The effect of polarization ratio on RADARSAT wind vector retrievals

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***Abstract*—In this presentation, the polarization ratios were calculated from AIRSAR polarimetric SAR data and ENVISAT ASAR dual-polarization data; and their empirical α parameters which depend on incidence angle were obtained. Five C band HH polarization RADARSAT-1 SAR images are used to validate these polarization ratios and we found that the empirical parameter $\alpha = 0.5$ is superior to other possible parameter α values.**

Keywords-wind vector retrieval; polarization ratio; RADARSAT; SAR

I. INTRODUCTION

In recent years, the high-resolution, all-weather capability of synthetic aperture radar (SAR) images has been used to estimate marine wind vector fields. There are three main approaches for extracting winds from SAR images. The first approach estimates wind speed from the degree of azimuth cut-off in the SAR spectrum according to the relationship among wind speed, cut-off wave-length, and wave height[1]-[3]. The second approach uses an optimal inversion method to estimate vector winds, combining the SAR data and background numerical weather prediction model data [4]. The third approach is based on an empirical relationship, also denoted the geophysical model function (GMF), between wind vectors and the NRCS (normalized radar cross section) or σ^0 image, for example CMOD-4. Because σ^0 depends on the incidence angle, radar wavelength, and polarization as well as both wind speed and direction, it is impossible to uniquely determine the wind from a single σ^0 image. Normally wind direction is derived from the orientation of wind-induced streaks, such as boundary layer rolls, by using Fourier transforms[5], [6] or a wavelet transform method [7]. In many cases, the wind direction ambiguity can also be resolved by the analysis of shadowing effects at the coast. Ancillary data from buoys, scatterometers or weather models are used to remove the direction ambiguity. He et al. [8] developed a new algorithm to retrieve wind vectors from even those with insufficient visible wind-induced streaks in the SAR images. This method determines wind vectors from VV SAR polarization images. Zou et al.[9] extended the algorithm to RADARSAT HH polarization SAR data to retrieve wind vectors. This third approach is similar to the second approach (above), although the latter uses a priori information on both speed and direction. Moreover, for HH polarization the geophysical model function CMOD4 is modified by a polarization ratio conversion factor [10],

$$\sigma_H{}^0 = \left(\frac{1+\alpha\tan^2\theta}{1+2\tan^2\theta}\right)^2 \sigma_V{}^0 \quad \text{...............................(1)}$$

where θ is the incidence angle and parameter α is zero for Bragg scattering theory, whereas α is 2, assuming Kirchhoff scattering theory. With this modification, wind vectors are extracted by the same method as is used for VV polarization. Thompson et al. [10] examine the polarization ratio for C-band RADARSAT data and draw a conclusion that when the incidence angle is in the range between 20^0 and 50^0, α is a constant and should be set to 0.6. However, because the polarization ratio also actually depends on wind vector and white noise, therefore α is not constant, but depends on wind vector, incidence angle and related variables. Therefore, we assume equation (1) is the polarization ratio of the sea surface with parameter α that is between 0 and 2 and dependents on the radar incidence angle, as well as the radar frequency. Several different values for α have been suggested recently, considering RADARSAT-1 SAR data, varying between 0.4 and 1.2. [11]-[13].

Recently, Mouche et al. [14]-[15] presented an analysis of measurements of the normalized radar cross-section (NRCS) in vertical and horizontal polarizations over the ocean obtained from the C-band airborne radar STORM. They found that the polarization ratio is dependent on incidence and azimuth angles. Its dependence with incidence angle is found to be significantly different from empirical models previously proposed in the literature. Two new analytical formulations were proposed to model the polarization ratio; one as a function of incidence angle only, and the second has additional dependence for the azimuth angle. It was shown that it is necessary to consider an azimuth-dependent polarization ratio for incidence angles larger than 30°.

II. POLARIZATION RATIO

In this paper, we examine the polarization ratio for microwave scattering using a C –band dual-polarization image from AIRSAR. Figure 1 is a C –band, VV polarization AIRSAR image of the Mid-Atlantic Bight. AIRSAR data acquisition parameters for the image are given in Table 1. The radar resolution cell had dimensions of 6.6 m (range direction) and 8.2 m (azimuth direction) and a Lee speckle filter [16] was done before fitting the relationship between polarization ratio and incidence angle.

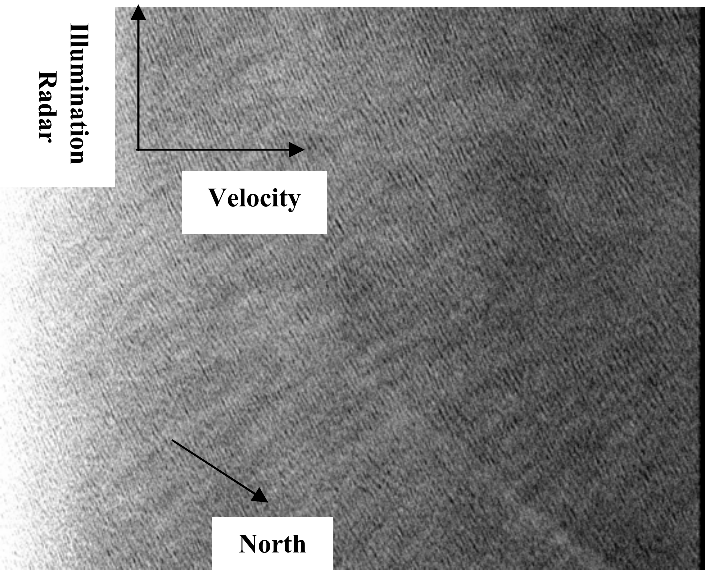

Fig. 1. A C-band, VV polarization, AIRSAR image of the Mid-Atlantic Bight

Table 1 AIRSAR data acquisition parameters

Image	Gulf of Altantic
Radar band	C –band
Incidence angle, near-far edges of images, Deg.	$20.7-60.1^0$
Altitude, m	8523
Platform velocity, m/s	215.6
Track angle, Deg	314.2^0
Date [mm/dd/yy]	4/13/94
Scene center Latitude/longitude, Deg.	37.590^0 N 72.188^0 E
Resolution cell dimension, m	Azimuth 8.2 m Range 6.6 m

