Measurement of Oil Slick Transport and Evolution in the Gulf of Mexico using L-band Synthetic Aperture Radar

Cathleen E. Jones, Jet Propulsion Laboratory/California Institute of Technology,
cathleen.e.jones@jpl.nasa.gov, USA
Martine Espeseth, UiT The Arctic University of Norway, martine.espeseth@uit.no, Norway
Benjamin Holt, Jet Propulsion Laboratory/California Institute of Technology,
benjamin.m.holt@jpl.nasa.gov, USA
Camilla Brekke, UiT The Arctic University of Norway, camilla.brekke@uit.no, Norway

Abstract

The transport and evolution of a mineral oil slick originating at a seep in the Gulf of Mexico approximately 16 km offshore of the mouth of the Mississippi River is measured using a series of images acquired at 40 minute intervals with the Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR), an L-band, high resolution, high signal-to-noise instrument operated by the U.S. National Aeronautics and Space Agency (NASA). A series of four images acquired over a 2-hour time period is used in the study. Both VV-intensity images and the VV-intensity contrast between the slick and clean water (damping ratio) are used. The intensity images show the spatial development and transport of the slick within an area extending from the source northward to near the Louisiana (USA) coast. The slick initially spreads to the northeast from the origin site, then become entrained in an along-shore current. From there, the direction of transport changes by nearly 180°, and the oil from the slick moves west along a path much closer to the Louisiana shoreline. Concentration of the oil within the slick is observed along fronts and internal waves. The oil that remains on the surface the longest shows increasing damping, which could indicate the formation of more stable emulsions that can persist in the environment.

1 SAR-based oil spill monitoring

Effective oil spill response requires accurate identification of the areas within a slick that contain the most oil, and well-informed forecasting of slick propagation to direct responders. Knowledge of spreading and transport path, relative or absolute thickness, and the total volume of the released oil is needed in the short term to support tactical response, and less pressingly for regulatory actions and determination of environmental and economic damages. A variety of methods are available to delineate slick extent, but the standard method for determining thickness is still visual inspection by trained observers using the Bonn Agreement Oil Appearance Code [1] to classify the oil types within the slick. This is manpower intensive, requiring manned low altitude overflights of the slick, must be done in daylight hours and under particular lighting conditions, and provides but a rough estimate of thickness for the thicker layers that contain by far the bulk of the oil. Accurate thickness and volume information for an oil slick in the marine environment is often unavailable during emergencies. Despite that, this information is useful even in the absence of low latency product generation because it would provide scientifically supportable release volumes.

Synthetic aperture radar (SAR) has been used for oil spill response because it does not require solar illumination of the surface, allowing all-weather, day-night operation, with detection done from satellite born instruments [2]. Oil slicks are radar-dark, and often radar-based measurement of the slick properties are limited by contamination from instrument noise [2, 3, 4]. Nevertheless, a method for determining the volumetric oil fraction based upon modification of the complex permittivity has been demonstrated [3] using data acquired over the Deepwater Horizon oil slick in the Gulf of Mexico in 2010 by a low noise L-band SAR instrument deployed on an aircraft, namely the Uninhabited Aerial Vehicle SAR (UAVSAR). However, most slicks are not nearly as thick as the main slick that formed in that disaster, so methods that rely upon measuring changes in the dielectric properties are not generally of use in responding to all but the highest volume spills. However, oil-on-water also alters the wave spectra, a change that is apparent even for very thin surface oil layers, so radar parameters that are sensitive to the wave structure are good candidates for oil slick characterization if they can be related to the volume or thickness of the surface layer of oil.

The use of signal contrast (damping ratios) between slick-covered and clean water has been shown to be a robust method to identify oil slicks [5, 6], and also has the advantage of requiring only single-polarization data. This parameter can be used to identify areas of relatively thicker oil within a slick [7], which is of value in directing responders. The identification of zoning within a thin slick is shown in Figure 1 for a slick of ~ micron average thickness imaged in a controlled release experiment off the coast of Norway in June 2015 [8]. The VV-intensity damping ratio shows zones of thicker oil measured within the slick, which was composed of emulsion with 60:40 oil-to-water ratio.

