AIRSAR AND POLSAR C-BAND DATA FOR WAVE REFRACTION SIMULATION

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Abstract: This work exploits radar airborne data to simulate ocean wave refraction pattern and spectra energy. Two radar airborne data of AIRSAR and POLSAR with C_{vv}-band are elaborated. In doing so, linear modulation algorithm of quasi-linear transform was implemented to retrieve the significant wave height from radar airborne data. Then, the first order Partial Differential Equation (PDEs) used to simulate wave refraction pattern. The study shows the convergence spectra refraction energy is 0.84 m^2 sec is higher than divergence refraction energy. It can be said that ocean wave spectra refraction can be retrieved from SAR data using quasi-linear model and (PDEs) of wave spectra transform.

INTRODUCTION

Wave refraction play tremendous rule for shoreline configuration. This can be presented in both convergence and divergence that can cause erosion and sedimentation, respectively. Wave refraction simulation is required standard algorithms to reconstruct its accurate pattern. Synthetic Aperture Radar (SAR) has been recognized as a powerful tool for modeling ocean waves and forecasting over an area of 300 km x 300 km. Hence, the sediment transport could be modeled by the wave spectra information extracted from a SAR image. Currently, a number of investigations have been carried out on the assimilation of SAR wave mode data into wave forecasting models. This is because the SAR image spectrum has turned out to be far removed from the actual wave spectrum and rather complicated post-processing is necessary for extracting quantitative wave information In this regards, previous studies were carried out by Beal et al., (1983), Hasselmann and Hasselmann, (1991), Vachon et al. (1994) and Forget and Brochel (1995) to develop an inversion algorithm to map SAR wave spectra into ocean wave spectra. Hasselmann and Hesselman (1991) introduced a non-linear algorithm which was developed by Vachon et al. (1995) to model the significant wave height based on the azimuth cut-off. Vachon et al. (1995) defined the azimuth cut-off as the degree to which the SAR image spectrum is constrained in the azimuth direction. The azimuth cut-off is affected by the wind and wave condition in a quasi-linear forward-mapping model (Vachon et al. 1997). Marghany (2001) and Marghany et al., (2011) utilized the azimuth cut-off model which was developed by Vachon et al. (1995) to estimate the significant wave height.
The question can be raised as to how an integration of quasi-linear algorithm with a first order Partial Differential Equation (PDEs) could use to develop a new approach to observe coastal wave refraction from AIRSAR and POLSAR C_{vv}-band data. The main objective is to modify the conventional azimuth algorithm to model significant wave height in coastal water of Malaysia. The sub-objectives are :(i) to model the physical properties of wave spectra such as wavelength, significant wave height and spectra energy in azimuith direction using C_{vv}-band data; (ii) to simulate wave refection pattern using first order Partial Differential Equation (PDEs); and to model spectra energy variation of wave refraction pattern.

MODEL

Quasi-linear Model

To map observed SAR spectra into the ocean wave spectra, a quasi-linear model was applied. The simplified quasi-linear theory is explained below: according to the Gaussian linear theory, the relation between ocean wave spectra $S(\vec{K},\phi)$ and AIRSAR image spectra $S_Q(\vec{K})$ could be described by tilt and hydrodynamic modulation (real aperture radar (RAR) modulation). The tilt modulation is linear to the local surface slope in the range direction i.e. in the plane of radar illumination. The tilt modulation in general is a function of wind stress and wind direction for ocean waves and AIRSAR/POLSAR polarization. According to Vachon et al., (1994) the tilt modulation is the largest for HH polarization. Alpers et al., (1981) and Alpers and Bruning (1986) reported that hydrodynamic interaction between the scattering waves (ripples) and longer gravity waves produced a concentration of the scatterer on the up wind face of the swell. In order to estimate the significant wave height from the quasi-linear transform, we adopted the algorithm that was given by Marghany (2003) to be appropriate for the geophysical conditions of tropical coastal waters:

$$\lambda_c = \beta\left(\int_{H_{s0}}^{H_{sn}} \sqrt{H_s}\, dH_s + \int_{U_0}^{U_n} \sqrt{U}\, dU\right) \qquad (1)$$

where λ_c is cut-off azimuth wavelength, H_s and U are the in situ data of significant wave height and wind speed along the coastal waters of Kuala Terengganu, Malaysia. The measured wind speed was estimated at 10 m height above the sea surface. The changes of significant wave height and wind speed along the azimuth direction are replaced by dH_s and dU, respectively. The subscript zero refers to the average in situ wave data collected before flight pass over by two hours while the subscripts n refers to the average of in situ wave data during flight pass over the study area. β is an empirical value which results of R/V multiplied by the intercept of azimuth cut-off (c) when the significant wave height and the wind speed equal zero. A least squares fit was used to find the correlation coefficient between cut-off wavelength and the one calculated directly from the AIRSAR/POLSAR spectra image by equation (1). Then, the following equation was adopted by Marghany (2001) and (2003) to estimate the significant wave height (H_{sT}) from the AIRSAR images

$$H_{sT} = \beta^{-2} \int_{\lambda_{c0}}^{\lambda_{cn}} (\lambda_c)^2\, d\lambda_c . \qquad (2)$$

where β is the value of $\left(c\dfrac{R}{V}\right)^{-1}$ and H_{sT} is the significant wave height simulated from AIRSAR images. The introduced method (azimuthally cut off) is designed for homogeneous wave fields as waves can be found over the open ocean under deep water condition with homogeneous bathymetry. A linear wave transform model can be used to solve the problem of homogeneous wave fields by simulating the physical wave parameters nearshore.

