International Journal of the Physical Sciences Vol. 5(12), pp. 1908-1914, 4 October, 2010
Available online at http://www.academicjournals.org/IJPS
ISSN 1992 - 1950 ©2010 Academic Journals

Full Length Research Paper

Velocity bunching and Canny algorithms for modelling shoreline change rate from synthetic aperture radar (SAR)

Maged Marghany* and Mazlan Hashim

Institute of Geospatial Science and Technology (INSTEG), Universiti Teknologi Malaysia 81310 UTM, Skudai, JohoreBahru, Malaysia. E-mail: maged@utm.my, magedupm@hotmail.com.

Accepted 17 September, 2010

This paper presents a new approach for modeling shoreline change due to wave energy effects from remotely sensed data. The multi SAR data were employed to extract wave spectra information and integrate them with historical remotely sensed data such as aerial photography data to model shoreline change rates. A partial differential equation (PDF) of the wave conversation model was applied to investigate the wave refraction patterns. The volume of sediment transport at several locations was estimated based on the wave refraction patterns. The shoreline change model was designed to cover a 14 km stretch of shoreline of Kuala Terengganu in peninsular Malaysia. The results showed that the shoreline change rate modeled from the quasi-linear wave spectra model has a significant relationship with one modeled from historical vector layers of aerial photography, SAR data. With the velocity bunching model an error of ± 0.18 m/year in shoreline change rate determination was obtained.

Key words: Synthetic aperture radar (SAR), shoreline, velocity bunching, partial differential equation (PDF).

INTRODUCTION

The operation of synthetic apreature radar (SAR) for modelling ocean wave spectra impacts on coastline change is still in early stages. Indeed, SAR wave imagine is considered as barely task. In this context, the SAR wave imagined being controlled by three mechanisms: (1) tilt modulation; (2) hydrodynamic modulation, and (3) velocity bunching modulation. This study concerns the velocity bunching modulation for modelling shoreline change using SAR data. In this context, veclocity-bunching is refereed to azimuth-traveling waves. The SAR achieves high azimuth resolution by using the Doppler shift of return signals. In case of ocean waves, the velocity-bunching mechanism can produce wave-like patterns on the image even no modulation of microwave backscattering cross-section by long wave are presented. Velocity-bunching is caused by the fact that SAR finds azimuth of the target via Doppler coordinate and the motion of the target in range effects this resolution. According to Maged (2004), these target motions sometimes induced well-known peculiarities in the SAR image. This concept has explained in details in several studies (Vachon et al., 1991, 1992, 1995; Maged, 2003, 2004; Caires and Sterl, 2003; Li et al., 2008).

At presents, there are few attempts to model shoreline change rate based on wave spectra information derived from SAR data. Maged (2001) has introduced a new approach for modeling shoreline rate of change using retrieval wave spectra from airborne TOPSAR data. Further, Maged (2003) studied the impact of wave spectra modulation transfer function (MTF) (Hasselmann and Hasselmann, 1991; Vachon et al., 1991, 1992, 1995) in shoreline change model precision. Maged (2003) found that the velocity bunching model has the lower error of 33.5% than the quasi-linear model. Using velocity-bunching algorithm shows accurate promise in comparison with conventional coastal erosion methods using digitizing and overlaying techniques (Frighy et al.,

---

*Corresponding author. E-mail: maged@utm.my, magedupm@hotmail.com.

1995; Chatterjee and Ghosh, 1995; El-Raey et al., 1995).

In fact, digitizing and overlaying techniques induce high rates errors and require a lot of time to process the data (Teodoro et al., 2009; Shu et al., 2010).

According to Maged (2001) in this process, the sum of thematic errors and digitizing errors account for the low accuracy of the interpretation results. This often results in adequate solutions of the problems for coastal engineers and decision makers. Another critical problem often observed in coastal erosion studies is the misunderstanding of the dynamic relation between waves, tides and current movements with sediment transport (Maged, 2001).

Recently, tremendous studies have been conducted in automatic detection of coastline from various remotely sensing data (Maged, 2002; Liu and Jezek, 2004). Indeed, advance image processing tool of edge detection methods have been implemented to identify coastline. Maged (2002) and Liu et al. (2004) utilized edge detection algorithm such as Canny for coastline detection. Liu et al. (2004) reported that the absolute accuracy is influenced not only by the coastline extraction method but also by the geo-referencing accuracy of the source images. To derive a coastline with precise absolute geographical coordinates and correct geometric shape, the source images used to extract the coastline must be geocoded and orthorectified before applying our coastline extraction algorithms. Further, Shu et al. (2010) implemented narrow band level set segmentation approach for semi-automatic detection of shoreline using RADARSAT-2 SAR fine mode data. The aim of this work is to utilize the Canny edge detection algorithm with velocity bunching model to simulate the rate change of shoreline from historical multi-SAR data (ERS-1 and RADARSAT-1 SAR data).

