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Oil slick morphology derived from AVIRIS measurements of the Deepwater Horizon oil spill: Implications for spatial resolution requirements of remote sensors

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ABSTRACT

Using fine spatial resolution (~7.6 m) hyperspectral AVIRIS data collected over the *Deepwater Horizon* oil spill in the Gulf of Mexico, we statistically estimated slick lengths, widths and length/width ratios to characterize oil slick morphology for different thickness classes. For all AVIRIS-detected oil slicks (N = 52,100 continuous features) binned into four thickness classes (≤50 μm but thicker than sheen, 50–200 μm, 200–1000 μm, and >1000 μm), the median lengths, widths, and length/width ratios of these classes ranged between 22 and 38 m, 7–11 m, and 2.5–3.3, respectively. The AVIRIS data were further aggregated to 30-m (Landsat resolution) and 300-m (MERIS resolution) spatial bins to determine the fractional oil coverage in each bin. Overall, if 50% fractional pixel coverage were to be required to detect oil with thickness greater than sheen for most oil containing pixels, a 30-m resolution sensor would be needed.

1. Introduction

Oil spills in the ocean can pose a significant threat to the ecosystem (NRC, 2003). One recent example is the Deepwater Horizon (DWH) oil spill in the northern Gulf of Mexico (Fig. 1), a result of the explosion and sinking of the DWH oil rig on 20 April 2010. The spill continued until the oil well was capped on 15 July 2010, with an estimated 3.19 million barrels of crude oil released into the ocean (Crone and Tolstoy, 2010; McNutt et al., 2011; U.S. v. BP et al., 2015) and a significant portion accumulated on the sea surface (De Gouw et al., 2011).

Accurate detection of surface oil distribution and estimation of oil volume are valuable for oil spill response and for understanding the spill's potential environmental impacts. Remote sensing has been used effectively for some of these assessments (Fingas and Brown, 1997; Brekke and Solberg, 2005; Leifer et al., 2012). Of all remote sensing techniques, Synthetic Aperture Radar (SAR) is the most frequently used (e.g., Garcia-Pineda et al., 2013), which offers synoptic data under all sky conditions. Because oil can dampen short-gravity and capillary waves on the ocean surface, a reduction in the backscattering SAR signal can be observed in oil containing image pixels under optimal wind conditions. Although recent research has shown the potential of using SAR to discriminate thick emulsified oil from other oil (Garcia-Pineda et al., 2013; MacDonald et al., 2015), SAR has been primarily used to delineate surface oil footprint instead of estimating oil thickness. The same concept of wave dampening can also be extended to passive optical remote sensing when sun glint is present (e.g., MacDonald et al., 1993; Adamo et al., 2009; Hu et al., 2003, 2009; De Carolis et al., 2014). When oil slicks are sufficiently thick, they can also be observed in optical remote sensing imagery in the absence of sun glint (Bulgarelli and Djavidnia, 2012).

While determining the oil spill footprint can be achieved through different remote sensing techniques (e.g., SAR, optical, thermal, and others), estimating the surface oil volume (or thickness) is much more difficult (Svejkovsky et al., 2015; Fingas and Brown, 2015). Some recent advances showed that spectral and spatial contrast analyses could be used to infer relative oil thickness from optical remote sensing imagery, which could then be used for management actions during a spill (Svejkovsky et al., 2012). Some case studies showed the possibility to infer oil thickness from optical remote sensing imagery based on laboratory-derived look up tables (e.g., Lu et al., 2013). Furthermore, recent research demonstrated the use of hyperspectral C–H absorption

