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Chronic, Anthropogenic Hydrocarbon Discharges in the Gulf of Mexico

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ABSTRACT

Satellite-borne Synthetic Aperture Radar (SAR) was used to obtain more precise estimates of the magnitude of the chronic hydrocarbon discharges described in qualitative pollution reports associated with the production and transportation network of the U.S. coast of the Gulf of Mexico. The National Response Center (NRCen) oil pollution reports were collected and filtered for the period of 2001 to 2012 to determine which of the reports coincided with archived SAR images. Some of the images covered multiple reports and some of the oil discharges described in one report could be observed in more than one image. In all, 177 reports could be investigated from 137 SAR images collected on or near the corresponding report dates. Further analysis found that oil slicks observed in 66 of these SAR images could be attributed to 67 of the reported incidents. Objective measurements indicated that the area of these transient oil slicks *visible* in SAR images was, on average, significantly larger than what was reported to the NRCen. The only recurring point source for oil slicks was the former site of the Taylor offshore platform. Here chronic, oil slicks were observed that were consistently much larger than other anthropogenic discharges. The SAR images of floating oil discharged from the Taylor site were verified by visual inspection from a boat and aerial photography. For some of the oil slicks discharged from the Taylor site, the accuracy of SAR images for detecting oil slick areas was validated by comparing SAR results to Landsat 7 Enhanced Thematic Mapper Plus (ETM+) and Moderate Resolution Imaging Spectroradiometer (MODIS) images. These results show that surveillance by SAR would improve accuracy for estimates of chronic anthropogenic oil pollution, particularly where continuous discharges are on-going.

1. Introduction

Petroleum discharges are a common source of toxic substances in marine ecosystems (National Research Council, 2003). As point-sources, they originate from natural seeps at the seabed and from discharges that occur during the production and transport of petroleum; there is substantial additional input from non-point-source discharges associated with the consumption of petroleum (National Research Council, 2003). Catastrophic oil spills, like the *BP / Deepwater Horizon* Blowout of 2010 (Ryerson et al., 2011), are a major concern in the Gulf of Mexico, which has large-scale offshore oil and gas operations and is the most developed offshore petroleum province in the world (Managi et al., 2005; Priest, 2007). However, chronic discharges are also an issue in the Gulf of Mexico. Chronic oil pollution is defined as discharge of small amounts of oil over long periods of time, which exposes marine organisms to oil and its chemical components (Lagring et al., 2012; Suchanek, 1993). It has been shown that the ecological impact of chronic exposure to small amounts of oil can be greater than acute exposure during larger, but shorter-lasting spills (Serra-Sogas et al., 2008). Previous studies have suggested that chronic oil pollution from oil production and transportation comprised less than 5% of total annual input in North American marine waters (National Research Council, 2003). However, these conclusions were based on qualitative estimates and have not been validated by independent assessments. Routine remote sensing surveillance has been shown to be an effective means for detecting and reducing oil pollution in the North Sea (Lagring et al., 2012). Improved detection and quantification of chronic oil pollution in coastal North American waters could therefore improve estimates for its magnitude and could potentially reduce overall discharges.

Surface films of oil, which damp the capillary surface waves in the ocean, increase specular reflection and enhance sun-glint; this causes bright targets in optical data (MacDonald et al., 1993). The same

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process reduces radar back-scatter and generates dark targets in SAR images (Espedal and Wahl, 1999; Gade et al., 1998). SAR images are particularly useful in oil spill detection and monitoring because of their large coverage and all-sky capabilities (Espedal and Wahl, 1999; Garcia-Pineda et al., 2008). Satellite detection of floating oil is challenged by the possibility of false positives, that is, non-hydrocarbon features that could have similar signatures in remote sensing data. Low wind conditions, upwelling effects, current fronts, seaweeds, and biogenic materials appear dark in SAR images and can give the false impression of oil (Girard-Ardhuin et al., 2005; Jha et al., 2008).

SAR-based oil pollution monitoring capabilities were demonstrated in Norwegian waters in the early 1990s using ERS-1 satellite images (Brekke and Solberg, 2005). The usefulness of ERS-2 SAR images for routine oil spill detection was demonstrated by two-year oil pollution study of the southern Baltic Sea, the North Sea, and the northwestern Mediterranean Sea (Gade and Redondo, 1999). From 1999-2004, the Joint Research Center (JRC) of the European Commission monitored the oil spills for the Mediterranean and the Black Sea in low resolution (~ 200 m) SAR images and numerous, possibly illicit, discharges were detected (Ferraro et al., 2009). About 7000 oil spills were detected from 1999-2002 among 11,000 SAR images collected over the Mediterranean Sea during the Monitoring Illicit Discharges from Vessels project of JRC. During the same project, 2695 oil spills were detected in the Baltic Sea by aerial surveillance from 1998-2004. From 2000 to 2002, 700 oil spills were detected among 1840 SAR images in the Black Sea (Camphuysen, 2007). SAR images have also been used for detecting small-volume natural discharges of oil in the Gulf of Mexico (De Beukelaer et al., 2003).