Simulation of Wave Refraction Pattern by Partial Differential Equation (PDEs)

The wave refraction model over the AIRSAR and POLSAR images is formulated on the basis of wave number and wave energy conversation principle, gentle bathymetry slope, steady wave conditions and only depth refractive (Figure 1). According to Herbers et al. (1999) wave refraction equation takes the following form:

$$\frac{\partial}{\partial x}(H_s^{\,2} c_g \cos\phi) + \frac{\partial}{\partial y}(H_s^{\,2} c_g \sin\phi) = 0 \qquad (3)$$

where the coordinates and the wave angle ϕ. Equation 3 is a first order Partial Differential Equation (PDEs) in the unknown variables $\phi(x, y)$ and $H_s^{\,2}(x, y)$; the group velocity c_g is a known function of the wave period T and the known local depth $h(x,y)$. Following, Herbers et al (1999), the explicit finite difference scheme, centred in x, proposed for the solution of equation 3 takes the form:

(1) Wave angle equation: solved for ϕ_{ij+1}

$$\phi_{ij+1} = \arccos\left[\begin{array}{l} \left(\dfrac{\Delta y_j}{2}\left(\left(\dfrac{\sin\phi_{i+1j}}{c_{i+1j}} - \dfrac{\sin\phi_{ij}}{c_{ij}}\right)\Delta x^{-1} + \right.\right. \\ \left(\dfrac{\sin\phi_{ij}}{c_{ij}} - \dfrac{\sin\phi_{i-1j}}{c_{i-1j}}\right)\Delta x^{-1}{}_{i-1}\Big) + \dfrac{\cos\phi_{ij}}{c_{ij}}\Big).c_{ij+1} \end{array}\right]. \qquad (4)$$

(2) Significant wave height equation: solved for Hs_{ij+1}

$$H_{s_{ij+1}}{}^{2}=\frac{1}{c_{gij+1}\sin\varphi_{ij+1}}\left[\begin{array}{l}(H^{2}{}_{s}c_{g}\sin\varphi)_{ij}\text{-}0.5\Delta y_{j}(\frac{(H^{2}{}_{s}c_{g}\cos\varphi)_{i+1j}}{\Delta x_{i}}-\\ \frac{(H^{2}{}_{s}c_{g}\cos\varphi)_{ij}}{\Delta x_{i}}+\\ \frac{(H^{2}{}_{s}c_{g}\cos\varphi)_{ij}\text{-}H^{2}{}_{s}c_{g}\cos\varphi)_{i\text{-}1j}}{\Delta x_{i}\text{-}1})\end{array}\right]. \qquad (5)$$

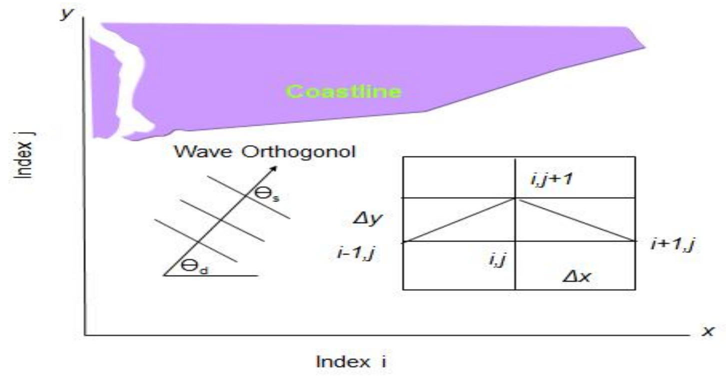

Figure 1: Simulation of wave refarction pattern

The boundary conditions completing the model are:

(i) It is assumed that the parallel depth contours The ϕ and H_s values are given as initial conditions on the open sea boundary $(j=1)$.

(ii) The computation is terminated on the coastal boundaries $(h=0)$. The wave breaking criterion is applied in shallow waters. The computed significant wave height H_s is compared to $0.78\ h_{ij}$; if $Hs_{ij+1}\rangle 0.78h_{ij}$, $Hs_{ij+1}=0.78h_{ij}$ (6)

The spectra energy of significant wave height distribution due to wave refraction is then estimated by using the following formula adapted from Hasselmann and Hasselmann (1991):

$$E(\vec{K},H_S)=S(k_x,k_y)p(H_S) \qquad (7)$$

where $S(k_x,k_y)$ is the distribution for the wave number and $p(H_S)$ is the probability distribution of the significant wave height in the convergence and divergence zone. According to Herbers et al (1999),the refraction index (K_r) for a straight coastline with parallel contours can be estimated by using the following equation:

$$K_r=\sqrt{\frac{\cos\theta_d}{\cos\theta_r}}. \qquad (8)$$

where θ_d and θ_r are the deep and shallow waves incidence angles.

