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Assessment of Offshore Wind Resources Within Japan's EEZ Using QuikSCAT Data

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Abstract

In this paper, offshore wind resources within the Japan's EEZ (Exclusive Economic Zone) are assessed using wind speed data from the microwave scatterometer SeaWinds onboard QuikSCAT. At first, from the 10m-height wind speed from QuikSCAT, 60 m-height wind speed is estimated by using an empirical equation for height correction. Based on the 60m-height wind speeds, annual energy production is calculated under an assumption of installing 2 MW wind turbines every 0.64 km^2. The annual energy production is then accumulated for the entire Japan's territorial waters and EEZ (4.47×10^6 km^2). As a result, it is shown that the total energy production is estimated to be 4.86×10^4 TWh/yr. This offshore wind energy potential within the EEZ is approximately 50 times higher than the actual annual electricity production in Japan.

Key Words : Offshore, Wind resource assessment, Japan, EEZ (Exclusive Economic Zone), QuikSCAT

1. Introduction

Japan is an island nation surrounded by seas, and offshore wind energy is expected as one of promising renewable energy resources. The biggest problem is the depth of the seas, which are too deep for offshore wind power generation. However, future developments of floating and sailing offshore wind turbine systems[1, 2] seem to have a strong possibility for solving this problem. Toward the realization of floating and sailing offshore wind farms in the huge sea areas, we assess offshore wind potential within not only shallow coastal areas but also the entire Japan's territorial waters and EEZ (Exclusive Economic Zone).

Up to the present, offshore wind resource assessment in Japanese waters has been reported in some papers[3~5]. However, they mostly focus on coastal waters and this study is thus the first attempt to present the offshore wind energy potential within the Japan's EEZ.

Since the target area is large and most of the parts are in open oceans, we choose to use wind data from the NASA/JPL's SeaWinds scatterometer aboard the QuikSCAT satellite, although there are still uncertainties in accuracy of the data[6]. The original spatial and temporal resolutions of the SeaWinds are 25 km and 12 hours, respectively. Such relatively low resolutions may not be enough for coastal waters (for example less than 100 km from land) due to dynamical effects of onshore terrain and thermo-dynamical effects such as land-sea breezes with intense diy not vas ation of wind speed. But for open ocean areas the low resolutions probably have no effects on eslanating annall mean wind speed or energy production, because wind speed is relatively homogeneous and diy not vas ation is weak there.

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2. 10M-Height Wind Speed from Quikscat

2.1. QuikSCAT Data

Wind data used in this study is the QuikSCAT Level-2B Winds in 12.5 km Swath Grid product, provided from Jet Propulsion Laboratory, NASA[3]. Outline of QuikSCAT and the Level 2B data are shown in Table 1. QuikSCAT is a sun-synchronous polar orbiting satellite and observes 10m-height wind speed mostly twice a day at an arbitrary area on the globe. Around Japan, it passes at roughly 8 a.m. and 20 p.m. All of the semi-daily data for the year of 2004, approximately 730 data, are used in this study.

2.2. 10m-height Wind Speed

The annual mean 10m-height wind speed in 2004 is shown in Fig. 1. It is found that characteristics of the wind speed pattern are almost the same as those of 2005, shown in our previous paper[4].

Fig. 2 shows the anomaly of the 2004 wind speed from the 30-years average obtained from the NCEP/NCAR Reanalysis data. From Fig. 2, it is found that the anomalies are mostly between 90% and 110%. This implies that the year of 2004 is not an extreme year in terms of wind speed around Japan.

Table 1. Outline of QuikSCAT/ Sea Winds

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	98.6 degrees
Sea Winds Sensor	
Microwave	13.4 GHz(Ku-band)
Spatial resolution	25 km
Coverage	90% of ice-free ocean every day
Wind speed	RMSE 2.0m/s (3 to 20m/s)
	10% (20 to 30m/s)
Wind direction	RMSE 20 degrees
Level 2B Product	
Spatial resolution	12.5km x 12.5km
Contents	1 file/orbit
Number of grids	3248 (along-track) x 52(cross-track)
Parameters	lon, lat, wind speed and direction, etc.

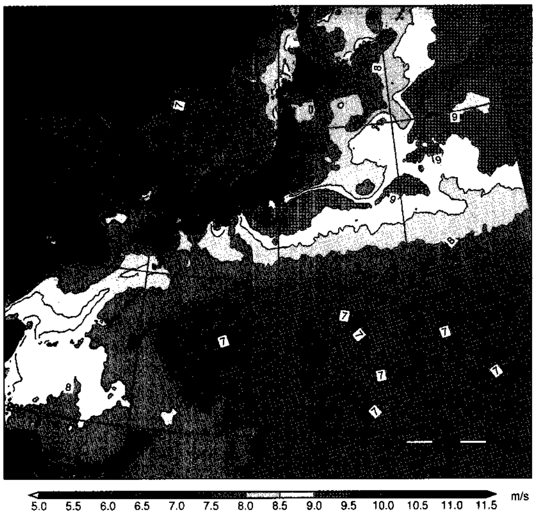

Fig. 1. Annual mean 10m-height wind speed in 2004, based on QuikSCAT/SeaWinds.

