Remote Sensing of Coastal Environments using Synthetic Aperture Radar

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Abstract

Coastal zones are the most productive and the rapidly changing places. But the areas are facing many environmental challenges related to climate change and human-induced impacts. The methods for monitoring of oil spills, strong wind waves, and oysters in tidal flats were investigated using space-borne synthetic aperture radar.

Keywords : Remote Sensing, Synthetic Aperture Radar, Coastal Environment

1. Introduction

Many of the world's major cities have been built on or near coastal areas. The coastal lands and near-shore marine areas are the most productive and the rapidly changing places. But the areas are facing many environmental challenges related to human-induced impacts. Oil spills, strong wind waves, sea level rise due to the global warming, as well as coastal erosion, flooding, declining water quality, all of these threats are involved and occurred in coastal environments. Moreover, the occurrence of these disasters has been continually increasing over the past thirty years [1]. Routine observations are urgently needed for monitoring and predicting these disasters. In this point of view, remote sensing using space technology may be the most promising tool for monitoring these areas of the rapid changing environment, since it can provide large spatial coverage and non-intrusive measurements frequently and periodically. In particular, microwave remote sensing using synthetic aperture radar (SAR) system has great potential for quantitative monitoring and mapping of the coastal areas, due to its ability to penetrate cloud cover and the capability of high resolution imaging at day and night. In this study, many potential applications of SAR in the coastal regions will be introduced and discussed. Researches on high-resolution coastal wind and internal waves, as well as Hebei Spirit oil spill and oyster reef detection in tidal flat, are interesting topics for the monitoring of coastal environments.

2. SAR Remote Sensing of Coastal Environments

2.1 Oil Spill Monitoring

On December 7, 2007, the nation's largest maritime oil spill occurred on the west coast of the Korean peninsula. More than 10,000 tons of crude oil was spilled in the sea after a crane barge collided with an anchored oil tanker, the Hebei Spirit. The spill contaminated an ecologically-pristine region as well as polluted the western coastline of the Korean peninsula. Fig. 1 shows SAR images acquired after the oil spill accident. Clear dark patches can be seen in these SAR images, which reveal the presence of oil spills. In general, the presence of oil spills on the sea surface damps down short gravity-capillary waves (Bragg waves), resulting in a reduction of radar backscatter and darker patches in SAR images. However, the dark patches can also be caused by natural slicks, such as organic materials produced by algae, plankton, and fish, or by atmospheric effects like wind shadows on lee, low wind speed areas, or rainy weather. However, by analyzing SAR image mechanism of oil spills and by applying several processing techniques for SAR data [2], we obtained very valuable information about where the oil spills exist and how they migrate. We can also estimate the areal extent of oil spills at each stage (Fig. 2).

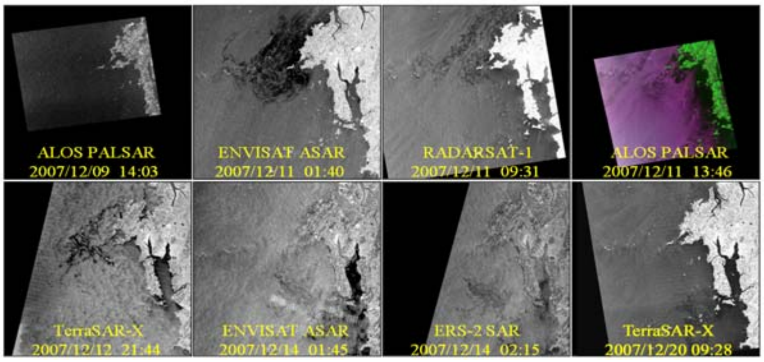
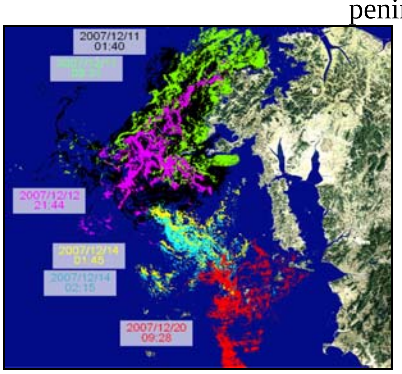


Figure 1. SAR images capturing the Hebei Spirit oil spill on the western coast of the Korean peninsula.



