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Takeyama, Yuko; Ohsawa, Teruo; Kozai, Katsutoshi; Hasager, Charlotte Bay; Badger, Merete

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# Effect of Wind Direction on ENVISAT ASAR Wind Speed Retrieval

Yuko Takeyama

National Institute of Advanced Industrial Science and Technology, JAPAN

Teruo Ohsawa, Katsutoshi Kozai

Graduate School of Maritime Sciences, Kobe University, JAPAN

Charlotte Hasager, Merete Badger

Risoe National Laboratory for Sustainable Energy, Technical University of Denmark

**Abstract** - This paper presents an evaluation of effects of wind directions (NCEP, MANAL, QuickSCAT and WRF) on the sea surface wind speed retrieval from 75 ENVISAT ASAR images with four C-band Geophysical model functions, CMOD4, CMOD\_IFR2, CMOD5 and CMOD5N at two target areas, Hiratsuka and Shirahama. As results, the WRF wind direction retrieves sea surface wind speeds with higher accuracies of the other wind directions at Hiratsuka. On the other hand, at Shirahama, it is not found an advantage of the WRF wind direction. Thus, the WRF wind direction cannot always retrieve wind speed with a high accuracy. However, a wind speed error generated with the WRF wind direction is the smallest of those with the other wind directions, and the error is as small as the level of SAR original radiometric errors. Consequently, the WRF wind direction is the most suitable of the four wind directions on the SAR wind speed retrieval when other error factors of the SAR wind speed retrieval are eliminated.

## I. INTRODUCTION

Offshore wind resources can be assessed from wind speeds retrieved by satellite-borne Synthetic Aperture Radar (SAR) images and the Weibull fitting method. The SAR wind speed retrieval with a high accuracy is required for correct estimation of the amount. In a previous study, it was shown that the SAR wind speed has a Root Mean Square Error (RMSE) of around 1.5 m/s [1]. In general, when the SAR wind speed is retrieved, wind direction is necessary as an input value for the geophysical model function (GMF). In order to obtain the wind direction, two methods have been proposed in previous studies. One is the method to use wind streak detection from a SAR image itself [2], and the other is the utilization of the objective analysis data. In the case of the former, the wind direction retrieved from the wind streak is temporally and spatially synchronized with the SAR wind speed. However, the wind streak cannot always be detected from all SAR images. On the other hand, the latter has the advantage of obtaining the wind direction field at constant temporal and spatial intervals. A problem is the accuracy and its effect on the accuracy of the SAR-retrieved wind speed has not been well discussed. In this paper, SAR wind speeds are retrieved with four kinds of wind directions including

objective analysis data, satellite data and numerical meteorological simulation data, and these accuracies are examined to investigate the effects of wind directions on the SAR wind speed retrieval.

## II. METHODOLOGY

### A. ENVISAT ASAR images

ASAR images (image mode precision (IMP)) have been collected over the period 2003-2008 in this study. Two target areas are Hiratsuka ( $35^{\circ} 18' 20''$  N,  $139^{\circ} 20' 45''$  E) and Shirahama ( $35^{\circ} 42' 32''$  N,  $135^{\circ} 19' 58''$  E) in Japan (Fig. 1), and sea surface wind speeds are retrieved from total of 75 ASAR images covering either Hiratsuka (33 images) or Shirahama (42 images). The observation time of ASAR is around 01 (descending) or 21 (ascending) UTC in Japan. The ASAR IMP mode observes approximately  $100 \text{ km} \times 100 \text{ km}$  earth surface with  $30 \text{ m} \times 30 \text{ m}$  special resolutions. All grids of ASAR images are

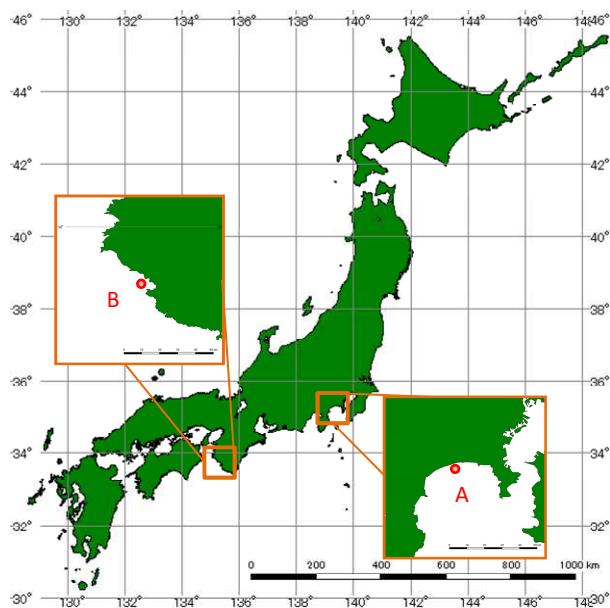


Fig.1 Geographical location of Hiratsuka (A) and Shirahama (B).

resampled to  $200 \text{ m} \times 200 \text{ m}$  grid size after wind speeds are retrieved with GMFs.

