VALIDATION OF RADARSAT-2 POLARIMETRIC SAR MEASUREMENTS OF OCEAN WAVES

Yijun He[1,2], Biao Zhang[3], and William Perrie[3]

[1] Institute of Oceanology, Chinese Academy of Sciences, Qingdao, 266071, China
[2]Key laboratory of ocean circulation and waves, CAS, Qingdao, 266071,China
[3]Bedford Institute of Oceanography, DFO, Dartmouth, Nova Scotia, Canada
E-mail: heyj@ms.qdio.ac.cn

I INTRODUCTION

Synthetic Aperture Radar (SAR) systems have been widely used in observing oceanic phenomena, such as ocean waves, shallow sea bottom topography, internal waves, boundary currents, oil spills, ship wakes and so on [1]. In the last decades, considerable efforts have gone into retrieving quantitatively surface wave information from SAR images [2]-[3]. To extract ocean wave spectra from SAR images accurately, several nonlinear methods have been developed following the theory presented by Hasselmann et al. [4].

An inversion algorithm with fully polarimetric SAR image data has been developed to measure wave slopes in range and azimuth directions [5]-[7]. Using Fourier transforms, the complete directional ocean wave slope spectrum can be measured by the orthogonal slope information. The advantage of the polarimetric method is that a nearly direct measurement of the slope is made without the use of a parametrically complex modulation transfer function (MTF).

The variation of polarization orientation angle is mainly caused by waves traveling in the azimuth direction. To a lesser extent, it is affected by waves traveling in the range direction. A new method, originally used in topographic measurements [8], was proposed by Schuler et al. [7] to derive the wave slope information in the azimuth direction, and also the wave spectra. Additionally, an eigenvector / eigenvalue decomposition average parameter $\overline{\alpha}$, proposed in Pottier [9], is adapted to measure wave slopes in the range direction. The incident angle θ is affected by waves in the range direction that, in turn, modifies the "roll-invariant" $\overline{\alpha}$. Thus, wave slopes in the azimuth direction have no effects on $\overline{\alpha}$. Otherwise, the oriental angle $\Delta\varphi$ is largely sensitive to wave slope in the azimuth direction, not range direction. Therefore, both $\overline{\alpha}$ and $\Delta\varphi$ are capable of measuring wave slopes in any direction. He et al. [10][11] developed an algorithm to retrieve ocean wave spectra from linearly polarized SAR data.

II FORMULAE AND RESULTS

In this presentation, we consider polarimetric SAR measurements of ocean waves using linearly polarized SAR images and the polarization orientation angle method. We use various sea states to validate RADARSAT-2 polarimetric SAR measurements of ocean wave spectra; specifically, we consider C-band quad-polarization SAR data.

The formulae for polarimetric SAR measurements of ocean wave spectra is as follows[11]:

$$\frac{\Delta\sigma_{hh}}{\sigma_{hh}^{0}} - \frac{\Delta\sigma_{vv}}{\sigma_{vv}^{0}} = -\frac{8\tan\theta}{1+\sin^2\theta}\frac{\partial\xi}{\partial x} \tag{1a}$$

$$\frac{\Delta\sigma_{\varphi\varphi}}{\sigma_{\varphi\varphi}^{0}} - \frac{\Delta\sigma_{vv}}{\sigma_{vv}^{0}} = A\frac{\partial\xi}{\partial x} + B\frac{\partial\xi}{\partial y} \tag{1b}$$

where,

$$A = \frac{a_2}{a_0} - a_3 \qquad B = \frac{a_1}{a_0} \tag{2a}$$

$$a_0 = \frac{1}{4}\left(1+\left(\frac{(1+\sin^2\theta)}{(1-\sin^2\theta)}\right)^2\right)\left(1+\cos^2(2\varphi)\right) - \frac{2\sin^2\theta}{1-8\sin^2\theta+8\sin^4\theta}\cos(2\varphi) + \frac{1+2\tan^2\theta}{2}\sin^2(2\varphi). \quad (2b)$$

$$a_1 = -\left[\left(1+\left(\frac{(1+\sin^2\theta)}{(1-\sin^2\theta)}\right)^2\right)\cos(2\varphi) + \left(1-\left(\frac{(1+\sin^2\theta)}{(1-\sin^2\theta)}\right)^2\right) - 2\left(\frac{(1+\sin^2\theta)}{(1-\sin^2\theta)}\right)\cos(2\varphi)\right]\frac{\sin(2\varphi)}{\sin\theta} \quad (2c)$$

