Wind Field Estimation Using ERS-1 SAR Data: The Initial Report

Joong-Sun WON*, Hyung-Sup JEONG* and Taerim KIM**

*Dept. of Earth System Sciences, Yonsei University
**Korea Ocean Research & Development Institute
Ph.) +82-2-361-2673, Fax) +82-2-392-6527
e-mail) jswon@bubble.yonsei.ac.kr

Abstract

SAR has provided weather independent images on land and sea surface, which can be used for extracting various useful informations. Recently attempts to estimate wind field parameters from SAR images over the oceans have been made by various groups over the world. Although scatterometer loaded in ERS-1 and ERS-2 observes the global wind vector field at spatial resolution of 50 Km with accuracies of ±2m/s in speed, the spatial resolution may not be good enough for applications in coastal regions. It is well known the sea surface roughness is closely correlated to the wind field, but the wind retrieval algorithms from SAR images are yet in developing stage. Since the radar backscattering properties of the SAR images are principally the same as that of scatterometer, some previous studies conducted by other groups report the success in mesoscale coastal wind field retrievals using ERS SAR images.

We have tested SWA (SAR Wind Algorithm) and CMOD4 model for estimation of wind speed using an ERS-1 SAR image acquired near Cheju Island, Korea, in October 11, 1994. The precise estimation of sigma nought and the direction of wind are required for applying the CMOD4 model to estimate wind speed. The wind speed in the test sub-image is estimated to be about 10.5m/s, which relatively well agrees to the observed wind speed about 9.0m/s at Seoguipo station. The wind speed estimation through the SWA is slightly higher than that of CMOD4 model. The sea surface condition may be favorable to SWA on the specific date. Since the CMOD4 model requires either wind direction or wind speed to retrieve the wind field, we should estimate the wind speed first using other algorithm including SWA. So far, it is not conclusive if the SWA can be used to provide input wind speed data for CMOD4 model or not.

Since it is only initial stage of implementing the wind field retrieval algorithms and no in-situ observed data is currently avaliable, we are not able to evaluate the accuracy of the results at the moment. Therefore verification studies should be followed in the future to extract reliable wind field information in the coastal region using ERS SAR images.

1. Introduction

Synthetic aperture radar(SAR) has provided very useful images over the land and ocean which can be utilized for various applications. In addition to the valuable rendition of ocean surface features including wave spectra, internal wave, and etc., SAR images over the ocean has been considered to have potential of providing wind vector information. The wind fields over the ocean has been accurately measured by the scatterometer(SCAT) aboard the ERS-1 and ERS-2. The SCAT can access wind direction in addition to the wind speed by utilizing its three antennas. The resolution of SCAT is about 45x45km with accuracies of ±2 m/sec in speed and 20° in direction with a directional ambiguity of 180° (Stoffelen and Anderson, 1993). The ERS SAR is an instrument operating at the same wavelength as ERS SCAT with spatial resolution of 25x25m, and therefore ERS SAR images could be useful to retrieve wind vector information. Finer resolution wind vector can be useful particularly in coastal region. Therefore SAR systems provide the promise of such higher resolution wind data if appropriate algorithms are developed. The possibility of the wind field retrieval using ERS SAR imagery have recently been reported by various groups, for instances Vachon and Dobson(1996), Wackerman et al.(1996), Korsbakken et al.(1997).

In this paper we report on some preliminary test results of extracting wind speed from ERS SAR imagery of the ocean near to the Cheju Island, Korea. Unfortunately, no in-situ observation data is not available on the specific date of the ERS SAR acquisition. Instead of sea-truth data, we have used the wind speed and direction data measured at Seoguipo to evaluate the estimated wind speed. The main object reported in this paper is to evaluate the feasibility and effectiveness of two types of known wind field retrieval algorithms, the SAR wind algorithms(SWA) and the CMOD4 model based approach. For this test, we have implemented the ERS SAR calibration program in C-language for extracting the normalized radar cross-section in addition to the two main algorithms for wind speed estimation. In the next sections we will briefly review the algorithms followed by the test results.

