GDAS), which continuously collects observational data from the Global Telecommunications System (GTS), and other sources, for many analyses. To estimate the stability-dependent wind speed, the air temperature, sea surface temperature and relative humidity data are utilized from FNL data. The reason to choose FNL is that it has relatively high spatial resolution covering Chinese coastal sea and the recording time of FNL data has good agreement with QuikSCAT data during the period from 2006 to 2008.

2.3 Buoy data

The validation for the estimated wind speed data utilizes buoy data from the Kuroshio Farm, Kochi Prefecture, Japan. These buoys are installed off Kochi Prefecture since 1984 and the measurement has been carried out every two hours since August 3, 1994. The No.10 and No.13 buoys are used in the study, and they are located 33° 01.83 N, 134° 07.42 E and 32° 22.85 N, 132° 51.96 E , measuring the wind speed and other meteorological data at 10m height.

3. METHOD

3.1 Stability dependent wind (SDW)

SeaWinds-derived wind speeds are calibrated to equivalent neutral wind (ENW) speeds rather than actual wind speeds. Equivalent neutral wind speed is calculated by using the stress and roughness length consistent with the observed atmospheric stratification, but setting the atmospheric stratification term in the modified log-wind profile equal to zero (Liu and Tang, 1996). Therefore for more accurate description about wind speed and resource assessment, the stability dependent wind (SDW) speed needs to be considered. The LKB FORTRAN computer code (Liu and Tang, 1996) can be used for this calculation

$$Uz - Us = (u^*/k)\,[ln\,(z/z0) + \varphi\,(z, z0, L)] \quad (1)$$

Where z = 80m(wind speed height)

u^*= friction velocity

k = 0.4 (Von Karman constant)

φ (z, z0, L) = dimensionless stability function

L = the Monin-Obukhov length

z_0 = momentum roughness length

The equation (1) is the wind profile equation which is based on Monin-Obukhov similarity theory. When the atmospheric stability is neutral, the φ (z, z_0, L) is zero. z_0 is calculated following with a Charnock parameter of 1.1×10^{-2}(Smith,1980). *Us* is zero at the surface. Thus *Uz* is the stability dependent wind speed at 80m height. We also computed the 10m height SDW using the same method.

3.2 Wind energy density

Wind energy density distribution of Chinese coastal seas is estimated by using the Weibull distribution that has well characterized the wind feature (Pavia and O'Brien, 1986). The following equation is the Weibull probability function with two parameters, scale and shape.

$$P(u) = \left(\frac{k}{c}\right)\left(\frac{u}{c}\right)^{k-1} \exp\left[-\left(\frac{u}{c}\right)^{k}\right] \qquad (2)$$

$$c = \frac{\bar{u}}{\Gamma(1+\frac{1}{k})}$$

$$k = \left(\frac{\bar{u}}{\sigma}\right)^{.086} \qquad (3)$$

$$E = \frac{1}{2}\rho c^3 \Gamma\left(1+\frac{3}{k}\right)$$

Where c = scale parameter (m/s)

k = shape parameter

u = wind speed (m/s)

Ū = mean wind speed (m/s)

ρ=air density (1.225kg/m^3)

σ=standard deviation of wind speed (m/s)

Γ=Gamma function

E = energy density (W/m^2)

Among a number of methods to estimate the parameters, the simplest method was chosen because the result is essentially equivalent to maximum likelihood estimates (Monahan, 2006).

4. RESULTS AND DISCUSSION

The annual mean wind speed based on QuikSCAT data from 2006 to 2008 is shown in Figure 1. From the year 2006 to 2008, the annual mean wind speed has no variation from each other around Chinese coastal sea. The Taiwan Strait shows the highest wind speed area. Figure 2 illustrates the stability dependent wind speed at 10m height. And Figure 3 shows the difference of SDW and ENW. The marine boundary layer of the East China Sea and the South China Sea is almost unstable, and the wind speed decreases by 0.3m/s, whereas the Bohai Sea and the Yellow Sea shows stable atmospheric condition. In the northeast Bohai Sea the increase of wind speed is remarkable by nearly 0.5m/s.

