INVESTIGATION ON METHODOLOGY OF OFFSHORE WIND RESOURCE ASSESSMENT BY USING SYNTHETIC APERTURE RADAR

PI No.394

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ABSTRACT

In the aim of promoting the development of offshore wind power generation around Japan, this study investigates the methodology of offshore wind resource assessment by synthetic aperture radar. Target sites are Tanabe Bay in Wakayama Prefecture and Sagami Bay in Kanagawa Prefecture, where in situ offshore wind measurements are available at marine tower stations of Kyoto University and National Research Institute for Earth Science and Disaster Prevention, respectively. For wind speed estimation, ALOS/PALSAR data is used and then the results are compared with those from ENVISAT/ASAR, which have already been used to estimate wind speed at both sites under other our projects. This study mainly consists of two tasks as follows: 1) Comparison of wind speed estimation accuracy among sensors, bands, modes, polarizations and model functions, etc., and 2) Utilizing wind direction from a mesoscale meteorological model as input to SAR-based wind estimation method. As a result of the above tasks, this study finally proposes a promising SAR-based method for offshore wind resource assessment.

1. INTRODUCTION

Offshore wind estimates in open oceans are generally provided by satellite scatterometers. However those estimates are not directly applicable for coastal waters due to the scatterometer's spatial resolution more than 20km. On the other hand the needs for evaluating offshore wind as an energy resource have been growing rapidly with increasing interests of offshore wind as a renewable energy. Offshore wind estimates with high spatial resolution by using C-band synthetic aperture radar (SAR) show a promising approach to evaluate offshore wind energy potential [1]. However no established approaches exist to evaluate offshore wind resource by using L-band model function [2]. Therefore the purpose of this study is to validate a new methodology for the offshore wind resource assessment suitable for Japanese coastal waters.

2. DATA AND METHOD

12 PALSAR Fine Beam mode scenes covering the Shirahama offshore marine meteorological station in Tanabe Bay and 23 ScanSAR mode scenes covering Hiratsuka offshore marine meteorological station in Sagami Bay are acquired from Japan Aerospace Exploration Agency (JAXA) from 2006 to 2008. The PALSAR scenes are processed to derive Normalized Radar Cross Section (NRCS) called sigma nought using the equation proposed by Shimada et al. [3]. An example of geometrically-corrected PALSAR scene is shown in Figs. 1 and 2. As far as the in situ data is concerned, the Shirahama and Hiratsuka marine meteorological stations recording hourly 10-min averaged wind speed and direction in Tanabe Bay and Sagami Bay are indicated in Fig. 3. These wind speeds and directions are measured at the height of 23m above the mean sea level at both stations. Since the wind speed estimates based on the L-band model function are provided at the height of 10m, a logarithmic wind profile model assuming neutral stability is applied to convert the wind speed at the height of 23m to the one at the height of 10m for validation as follows.

$$V_{10}=\ln(10/Z_0)/\ln(23/Z_0)*V_{23} \qquad (1)$$

where V_{10}, V_{23} are the wind speeds at the height of 10m and 23m respectively. Z_0 represents sea surface roughness (2.0×10^{-4}m).

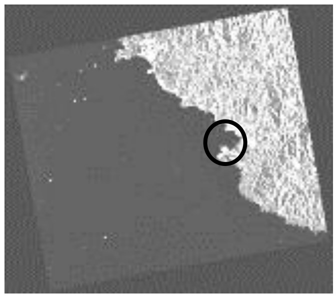

Fig.1 Example of PALSAR scene (Fine beam mode, Dec.13, 2007 (left), Circle indicates the location of the marine meteorological station at Shirahama.)

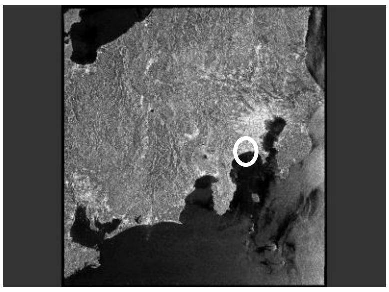

Fig.2 Example of PALSAR scene (ScanSAR mode, Jul.9, 2008). Circle indicates the location of the marine meteorological station at Hiratsuka.)

