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COMPARISON OF SAR WIND SPEED RETRIEVAL ALGORITHMS FOR EVALUATING OFFSHORE WIND ENERGY RESOURCES

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ABSTRACT

Envisat/ASAR-derived offshore wind speeds and energy densities based on 4 different SAR wind speed retrieval algorithms (CMOD4, CMOD-IFR2, CMOD5, CMOD5.N) are compared with observed wind speeds and energy densities for evaluating offshore wind energy resources. CMOD4 ignores effects of atmospheric stability, while CMOD5.N assumes a neutral condition. By utilizing Monin-Obukov similarity theory in the inverse LKB code, equivalent neutral wind speeds derived from CMOD5.N are converted to stability-dependent wind speeds (CMOD5N_ SDW). Results of comparison in terms of energy density indicate the CMOD5N_SDW shows the lowest level of errors compared with the other algorithms.

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1. INTRODUCTION

Offshore wind is expected as a r enewable energy resource and one of countermeasures to solve global warming issues. In order to evaluate offshore wind as an energy resource Kozai et al. (2009) demonstrated mapping of Weibull energy density based on 49 scenes of Envisat/ASAR-derived wind speeds. Results of mapping indicated the existence of maximum Weibull energy density located from 33.50 to 33.55 degrees North along the meridional transect. These maximums correspond to the northern edge of the Kuroshio where sea surface temperature is much higher than air temperature during the winter period. In these extremely-unstable conditions a high degree of atmospheric mixing compared to neutral conditions would lead to an overestimation of the wind speed at a given height according to the logarithmic profile law (Christiansen et al., 2006). As far as the atmospheric stability effect on w ind speed is concerned, a wind speed retrieval algorithm like CMOD4 ignores the stability effect (Stoffelen, 1997), while CMOD5.N assumes a neutral condition (Hersbach, 2008).

The purpose of the present study is to compare accuracies of four SAR wind speed retrieval algorithms against observed wind speed for evaluating offshore wind energy resources considering atmospheric stability.

2. DATA AND METHODS

Twenty-seven ASAR scenes covering the offshore wind observation station at Shirahama were acquired from the European Space Agency from January, 2005 to March, 2008. S pecifications of Envisat/ASAR and its scene coverage are described in Table 1 and Figure 1 respectively. ASAR scenes were processed to derive a Normalized Radar Cross Section (NRCS) called sigma nought. Then each image was resampled at 1500m spatial resolution after taking the mean of 1500m x 1500m for each pixel. These NRCSs, incidence angles and relative wind directions are used to estimate wind speeds using CMOD4 (Stoffelen, 1997), CMOD-IFR2 (Quilfen, 1998), CMOD5 (Hersbach et al., 2008) and CMOD5.N (Hersbach, 2008) algorithms respectively. Relative wind directions are defined as the ASAR viewing direction relative to the observed wind direction at the time of ASAR overpass. In this study WRF-simulated wind direction field is used as a substitute of the observed wind direction. WRF is the next generation mesoscale model of MM5 developed by University Corporation for Atmospheric Research (UCAR) and the National Center for Environmental Prediction (NCEP). The WRF simulation is performed with the 2-way nesting option for the two domains gradually focusing on Shirahama. The simulated 1.5km-gridded wind direction field is used for the input into the wind speed retrieval algorithms above.

At Shirahama there is a m arine tower of the Shirahama Oceanography

Observatory, Disaster Prevention Research Institute, Kyoto University. This tower has a height of 23m and is located offshore at 135.333°E, 33.709°N, 2km away from the nearest coastline (Fig. 1). At the Shirahama station a propeller anemometer is equipped at the height of 23m above mean sea level and measures wind speed and direction. Since ASAR-derived wind speeds using four wind speed retrieval algorithms are defined as those at the height of 10m, all measured wind speeds are converted to wind speeds at the height of 10m using Monin-Obukhov similarity theory. And equivalent neutral wind speeds derived from CMOD5.N are converted to stability dependent wind speeds (CMOD5N_SDW) by using an inverse LKB code which is based on the LKB code developed by Liu et al. (1996). Stability-dependent wind speeds have been used for evaluating effects of air-sea stability on QuikSCAT-derived wind speeds (Kara et al., 2009).

