Remote Sensing of Environment 189 (2017) 96–107

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

Hindcast modeling of oil slick persistence from natural seeps

Samira Daneshgar Asl [a], Dmitry S. Dukhovskoy [b], Mark Bourassa [a,b], Ian R. MacDonald [a,*]

[a] Florida State University, Department of Earth, Ocean and Atmospheric Science, Tallahassee, FL 32306, USA
[b] Center for Ocean-Atmospheric Prediction Studies, Florida State University, Tallahassee, FL 32306, USA

ARTICLE INFO

Article history:
Received 9 June 2016
Received in revised form 13 October 2016
Accepted 3 November 2016
Available online xxxx

Keywords:
Natural seep
Oil slick
Green Canyon 600
Synthetic aperture radar
Surface oil drift model

ABSTRACT

Persistence of oil floating in the ocean is an important factor for evaluating hydrocarbon fluxes from natural seeps and anthropogenic releases into the environment. The objective of this work is to estimate the surface residence-time of the oil slick and to determine the importance of wind and surface currents on the trajectory and fate of the released oil. Oil slicks released from natural hydrocarbon seeps located in Green Canyon 600 lease block and its surrounding region in the Gulf of Mexico were analyzed. A Texture Classifying Neural Network Algorithm was used to delineate georectified polygons for oil slicks from 41 synthetic aperture radar images. Trajectories of the oil slicks were investigated by employing a Lagrangian particle-tracking surface oil drift model. A set of numerical simulations was performed by increasing hindcast interval in reverse time order from the image collection time in order to obtain the closest resemblance between the simulated oil pathways and the length and shape of the oil slicks observed in synthetic aperture radar images. The average surface residence-time predicted from the hindcast modeling was 6.4 h ($\pm$5.7 h). Analysis of a linear regression model, including observed oil slick lengths and variables of wind, surface current, and their relative direction, indicated a statistically significant negative effect of wind speed on the surface oil drift. Higher wind speed (>7 m s^{-1}) reduced length of the oil slicks. When wind and surface currents were driving forces of the surface oil drift model, a good agreement between simulated trajectories and subsequent satellite observations ($R^2 = 0.9$) suggested that a wind scaling coefficient of 0.035 and a wind deflection angle of 20° to the right of the wind direction were acceptable approximations for modeling wind effects in this study. Results from the numerical experimentation were supported by in situ observations conducted by a wind-powered autonomous surface vehicle (SailDrone). Results indicated that the surface currents are, indeed, responsible for stretching oil slicks and that surface winds are largely responsible for the disappearance of the oil slicks from the sea surface. Under conditions of low wind and strong current, natural seeps can produce oil slicks that are longer than 20 km and persist for up to 48 h.

1. Introduction

Natural hydrocarbon seeps are important for carbon cycle processes (Kvenvolden, 1993; MacDonald et al., 1996; Kvenvolden, 2002; MacDonald et al., 2002; Judd, 2004), marine pollution (Allen et al., 1970; Spies et al., 1996; Espedal and Wahl, 1999; Kvenvolden and Cooper, 2003; DiGiacomo et al., 2004), and marine ecosystems (MacDonald et al., 1989; MacDonald et al., 1990; Guinnasso and Kennicutt, 1994; MacDonald et al., 2004; Orcutt et al., 2010; D'souza et al., 2016). Based on the global estimates of crude-oil seepage rates, 47% of the crude oil entering the marine environment is from natural oil seeps (Kvenvolden and Cooper, 2003). At natural seeps, the oil that makes it to the sea surface spreads out in a thin layer (<1 μm) from the oil slick origin (OSO) and floats downstream with wind and surface currents (MacDonald et al., 2002; Garcia-Pineda et al., 2010). When the wind speed is under about 6 m s^{-1} the oil tends to remain on the surface, except for that which dissolves or evaporates (Reed et al., 1994). For wind speeds >7 m s^{-1}, the frequency of breaking waves increases (Samuels et al., 1982) which disperses substantial portions of the oil subsurface. The oil slick gradually dissipates through weathering processes such as spreading, flocculation, dissolution, and evaporation over ensuing time (MacDonald et al., 1993; Guinnasso and Murray, 2003). Seeps are indicators for economically significant hydrocarbon deposits and a dynamic component of the carbon cycle; however, the rates and magnitudes of this process are not well constrained in regard to the dissipation of oil that reaches the sea surface (Leifer et al., 2000; MacDonald et al., 2002).

