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Depth Contours Appeared on SAR Images by Interactions Between Tidal Currents and Bottom Topography

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Abstract : X-SAR images taken on the coastal waters of Hwanghe province in Korea during SIR-C/X-SAR campaign in April and October 1994 are analysed. The SAR images show the peculiar signatures like nail marks, curved long string, and vortex street patterns and they all seem to be produced by strong interactions between the topography in the coastal waters and tidal currents. The nail mark signatures are located at the same position of small scaled sand banks and the curved line patterns are almost identical to the outer boundary of large sand banks. Based on the tidal records, all the three images are taken at the almost same phase of tidal cycles, which are close to the low tide. It seems that bottom shapes are more strongly appeared on the SAR images when the tidal currents are slow. The front between two different current velocities caused by the flows along the steep boundaries of sandbanks is also the main factors imprinting the bottom features to the sea surface SAR images.

Key Words : X-SAR, Topography, Depth contours, Tidal current, Sand banks.

1. Introduction

During the last 35 years, synthetic aperture radar (SAR) remote sensing of the sea surface has shown that it can be strongly correlated with bottom topography in coastal waters through the refraction of gravity waves, the modulation of the surface roughness by current velocity changes over shallow bottom, and internal wave propagating patterns. Among the above three mechanisms, the bottom features on SAR images caused by interactions between the currents and bottom topography are the most dominant phenomena and studied by many researchers.

Lodge (1983) identified that linear features on SEASAT images of the English Channel and Thames Estuary Approaches is linked to the steep edge of sand banks which is associated with a bright backscattering, that is a prevalence of short gravity waves. Alpers and Hennings (1984) described the bottom topography-current interaction using the continuity equation and showed the relationship between radar image intensity, sea surface roughness, tidal flow, and underwater bottom topography by schematic plot. They assumed that the velocity component normal to the direction of the ridge or

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sand wave obeys the continuity equation and the velocity component parallel to it remains constant. Shuchman and *et al.*(1985) explained the relationship between the SEASAT SAR signatures and the bottom topography of the ocean in the Southern Bight of the North Sea and Nantucket Shoals, and found these SAR-observed features are only present when a tidal current (0.4 m/s or greater) is flowing over the bottom and wind conditions are moderate (less than 10 m/s). The relation between radar imagery and bathymetry is also studied using a Side Looking Airborne Radar (SLAR)(Vogelzang and *et al.*, 1992). They concluded that the extremes in the radar backscatter are located right above regions with maximum bottom slopes, within the positional accuracy of 30 m. In order to deepen the theoretical foundations of the patterns on SAR images caused by underwater topography, Calhoun and Street (2002) approached with large-eddy simulations using the full Navier-Stokes Equations other than simple continuity equations. The bottom features also often appear on SAR images by intensified bragg scattering at the coastal current front lines caused by sudden depth changes such as shelf break and edges of estuarine channels (Valle-Levinson *et al.*, 2000).

This paper examines depth contours on X-SAR images generated by strong interaction between tidal flow and bottom topography.

2. Description of Study Area

X-SAR images taken on the coastal waters of Hwanghe province in Korea during SIR-C/X-SAR campaign in April and October 1994 are analyzed. The space shuttle loaded with SIR-C/X-SAR acquired X-band images on the coastal waters of Hwanghe province and KyungGi Bay in the Yellow sea flying from the northwest to the southeast three times on April 15, 16 and October 7, respectively. The swath was 15 km~40 km and the incidence angle was 15°~55° and the frequency was 9.6 GHz(VV). The SAR image composed of 2920 × 8196 pixels covering 36.5 km × 102.45 km area with a resolution of 12.5m.

The study area is characterized with tide dominated coastal waters having complicated coastal lines and bathymetry with many sand banks. The depth is less than 40 meters and the tidal range is about 8 meters with strong tidal currents. It is anticipated that the interaction between tidal currents and bottom topography is very strong causing complicated flow regime. Unfortunately, this area is very near to the Demilitarized Zone (DMZ) between South Korea and North Korea and access to this area for in-situ measurements is prohibited and not much in-situ data are available. Fig. 1 shows the map of study area near Incheon international port. The tide and wind information were obtained from the site outside the Incheon port.