2. Wind Retrieval Algorithms

In recent years, two algorithms are popularly applied to estimate wind speed from ERS SAR images: the one is SAR wind algorithm(SWA), and the other is CMOD4 model. The former is based upon the extraction of wind field (so called azimuth cut-off wavelength) from different parts of the ocean surface wave spectra (Chapron et al., 1995), while the latter is upon the empiric C-band radar backscattering model (CMOD4) developed for ERS SCAT (Stoffelen and Anderson, 1993).

a) SAR Wind Algorithm (SWA)

Gravity wave orbital motions are known to induce Doppler misregistrations during integration to lead to a distortion of the imaged spectrum and a strong cutoff in the azimuth direction which has been shown to be wind speed dependent (Vachon et al., 1995). Kerbaol et al.(1996) proposed a method to estimate the SAR azimuth cutoff by fitting the azimuthal autocorrelation function with a Gaussian function defined as:

$$C(x) \sim e^{-\pi \frac{x^2}{\lambda^2}} \qquad (1)$$

where λ is SAR azimuth cutoff, and it is directly bound to the standard deviation of the standard deviation of the total azimuthal displacements field. The empirical relationship between the azimuth cutoff and the wind speed is given by

$$\lambda \approx 25\, U_{10} \quad (m/\sec) \qquad (2)$$

where U_{10} is the wind speed at 10m above the sea surface (Kerbaol et al., 1996).

Assuming a Gaussian shaped low pass filter for the azimuth cutoff, the azimuth cutoff can be estimated from the autocorrelation function(ACF) derived from an inverse Fourier transform of the SAR image power spectrum.

b) CMOD4 Model

The CMOD4 wind retrieval model (Stoffelen and Anderson, 1993) is developed for the ERS-1 C-band scatterometer but it is also shown to be useful to estimate wind speed from ERS SAR images (Vachon et al., 1995; Wackerman et al., 1996). For moderate incidence angle between 20° and 60° the backscatterer from the rough ocean surface is primary explained by resonant Bragg's scattering. The backscattered signal is caused by the water wave component which is in resonance with the incidence radiation. In case of ERS SAR with incidence angles between 20° and 23° the range of scattering wavelength extends from 8.2m to 6.5cm. Therefore, the normalized radar cross section can be used to evaluate the wind speed. The wind speed and incidence angle in CMOD4 model is given by

$$\sigma_0 = B_0[1 + B_1 \cos\varphi + B_2 \cos 2\varphi] \qquad (3)$$

where σ_0 is the normalized radar cross section and φ is the incidence angle. The coefficients B_0, B_1, and B_2 depend on the local incidence angle and wind speed given wind direction.

To apply the CMOD4 model to the ERS SAR images, one have to precisely derive the σ_0 from the image data. In the work, we have implemented the calibration scheme provided by ESA (Laur et al., 1997). The other problem to apply the CMOD4 model to ERS SAR images relies on the fact that CMOD4 model requires the wind direction parameter to estimate wind speed. One can use the in-situ data for the wind direction information or can estimate the wind direction from CMOD4 model if the wind speed is provided by other method, for instance, SWA as suggested by Korsbakken et al.(1997).

3. Test Results

The test ERS-1 SAR image was acquired on October 11, 1997, and processed on August 22, 1997, by Italian station with ESRIN format. Not only the acquisition date, but also the processed date and receiving station is required for deriving the σ_0 from the ERS SAR images. Unfortunately, no in-situ data associated with the wind field of the specific date. The observed wind speed and direction at Seoguipo meterological station are about 9m/sec and N70° E, respectively.