RESEARCH METHODS

Study area

The study area is located in the coast of Kuala Terengganu, on eastern part of Peninsular Malaysia. This area is approximately 20 km along the north of Kuala Terengganu coastline, located between 5° 21' N, 103° 10' E and 5° 30' N, 103° 20' E). Sand materials make up the entire area of this beach (Maged, 2000). The east coast of Peninsular Malaysia is annually subjected to the northeast monsoon wind (November to January) (Stanley, 1985). Another study showed that the mean and longer significant wave periods were 8 to 10 s. Significant wave heights maximum reported were 4 and 2.4 m, respectively which are experienced in February and March However, during the southwest monsoon wave height ranged between 0.4 - 0.7 m (Maged et al., 2002). During the inter-monsoon period (September to mid November), the wave height ranged between 0.37 to 1.6 m (Maged, 2002).

Data acquisition

SAR data used in this study involved ERS-1 and RADARSAT-1 SAR data. ERS-1 data in the C_{vv} band (12.5 m) is acquired on 12 December, 1999. The *in situ* wave measurements data were obtained from Malaysian PETRONAS oil platform observation through Malaysian Meteorological Service. RADARSAT-1 SAR image is acquired on March 30, 2005 with standard 2 mode. During its overpasses, *in situ* measurements is collected by using AWAC wave rider buoy.

SAR velocity bunching model

According to Maged (2003), the along-shore sediment transport volume rate Q, is calculated as

$$Q = 1.1\rho g^{3/2} (H_{sb})^{5/2} \sin\alpha_b \cos\alpha_b \tag{1}$$

Where ρ =1020 kg/m^3 for sea water and α_b is the breaking wave angle estimated from linear wave transformation model.

The ambiguity of SAR wave spectra are resolved by using the sea direction *in situ* measurements. The significant wave height H_{sb} is estimated by using the velocity-bunching model then used to model the rate of volumetric sediment transport based on the depth of significant wave breaking by using the following formula derived from Maged (2003)

$$H_{Sb} = 0.4 g^{1/5} [[(0.6\sqrt{\rho_{\zeta\zeta}} (\frac{1+\theta^2/4}{R/V}) T_0)(T)]^2]^{2/5} \tag{2}$$

The mean wave period T_0 is equal to $2\pi(\langle\langle k_x \rangle g)^{-0.5}$ as

$$H_s = 0.6(\rho_{\zeta\zeta})^{0.5} [\frac{1+\theta^2/4}{R/V}] T_0 \tag{3}$$

In this circumstance, an azimuth wave number (k_x) is estimated based on the velocity bunching modulation transform function MTF (Vachon et al., 1994, 1995), in which the velocity bunching can contribute to linear MTF based on the following formula

$$M_v = \frac{R}{V}\omega\left[\frac{k_x}{k}\sin\theta + i\cos\theta\right] \tag{4}$$

Where R/V is the scene range to platform velocity ratio; θ is ERS-1 and RADARSAT-1 SAR incidence angels (23 and 27.49°), and ω is wave spectra frequency which equal 2Π/K.

To estimate the velocity bunching spectra $S_{vb}(k)$, we modified the algorithm that was introduced by Krogstad and Schyberg (1991). The modification is to multiply the velocity bunching MTF by ERS-1 SAR and RADARSAT-1 SAR spectra variance of the Azimuth shifts. This can be given by

$$S_{vb}(k) = [I_0 \sum_{n=1}^{\infty} \frac{\psi(k_x)^{2n}}{n!} S_{\zeta\zeta}{}^{*n} \psi(k)^2 e^{-K_x{}^2 \rho_{\zeta\zeta}}][M_v] \tag{5}$$

Where $S_{\zeta\zeta}$ is the SAR spectra variance of the azimuth shifts due to the surface motion, which induced by the velocity bunching effect in azimuth direction due to high value of R/V. The relation between standard deviation of the azimuth shift and significant wave height can be given by

$$\sigma = (\frac{R}{V})(1-\frac{\sin^2(\theta)}{2})^{0.5}(\frac{k_x g}{8})^{0.5} H_s \quad \text{(Vachon et al., 1993)} \tag{6}$$

Where, θ is the ERS-1 and RADARSAT-1 SAR incidence angles and Equation 5 is used to estimate the significant wave height which is based on the standard deviation of the azimuth shift. According to Maged (2002), the shoreline change rate based on volume change of sediment transport can be estimated by the following equation

$$\int_{x_0}^{x} y dx = -\int_{t_0}^{t} 2hQdt \tag{7}$$

Where *t* is period of change; *x* is along shore distance and *h* the depth of closure (m).