In this paper, surface residence-time means the maximum time that oil in a slick can be detected by synthetic aperture radar (SAR). In a typical slick, this oil will be found at the point most distant from the OSO. A given natural oil slick includes oil near the OSO that has newly arrived at the surface and oil at the opposite end of the slick, which has been drifting on the surface for the residence-time determined by the specific

* Corresponding author.
E-mail addresses: samira.daneshgar@gmail.com (S. Daneshgar Asl), imacdonald@fsu.edu (I.R. MacDonald).

http://dx.doi.org/10.1016/j.rse.2016.11.003
0034-4257/© 2016 Published by Elsevier Inc.

environmental conditions and the properties of the oil. Accurate estimate of residence-time for oil slicks released from a natural seep can be used to calculate a flux based on the amount of oil present (National Research Council Committee on Oil in the Sea, 2003); however, there have been few studies that quantify this aspect of the seepage process.

Satellite remote sensing offers a means to analyze the characteristics of floating oil. Natural seeps produce persistent oil slicks at predictable locations. Surface films of oil dampen the short gravity-capillary ocean surface waves, reduce radar back-scatter, and generate dark targets in SAR images (Gade et al., 1998; Espedal and Wahl, 1999). Comprehensive remote sensing surveys showed that there are about 914 seep zones in the Gulf of Mexico (GoM) producing persistent oil slicks seen by SAR (MacDonald et al., 2015). Some of the oil slicks are relatively short and some of them are longer. This raises two important questions. First, are very long oil slicks caused by an increased rate of discharge at the natural hydrocarbon seep? Second, what is the relative contribution of wind and surface currents to the length and shape of the oil slicks? Addressing these questions can improve use of remote sensing during oil spills and for research on natural seeps.

The most important factors that determine the direction, rate of the movement, and persistence of an oil slick are the strength of surface winds and currents (MacDonald et al., 2002; Guinnasso and Murray, 2003; Korotenko et al., 2004; Garcia-Pineda et al., 2010). Previous studies performed in the North Sea proposed that oil released at a fixed point source moves with approximately 3% of the wind speed in a direction 15° to the right of the wind direction (Bern, 1993; Espedal and Wahl, 1999). This assumption was made under the conditions of no (strong) surface current and no other factors influencing the spread pattern (Espedal and Wahl, 1999). Based on drift card experiments, the results of computations using data from the Bravo blowout, wind, and tidal currents in the North Sea a wind scaling coefficient of 2.5–3% and a Coriolis deflection of 12–15° gave results in good agreement with observations (Audunson, 1980). Repeated observations of natural oil slicks should make it possible to refine wind scaling coefficient and deflection angle and to consider the combination of wind and surface current components which vary over time. Strong surface current fields can either deflect an oil slick in an opposing direction from the wind or elongate it in the same direction as the wind (Espedal and Wahl, 1999).

In this study, a two-dimensional surface oil drift model forced by 10-m wind fields and surface ocean currents was used to simulate the evolution of the oil slicks released from Green Canyon 600 (GC600) natural seep that were observed by SAR satellite imagery. The simulation results were analyzed to estimate the surface residence-time of the oil slicks. To verify our findings and the importance of the wind and surface currents in deriving the trajectory of oil slicks on the sea surface, high resolution aerial photography, a Landsat 8 satellite image, and real-time surface winds from a wind-powered autonomous surface vehicle (SailDrone) study were analyzed.