SAR data acquisition date	Oil slick covered area
ENVISAT 2007/12/11	1400 km²
RADARSAT-1 2007/12/11	700 km²
TerraSAR-X 2007/12/12	400 km²
ENVISAT 2007/12/14	350 km²
ERS-2 SAR 2007/12/14	340 km²
TerraSAR-X 2007/12/20	>410 km²

Figure 2. Oil spill areas identified from SAR data (left), and estimated amount of oil contaminated areas (right), as determined from multi-temporal and multi-platform SAR images.

2.2 **Internal Wave Parameter Extraction**

Interval waves can be observed all around the world ocean. But most of them are observed in coastal region. Fig. 3 shows a typical pattern of internal waves shown by SAR images. In order to obtain quantitative geophysical parameters regarding the internal wave, we employed numerical models by combining hydrodynamic interaction model, radar backscattering model, and internal wave propagation model. The hydrodynamic interaction model predicts the ocean surface roughness variations due to wave-current interactions using action balance equation [3]. The radar backscattering coefficient is calculated using the two-scale tilted Bragg model. The propagation and the evolution of internal waves over variable bathymetry were simulated under a two-layer fluid system with the upper layer depth being constant and the lower layer depth being variable. The simulated SAR intensity profiles were compared with the observed SAR intensity profiles at A and B positions in Fig. 3 (Fig. 4). The degree and the shapes of the simulated modulations agree fairly well with the SAR observation, which implies that the physical information about an internal wave can be extracted from SAR data by using the inversion of a radar backscattering model.

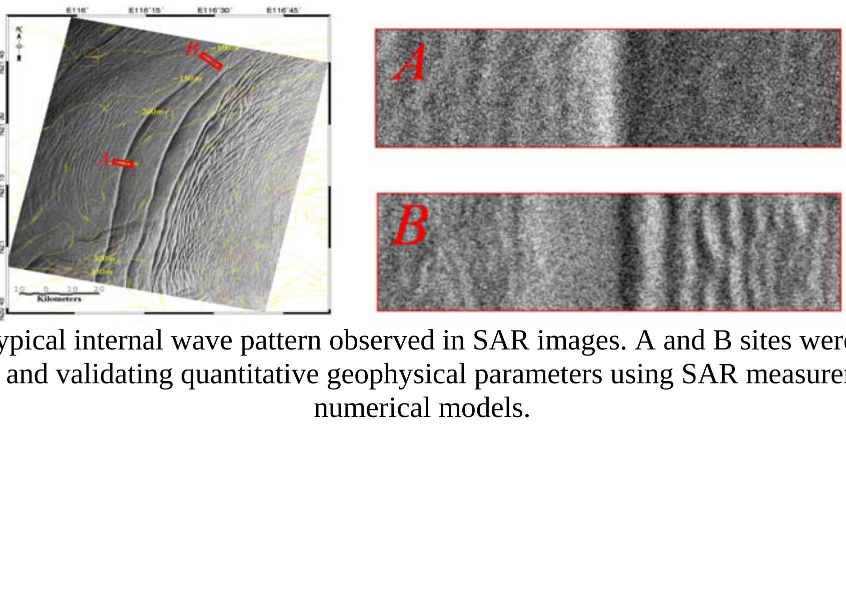


Figure 3. A typical internal wave pattern observed in SAR images. A and B sites were selected for extracting and validating quantitative geophysical parameters using SAR measurements and numerical models.