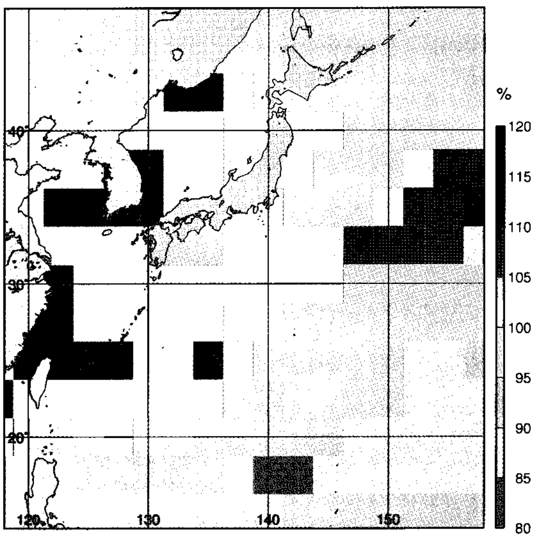

Fig. 2. Anomaly of 2004 wind speed from 1976-2005 average.

3. Hub-Height Wind Speed

3.1. Estimation Method

Wind speed needed in the assessment of wind energy potential is not the 10 m-height but the turbine hub height wind speed. In this study, 60 m is defined as the hub height. Thus the 60 m-height wind speed is estimated from the QuikSCAT 10 m-height wind speed by using the empirical equation for height correction derived in our previous study[5]. The empirical equation is a function of the bulk Richardson number R_{iB} and written as

$$\frac{U_{60}}{U_{10}} = \begin{cases} (\alpha-\gamma)\left[1-\frac{\beta}{(\alpha-\gamma)}R_{iB}\right]^{-1}+\gamma & (R_{iB}<0) \\ \alpha+\beta\cdot R_{iB} & (0 \le R_{iB} \le R_{iC}) \\ \alpha+\beta\cdot R_{iC} & (R_{iC} < R_{iB}) \end{cases} \quad (1)$$

where R_{iC} (=0.017) is the critical value for R_{iB} and the coefficients α, β and γ are as follows.

$$\alpha = 1.17, \quad \beta = 25.5, \quad \gamma = 1.08 \quad (2)$$

The relation of Eq. (1) is shown in Fig. 3.

3.2. RANAL and NGSST

The parameters for calculating R_{iB} (air and sea surface temperatures) are obtained from the Japan Meteorological Agency (JMA) Regional Analysis (RANAL) and the New Generation Sea Surface Temperature (NGSST) produced by Tohoku University. Outline of RANAL and NGSST are shown in Tables 2 and 3, respectively. RANAL is 6-hourly 20 km × 20 km-gridded objective analysis data, produced by the JMA numerical weather forecasting system including a regional scale model RSM. NGSST is daily 0.05°× 0.05°-gridded SST data in which satellite SST observations from infrared radiometers (AVHRR, MODIS) and a microwave radiometer (AMSR-E) are merged.

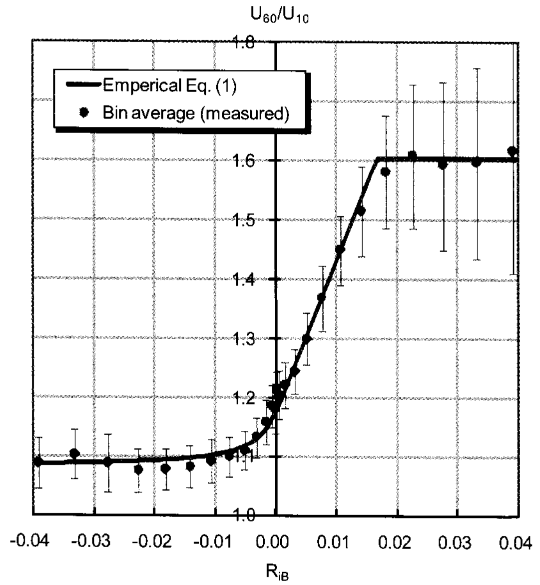

Fig. 3. Ratios U_{60}/U_{10} from the empirical equation Eq. (1) and measured at Horns Rev[5].

Table 2. Outline of JMA Regional Analysis (RANAL)

Model	JMA Regional scale Model (Hydrostatic)
Interval	6-hourly (00, 06, 12, 18 UTC)
Hor.grids	20 km x 20 km, 325x57 grids (Lambert Con.)
Ver.levels	20 levels (1000 hPa to 10 hPa)
Surf.Param.	PMSL,Wind (U,V),Temp, RH
Upper Param.	Geopotential Heihgt, Wind (U,V),Temp, RH

Table 3. Outline of NGSST

Data merged	AVHRR, MODIS, AMSR-E
Interval	daily(using data from previous 5days)
Coverage	13-62N, 116-166E
Grids	0.05deg x 0.05deg, 1000x1000 grids
Accuracy	Bias: -0.31 K, RMSE: 0.79 K

3.3. 60m-height Wind Speed

The estimated annual mean 60m-height wind speed is shown in Fig. 4. It is found that the 60m-height wind speed ranges between 8 and 12 m/s around Japan. Wind speed is particularly high (> 9m/s) over the Kuroshiet(warm current), which flows along the Nansei Islands and south coasts of the main islands of Japan. The wind speed above 9 m/s can be aspo found in the northern part of Japan; Tohoku and Hokkaido, and off the north coast of Kushu.