### B. In situ measurement

There are marine observation platforms at both Hiratsuka and Shirahama, respectively. Sea surface wind speed and direction have been continuously measured at 23 m above the mean surface level (MSL) at both platforms. Moreover, at the platforms, air and sea temperature are also measured. Respective measured elements are described in Table I.

### C. SAR wind speed retrieval

Sea surface wind is retrieved from the SAR image with GMF, which empirically relates the normalized radar cross section (NRCS) with sea surface wind speed, relative wind direction and radar incidence angle. That is, the GMF assumes that the NRCS at a specific grid is only influenced by local changes in both wind speed and direction. Based on this assumption, four C-band GMFs, CMOD4 [3], CMOD\_IFR2 [4], CMOD5 [5] and CMOD5N [6], were developed. In this paper, all of the four C-band GMFs are used for wind speed retrieval, and retrieved wind speeds are compared each other.

Since the all GMFs have been developed for VV-polarized NRCS, HH-polarized NRCS must be corrected by an empirical equation before the GMF processing. In order to convert from the HH-polarized NRCS to the VV-polarized NRCS, Mouche *et al.* (2005)'s equation [7] is used in this study.

In situ measurement (ISM) and four kinds of wind directions; the National Cholesterol Education Program (NCEP) Re-analysis data, the Japan meteorological agency (JMA) mesoscale analysis data (MANAL), the QuickSCAT winds, the output of Weather Research and

Forecasting model (WRF) are used for the sea surface wind retrieval from SAR images. Temporal and horizontal resolutions of all of the five wind directions are described in Table II.

### D. Height correction

Using GMFs, wind speed is obtained at 10 m above sea surface, while in situ wind speed is measured at 23 m at both platforms. Therefore, height correction of the in situ wind speed is necessary to enable direct comparison with the retrieved wind speed from SAR. In order to estimate the wind speed at 10 m from that at 23 m, this study uses the LKB code [8], which can calculate a vertical wind profile based on the Monin-Obukhov similarity theory.

## III. RESULTS AND DISCUSSION

### A. Accuracies of four wind directions

As a first step, accuracies of wind directions themselves are discussed in this section. In Table III, Mean Absolute Errors (MAEs) of four wind directions are shown. At both Hiratsuka and Shirahama, MAEs of the WRF wind direction are the smallest of the other wind directions. Moreover, the NCEP, MANAL and QuickSCAT wind directions have large MAEs of 67 degrees or more. Since the WRF wind direction has higher temporal and horizontal resolutions, those MAEs are considered to become lower than the other wind directions.

### B. Effect of four wind directions

Figs. 2 and 3 show RMSEs and biases of SAR-retrieved wind speeds using four GMFs with five kinds of wind directions at Hiratsuka, respectively. Notice the average (orange line) of GMFs, the NCEP and WRF wind directions have smaller RMSEs of wind speeds than the MANAL and QuickSCAT wind directions. The difference of RMSE between ISM and NCEP is 0.07 m/s and that between ISM and WRF is 0.02 m/s. Moreover, the absolute bias in the case of using the WRF wind direction is lower than those using the other three wind directions. These results imply that the WRF is the most suitable wind direction in the four wind directions at Hiratsuka.

In the case of Shirahama (Figs. 4 and 5), all wind directions have RMSEs of 2.0 to 2.3 m/s, and there are no large differences of those RMSEs. Moreover, the biases using the MANAL, QuickSCAT and WRF wind directions have large differences from biases of the case of Hiratsuka. These results suggest that the WRF wind direction cannot always retrieve the SAR wind speed with a high accuracy.

As the next step, Table IV shows RMSEs of SAR-retrieved wind speeds using CMOD5 with four wind directions; NCEP, MANAL, QuickSCAT and WRF under the assumption that the SAR-retrieved wind speed with ISM is an actual wind speeds. In other words, these RMSEs are errors generated only by differences of wind directions. This table shows that errors of wind directions contribute 26 % of relative errors of SAR wind speed at the

TABLE I

Measured elements at marine platforms.