Wave refraction graphical method

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

$$\frac{\partial}{\partial x}(H_s{}^2 c_g \cos\phi) + \frac{\partial}{\partial y}(H_s{}^2 c_g \sin\phi) = 0 \tag{8}$$

Where the coordinates and the wave angle ϕ are orientated according to the notation of Equation 8, a first order partial differential equation (PDEs) in the wave direction $\phi(x, y)$ and significant wave height $H_s{}^2(x, y)$ varaibles; the group velocity c_g is a known function of the wave period *T* and the known local depth *h(x, y).*

Automatic detection of shoreline

According to Maged (2002), the shoreline of east Coast of the Peninsula of Malaysia is defined by the boundary between vegetation and the bar sandy area (beach). Following Maged (2002) Canny algorithm has applied to SAR images after performing linear filters by using Guassian and Lee algorithms. The Canny algorithm has applied as follows: The input of the SAR image intensity *I*, which is corrupted by noise. Let *G* be a Gussian with zero mean and standard deviation σ. The value of σ to be relied on the length of interesting connected contours, the noise level, and the localization-detection trade off. The Gaussian algorithm was applied and smoothens the image intensity to image *J* that is, *J=I*G* for each pixel (*i,j*): (a) compute the gradient components, J(x,y) (b) estimate the edge strength as given by

$$e_x(i, j) = \sqrt{J_x{}^2(i, j) + I_y{}^2(i, j)} \tag{9}$$

The historical edge detection vectors then overlaid and the rate change *(R)* of shoreline estimated by given simple formula (Maged, 2001)

$$R = \frac{x_n - x_0}{t_n - t_0} \tag{10}$$

Where x is the horizontal measured distance between initial vector (x_0) of ERS-1 image and second vector x_n of RADARSAT-1 SAR image over period *t.*

Accuracy assesement

The Kappa statistic is used to detrmine the accuracy of velocity-bunching model and Canny algorithm. The Kappa statistic is a measure of the difference between the actual agreement between reference data, automated shoreline detection and change agreement between the reference data and a velocity-bunching model. According to Teodoro et al. (2009) Kappa statistic can be defined as

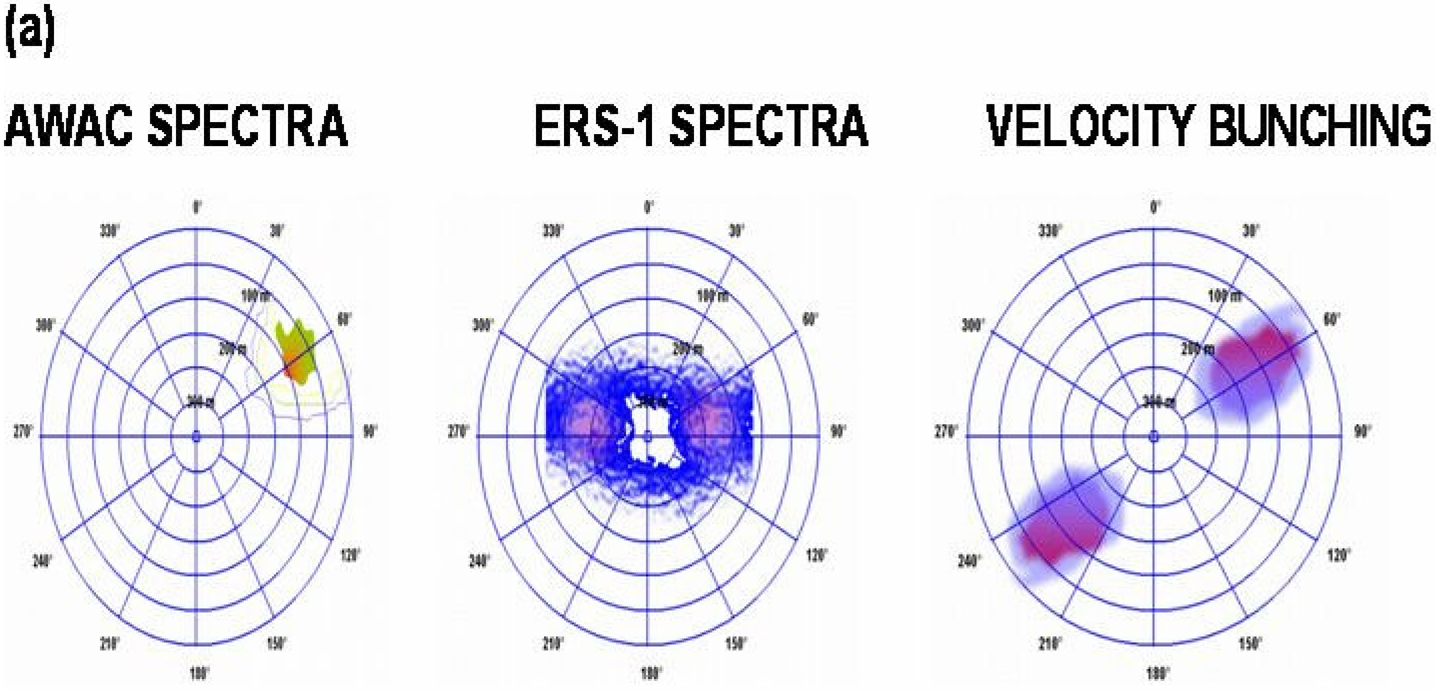
Kappa= (observed accuracy-change accuracy) x (1- change accuracy)$^{-1}$ (11)