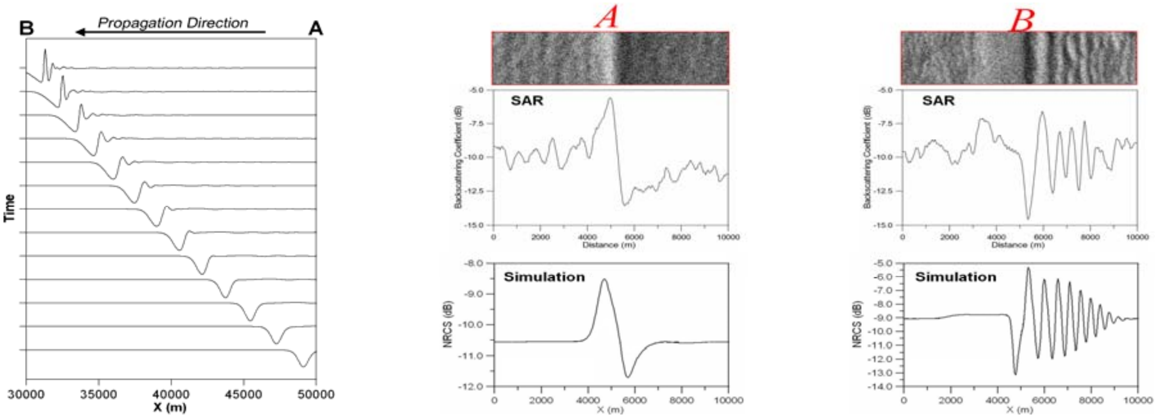


Figure 4. Numerical simulation of internal wave propagation (left), and the comparison results of the predicted SAR intensities with the actual SAR measured profiles (right).

2.3 **High Resolution Coastal Wind Retrieval**

SAR can measure, very accurately, the surface roughness of the ocean, and this is closely related to local sea surface wind. Fig. 5 shows schematically how the wind speed and direction can be estimated from SAR data. This technique can be directly applied to typhoon monitoring as well as coastal ocean. We have applied the developed wind-retrieval model to the coast of Daebu island and Typhoon Man-Yi (2007) (Fig. 6). For the wind retrieval, we have converted digital numbers into backscattering coefficients and used CMOD geophysical model function [4]. The wind directions used for CMOD model calculation were derived directly from wind aligned signatures (wind streaks) shown in the RADARSAT images.

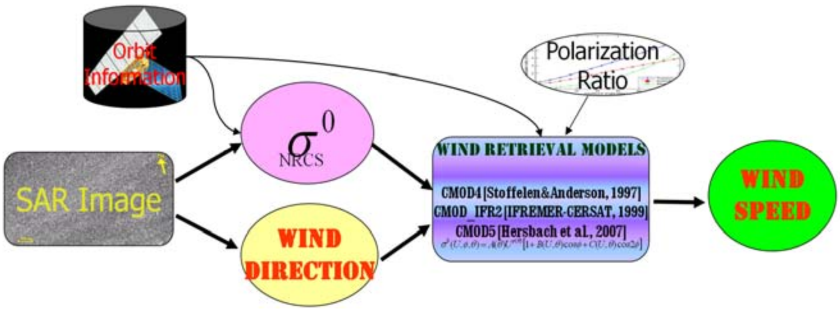
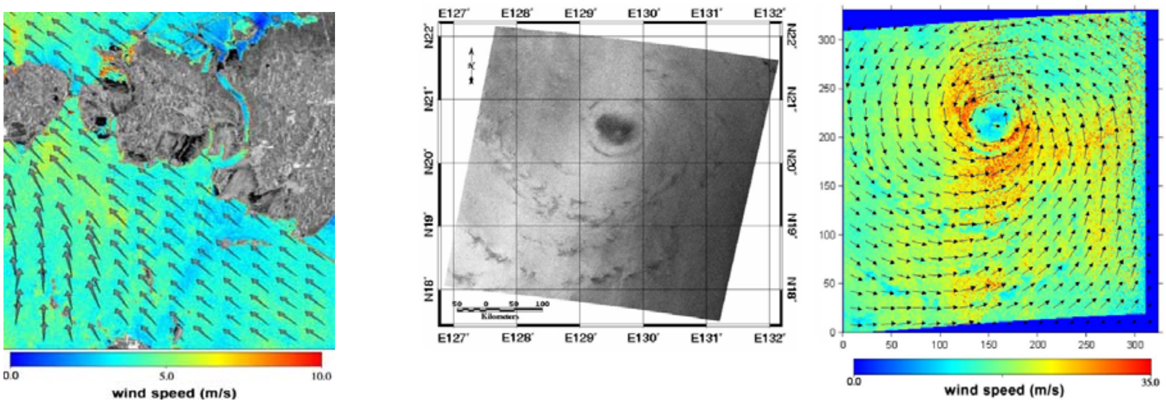