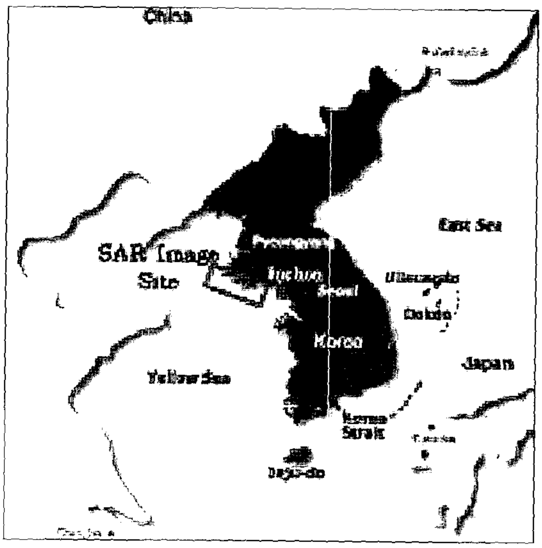

Fig. 1. Map of study area.

3. Depth Contours on SAR Images

The three X-SAR images show very interesting features related tidal current interaction with topography of coastal waters such as bottom contours and vortex streets behind small islands. Coincidently, all three images are taken near low tide when tidal current velocity is relatively slow compared to the other phase of tidal cycles. Specially, both images on April 15 and 16 indicate very precisely the boundary of sand banks along the 10 m depth contour line. In case of the image on October 7 the depth contour line is not clearly appeared but the bank area is blurred overall with high intensity backscattering. Fig. 2 shows three SAR images overlaid coastal bathymetry and Fig. 3 expresses the peculiar features on SAR images with lines. All the nail mark features are corresponding to the boundary of sand banks with different intensity. The curved line features indicating 10 m depth contour seem to be originated by current gradient generated by strong bottom slope. The average depth of the sand bank is about 7 m and the outside the bank is about 35 m and the tidal current during the ebb flows along the 10 m depth contour to the northwest. The current gradient is caused by the effect of bottom friction. The tidal flows over the sand bank is more slowed down by the friction compared to the flows at the channel and the strong gradient of the flow is appeared on the SAR image as high intensity backscattering. Since SAR images at the different phase of tidal cycles are not acquired, it is difficult to conclude that which current velocity is the best to express the depth contours on the SAR image. In case of ENVISAT ASAR image, the depth contours are also appeared on the SAR images at the various phases of tidal cycles but they are not sharp and distinct like the features on X-SAR images. It seems that X-SAR is good at detecting current gradients caused by bottom slope specially when the