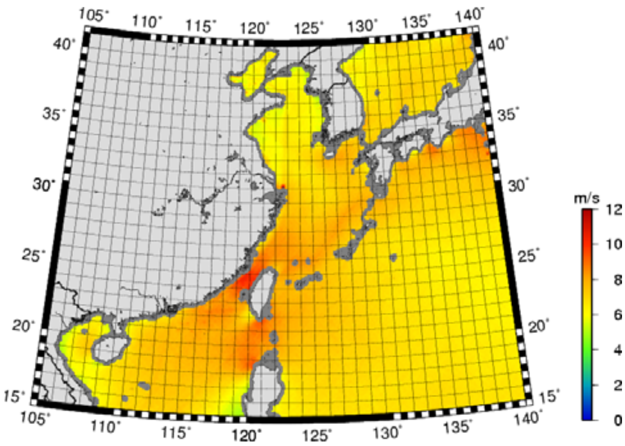

Figure 1 ENW at 10m-height (2006 – 2008)

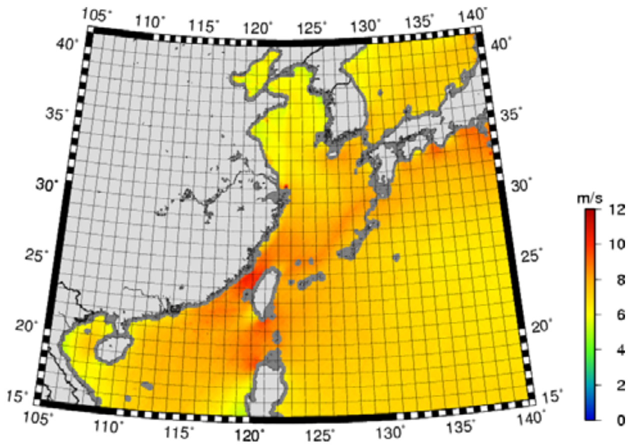

Figure 2 SDW at 10m-height (2006-2008)

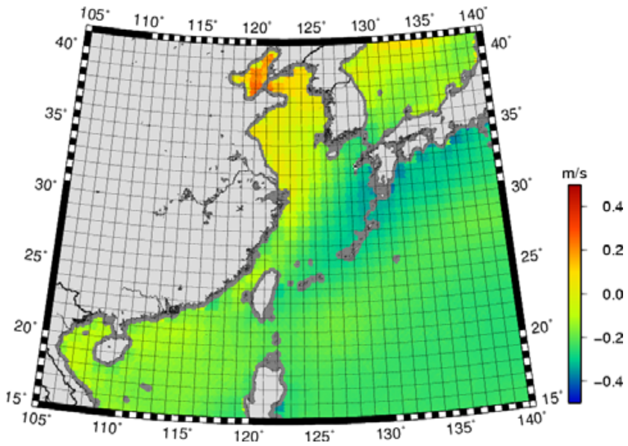

Figure 3 SDW-ENW at 10m-height (2006-2008)

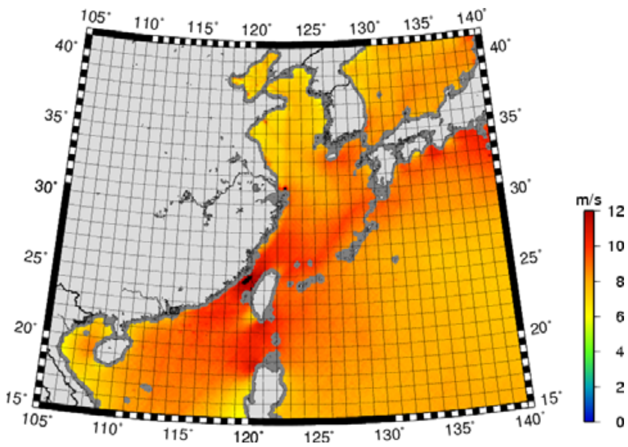

Figure 4 SDW at 80m-height (2006-2008)