Figure 5. Schematic diagram for wind retrieval from SAR data.



(a) (b)

Figure 6. (a) Wind retrieval result from RADARSAT-2 SAR data in coastal ocean. (b) SAR image of typhoon Man-Yi (2007) acquired from RADARSAT-1 on July 11, 2007, and the estimated wind speed (color) and wind vectors (arrows).

2.4 **Oyster Detection in Tidal Flat**

We investigated the microwave scattering signatures occurred by the regional distribution of oysters in tidal flats, applying polarimetric analysis techniques to fully polarimetric RADARSAT-2 (C-band) and ALOS PALSAR (L-band) data. Tidal flats of Jebu Island in the western coastal region of the Korean peninsula were selected for the investigation. The scattering mechanisms for oyster reefs were analyzed using polarimetric target decomposition theorem and depolarization effects. The target depolarization was quantitatively measured using the cross-polarized ratio (HV/HH), co-polarized correlation (ρ_{HHVV}), and phase difference between HH and VV. Strong volume and multiple scattering with depolarization effects were observed in the oyster reefs of C-band SAR data, while only surface scattering was dominant in the L-band SAR data (Fig. 7a). We have also obtained the similar scattering signatures from the in-situ measurements using a ground-based microwave scatterometer system (Fig. 7b). This study suggests that multi-frequency polarimetric SAR measurements can be used for detecting the naturally distributed oysters in tidal flats.

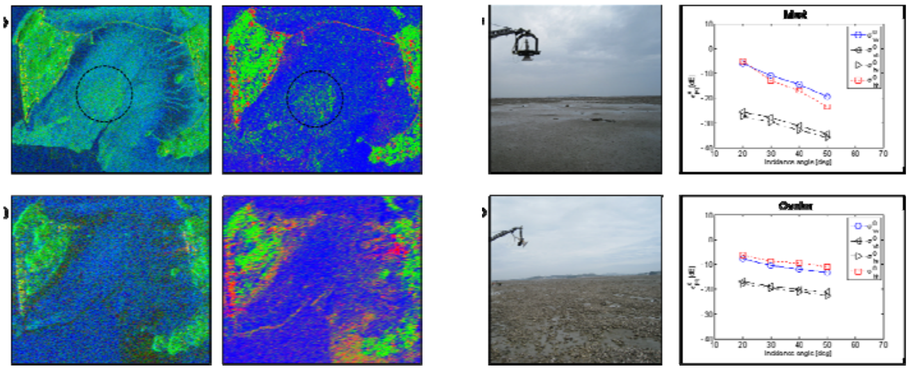


Figure 7. Freeman-Durden three component decomposition of fully polarimetric RADARSAT-2 and ALOS PALSAR data (left). Measurements of radar backscattering using a ground-based microwave scatterometer system (right).

3. Summary

Coastal zones, represented by the region between land and ocean, are important for environmental and natural hazard aspects. In this study, we have utilized the space-borne synthetic aperture radar data and successfully applied for oil spill monitoring, coastal wind field retrieval, internal wave extraction, and oyster reef detection in tidal flat.

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Acknowledgments

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