Fig. 3 Marine meteorological stations at Shirahama (right) and Hiratsuka (left)

Estimation of offshore wind speed by using L-band SAR is usually carried out by an algorithm so called L-band model function (LMOD) [2], which requires inputs of relative wind direction. This is defined as the observed or estimated wind direction relative to the SAR viewing direction at the time of SAR overpass. In this study in situ wind directions recorded at the marine meteorological station at Shirahama and Hiratsuka are used for estimating wind speed distribution. Fig. 4 indicates an example of the relationship between the sigma nought (Normalized Radar Cross Section, NRCS) and wind speed at the incidence angle of 36 degrees and the relative wind direction of 253 degrees derived from the L-band model function.

However the observed offshore wind direction at the time of SAR overpass is hard to acquire for the whole of the SAR image. Therefore we propose the use of mesoscale model-simulated wind direction as input to the L-band model function. We here use the mesoscale model MM5, which is described as follows and in Table 1 and Fig. 5.

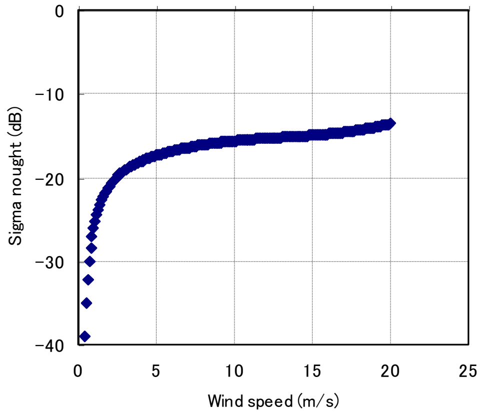

Fig. 4 Relationship between sigma nought (Normalized Radar Cross Section, NRCS) and wind speed at the incidence angle of 36 degrees and the relative wind direction of 253 degrees derived from the L-band model function.

MM5 is the Fifth-Generation Mesoscale Model (MM5, version 3.7) and a non-hydrostatic, fully compressible, terrain-following sigma-coordinate model designed to simulate mesoscale meteorological phenomena. The model is developed by Pennsylvania State University and National Center for Atmospheric Research (NCAR) and includes a large number of physics options regarding cloud microphysics, cumulus parameterization, short and long wave radiation, planetary boundary layer (PBL) and surface processes. Additionally, the model supports multiple nesting and four-dimensional data assimilation options, which enable to simulate past meteorological conditions precisely. General descriptions of MM5 are given by Dudhia [5] and Grell et al. [6]. MM5 is found to be a powerful tool to estimate wind fields in Japanese coastal waters over a long period of time [7]. However the accuracy of the instantaneous wind field simulated in the mesoscale model is known to be less than that retrieved from SAR [8]. Therefore we attempt to develop a new method for the offshore wind resource assessment suitable for Japanese coastal waters by combining each advantage of SAR and the numerical simulation with MM5.

Table 1 Model configuration and input data used in the simulation

Period	For Descending Case 18:00 UTC Day N-1 to 6:00 UTC Day N For Ascending Case 6:00 UTC Day N to 18:00 UTC Day N
Input data	JMA 6-hourly 10kmx10km Meso Analysis Weekly NOAA OI SST
Nesting	2-way nesting
Domain	Domain 1: 3km (120x120 grids) Domain 2: 1km (69x69 grids)
Vertical layer	26 levels (Surface to 100 hPa)
Time step	Domain 1: 10 sec Domain 2: 3.3 sec
Physics Options	Reisner graupel (Reisner 2) microphysics scheme Cumulus parameterization scheme not used Shallow convection scheme Cloud-radiation scheme Eta planetary boundary layer scheme Five-layer soil model