4. Wind Energy Potential

4.1. Annual Energy Production

Next, annual energy production is calculated from the 60m-height wind speed by assuming that wind turbines are installed in the seas as much as possible. As the wind turbine, a 2 MW machine with the power curve[6] shown in Fig. 5 is chosen. The cut-in and cut-out wind speeds are 4 and 25 m/s, respectively. It is also assumed that blade diameter (D) of the turbine is 80 m and configuration of turbines is 10D×10D. That is, the wind turbines are installed every 0.64 km^2.

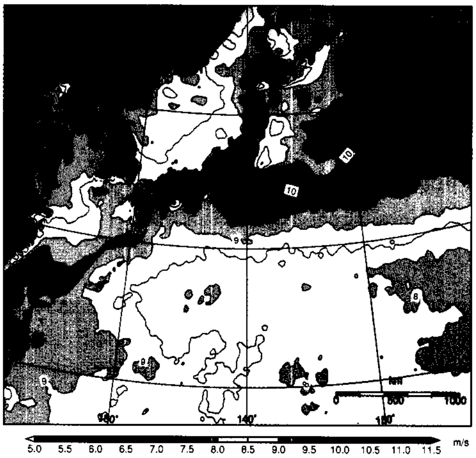

Fig. 4. Annual mean 60m-height wind speed in 2004.

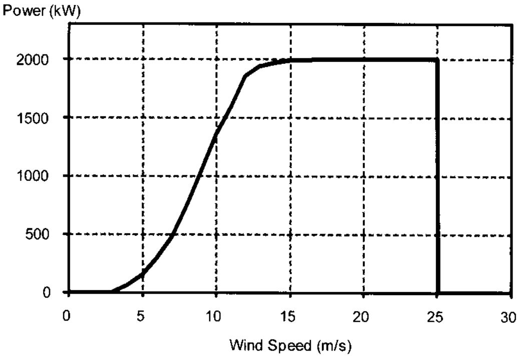

Fig. 5. Power curve for 2 MW wind turbine used in this study[6].

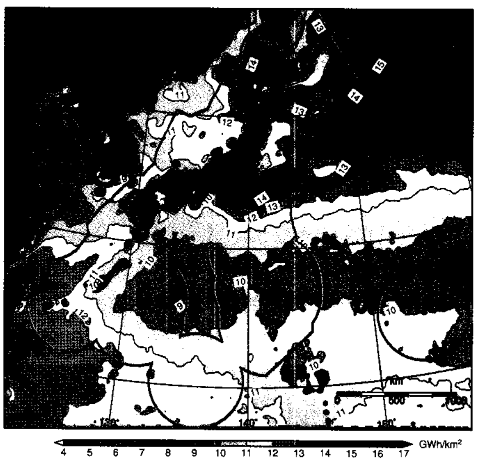

Fig. 6. Annual energy production per squared kilometer (GWh/km^2). Blue lines show boundaries of Japan's EEZ (including disputed areas).

Fig. 6 shows the estimated annual energy production per squared kilometer. It is found that the annual energy production around Japan ranges between 9 and 14 GWh/km^2. Areas of more than 13 GWh/km^2 can be seen only in areas along the southern coast of Honshu and around Hokkaido.

4.2. Total Energy Production within EEZ

Finally, the annual energy production is accumulated for the entire Japan's territorial waters and EEZ (4.47×10^6 km^2). The boundaries of the EEZ, shown by blue lines in Fig. 6, are based on the data provided by the Vlaams Instituut voor de Zee (VLIZ, Flanders Marine Institute) in Belgium (www.vliz.be). It is noted that the Japan's EEZ shown in Fig. 6 includes disputed areas with neighboring countries.

As a result of the accumulation of annual energy production within the Japan's EEZ, the total wind energy production within the EEZ is estimated to be 4.86×10^4 TWh/yr. This amount is approximately 50 times higher than the annual electricity production in Japan, which is 971.87 TWh/yr in 2008.

5. CONCLUSIONS

In this paper, offshore wind resources within the Japan's exclusive economic zone (4.47×10^6 km^2) are assessed using the wind speed data from QuikSCAT/SeaWinds. As a result, it is found that the 60m-height wind speed around Japan ranges between 8 and 12 m/s, corresponding to annual energy production of 9 to 14 GWh/km^2. Total offshore wind energy production within the EEZ is estimated to be 4.86×10^4 TWh/yr. This amount is approximately 50 times as high as the actual annual electricity production in Japan.

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