The Fig. 1 shows the normalized radar cross section estimated from the ERS-1 SAR image, and one can see the sharp boundary between high and low radar brightness. Since the observed data is only available at Seoguipo area, we first selected a small test region (about 6.25km$\times$6.25km) near to the Seoguipo city as marked by a square "A". By applying the SWA method, we have the azimuth cutoff of 314m as shown in Fig. 2 which corresponds to the wind speed of 12.8m/sec. In Fig. 2, the central parts of the ACF shaped as the narrow point spread function is the contribution of speckle noise. The estimated wind speed from CMOD4 model is summarized in Table 1. If the wind direction is assumed between 20° and 30° relative to the radar look direction, the wind speed from CMOD4 is ranging from 10.5m/sec to 11.3m/sec which matches well to that of the observed wind speed (9m/sec) at Seoguipo.

The SWA result is slightly higher than that of CMOD4 and the deviation is about 2.3m/sec. The main reason of this overestimation may be caused by the assumption of the SWA in Eq.(2) that all wavelengths are equally fully developed which is not always true under high wind conditions. Swell contribution is another factor should be considered in this approach. Since it is only initial stage of the test with no ground-truth data, we are not able to accurately compare the results of the two algorithms. Generally speaking, the CMOD4 model provides less fluctuated wind speed rather than SWA algorithm in our test. In the next step, we have extended the estimation to the large region marked by square "B" in Fig. 1. The region "B" (about 37.5km$\times$75km) consists of a total of 200 sub-images with each sub-image of 300$\times$300 pixels (3.75km$\times$3.75km). The results of the two algorithms are shown in Fig. 3. For the CMOD4 model, we have assumed the wind direction as 20° of relative radar look-wind direction.

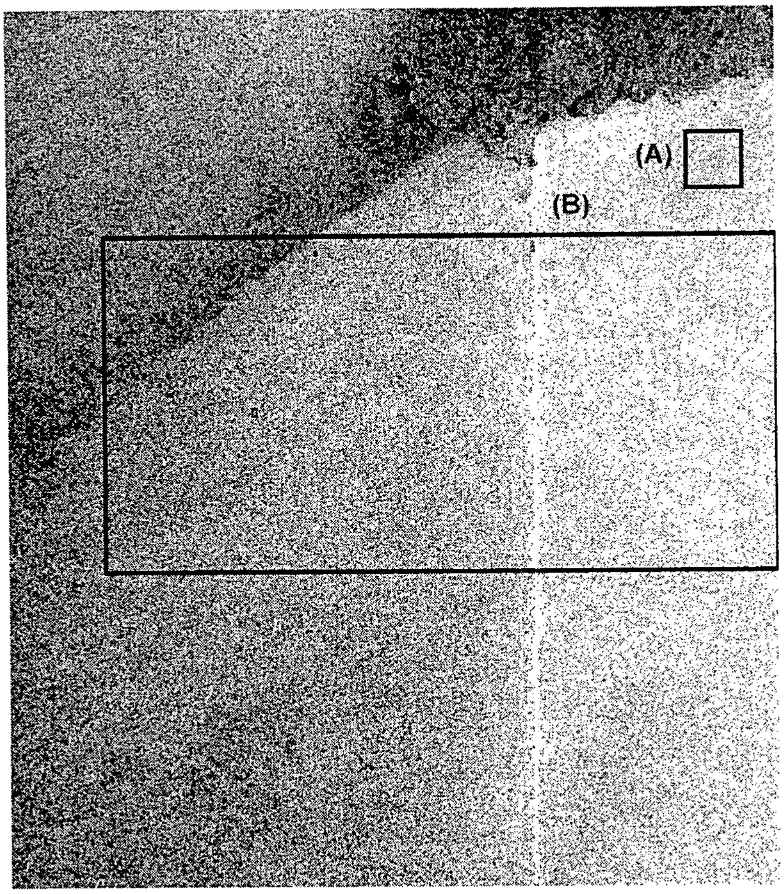


Fig. 1 Sigma nought estimated from ERS-1 SAR images used in this study.