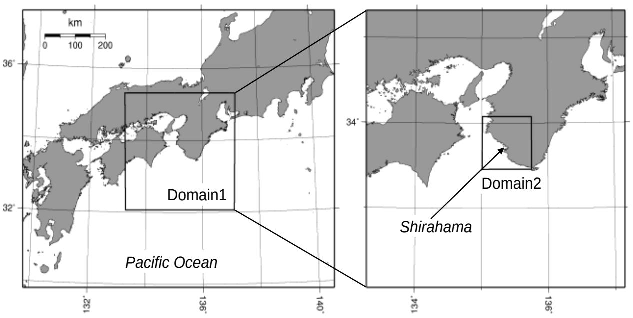

Fig. 5 MM5 domains for Shirahama

3. RESULTS AND DISCUSSION

The ScanSAR-estimated wind speed with the in situ wind direction is compared with in situ measurements from the marine meteorological stations at Shirahama and Hiratsuka. The result of the comparison is shown in Fig. 6 for Hiratsuka. Estimated wind speeds are mostly overestimated in comparison with observed wind speeds. In order to clarify the relationship between the wind speed error (estimated – observed) and the incident angle it is illustrated in Fig.7 for Hiratsuka. Based on this figure it is found that wind speed errors are increased as the incident angle is increased. Since these errors are seemed to be systematic, it is suspicious that ScanSAR mode image itself includes some systematic noises. Fig.8 is an example of the ScanSAR mode image including some striped noises in Sagami Bay. Since these noises are seemed to be aligned with the range direction, azimuth ambiguity is suspected [9]. It is also reported that ground radar interference sometimes degrades PALSAR image quality near the coast, which results in errors in detecting wind speeds [9]. Fig. 9 shows the distribution of estimated wind speed. Estimated wind speed at Hiratsuka is 7.6m/s, while observed wind speed and direction is 3.6m/s, 203 degrees respectively. The cause of this error is attributable to azimuth ambiguity along the coast of Hiratsuka.

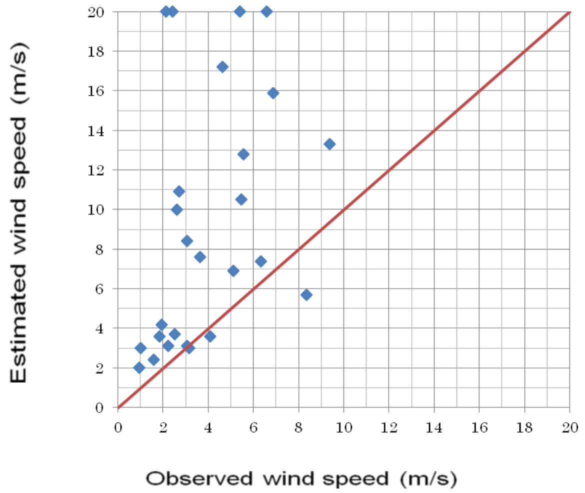

Fig. 6 Result of comparison between estimated (500m, ScanSAR mode, in situ wind direction as input) and observed wind speed at Hiratsuka

Fig. 7 Result of comparison between estimated-observed wind speed and incident angle at Hiratsuka

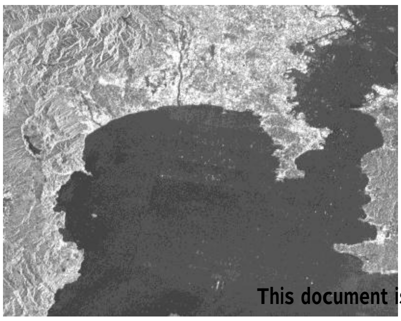

Fig. 8 Enlarged PALSAR ScanSAR mode image (Jul.4, 2008) including some striped noises along the range direction in Sagami Bay

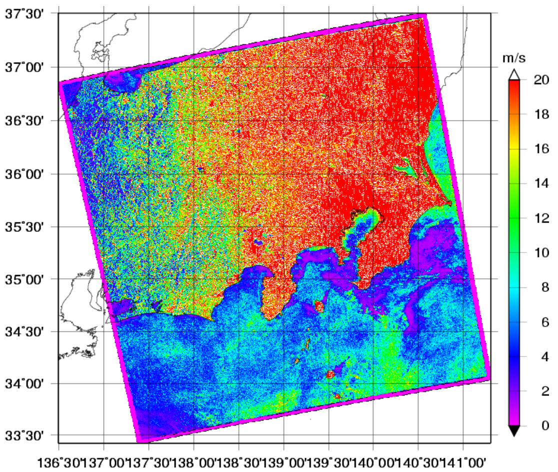

Fig. 9 Distribution of estimated wind speed (Jun.23, 2006) based on L-band model function and in situ wind direction