In order to evaluate offshore wind as energy resources, energy density needs to be calculated. Energy density (E(W/m^2)) is proportional to the wind speed cubed and defined as follows.

$$E=0.5\times\rho\times U^3 \quad \text{.................................... (1)}$$

where ρ(kg/m^3)is the air density and U(m/s) is the wind speed at the height of 10m.

Table 1 Specifications of ENVISAT/ASAR

Mode/Product	Image mode(IM)/Precision
Beam/Swath	IS2/107.7km
Incidence angle	18.7~26.2 degree
Polarization/Pixel spacing	VV/12.5m

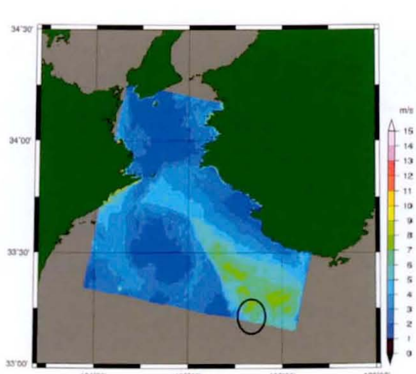

Fig. 1 ASAR-derived wind speed (Aug.20, 2003, 01h 09m (UT)) [Circle indicates the location of Shirahama offshore wind observation station (right).]

3. RESULTS AND DISCUSSION

Figure 1 shows an example of ASAR-derived wind speed based on CMOD4 while Figure 2 and Table 2 indicate the results of a comparison of stability-dependent and estimated wind speeds and energy density based on four wind speed retrieval algorithms. In Table 2 CMOD5N_SDW shows the smallest bias in terms of wind speed and energy density, while CMOD5 and CMOD5N_SDW indicate the lowest RMS errors in terms of wind speed. These results suggest that the SAR wind speed retrieval algorithm considering atmospheric stability (CMOD5N_SDW) shows lower errors and biases than those that do not take into account atmospheric stability. This indicates that it is inevitable to consider atmospheric stability effects on wind speed retrieval using synthetic aperture radar. Furthermore, the results point to the fact that mean wind speed and energy density considering atmospheric stability are higher than those that give no consideration to atmospheric stability at Shirahama. These differences of wind speed among wind speed retrieval algorithms become more emphasized offshore to the south of Shirahama than those along the coast. Figure 3 illustrates average wind speed distribution based on CMOD4 (a), CMOD-IFR2 (b), CMOD5 (c) and CMOD5N _SDW (d) algorithms respectively. The results reveal that a strong wind passage can be seen from 20 to 30km off the coast. Differences of average wind speed among the four algorithms in the passage are more than 1m/s.

Table 2 Bias, RMS errors and mean of wind speed and energy density based on four wind speed retrieval algorithms at Shirahama

	CMOD4	CMOD-IFR2	CMOD5	C MOD5N_SDW
Wind speed (m/s)				
Bias	-0.85	-0.65	-0.37	-0.28
RMSE	1.95	1.83	1.65	1. 66
Mean	4.97	5.16	5.44	5.54
Energy density(W/m^2)				
Bias	-104.1	-78.6	-59.9	-55.3
RMSE	196.7	175.6	155 .9	154. 7
Mean	10 1.4	126.9	145 .6	150.2

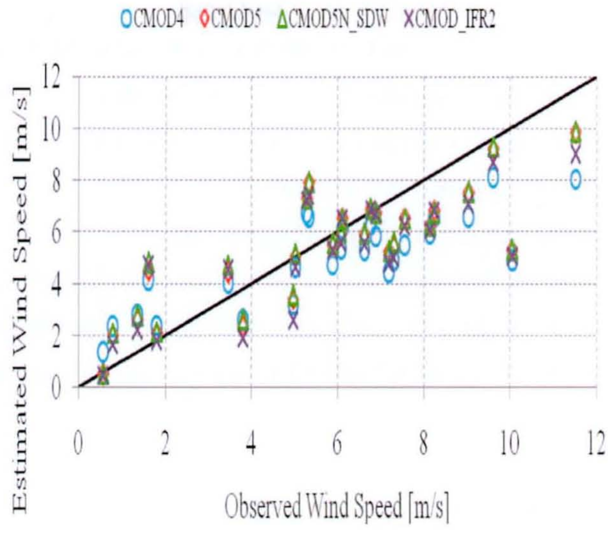

Fig. 2 Comparison of observed and estimated wind speed based on four wind speed retrieval algorithms