The estimated wind speeds in CMOD4 are not accurate because we only used one direction of wind over the whole region. However, the distribution of wind speed shows gradual changes and the low and high wind speed zone is distinctively separately. On the contrary, the result of SWA in Fig. 3(b) do not agree with Fig. 3(a) and less reliable than the result of CMOD4. Fig. 4 is the plot of CMOD4 versus SWA wind speed. Among the total of 200 sub-images, about 60% has a CMOD4-SWA wind speed difference of less than 2m/sec. The largest difference between two algorithms is up to 6m/sec. As discussed above, the sea condition on that specific moment may not be ideal to apply to SWA method or the fitting process was not proper due to noise of ACF. In any case, it is not conclusive at this moment and further tests using additional data sets with in-situ data are required.

Table 1. The estimated wind speed over the test region "A" in Fig. 1 with respect to the wind direction.

Wind direction*	0°	10°	20°	30°	45°
Wind speed	9.9m/sec	10.1m/sec	10.5m/sec	11.3m/sec	13.0m/sec

* the wind direction is the relative radar look-wind, i.e. that is zero when the wind is blowing towards to the radar

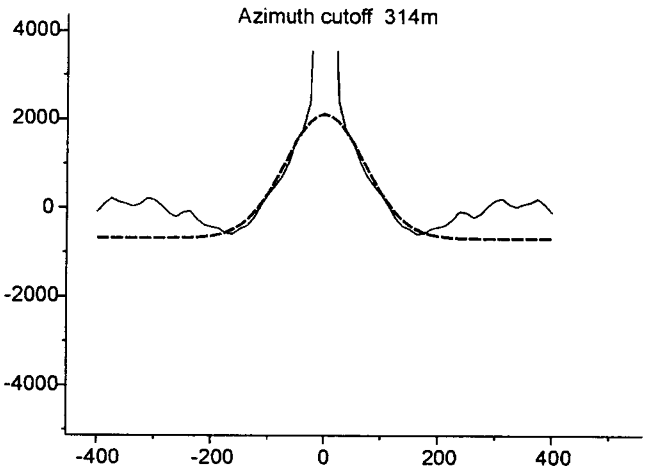
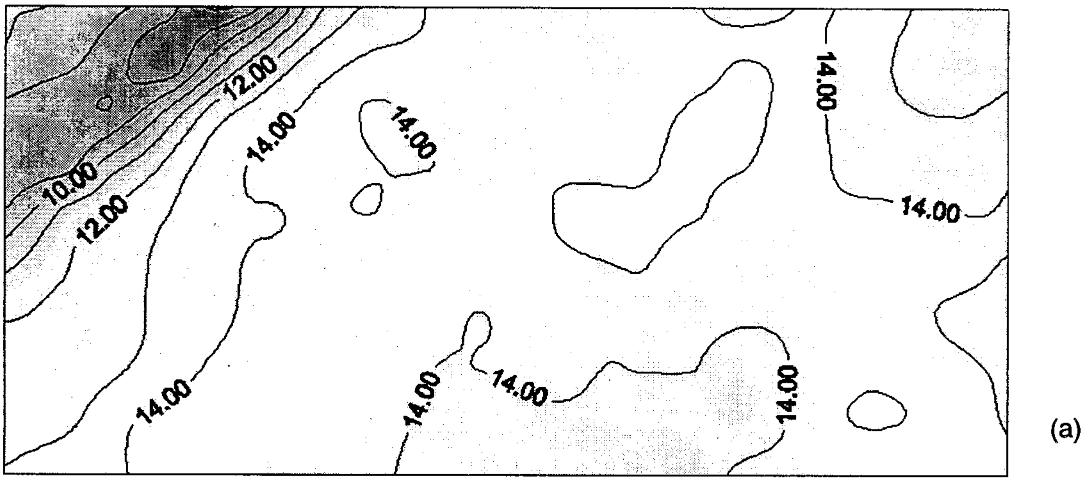