The accuracy of offshore wind for the Fine Beam mode image is evaluated using in situ measurements from the marine meteorological station at Shirahama. Fig. 10 shows the result of comparison between the estimated and observed wind speeds at Shirahama for two cases. One is to use in situ wind direction as input to L-band model function. The other is to use MM5-simulated wind direction as input to L-band model function. The bias and RMS errors are 0.07m/s, 1.97m/s for in situ wind direction as input, -0.13m/s, 2.25m/s for MM-5 simulated wind direction as input respectively. Since the previous study using ASAR (C-band SAR onboard ENVISAT) for the same study area indicates that the bias is 0.13m/s and the RMS error is 1.93m/s for the in situ wind direction as input [4], these errors of PALSAR Fine Beam mode image are comparable to those of ASAR image.

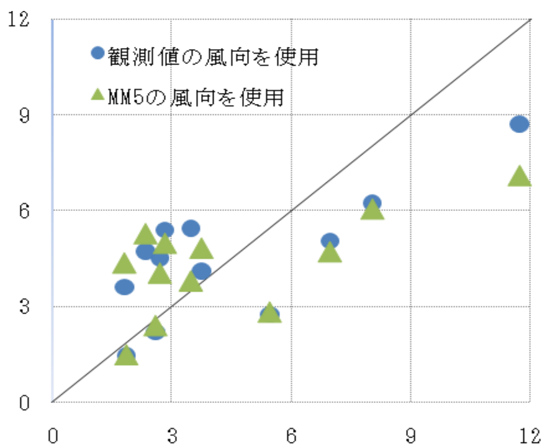

Fig. 10 Result of comparison between the estimated and observed wind speeds at Shirahama for two cases. One is to use in situ wind direction. The other is to use MM5-simulated wind direction.

Fig. 11 shows an example of estimated offshore wind speed distribution based on in situ wind direction as input. Note the estimated wind speed at Shirahama is 4.4m/s, while the observed wind speed and direction at Shirahama are 2.7m/s and 35 degrees respectively. A calm area is seen around the Shirahama meteorological station and along the coast. Fig. 12 is another example of estimated offshore wind speed distribution based on MM5-simul nated wind speed at Shirahama is 4.1m/s, while the observed wind speed and direction at Shirahama are 2.7m/s, 35 degrees respectively. The differences between the estimated wind speeds based on in situ wind direction and the estimated wind speeds based on the MM5-simulated wind direction are shown in Fig.13. The differences are calculated as the estimated wind speed based on in situ wind direction minus the estimated wind speed based on the MM5-simulated wind direction. These positive differences along the coast are attributable to the fact that the easterly wind is influenced by the onshore complex terrains. These phenomena are also seen in the estimated wind speed distribution by using C-band synthetic aperture radar ASAR onboard ENVISAT [10] and are consistent with the results obtained by Hasager et al. [11], which indicates that SAR wind estimates work well for onshore flow (wind from sea), and not for offshore flow (wind from land) near the coastline.