$$a_2 = \left[2\frac{\tan\theta}{\sin^2\theta\cos^2\theta}(1+\cos^2(2\varphi)) - 4\frac{\tan^3\theta}{\sin^2\theta}\cos(2\varphi) + 2\frac{\tan^3\theta}{\sin^2\theta}\sin^2(2\varphi)\right] \quad (2d)$$

$$a_3 = \frac{4-0.5(1-\sin^2\theta)}{\tan\theta(1-\sin^2\theta)} \quad (2e)$$

Here, φ is the polarization orientation angle. Subscript $\varphi\varphi$ indicates a copolar channel of linear polarization at φ degrees. It indicates HH polarization when $\varphi = 0$, and VV polarization when $\varphi = \pi/2$. Therefore the polarization subscript p can be neither h nor v in equation (1) in order to allow solution for the range and azimuth slopes in this relation. Note that equation (1b) degenerates into equation (1a) if $\varphi = h$, and when $\varphi = v$, equation (1b) vanishes.

Comparisons are made between ocean wave spectra measured using RADARSAT-2 Synthetic Aperture Radar C-band quad-polarization backscatter data and in situ buoys maintained by the National Oceanic and Atmospheric Administration (NOAA)/National Data Buoy Center (NDBC). The estimated ocean wavelengths, wave directions, and significant wave heights are in very good agreement with those measured by the buoy.

III REFERENCES

[1]. J. F. Vesecky and R. H. Stewart, "The observation of ocean surface phenomena using imagery from SEASAT synthetic aperture radar –an assessment", *Journal of Geophysical Research,* vol. 87, pp.3397-3430, 1982.

[2]. W. J. Plant and L. M. Zurk, "Dominant wave directions and significant wave heights from SAR imagery of the ocean", *Journal of Geophysical Research,* vol. 102(C2), pp.3473-3482, 1997.

[3]. D. Kasilingam and J. Shi, "Artificial neural network based-inversion technique for extracting ocean surface wave spectra from SAR images", *Proc. IGARSS'97,* Singapore , pp.1193–-1195. IEEE Press, 1997.

[4]. K. Hasselmann and S. Hasselmann, "On the nonlinear mapping of an ocean wave spectrum into synthetic aperture radar image spectrum and its inversion", *Journal of Geophysical Research,* vol. 96, pp.10713-10729, 1991.

[5]. D. L. Schuler, R. W. Jansen, J. S. Lee and D. Kasilingam, "Polarisation orientation angle measurements of ocean internal waves and current fronts using polarimetric SAR", *IEE Proc. On Radar, Sonar and Navigation*, pp.123 − 131. Cambridge, UK: Black Bear Press Ltd, 2003.

[6]. D. L. Schuler, D. Kasilingam, J. S. Lee and E. Pottier, "Studies of ocean wave spectra and surface features using polarimetric SAR", *Proc. Int. Geosci. and Remote Sensing Symposium (IGARSS'03),* Toulouse, France, 21-25 July, 2003.

[7]. D. L. Schuler, J. S. Lee, D. Kasilingam and E. Pottier, "Measurement of ocean surface slopes and wave spectra using polarimetric SAR image data", *Remote Sensing of Environment*, vol 91, pp.198-211, 2004.

[8]. D. L. Schuler, J. S. Lee and G. De Grandi, "Measurement of topography using polarimetric SAR images", *IEEE Transactions on Geoscience and Remote Sensing,* vol. 34, pp.1266-1277, 1996.

[9]. E. Pottier, "Unsupervised classification scheme and topography derivation of POLSAR data on the «H/A/a» polarimetric decomposition theorem", *Proc. of the 4th International Workshop on Radar Polarimetry*.53-548. Nantes, France: IRESTE, 1998.

[10]. Y. He, W. Perrie , T. Xie and Q. Zou "Ocean wave spectra from a linear polarimetric SAR", *IEEE Trans. Geosci. Remote Sens.*, vol. 42(11), pp.2623-2631, 2004.

[11]. Y. He, H. Shen, and W. Perrie, "Remote sensing of ocean waves by polarimetric SAR", *Journal of Atmospheric and oceanic technology*, Vol.23, pp1768-1773, 2006.