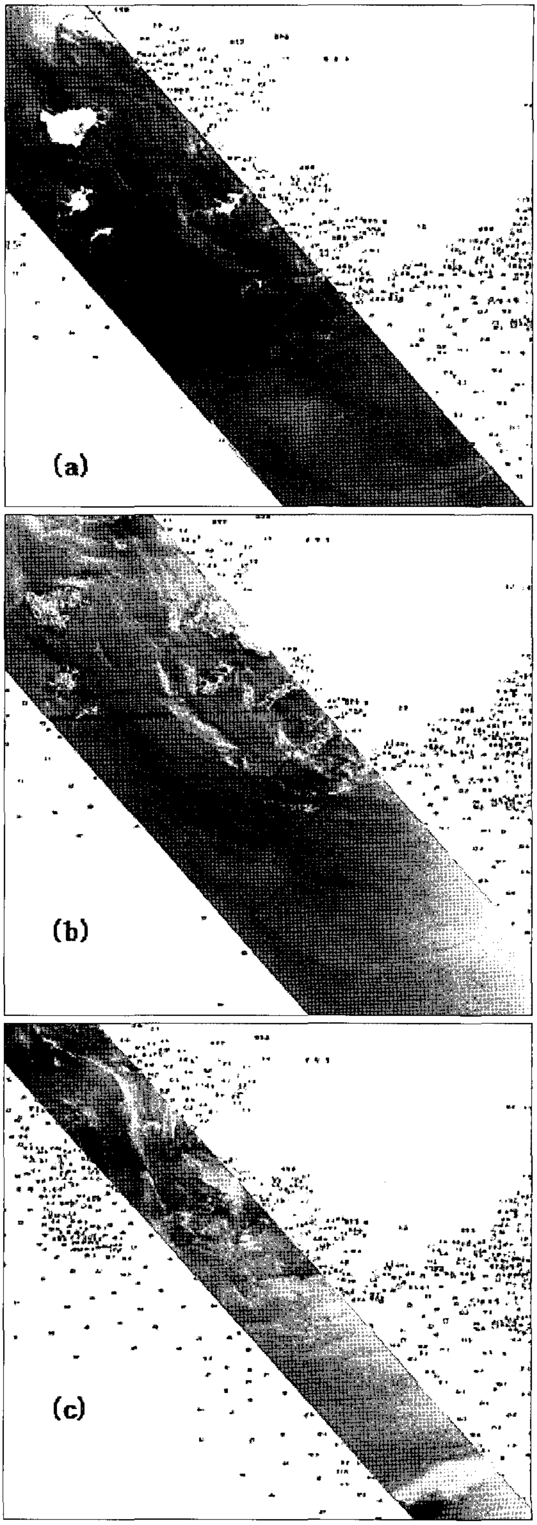

Fig. 2. X-SAR image acquired (a) at 12:44:33 on April 15 (b) at 12:24:09 on April 16 (c) at 12:36:02 on October 7, 1994.

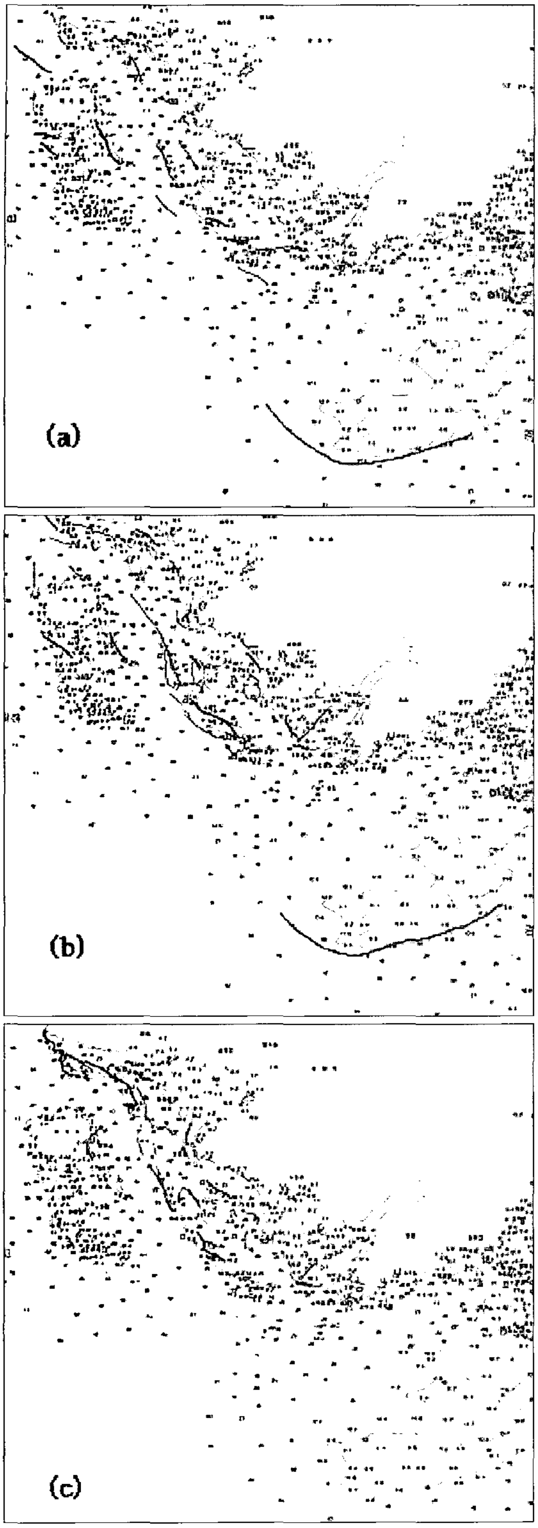

Fig. 3. Overlapping the bathymetry with the signatures on the SAR image (a), (b), and (c) in Fig. 2.

current velocity is not so strong. For further study, X-SAR images at different tidal conditions needs to be examined. Different band SAR images will provide more clearly the interaction mechanism between tidal current and bottom topography in the coastal waters.

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