2 Results: Slick transport & evolution

The work reported here used UAVSAR data acquired over of a much larger slick than that in the 2015 North Sea experiment to explore the use of contrast to measure slick transport and evolution. Data from a persistent seep in the Gulf of Mexico were acquired by UAVSAR in quad-polarimetric mode, but the analysis reported here used only the VV-polarization channel, which has been observed to have better contrast than the HH co-polarized returns [4, 6]. The slick originated near the Taylor Energy (TE) rig site, ~16 km off the coast of Louisiana (USA), south of the main outlet of the Mississippi River. The seep is associated with an oil platform that was destroyed in 2004 during Hurricane Ivan. This location has been observed to be the origin of chronic discharge, documented using satellite SAR imagery [9].

On 17 November 2016 between 15:00-17:00 UTC, winds were from the southeast (138°-145°) at 3.8 – 4.2 m/s at the NOAA BURL1 station at Southwest Pass, Louisiana, near former TE oil platform. A long slick extended from near TE, offset from what appeared to be an older slick that had moved and spread to the northwest (Figure 2). The more recent slick spread northeast from the TE site, bounded to the south by a front that is visible in the VV-intensity image (Figure 2). This study focuses on the newer of the two slicks because we do not know how long the other slick had been on the surface.

The area around the destroyed TE platform was imaged by UAVSAR at ~20 minute intervals, and four of the images covering a two-hour period are shown in Figure 2. The series of images show that the main slick extended to the northeast for ~9.5 km, then became entrained in a west-northwest along-shore current closer to the Louisiana coast. The slick is visible extending ~12.5 km to the west from the location where it entered the nearshore current.

A number of fronts and internal waves are visible in the SAR intensity images. The plots on the right in Figure 2 focus on the area within the newer slick where a feature that appears to be a front develops within the slick. The feature is first apparent in the image acquired at 15:10 UTC developing near the much longer front at the southern edge the slick. The cause of the feature's development is unknown. However, by 17:09 UTC, areas of concentrated oil exhibiting larger damping ratios are visible between rows of near parallel features within the slick that show little-to-no visible surface oil at their center.

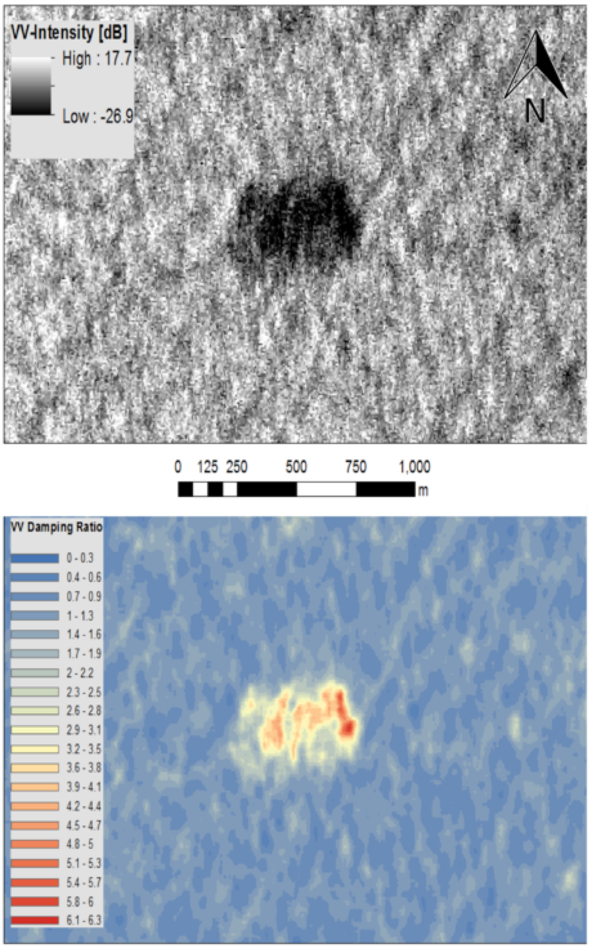

Figure 1 (Top) UAVSAR VV-intensity image acquired during the 2015 oil-on-water exercise in the North Sea, showing the slick that formed from release of 3 barrels (0.5 m^3) of mineral oil emulsion. The oil, released 30 min. earlier, formed a slick of area 0.2 km^2 (silver to rainbow sheen). (Bottom) The damping ratio showing zoning, indicative of areas of thicker oil.