Firstly, we use the C –band AIRSAR dual-polarization image and theoretical C –band polarization ratio (PR) formula to calculate the observed polarization ratio. Then the function lsq curve fit of MATLAB Optimization Toolbox is employed to perform a non-linear least squares fit to get the relationship between observed PR and incidence angle. We assume that the initial guess function between the observed PR and incidence angle has following expression,

$$PR=\left[\frac{a+b\tan^2\theta}{c+d\tan^2\theta}\right]^2 \tag{2}$$

where a, b, c and d are empirical parameters. When the algorithm has achieved convergence after maximum number of iterations, the values of empirical coefficients are given as,

$$a=0.54,\ b=0.35,\ c=0.45,\ d=1.09 \tag{3}$$

Finally, inserting the equations (2) and (3) into (1), we obtain the empirical relationship between the α parameter and the incidence angle, which is given as following

$$\alpha=\frac{0.09+\tan^2\theta\left(0.34+0.7\tan^2\theta\right)}{\tan^2\theta\left(0.45+1.09\tan^2\theta\right)} \tag{4}$$

Figure 2 shows a plot of the α parameter versus the incidence angle for AIRSAR data.

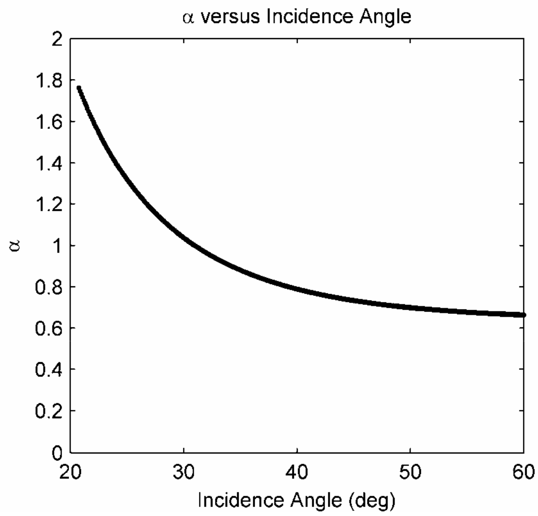

Fig. 2. α parameter computed from (4) as a function of incidence angle from 20^0 and 60^0.

Moreover, empirical parameter α for ENVISAT ASAR is given as,

$$\alpha=\begin{cases}\dfrac{-0.13+\tan^2\theta\left(2.1+0.2\tan^2\theta\right)}{\tan^2\theta\left(1.52+0.78\tan^2\theta\right)} & \theta<30^\circ\\ 1.0 & \theta\geq 30^\circ\end{cases} \tag{5}$$

III WIND SPEED RETRIEVAL FROM RADARSAT SAR

Five C-band, HH polarization RADARSAT-1 images, which were acquired over the Bay of Fundy, the northeast and northwest coasts of the US, and the east coast of Canada between 25 December 2002 and 13 March 2003, were used to estimate wind vectors using Zou's algorithm[9] and the polarization ratio for our empirical parameter α (including AIRSAR and ENVISAT ASAR data) and a constant α (0.6

and 0.5). The results were compared with those calculated by combining the wind directions predicted by SWDA [12] and observed by co-located QuikSCAT measurements[9].Wind vectors for incidence angles smaller than 23° are excluded in Zou et al.'s algorithm.

Table 2 comparisons of buoy winds with estimates from Zou et al.'s algorithm when $\alpha = 0.5$, 0.6, 1.0, and empirical parameter α, wind directions by the spectral analysis and co-located QuikSCAT data.

Parameters		Wind speed(m/s)		Wind direction (degree)	
Error		Mean	RMS	Mean	RMS
Zou et al.'s algorithm	$\alpha = 1.0$*	-1.49	3.5	0.43	16.6
	$\alpha = 0.5$	-1.86, -1.32*	2.90, 2.13*	10.6, 17.6*	30.75, 25.8*
	$\alpha = 0.6$	-2.54, -1.6*	3.49, 2.33*	11.6, 18.2*	33.14, 27.6*
	ENVISAT α	-4.31	5.06	4.42	34.89
Vachon et al.*		0.44	3.6	-7.6	38.0
QuikSCAT*		1.95	3.9	1.4	34.6

* indicates the results without incidence angles smaller than 23°[9]

The result shows that the empirical parameter $\alpha = 0.5$ is superior to the other models. In fact, the polarization ratio needs further study because it depends on additional factors, such as incidence angles, wind vectors, frequency, platform state and related considerations.

IV CONCLUSIONS

Polarization ratios were calculated from AIRSAR polarimetric SAR data and ENVISAT ASAR dual-polarization data. Empirical parameters α which depend on incidence angle were obtained. Five C band HH polarization RADARSAT-1 SAR images are used to validate these polarization ratios and we found that the empirical parameter $\alpha = 0.5$ is superior to the other α parameter values. Additional study and improvements are needed in the polarization ratio in order to improve accuracy in wind vector retrievals.

ACKNOWLEDGMENT

This investigation was funded by the National Natural Science Foundation of China, Grant 40676095, the Panel on Energy Research and Development of Canada (Environmental Offshore Factors), Canadian Space Agency.

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