2. Study area

This study was conducted in the GoM at seep zones located in the Bureau of Ocean Energy Management (BOEM) lease block GC600 and three adjacent lease blocks Green Canyon 557, 601, and 644 (GC557, GC601, and GC644). GC600 (Fig. 1) examined in this study is one of the most prolific natural hydrocarbon seeps that has been discovered and a perennial source of surface oil slicks in the Northern GoM (Garcia-Pineda et al., 2010). The GC600 seeps are situated at a low-relief ridge at a depth of about 1200 m and have been studied by analyzing satellite images (Garcia-Pineda et al., 2010; D'souza et al., 2016) and during oceanographic cruises with the use of submarines and Remotely Operated Vehicles (Garcia-Pineda et al., 2010; Roberts et al., 2010; D'souza et al., 2016). In addition, a wind-powered autonomous surface vehicle (SailDrone) deployment and aerial photography provided in-situ observations at the lease block Green Canyon 574 (GC574) and its surrounding region.

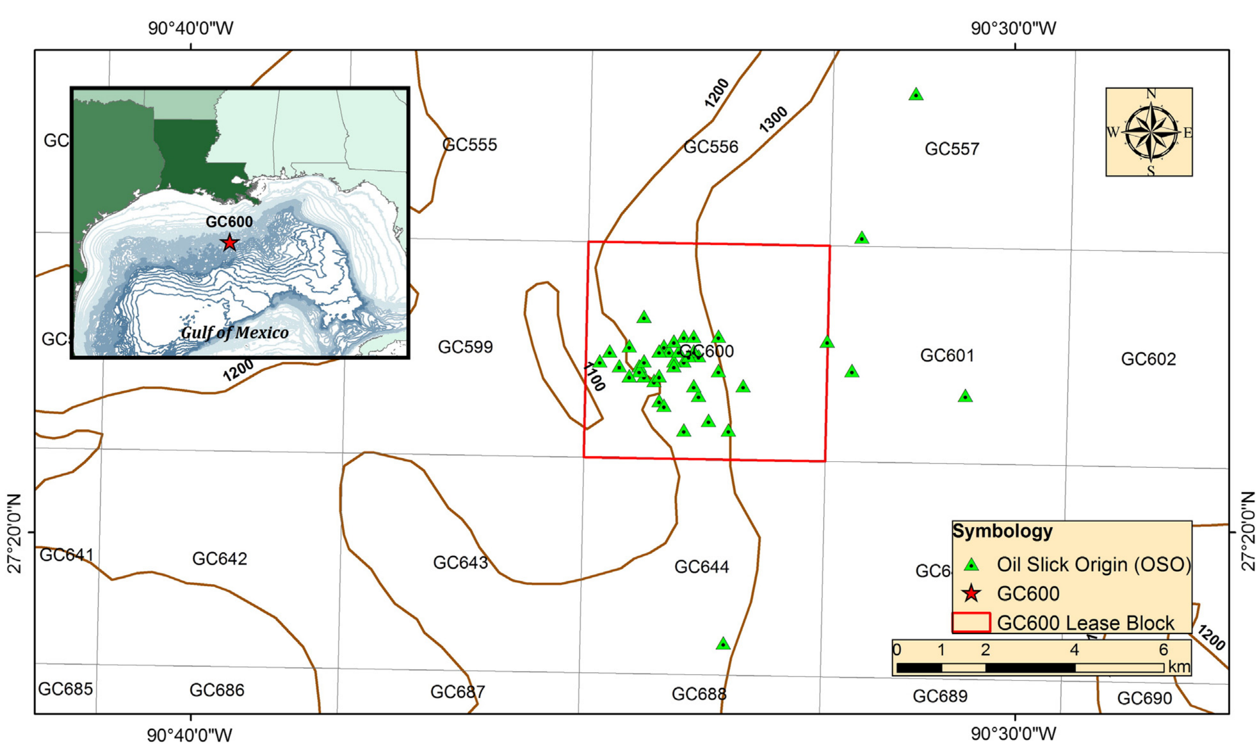

Fig. 1. Location of GC600 on the bathymetric map of the Northern GoM (marked with star). Grid shows lease block boundaries and designations. Location of all OSO points detected in 41 SAR images (green Triangles). The solid lines show the topography of the research area. Datum is WGS1984. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)