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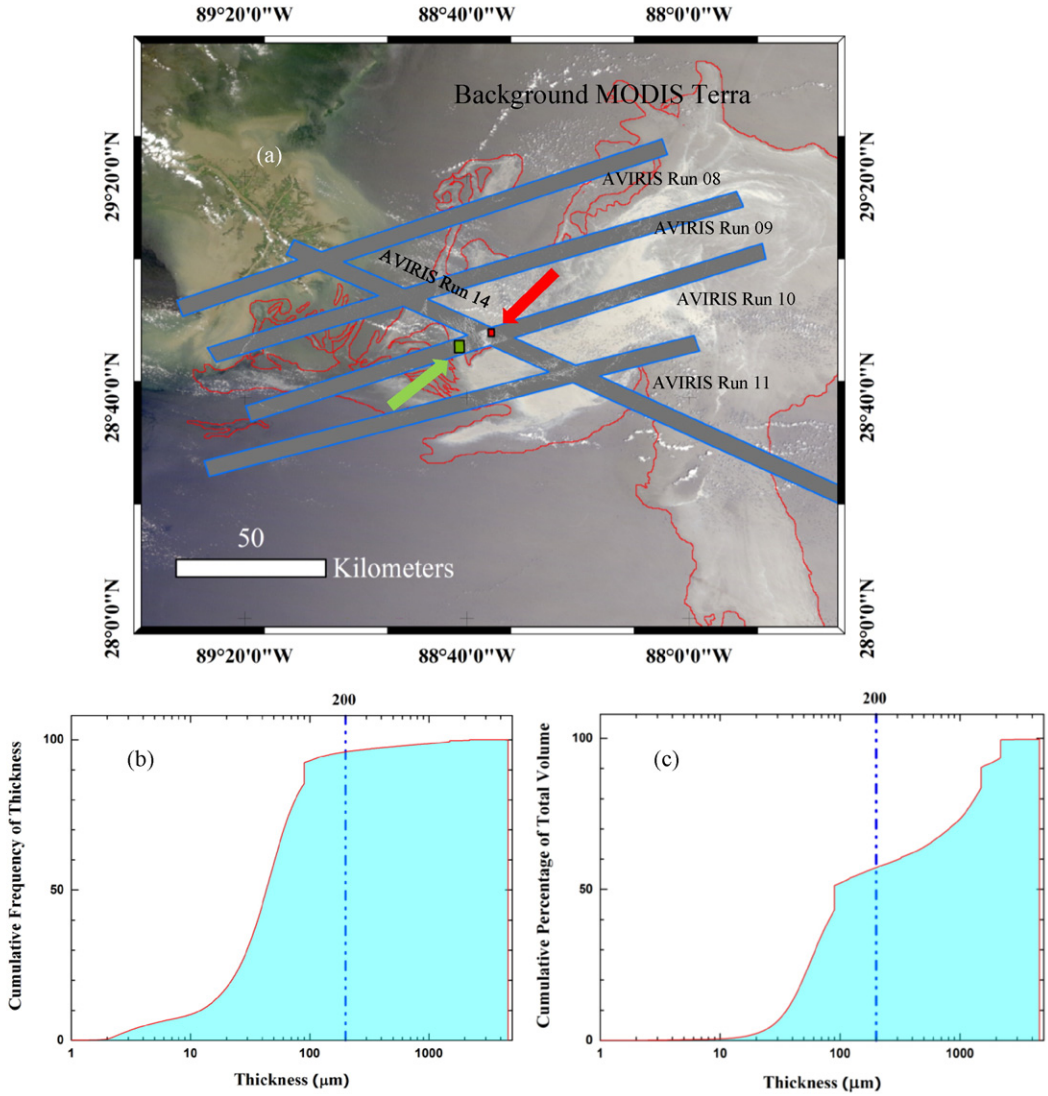

Fig. 1. (a) AVIRIS flight lines overlaid on MODIS Red–Green–Blue (RGB) image showing the DWH oil spill on 17 May 2010. The MODIS image was collected around 16:40 UTC and the 5 AVIRIS flight lines began on 19:07 UTC and were finished within 3 h. The gray scale of the AVIRIS lines represents oil volume derived from the approach of Clark et al. (2010). The red and green arrows annotate locations where examples of AVIRIS data are extracted and shown in Figs. 2 and 3. Cumulative frequency distribution of AVIRIS-derived surface oil thickness (b) and oil volume (c).

signatures in the near-infrared (NIR) and shortwave-infrared (SWIR) to quantify the oil:water ratio of emulsions and ultimately the oil volume (Clark et al., 2010). Given the availability of optical remote sensing data from a variety of satellite and airborne platforms, it is anticipated that the research community may make significant progress in estimating surface oil volume using optical remote sensing in the coming years.

Multiple factors can affect oil thickness/volume quantification from optical remote sensing imagery, such as the oil's weathering state (Svejkovsky et al., 2012), solar/view geometry, oil type (De Carolis et al., 2014) and sea state (Otremba et al., 2013). Another important factor in estimating surface oil volume is a sensor's spatial resolution. This critical parameter not only determines the detection limit of a remote sensor but also influences the ability to estimate oil thickness or volume from spectral and spatial contrast, as a large oil-containing pixel will contain oil of different thicknesses and emulsions of different water content (Leifer et al., 2012). Brown and Fingas (2001) noted that a spatial resolution of finer than 10 m was required because the width of a typical oil slick (defined as a continuous feature from the background water) was less than 10 m. Brekke and Solberg (2005) suggested that a spatial resolution of 50–150 m was sufficient for SAR to detect oil. However, these are based on the oil slick footprint instead of thickness, and there still lacks statistical analysis documenting slick size under typical conditions. In particular, there is no published report showing slick size distributions for different oil thickness classes, although such information can be very useful in interpreting oil footprint and thickness for sensors with different resolutions, in helping to make management decisions (e.g., physical removal or other mitigations for thick oil as it is more toxic and harmful to the marine environment).

The optical sensors that have been frequently used to detect oil slicks include the Moderate Resolution Imaging Spectroradiometer (MODIS) (Hu et al., 2009; Hu et al., 2011), MEdium Resolution Imaging Spectrometer (MERIS) (De Carolis et al., 2014), and Landsat Thematic Mapper (TM) (Zhao et al., 2014), with spatial resolutions of 250 m, 300 m and 30 m, respectively. To understand spatial resolution limitations of these sensors for detecting slicks and quantifying oil thickness, it is useful to document oil slick size of various thicknesses. Furthermore, knowledge of the oil slick morphology can also help differentiate oil slicks from other look-alikes (e.g., *Trichodesmium* mats) in unknown regions. Unfortunately, similar to SAR detections, despite numerous remote sensing studies of oil spills, to our best knowledge statistics of oil slick size for different thickness classes have never been reported through optical remote sensing or other means.