Fig. 2. Estimation of the azimuth cutoff through the azimuthal correlation function. The narrow central peak of the non-coherent scattering corresponds to the speckle noise



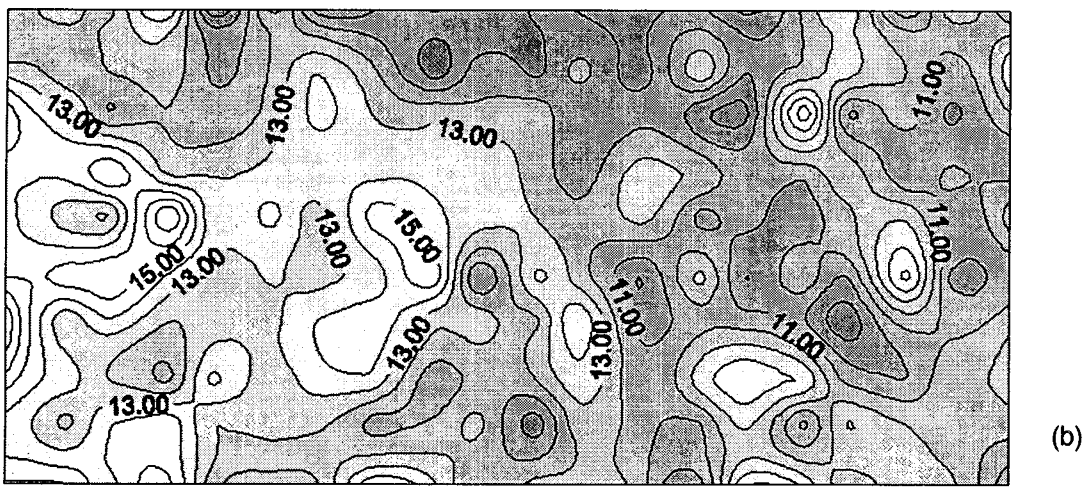


Fig. 3. The estimated wind speed from (a) CMOD4 with relative radar look-wind direction of 20° and from (b) SWA.

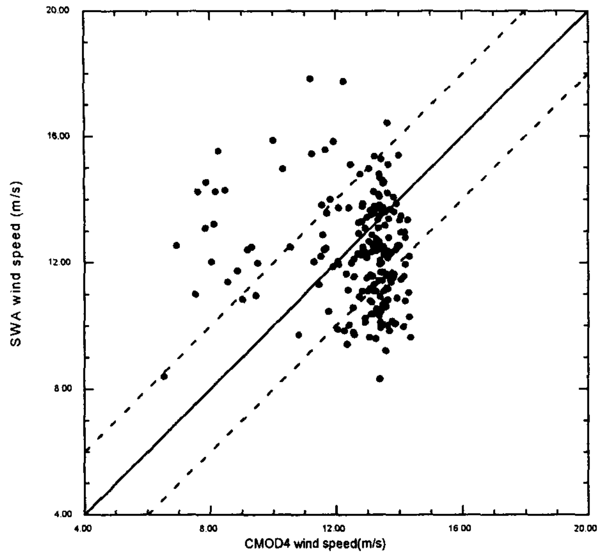


Fig. 4. CMOD4 wind speed versus SWA wind speed.

4. Conclusions and Discussions

The initial test of wind speed retrieval from ERS SAR image has been attempted by applying CMOD4 model and SWA. Since no in-situ data is available for the specific data, we have not been able to accurately compare the results of the two algorithms. The results of the two algorithms do not agree well in this initial test. CMOD4 seems to provide more reliable wind speed than SWA. However, CMOD4 model requires either wind direction or wind speed information to complete the wind vector retrieval. Therefore combined applications of both algorithms become necessary. Further tests should be followed with in-situ data to systematically compare the two algorithms and establish a complete approach to retrieve wind vector information from SAR images.

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