The kappa static ranges between 0 and 1. A value of 0 suggests less accuracy while a value between 0.80 and 1.00 means excellent accuracy (Teodoro et al., 2009).

RESULTS AND DISCUSSION

Figure 1 shows the significant wave height modeled by using velocity bunching model from ERS-1 and RADARSAT-1 SAR images. In December 1999 (ERS-1 SAR), significant wave heights ranged between 1.2 to 3.2 m while in March, 2005 (RADARSAT-1 SAR), significant wave heights are ranged between 0.2 to 0.7 m. Regression model shows (Figure 2) that the significant wave heights modeled by velocity bunching are in good agreement with *in situ* data. The degree of correlation is a function of r^2 and probability (*p*). The relationship between velocity bunching model and *in situ* data shows positive correlation as r^2 values for both ERS-1 and RADARSAT-1 SAR data are 0.69 and 0.73, respectively. According to Maged (2004), velocity bunching model produces precisely, information of wave spectra. Indeed, it is able to solve the matter of non-linearity between SAR observed spectra and ocean wave spectra. On other words, it can be used to map SAR observed spectra into real ocean spectra. This result confirms the studies of Vachon et al. (1993) and Maged (2004).

Figure 3 shows the wave refraction pattern modeled from the velocity bunching model. The input velocity bunching wavelength spectra and *in situ* wavelength spectra were 80 and 200 m, respectively. Both ERS-1 and RADARSAT-1 SAR images wave refraction pattern results indicated that the refractive index was 2.60 and 2.54 at the Sultan Mahmed Airport station and the location of Batu Rakit station, respectively, indicating convergence of wave energy (Figure 3). At the Batu Rakit



(b) RADARSAT-1 SAR

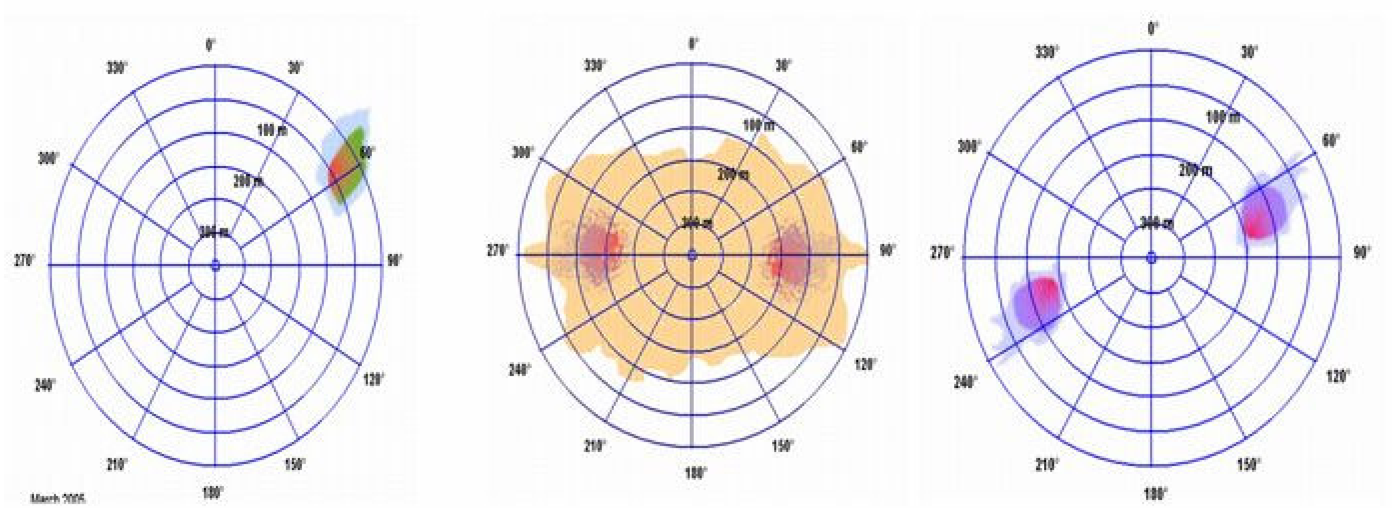


Figure 1. Wave spectra simulated during (a) ERS-1 and (b) RADARSAT-1 SAR acquisition periods.

station which is close to the river mouth of Kuala Terengganu, the refractive index values were less than 1.00 indicating divergence of wave energy. In other locations, the refractive index values were close to 0.99, (Figure 3b) indicating no change in the concentration of wave energy at the coastline.

