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Remote sensing assessment of oil spills near a damaged platform in the Gulf of Mexico

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ABSTRACT

An oil platform in the Mississippi Canyon 20 (MC-20) site was damaged by Hurricane Ivan in September 2004. In this study, we use medium- to high-resolution (10–30 m) optical remote sensing imagery to systematically assess oil spills near this site for the period between 2004 and 2016. Image analysis detects no surface oil in 2004, but ~40% of the cloud-free images in 2005 show oil slicks, and this number increases to ~70% in 2006–2011, and > 80% since 2012. For all cloud-free images from 2005 through 2016 (including those without oil slicks), delineated oil slicks show an average oil coverage of 14.9 km^2/image, with an estimated oil discharge rate of 48 to ~1700 barrels/day, and a cumulative oil-contaminated area of 1900 km^2 around the MC-20 site. Additional analysis suggests that the detected oil slick distribution can be largely explained by surface currents, winds, and density fronts.

1. Introduction

During Hurricane Ivan in September 2004, the oil platform and 25 of the 28 connected wells at the Taylor Energy's Mississippi Canyon 20 (MC-20) site, located in the northern Gulf of Mexico (GoM), were damaged and impacted. Subsequently, oil was found leaking, which was reported as the Taylor Energy oil spill or MC-20 oil spill (Herbst et al., 2016; Warren et al., 2014). Although mitigation efforts have taken place (including removal of the platform deck and subsea debris, decommissioning of the oil pipeline, and plugging 9 of the 25 impacted wells), there has been a continuous oil discharge from the platform site. Beginning in September 2014, over 7 months of near-daily aircraft overflights reported oil sheen observations, with an oil slick generally about 1.6 km wide and 9 km long, and an average oil coverage area of 20 km^2 (BSEE, 2017). The United States Bureau of Safety and Environmental Enforcement (BSEE) estimated that the oil discharge could continue for 100 years or more if left uncontrolled (BSEE, 2017). This crude oil spill from the MC-20 site is also documented in the National Response Center (NRC) reports (NRC, 2018), containing information like spill locations, spill materials, spill size, etc., with involved material documented as crude oil (NRC, 2018; NOAA, 2013). The NRC reports, however, depend largely on unverified reporting from responsible parties (polluters) and third parties, and therefore its reported slick size information was found to be significantly underestimated (Daneshgar Asl et al., 2016). Moreover, those traditional airborne and shipborne surveys are often too limited spatially and temporally to construct statistics about the discharged oil, as they often result in data gaps. Satellite remote sensing, which serves as a vital tool in response to oil spills (Leifer et al., 2012), provides frequently synoptic observations of the MC-20 oil locations over the entire spill period (since 2004) and may fill these data gaps in objectively assessing the oil spill near the MC-20 site.

The proximity of the MC-20 site to the Mississippi River Delta suggests that the oil slick extensions and fate are under the direct effect of the river plume dynamics, which play a significant role in the circulation around the Delta and over the broader Northern Gulf circulation (Walker et al., 2005; Schiller et al., 2011; Androulidakis and Kourafalou, 2013; Androulidakis et al., 2015). The brackish plume may either extend over the MC-20 site, forming a near-surface vertical barrier layer, or determine the oil transport pathways along the river-induced fronts. Based on satellite (remote sensing imagery) and field (drifters, ship-borne measurements) observations, Androulidakis et al.

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(2018) showed that the locations of the river's multiple fronts (outer and inner density fronts) are vital for the evolution and fate of the material at the sea surface that originates from the MC-20 site. The buoyancy-driven Mississippi plume waters generally reveal three major pathways where the Coriolis effect is important (Garvine and Monk, 1974; Kourafalou et al., 1996): an anticyclonic bulge around the Delta, a "downstream" coastal current toward the northwestern Gulf shelves, and an "upstream" current toward the northeastern shelves (Schiller et al., 2011; Zhang et al., 2012; Androulidakis et al., 2015). Although several other atmospheric (e.g. winds) and oceanic (e.g. local eddies, Loop Current) conditions determined the oil spill fate during the DeepWater Horizon (DWH) accident in 2010 (Walker et al., 2011; Le Hénaff et al., 2012), the river plume contribution was vital to the spreading of the hydrocarbons over the Gulf and especially around the Mississippi River Delta region (Kourafalou and Androulidakis, 2013). The use of remote sensing imagery benefits both the observation of oil slick dynamics over short-term (a few hours to a few consecutive days) and the long-term oil distribution frequency near the Mississippi River Delta region, enabling the study of river plume impacts on oil slick spreading in a region under strong influence of the Mississippi River plume. Despite sporadic field and airborne surveys, no comprehensive long-term picture currently exists regarding the oil spill near the MC-20 site. Therefore, there are two main goals in this study: first to geo-statistically analyze oil slicks using medium- to high-resolution (10–30 m) satellite imagery around the MC-20 site from September 2004 to December 2016; and to study how atmospheric and ocean conditions affect the oil slick distributions observed in remote sensing imagery in this region under strong river plume influence.

2. Data and methods

The MC-20 site is located approximately 17 km offshore from the Mississippi Delta in the GoM (Fig. 1). The location is in the frontal region of the Mississippi river plume, with associated wells at a water depth of 145 m. This MC-20 site is ~60 km away from the DWH (Macondo) blowout location (Fig. 1). The catastrophic explosion and sinking of the DWH oil platform on 20 April 2010 caused the second largest marine oil spill in history (McNutt et al., 2012; Murphy et al., 2016). The Macondo well emitted 3.19 million barrels of crude oil into the northern GoM (McNutt et al., 2012; U.S. v. BP et al., 2015) until the wellhead was finally capped on 15 July 2010.