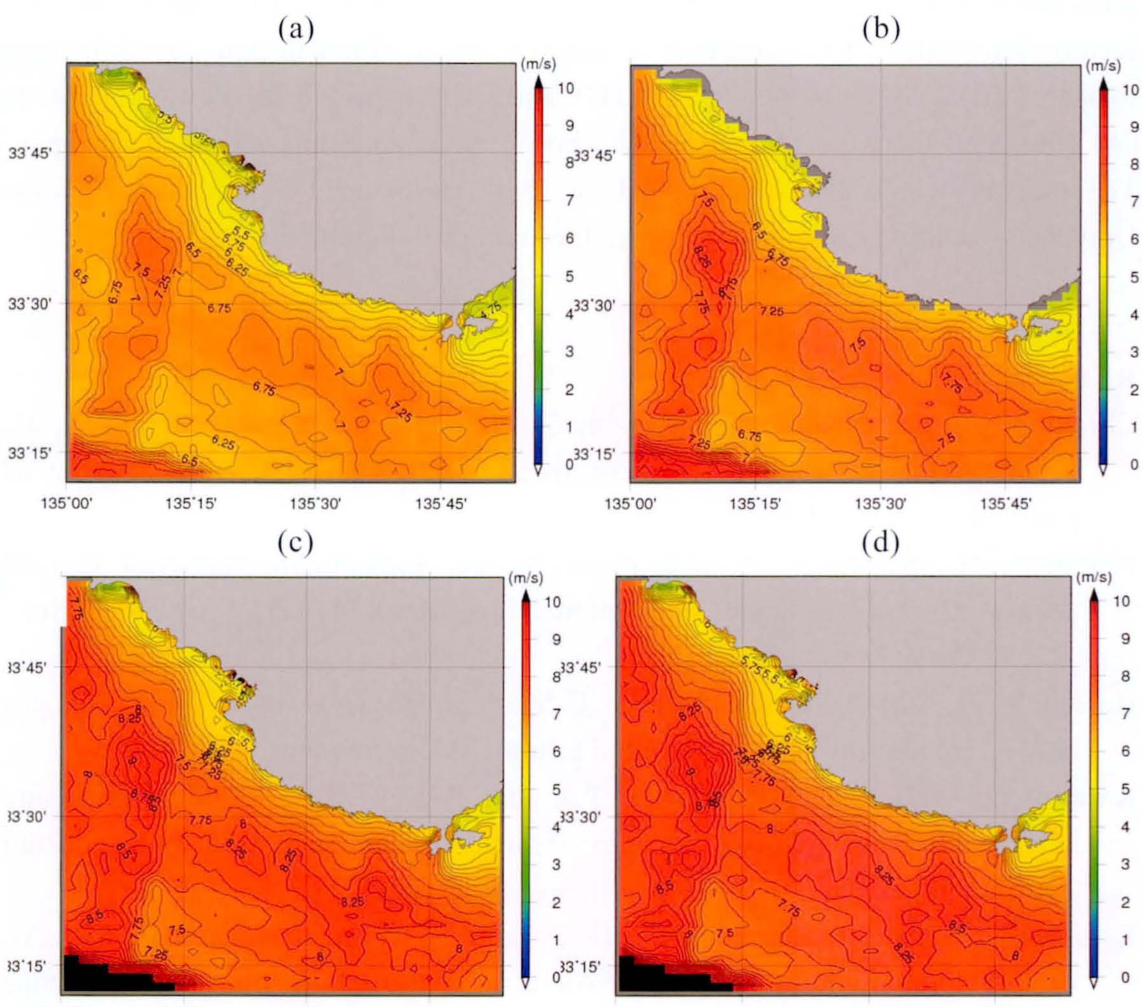

Fig. 3 Average wind speed distribution based on CMOD4(a), CMOD-IFR2(b), CMOD5(c) and CMOD5N_SDW(d) algorithms respectively

4. CONCLUSION

Based on the results above, conclusions are summarized as follows.

(1) SAR wind speed algorithms considering atmospheric stability (CMOD5N_SDW) show lower errors and biases of wind speed and energy density than the other algorithms applied in this study.

(2) Mean wind speed and energy density of CMOD5N_SDW considering atmospheric stability is higher than those of other algorithms used at Shirahama.

(3) The two conclusions above indicate that it is inevitable to consider the atmospheric stability effect on wind speed retrieval using synthetic aperture radar.

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