Figure 4 shows the result of Canny algorithm. It is interesting to note that the third level of Canny algorithm with threshold values ranged between 5 and 19 is provided an automatic digitizing for shoreline. Furthermore, it is also clear that small texture details have been detected. Indeed, Canny algorithm can perform pseudo-edge appearance. Additionally, the concave coastline is detected which is obvious along the coastline of Sultan Mohamed Airport. Maged (2002) stated that Canny algorithm produces pixel wide skeleton curves and able to extract the sequences of pixels along this curve. Maged (2002) concluded that each curve contains sequences of pixels which can be converted to vector layer by fitting piecewise line segments to it.

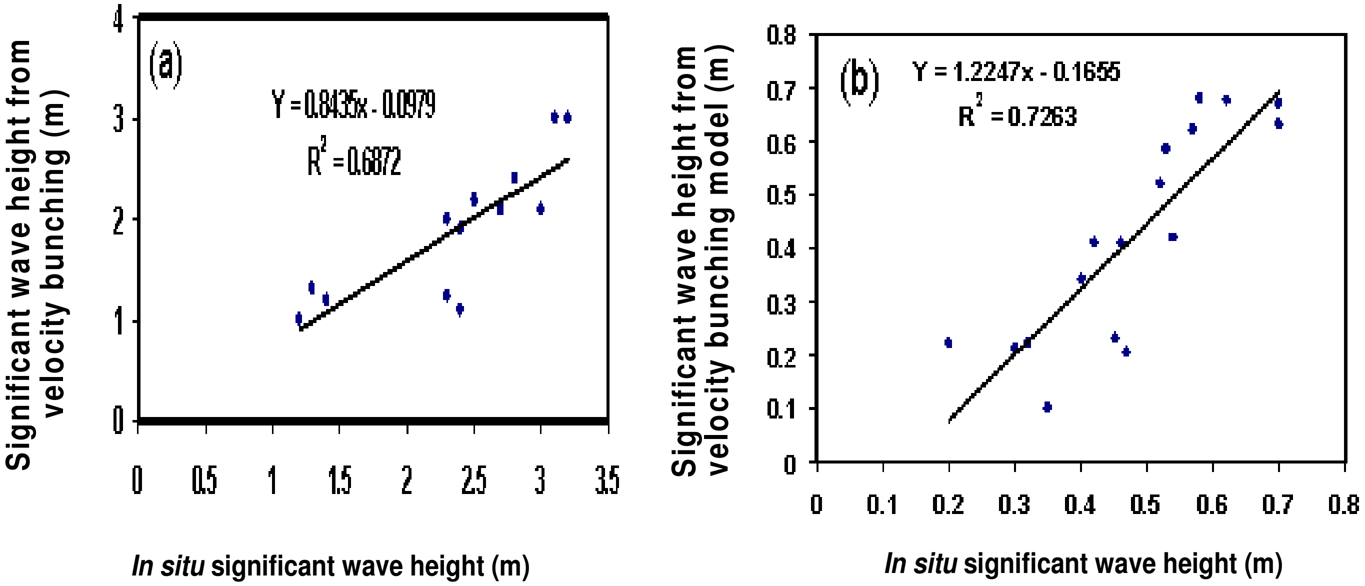


Figure 2. Regression model results of (a) ERS-1 and (b) RADARSAT-1 SAR with *in situ* significant wave height.