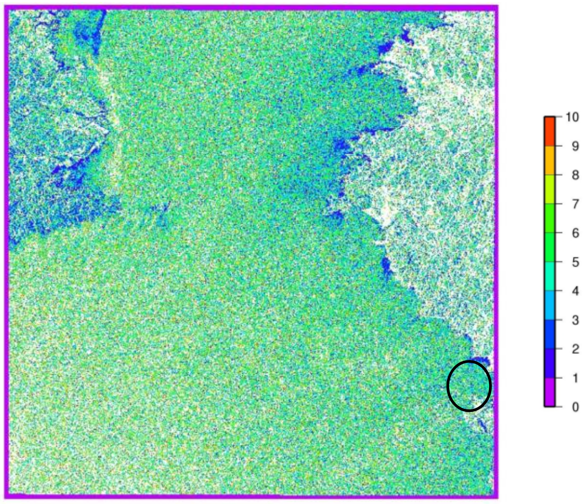

Fig. 11 An example of estimated offshore wind speed distribution based on L-band model function and in situ wind direction (Nov.18, 2006). Circle indicates the location of Shirahama meteorological station (unit:m/s)

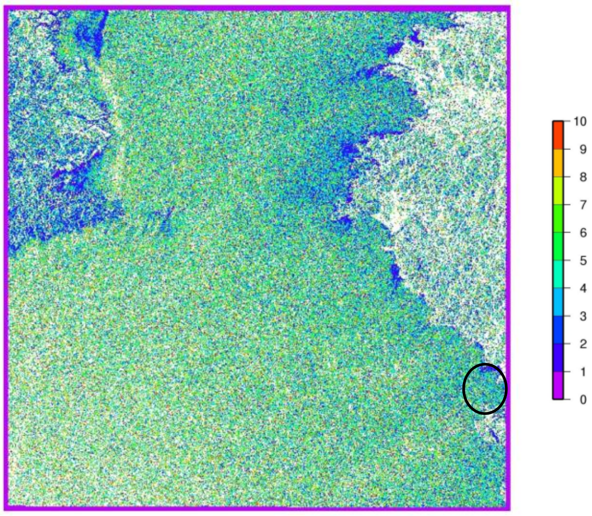

Fig. 12 An example of estimated offshore wind speed distribution based on L-band model function and MM5-simulated wind direction (Nov.18, 2006). Circle indicates the location of Shirahama meteorological station (unit:m/s)

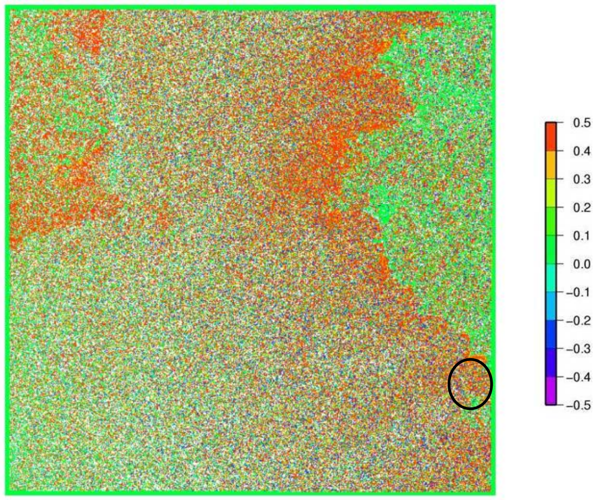

Fig. 13 Distribution of wind speed difference between the estimated (in situ wind direction as input) and the estimated (MM5-simulated wind direction as input) wind speed. Circle indicates the location of Shirahama meteorological station (unit:m/s)

4. CONCLUSION

Based on the results and discussion above, conclusions are obtained as follows.

1. The results of validation on the offshore wind speed using Fine Beam mode images at Shirahama are as follows. The bias and RMS errors are 0.07m/s, 1.97m/s for in situ wind direction as input, -0.13m/s, 2.25m/s for MM-5 simulated wind direction as input respectively. And these errors of PALSAR Fine Beam mode image are comparable to those of ASAR image described in previous studies.

2. Because of azimuth ambiguity seen in the coastal areas of ScanSAR images it should be cautious for using estimated offshore wind speeds by LMOD. Fine Beam mode images are recommended for estimating offshore wind speeds by LMOD with incidence angle corrections (ascending only).

3. Based on the first conclusion above the differences of biases and RMS errors between in situ wind direction as input and MM5-simulated wind direction as input are small, MM5-simulated wind direction as input to the L-band model function (LMOD) will be a promising approach for estimating wind speeds without observed wind directions.

5. ACKNOWLEDGEMENTS

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