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Detection of the Hebei Spirit oil spill on SAR imagery and its temporal evolution in a coastal region of the Yellow Sea

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Abstract

To investigate the evolution of a disastrous oil spill from a vessel collision, known as the Hebei Spirit accident, off the coast of Korea in the Yellow Sea on 6 December 2007, oil slicks were identified from Synthetic Aperture Radar (SAR) images using a neural network (NN) and an adaptive threshold method. The results from the two objective methods showed good agreement, enough for the estimation of the extent of oil patches and their trajectories, with the exception of negligible errors at the boundaries. Quantitative analyses showed that the detected oil slicks moved southward, corresponding to the prevailing wind and tidal currents, and gradually dissipated during the spill, except for an extraordinary rapid decrease in onshore regions at the initial stage. The initial dissipation of the spilt oil was induced by tidal mixing in the tidal front zone. The spatial and temporal variations of the oil slicks confirmed the influence of atmospheric and oceanic environmental factors. The overall horizontal migration of the oil spills detected from consecutive SAR images was mainly driven by Ekman drift during the winter monsoon rather than the tidal residual current.

Keywords: Hebei Spirit; Oil spill; SAR image; Neural network; Tidal current; Ekman drift

1. Introduction

Oil spills on the sea surface have increasingly occurred, leading to devastating environmental hazards in the ocean. Spills have significantly influenced the biological ecology on short-term and long-term scales in local seas. Many endeavors are required for the removal and cleanup of oil spill contamination from soil and marine ecosystems. Aerial observations and satellite images monitor oil spills using diverse methodologies for detection. Very recently, a few methods were developed that use satellite optical images and microwave images. Synthetic Aperture Radar (SAR) images are among the most representative images to identify oil spills regardless of atmospheric conditions, such as clouds, fog, other meteorological phenomena, and sun illumination.

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Much research has been performed to develop a methodology for oil spill detection using spaceborne SAR imagery due to its exceedingly high spatial resolution under all-weather conditions (e.g., Espedal and Wahl, 1999; Gade and Alpers, 1999; Fiscella et al., 2000; Jones, 2001; Brekke and Solberg, 2005; Nirchio et al., 2005; Shi et al., 2008; Topouzelis, 2008; Hu et al., 2009; Klemas, 2010; Liu et al., 2010; Cheng et al., 2011; Li et al., 2012; Mera et al., 2012; Minchew, 2012; Xu et al., 2013; Cheng et al., 2014; Nunziata et al., 2014). For single-polarized SAR images, three types of methods have been widely utilized for detection: an adaptive threshold method (Vachon et al., 1998; Solberg et al., 1999); a bimodal histogram method (Skøelv and Wahl, 1993; Kim et al., 2013); and a neural network (NN) method (Del Frate et al., 2000; Garcia-Pineda et al., 2009). SAR systems have improved in their ability to increasingly observe the oceanic surface at a full-polarized state (HH/HV/VH/VV), and new techniques for processing the full-polarized data have also developed rapidly. Representative methods for the multi-polarized SAR data, such as a decomposition analysis (Migliaccio et al., 2007; Liu et al., 2011; Li et al., 2014) and a conformity coefficient method (Zhang et al., 2011), have been attempted for monitoring oil spills.

Although the polarimetric approach was determined to be more accurate and more applicable to oil detection, particularly in the discrimination of oil slicks from look-alikes, such as low wind regions, rain cells, and shear zones (e.g., Velotto et al., 2011; Migliaccio et al., 2011; Li et al., 2014), a limited number of multi-polarized SAR data were unable to be used extensively for operational monitoring and for diverse purposes of scientific understanding on the spatial distribution and temporal evolution of oil patches. Such infrequent measurements allowed us more opportunity to use the single-polarized SAR data. In light of this, we used both an adaptive threshold method and the NN method for single-polarized SAR images in this study.

An unprecedented oil spill accident occurred due to a collision (126.05°E, 36.86°N) between the crude oil tanker Hebei Spirit and a towed crane barge in an off-coastal region off the Korean coast at 22:15 Universal Time Coordinated (UTC) on 6 December 2007, as marked by the black star in Fig. 1b. Due to the collision, a considerable amount of three types of crude oil immediately began to leak from three damaged tanks: Upper Zakum crude (density: 0.856 g/cm^3, American Petroleum Institute (API) gravity: 33.7); Kuwait export crude (0.868 g/cm^3, API gravity: 30.9); and Iranian heavy crude (0.870 g/cm^3, API gravity: 31.1). The oil leaks lasted for about one and half days until 14:40 UTC on 8 December 2007. As a result, a total of approximately 10,900 tons of crude oil spilled into the sea. Due to the strong winds and current at that time, the oil slick rapidly spread to the southeast from the area of the collision and caused considerable damage because of the extensive contamination of offshore and coastal regions along the western coast of Korea. It was evaluated as the largest and worst oil spill in the seas around Korea.

Previous research attempted to monitor these types of widely dispersed oil spills and their variations by utilizing SAR images (e.g., Yang et al., 2009; Kim et al., 2010, 2014). Some of the studies used both spaceborne optical data and SAR images to simulate the dispersion of the oil slicks through numerical model experiments (Yang et al., 2009; Kim et al., 2014). In addition, theoretical damping ratios for the detection of oil slicks were applied to the Hebei Spirit incident for a brief overview (Kim et al., 2010). However, all of the previous studies

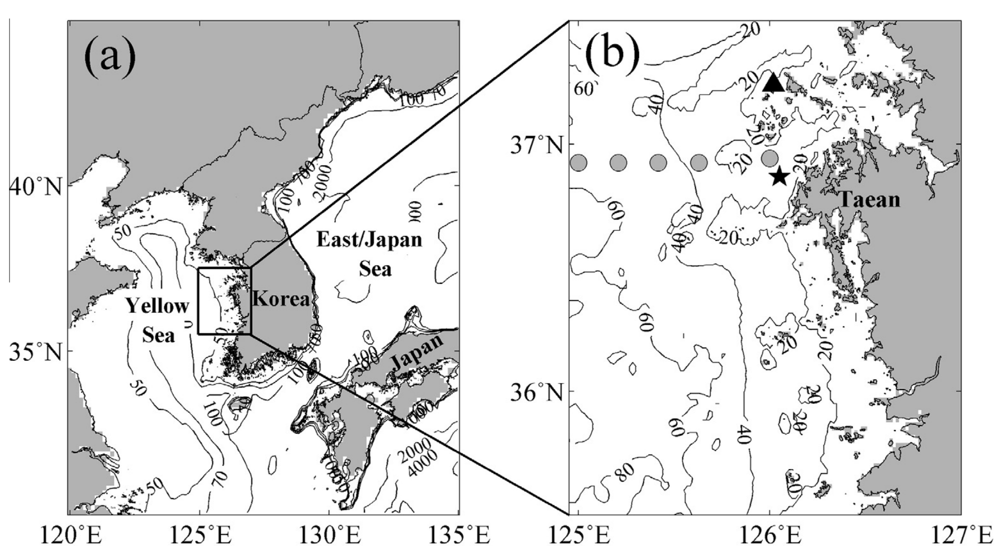

Fig. 1. (a) Contour of the water depth (m) in the seas around the Korean Peninsula, where the black box indicates the study area, and (b) an enlarged image of the bathymetry contour in the study area, where the black star symbol and the black triangle symbol indicate the collision point of the Hebei Spirit (126.05°N, 36.86°E) and the location of the KMA buoy station (126.02°N, 37.24°E), respectively. Gray circles along the section at 36.9°N indicate the stations where the in-situ measurements of the KODC were taken.