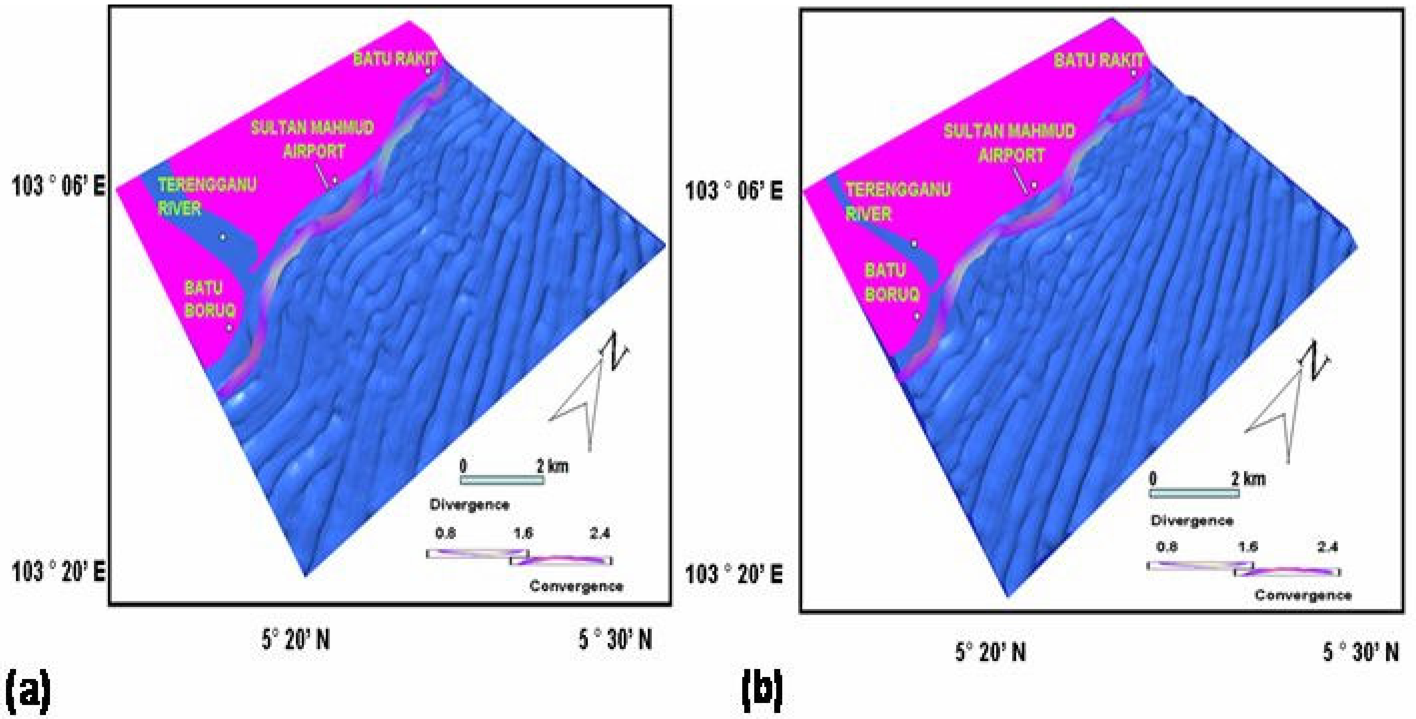


Figure 3. Wave refraction modeled from velocity bunching model by (a) ERS-1 and (b) RADARSAT-1 SAR images.

In addition, Canny is able to produce a polyline which is an approximation to the original pixel curve which could link pairs of polylines. Figure 5 shows the comparison between shoreline change rate simulated by velocity bunching and one based on historical vector layers extracted by Canny algorithm and ground data measurements. The different sorts of data are agreed that the high rate of erosion is recurred along the Mengabang Telipot coastline with maximum values of -3.0, -2.8, -2.6 m/ year obtained by velocity bunching model, Canny algorithm and ground beach profile surveying. Table 1 confirms that velocity-bunching