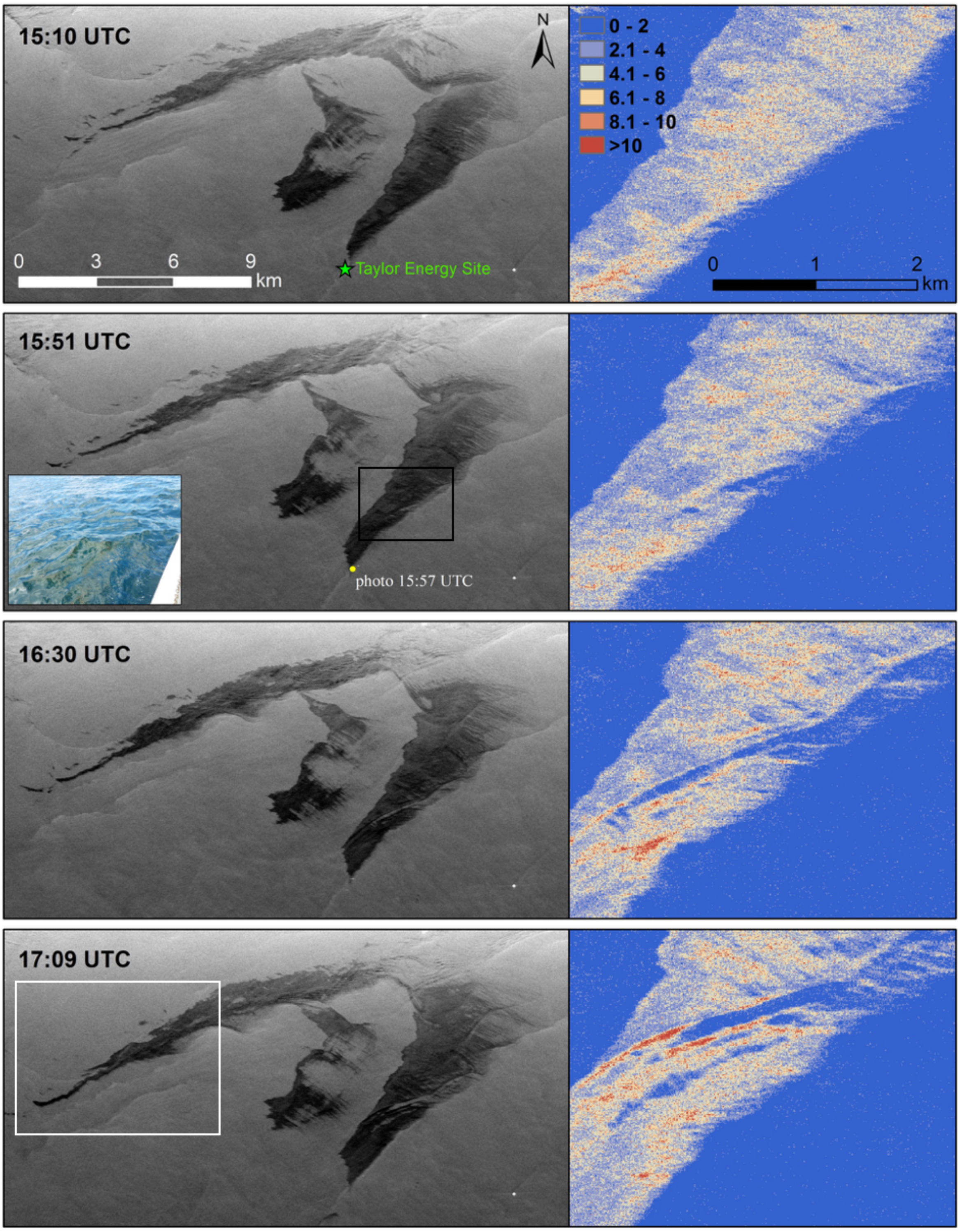

Figure 2 Taylor Energy slick imaged by UAVSAR on 17 November 2016. The source of the oil is near the former Taylor Energy rig site, at a depth of ~150 m. The location of the TE oil platform is indicated by the star in the upper left image. The plots show evolution and transport of the slick at ~40 minute intervals across a 2-hour period. VV-intensity images are shown on the left, and the VV-damping ratio (in linear units) for an area of more recently surfaced oil is shown on the right (black box outline). The damping ratio shows increased oil concentration along the edges of a feature within the slick, possibly a front that develops within the slick during the time that the UAVSAR images were acquired. By the last acquisition, several near-parallel features have formed within the slick. The white box in the lower left image shows the location of images in Figure 3.