RESULTS AND DISCUSSIONS

Figure 2 shows the wave refraction pattern modeled from the quasi-linear model and in situ wave data. The input quasi-linear wavelength spectra and in situ wavelength spectra were 80 m and 75 m, respectively. Both AIRSAR and POLSAR wave refraction pattern results indicate the refractive index is 2.60 and 2.54 at the Sultan Mahmed Airport station and the location of Batu Rakit station, respectively, showing convergence of wave energy (Figure 2). At the Batu Rakit station which is close to the river mouth of Kuala Terengganu, the refractive index values are less than 1.00 suggesting divergence of wave energy. In other locations, the refractive index values are close to 0.99, (Figure 2b) indicating no change in the concentration of wave energy at the coastline. Although the refractive index values for the quasi-linear model differed with those of the in situ wave spectra refraction, the same trend of wave energy dispersion and concentration occur at the coastline. This means that the wave refraction pattern simulated by using the quasi-linear model is similar to the wave refraction simulated from the in situ wave data.

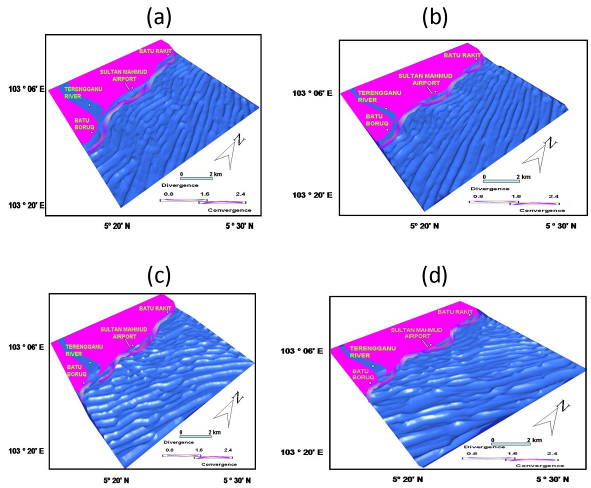

Figure 2: Wave Refraction Pattern from (a) AIRSAR, (b) in situ measurement 1996, (c) POLSAR and (d) in situ measurement 2000.

Figure 3 shows the wave refraction spectra energy because of convergence and divergence. The convergence spectrum has the sharper peak compared to divergence spectra. The sharp peak of the convergence spectrum is 0.84 m^2 sec (Figure 3a) while the divergence spectrum peak is less than 0.4 m^2 sec (Figure 3b). The convergence spectrum peak is located along the azimuth direction. It can be explained that the highest spectra energy propagated close to the azimuth direction is caused by the great influence of the Doppler frequency shift which is produced by convergence. This result agrees with the studies of Marghany (2003) and Marghany et al., (2011).

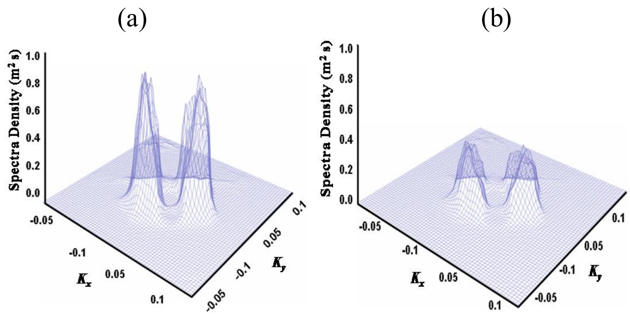

Figure 2: Wave refraction spectra (a) convergence and (b) divergence

This study agrees with study of Li et al., (2010) that radar satellite or airborne data can use as a good tool to investigate the coastal wave spatial variations. Nevertheless, this result contradicted the study Zelina et al., (2000). Therefore, the largest swell of 250 m occurred in December. Indeed, December is represented the maximum peak of the northeast monsoon season which induces the strongest wind input in the South China Sea 's coastal waters Wrytki, K. (1961); Wong (1981) ; Marghany (2004); Marghany et al., (2011) and Marghany (2011).

CONCLUSION

This study has explained new approach for simulation of wave refraction pattern in airborne radar data. This is exploited, the quasi-linear algorithm and first order Partial Differential Equation (PDEs). The quasi-linear algorithm used to model significant wave height based on new approach of azimuth cut-off algorithm. Then, wave transformation was achieved using first order Partial Differential Equation (PDEs). The study shows that wave refraction pattern can simulate from AIRSAR and POLSAR data with convergence and divergence spectra energy. In conclusion, modification of conventional azimuth cut-off algorithm can be used to retrieve significant wave height in C_{vv}- band data under circumstance of wave transformation using first order Partial Differential Equation (PDEs).

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