In optical remote sensing imagery, the contrast between surface oil and non-oil water comes from two sources. The first is the sun glint effect, which enhances the contrast of the otherwise non-observable oil due to the wave-damping effect (Adamo et al., 2009; Hu et al., 2009; Macdonald et al., 1993; Sun and Hu, 2016). The same mechanism affects the Synthetic Aperture Radar (SAR) detection of oil at the ocean surface (Brekke and Solberg, 2005). Depending on the viewing geometry and wind, the oil-water contrast can be either positive or negative in the optical imagery (Hu et al., 2009; Jackson and Alpers, 2010; Lu et al., 2016). The second is the difference between optical properties of oil and water. Crude oil is characterized by high absorption in blue wavelengths (Byfield, 1998) where the increased thickness of oil correlates to decreased reflectance in blue waves (Lu et al., 2013a; Wettle et al., 2009) until oil is too thick for light penetration (Lu et al., 2013b). When oil is emulsified, the water-in-oil emulsion causes strong scattering in the red, near infrared (NIR), and shortwave infrared (SWIR) wavelengths (Bulgarelli and Djavidnia, 2012; Clark et al., 2010; Svejkovsky et al., 2012). A combination of sun glint and optical properties of the oil-water contrast has been used to efficiently characterize oil spills in a marine environment (Bulgarelli and Djavidnia, 2012; Clark et al., 2010; Hu et al., 2009; Leifer et al., 2012; Lu et al., 2013b; Sun et al., 2015).

In this study, for oil slick delineation we mainly used optical remote sensing imagery from Landsat-5 Thematic Mapper (TM), Landsat-7 Enhanced Thematic Mapper Plus (ETM+), Landsat-8 Operational Land Imager (OLI), and Sentinel-2 MultiSpectral Instrument (MSI). Landsat sensors have a nominal resolution of 30 m while MSI has a nominal resolution of 10 m. Oil slicks from the DHW oil spill between April and July 2010 have been shown to reach the MC-20 region (Hu et al., 2011; MacDonald et al., 2015). To avoid confusion from the DWH oil spill, images collected in 2010 around the MC-20 site were not included in this study. Landsat imagery has a revisit time of 16 days alone (Table 1), and 8 days combined (TM with ETM+ in 2004–2011, and ETM+ with OLI in 2013–2016). A total of 513 medium- to high-resolution images (10–30 m) were explored, with 294 cloud-free images found in this region. A summary of the medium- to high-resolution optical imagery used in this study is shown in Tables 1 and 2. The average cloud-free images per year are 26 (excluding year 2004 since the oil spill started in September of that year), 15 of which were taken during favorable sun glint season in the GoM (April–September, from Hu et al., 2009; Sun and Hu, 2016). Thin oil sheens may not be efficiently detected under

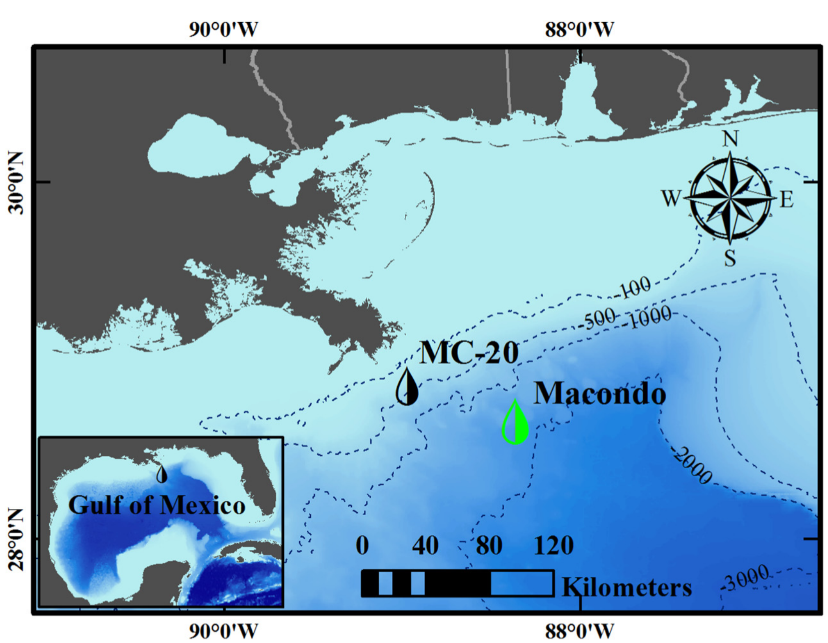

Fig. 1. The MC-20 site (black droplet top: latitude 28.94, longitude −88.97, which also applies to the following figures) is 17 km offshore of the Mississippi River Delta in the Gulf of Mexico (GoM) at a water depth of 145 m. The 2010 DeepWater Horizon (DWH) oil spill in the Macondo site (green droplet top: latitude 28.74, longitude −88.37) is ~60 km southeast of the MC-20 site with a water depth of ~1500 m. The background color in the GoM denotes the water depth, and major bathymetry contours (in units of meters) have been noted on the map.