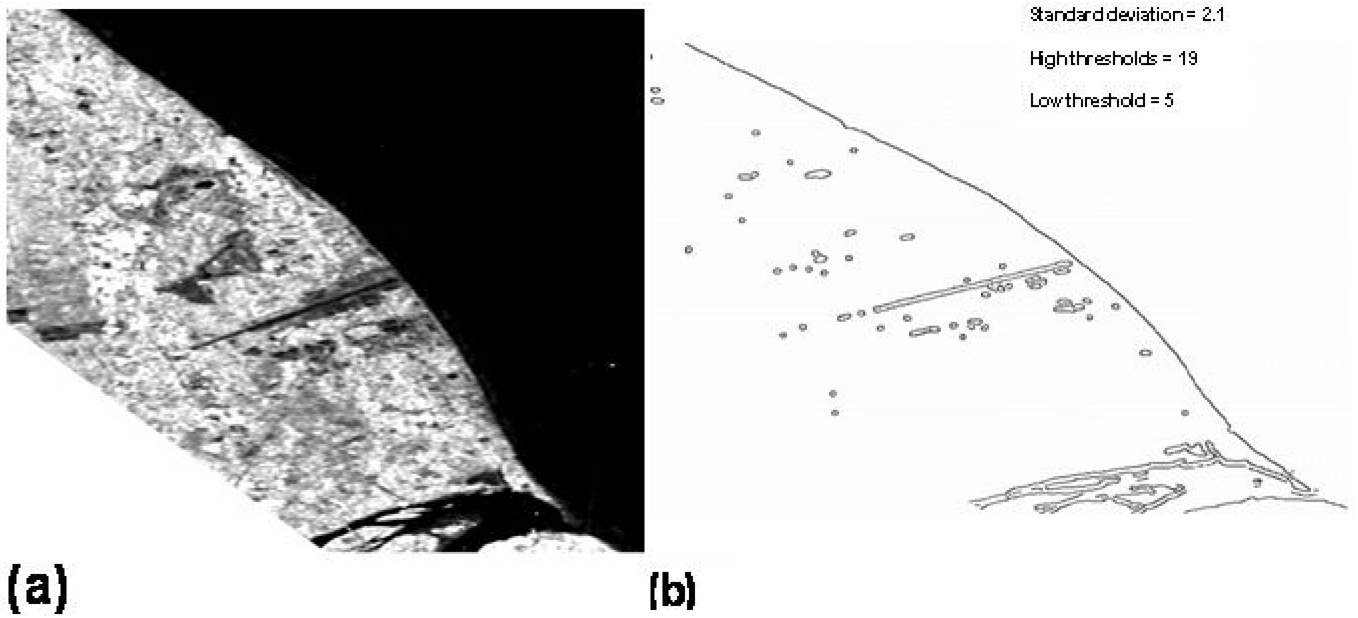


Figure 4. Example of Canny algorithm (a) Raw SAR data (b) Output result of Canny.

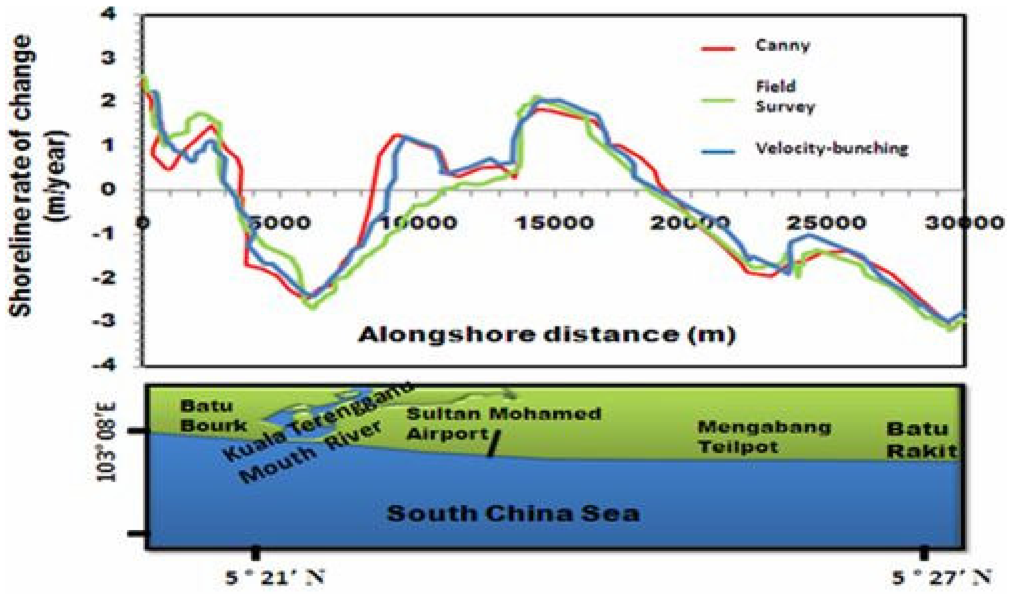


Figure 5. Rate change of shoreline from Canny, velocity bunching and field data.

provides a similar result as Canny algorithm. The velocity-bunching algorithm presents an overall accuracy of 94.45% and Kappa statistics of 0.9433. The results for Canny algorithm are similar, 93.55% and 0.936, respectively.

Clearly, Sultan Mohamed airport encountered high rate of erosion within maximum values of -2.4, -2.00, -1.93 m/year modeled from velocity bunching model, Canny algorithm and ground beach profile data collection. The sedimentation events have been observed along mouth river of Kuala Terengganu and Batu Bourq within average values of 1.89 m/year which are acquired from velocity bunching, Canny algorithm and ground data (Figure 5).

The shoreline change profile shows that erosion mostly occurred in Sultan Mahmed Airport. The wave orthogonal propagated from the north during the northeast monsoon (December and March) tended to converge along this area. According to Maged (2001), the convergence zone

Table 1. Accuary assement of Canny and velocity-bunching algorithms.

Accuarcy statistic	Velocity-bunching	Canny algorithm
Overall accuarcy	94.45	93.55
Kappa statistic	0.943	0.936

indicates an erosion events while the divergence zone indicates sedimentation events. This is due to the fact that convergence zone indicates high energy input. This high-energy input will induce strong littoral drift along the shoreline, which carried this material to an accretion place. The direction of littoral drift can be investigated from Figure 5. It can be said that the littoral drift moved from north to south during northeast monsoon.

Conclusion

This study has been demonstrated a new technique for modeling shoreline change based on velocity bunching model and Canny algorithm. It can be said that modification of sediment transport model based on velocity bunching model can be used to simulate rate change of shoreline from multi-SAR data. In fact, velocity bunching is provided quantity information on significant wave height from SAR data such as ERS-1 and RDARSAT-1 SAR images. It can be concluded that integration between velocity bunching model and Canny algorithm is considered as useful tool for modeling quantity of shoreline change pattern.