Site	Elements	Observation height (reference MSL)	Remark
Hiratsuka	Air temperature	above 20 m	Resistance temperature sensor
	Sea temperature	below 3 m	
	Wind speed and direction	above 23 m	Propeller anemometer
Shirahama	Air temperature	above 15 m	Resistance temperature sensor
	Sea temperature	below 5 m	
	Wind speed and direction	above 23 m	Propeller anemometer

TABLE II

Temporal and horizontal resolutions of wind directions.

Wind direction	Temporal resolution	Horizontal resolution
ISM	1 hour	on site
NCEP	6 hours (0, 6, 12, 18 UTC)	$2.5^\circ \times 2.5^\circ$
MANAL	6 hours (0, 6, 12, 21) or 3 hours (0, 3, 6, 9, 12, 15, 18, 21)	10 km $\times$ 10 km or 5 km $\times$ 5 km
QuickSCAT	1 day	12.5 km $\times$ 12.5 km
WRF	1 hour	500 m $\times$ 500 m

TABLE III

MAEs of four wind directions at Hiratsuka and Shirahama.

	ISM	NCEP	MANAL	QuickSCAT	WRF
Hiratsuka		76.5	71.9	77.3	<b>64.0</b>
Shirahama		73.1	67.3	79.3	<b>56.6</b>
					(deg.)

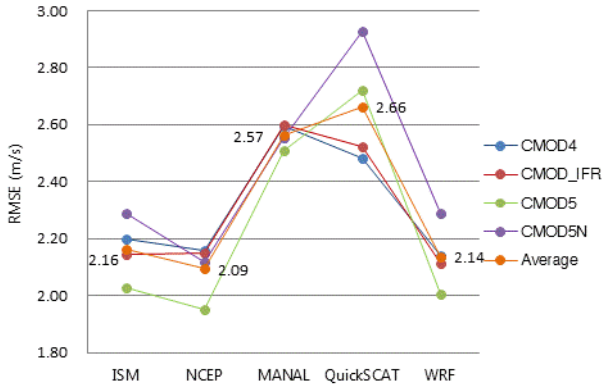


Fig. 2 RMSEs (m/s) of SAR wind speed retrieved by GMFs (CMOD4, CMOD\_IFR2, CMOD5 and CMOD5N) with five wind directions (ISM, NCEP, MANAL, QuickSCAT and WRF) at Hiratsuka.

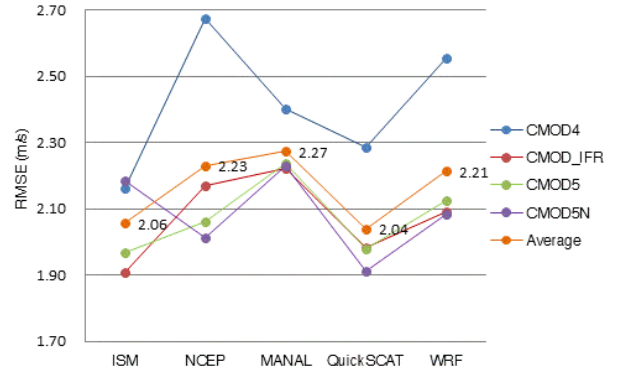


Fig. 4 RMSEs (m/s) of SAR wind speed retrieved by four GMFs with five wind directions at Shirahama. Five written values are average of all GMFs.

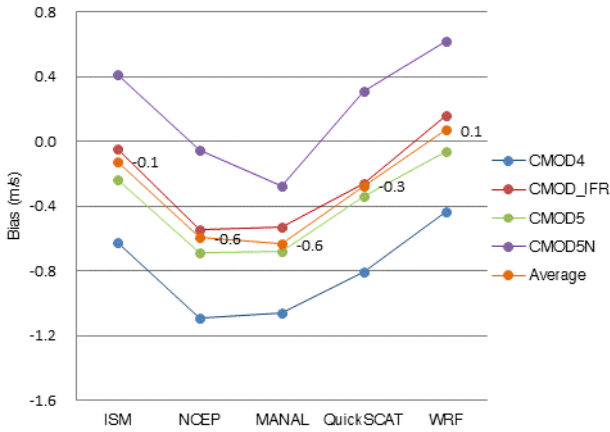


Fig. 3 Same as in Fig. 2 but for biases (m/s).

maximum. Moreover, relative errors with the WRF wind direction are smaller than the other three wind directions. Thus, the WRF wind direction, which is the closest to the actual wind direction, generates the smallest errors of the all wind directions. Consequently, the WRF wind direction can retrieve the SAR wind speed with a higher accuracy of the other wind directions if the SAR wind speed could be retrieved correctly using ISM and GMFs.