The National Contingency Plan (NCP) of the U.S. federal government details responsibility for responding to oil spills and hazardous substance discharges. The NRCen[1] is one of the key components of the NCP; it is located at the U.S. Coast Guard headquarters and is the U.S. government point of contact for reports of oil spills in the United States and its territories. By law, releases and discharges of oil that cause film, sheen, or discoloration of the surface of the water, or deposited sludge or emulsion beneath the surface of the water, must be reported to the NRCen (U.S. Environmental Protection Agency, 2013). The NRCen is responsible for collecting information about the location, size, nature of the release and discharge, and the facility or vessel and responsible parties which caused it, and for limiting damage from a spill and facilitating cleanup efforts by emergency managers (Klemas, 2010). All reports collected by the NRCen are maintained in a national database and are available to the general public online (http://www.nrc.uscg.mil).

However, the NRCen pollution records depend largely on unverified reporting from responsible parties (polluters) and third parties (passers-by). The NRCen system has not been validated by an independent assessment to show the accuracy of reports in terms of location and magnitude. This paper will investigate whether routine monitoring with satellite remote sensing coupled with the NRCen reports can provide an accurate estimate of chronic petroleum discharges.

2. Materials and Methods

The NRCen oil and hazardous materials spill reports in the Gulf of Mexico submitted by the polluters and by passers-by were collected and filtered for the period from 2001 to 2012. We did not consider the reports from 20 April to 5 August of 2010 to avoid the information associated with the BP / *Deepwater Horizon* oil spill. Updated information on energy platform locations and ages in the Gulf of Mexico was obtained from the Bureau of Ocean Energy Management (BOEM) to verify the location of discharges reported from production platforms (http://www.boem.gov/Oil-and-Gas-Energy-Program/Mapping-and-Data/Maps-And-Spa tial-Data.aspx). The available archive of SAR data included Environmental Satellite Advanced Synthetic Aperture Radar (ENVISAT ASAR) C band imagery from the European Space Agency, RADARSAT C band imagery from the National Aeronautics and Space Administration (NASA) and support from the Alaska Satellite Facility, and COSMO-SkyMed X band images from the National Oceanic and Atmospheric Administration. The MODIS data can be used for cost effective spill monitoring in near real time (Hu et al., 2009; Hu et al., 2003). For validation of the extent of oil slicks, MODIS data of 6 September 2010, 18 August 2011, and 9 September 2011 and Landsat data of 6 September 2010 and 9 September 2011 were obtained from NASA's Earth Observing System Data and Information System and U.S. Geological Survey Earth Explorer respectively.

Initially, we matched the times and the locations of the reported oil spills against the coverage and acquisition times of the satellite images and determined whether the reports coincided with archived SAR images. When matches were found, we used a semi-supervised image processing routine to determine the location and extent of oil-covered water. This routine, the Texture Classifying Neural Network Algorithm (TCNNA) has been used for SAR detection of the oil slicks produced by natural oil seeps in the Gulf of Mexico (Garcia-Pineda et al., 2009) and during the *BP / Deepwater Horizon oil spill* (Garcia-Pineda et al., 2013). Additional TCNNA routines were developed for the present work to broaden its application for ENVISAT ASAR, and RADARSAT SAR images. However, the TCNNA is not trained for COSMO-SkyMed images; therefore, we used the digitizing tool of ArcGIS to manually delineate oil slicks in COSMO-SkyMed images. After oil slicks had been extracted, we used ArcToolbox's Conversion and Spatial Statistics tools to calculate the area and location of the extracted oil slicks.

To validate the accuracy of SAR images in detection of the oil extent, some of the reported oil slicks that originated from the Taylor site were investigated in Landsat 30-m resolution data and MODIS Terra and Aqua medium resolution data (250–500 m). The *visible* oil slicks in these images were manually delineated and measured with ArcGIS digitizing tools.

To verify the appearance in SAR images of floating oil discharged from the Taylor site, we used high-resolution, aerial imaging of an oil slick coordinated with sea-level observations and collections taken from a small boat (7.6 m). A vertically oriented digital camera mounted in a small plane was used to collect color images from an average altitude of 270 m while the plane flew along the track of oil drifting away from the source. Location and the altitude of the plane for the

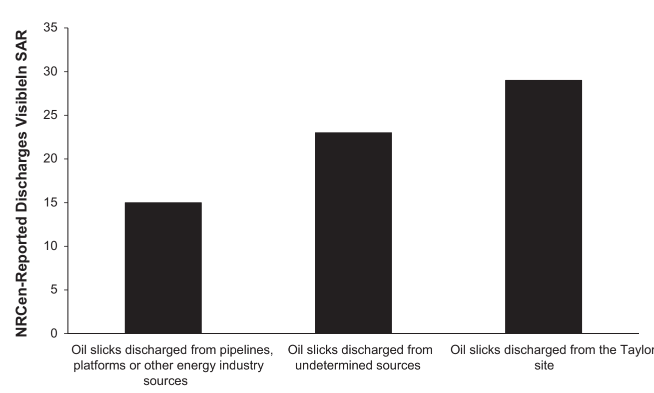

Fig. 1. Summary results show the relative frequency of discharges for 67 NRCen reports where oil slicks were detected in SAR images.

[1] The National Response Center is entirely separate from the National Research Council (cited in references) and the two institutions are not to be confused despite using identical acronyms.