REFERENCES

Caires S, Sterl A (2003). Validation of ocean wind and wave data using triple collocation. J. Geophys. Res., 108: 3098.

Chatterjee S, Ghosh BN (1995). Identification of the Cause of Coastal Erosion at Digha, India By Remote Sensing. Proceeding of the 3 rd Thematic Conference Remote sensing for marine and Coastal Environments. 18-20 September 1995, Seattle, Washington, USA. pp. 324-328.

El-Raey MSM, Nasr MM, El-Hattab (1995). Change Detection of Rosetta promontory over the Last Forty Years. Int. J. Remote Sens., 16(5): 825-834.

Frihy OE, Nasr SM, El Hatab MM, El Raey M (1995). Remote sensing of Beach Erosion Along the Rosetta Promontory, Northwestern Nile delta, Egypt. Int. J. Remote Sens., 15(8): 1649-1660.

Hasselmann K, Hasselmann S (1991). On the Nonlinear Mapping of an Ocean Spectrum and Its Inversion". J. Geophys. Res., 96(C6): 10,713-10,799.

Herbers THC, Elgar S, Guza RT (1999). Directional spreading of waves in the nearshore, J. Geophys. Res., 104: 7683-7693.

Krogstad HE, Schyberg H (1991). On Hasselman's nonlinear ocean – SAR transformation. Proceedings of IGARSS'91, Espo, Finland, June 3-6, 1991, pp. 841-849.

Liu H, Jezek KC (2004). Automated Extraction of Coastaline from Satellite Imagery by Integration Canny Edge Detection and Locally Adaptive Thresholding Methods. Int. J. Remote Sens., 35: 973-958.

Li XM, Lehnera S, He MX (2008). Ocean wave measurements based on satellite synthetic aperture radar (SAR)and numerical wave model (WAM) data–extreme sea state and Cross sea analysis. Int. J. Remote Sens., 29(10): 6403-6416.

Maged M (2000). Wave spectra and shoreline change by remote sensing data. Ph.D. Thesis, Universiti Putra Malaysia, Serdang, Kuala Lumpur, Malaysia.

Maged M (2001). TOPSAR wave spectra model and coastal erosion detection. Int. J. Appl. Earth Observ. Geoinfo., 3(4): 357-365.

Maged M, Ibrahim Z, Genderen JV (2002). Azimuth cut-off for significant wave height investigation along the coastal water of Kuala Terengganu, Malaysia. Int. J. Appl. Earth Observ. Geoinfo., 4(3): 147-160.

Maged M (2002). Opertional of Canny Algorithm on SAR data for Modelling Shoreline Change. Photogram. Ferner. Geoinformation, 93: 93-102.

Maged M (2003). ERS-1 Modulation Transfer Function Impact on Shoreline Change Model. Int. J. Appl. Earth Observ. Geoinfo., 4: 279-294.

Maged M (2004). Velocity Bunching Model for Modelling wave Spectra along East Copast of Malaysia. J. Ind. Soc. Remot. Sens., 32: 185-198.

Shu Y, Li J, Gomes G (2010). Shoreline extraction from RADARSAT-2 intensity imagery using a narrow band level set segmentation approach. Marine Geodesy, 33: 187-203.

Teodoro AC, Barbosa JP, Gomes FV, Pinto FT (2009). Evaluation of beach hydromorphological behaviour and classification using image classification techniques. J. Coastal Res., 56: 1607-1661.

Stanely Consultants Inc (SCI) (1985). Malaysian national coastal ersoion study, Volume II. UPEN, Kuala Lumpur, Malaysia.

Vachon PW, Raney RK (1991). Resolution of the ocean wave propagation direction in SAR imagery.IEEE Transactions on Geosci. Remote Sens., 29(91): 105-112.

Vachon PW, Ghogal AS, West JC (1992). Airborne SAR measurements of ocean waves during SWADE. Proceeding of 15 th Canadian Symposium on Remote Sensing, 1-4 June 1992. Toronto: Canada, pp. 352-356.

Vachon PW, Raney RK, Krogstad HE, Liu AK (1993). Airborne synthetic aperture radar observations and simulations for waves-in-Ice. J. Geophys. Res., 98: 16,411-16,425.

Vachon PW, Krogstad HE, Paterson JS (1994). Airborne and spaceborne synthetic aperture radar observations of ocean waves. Atmosphere-Ocean. 32(10): 83-112.

Vachon PW, Liu AK, Jackson FC (1995). Near-shore wave evolution observed by airborne SAR during SWADE. Atmosphere-Ocean, 2: 363-381.