### C. Evaluation of Wind Speed Errors caused by WRF wind direction

In this section, NRCSs estimated from in situ wind speeds, radar incidence angles and four wind directions with three GMFs; CMOD4, CMOD5 and CMOD\_IFR are compared with NRCSs estimated from ISM. Table V shows RMSEs of NRCS at Hiratsuka. In Table V, the case using the WRF wind direction has the smallest RMSE than other cases, and these RMSEs are smaller than 0.75 dB. Similarly, in the case of Shirahama (Table VI), the WRF wind direction exhibits the smallest RMSE. In a previous study, ASAR radiometric stability was reported to be 0.2 - 0.7 dB [9]. Consequently, the error generated by the WRF wind direction is considered to be the same level as the

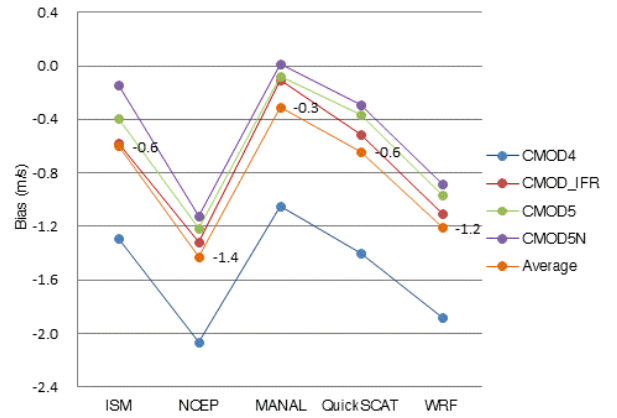


Fig. 5 Same as in Fig. 4 but for biases (m/s).

ASAR original error. Those results also indicate that the WRF wind direction leads the SAR-retrieved wind speed with a higher accuracy when the SAR wind speed can be retrieved with a high accuracy using ISM and GMFs.

## IV. CONCLUSION

In the present work, to disclose the effect of wind direction on ENVISAT ASAR wind speed retrieval, five kinds of wind directions have been attempted in the wind speed retrieval with four GMFs.

Results are as follows:

- 1) The AME of the WRF wind direction is smaller than the other three wind directions (NCEP, MANAL and QuickSCAT).
- 2) In the case of Hiratsuka, the WRF is the most suitable wind direction of the other wind directions. However, the WRF wind direction cannot always estimate the SAR-retrieved wind speed with a high accuracy.
- 3) Under the assumption that the SAR-retrieved wind speeds with ISM are actual wind speeds, the WRF wind direction has the smallest relative error of the other wind directions.
- 4) Errors of NRCS generated by the WRF wind direction

TABLE IV

RMSEs of SAR retrieved wind speed using CMOD5 with NCEP, MANAL, QuickSCAT and WRF wind directions when SAR wind speed with ISM is set as actual wind speeds.

	ISM	NCEP	MANAL	QuickSCAT	WRF
Hiratsuka		0.89 (17%)	1.28 (24%)	1.39 (26%)	0.64 (12%)
Shirahama		1.59 (23%)	1.83 (26%)	1.39 (20%)	1.33 (19%)
					(m/s)

TABLE V

RMSEs of NRCS at Hiratsuka.

	ISM	NCEP	MANAL	QuickSCAT	WRF
CMOD4		1.18	1.22	1.19	<b>0.68</b>
CMOD_IFR		1.17	1.43	1.15	<b>0.75</b>
CMOD5		0.99	1.00	1.05	<b>0.55</b>
					(dB)

TABLE VI

RMSEs of NRCS at Shirahama.

	ISM	NCEP	MANAL	QuickSCAT	WRF
CMOD4		1.03	1.00	0.91	<b>0.79</b>
CMOD_IFR		0.98	0.96	0.86	<b>0.73</b>
CMOD5		0.85	0.80	0.75	<b>0.66</b>
					(dB)

are the same level as original errors of ASAR images.

- 5) Those results indicate that the WRF wind direction is the most suitable for the sea surface wind retrieval with C-band GMFs when other error factors on the SAR wind speed retrieval are eliminated.

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