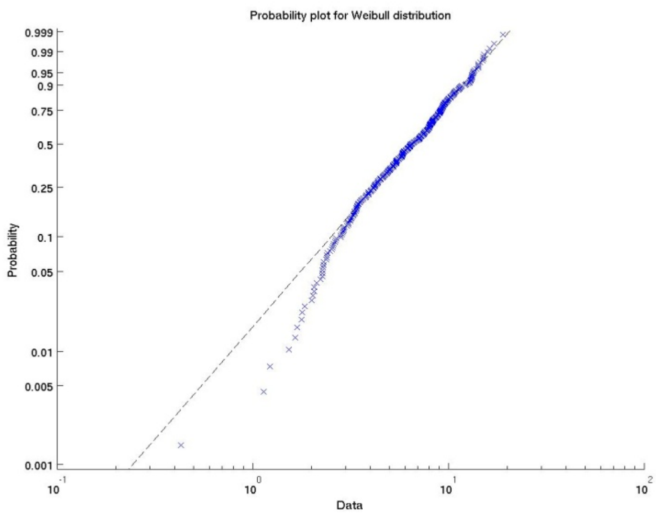

Figure 5 Weibull probability plot

Figure 4 indicates the hub height SDW for 3 years. It is found that the wind speed near the Taiwan Strait has the strongest wind speed that almost between 8m/s and 12m/s around the Chinese coastal seas.

One point in South China Sea was chosen to examine whether the Weibull probability density function is fitted to the Chinese coastal sea or not. It located at 20.50N, 109.10E around Hainan. It is found that the wind speed is fitted to the straight line from 3m/s to 20m/s, which indicates the wind speeds obey the Weibull distribution.

From Figure 6 it is found that wind energy density exceeds 1500W/m^2 at the Taiwan Strait. The East China Sea and the South China Sea are between 600W/m^2 and 1200W/m^2. The energy density of the Bohai Sea and the Yellow Sea is lower than 600W/m^2.

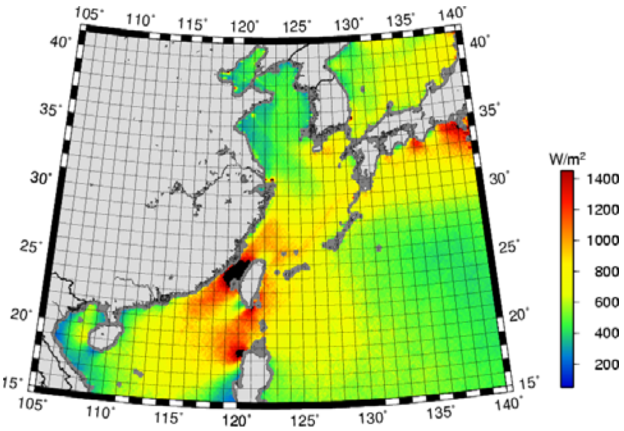

Figure 6 Distribution of wind energy density

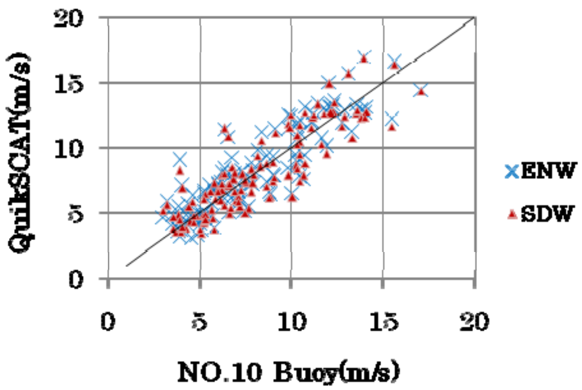

Figure 7 Comparison of QuikSCAT-derived and buoy wind speed (2008)

Table 2 Validation of wind speed (2008)

	ENW	SDW
NO. 10 Buoy	Bias: 0.23(m/s) RMSE:1.66(m/s)	Bias: -0.06(m/s) RMSE:1.67(m/s)
NO.13 Buoy	Bias:0.25 (m/s) RMSE:2.36(m/s)	Bias: -0.13(m/s) RMSE: 2.39(m/s)

Wind speed data of the year 2008 are compared with ENW and SDW. The results of validation are shown in Figure 7 and Table 2. Biases of SDW are lower than ENW, and the RMSEs show small differences.

5. CONCLUSIONS

In this paper, the offshore wind energy resources of Chinese coastal sea are estimated using QuikSCAT wind speed data and the NCEP FNL data by considering atmospheric stability in the marine boundary layer.

1. The potential of wind resource at the hub height is more than 1500W/m^2 at the Taiwan Strait. However the wind resource at the Bohai Sea is lower than 600W/m^2.
2. The atmospheric stability in most Chinese coastal sea is unstable, but stable in the Bohai Sea.
3. The Biases of SDW are between -0.13m/s and -0.16m/s, and the RMSEs are ranging from 1.67m/s to 2.39m/s at 10m height. The Bias is decreased considerably by calculating the stability dependent wind speed. However the RMSEs are increased though the differences between ENW and SDW are small.

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