Figure 3 shows the older part of the slick at the western end of the branch extending westward with the nearshore current. From the series of images in Figures 2 and 3, it appears that the nearshore slick is transported at ~1-1.3 km/hr to the west-northwest, following the trend of the fronts seen in the clean water, but not always concentrating along those fronts. It appears from the higher damping ratio that clumps of oil emulsions are forming as the slick narrows. This could occur as the oil that has not evaporated entrains water to form stable emulsions that stay on the surface for longer [10]. The series of images show that the concentrated oil becomes separated from the main slick, which contains both sheen and emulsion, at the western end of the slick.

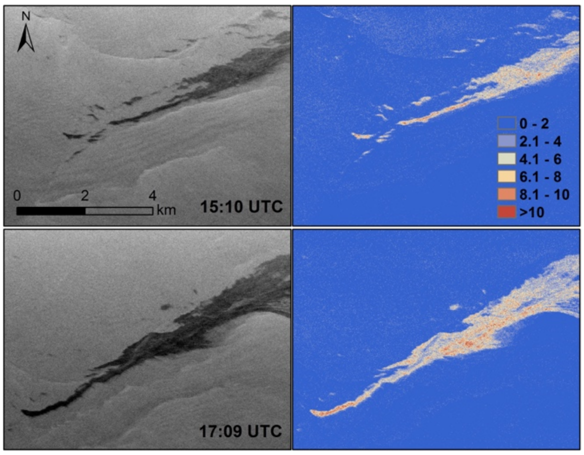

Figure 3 VV-intensity (right) and damping ratio (left) at the western end of the slick entrained in the along-shore current (location indicated by white box in Figure 2). This is the oil that has been on the surface the longest. Scene limits are the same in all four plots.

Figure 4 shows the change in the damping ratio from the more recently surfaced oil (segment 1) to the oil that has been on the surface the longest (segment 48) at time 15:10 UTC. The oil slick mask was obtained using a methodology based on the extended polarimetric feature space (EPFS) unsupervised classification [11,12], modified to be applied to the damping ratio. The procedure automatically corrects for the incidence angle dependence of the normalized radar cross section. After classification, manual selection was done to identify the classes that best represented slicked water. The mask was manually divided into 48 segments of increasing distance along the slick from the TE site. The mean value and 1-standard deviation limits within each segment are plotted to show the variation and progression of the damping ratio with distance from the Taylor Energy platform site. The damping ratios initially decline, then increase again as the slick narrows near its western end. This trend, combined with the formation of localized clumps of higher damping ratio visible in Figure 3, shows the weathering that occurs as the oil remains on the surface for a longer time and is concentrated along fronts.

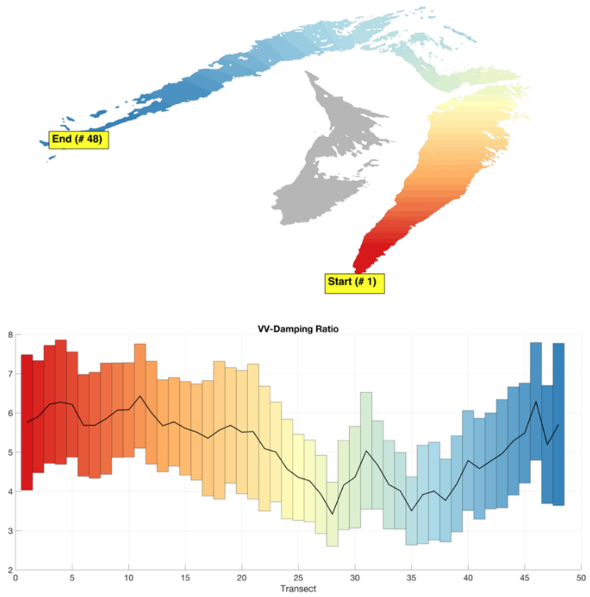

Figure 4 (Top) Mask of the oil slick at time 15:10 UTC separated into 48 segments along the length of the slick. (Bottom) VV-damping ratio mean values ± 1-sigma as a function of position within the slick. The oil at location #1 is nearest the Taylor Energy platform site, and the oil originates from the seafloor at a depth of ~150 m near this location.

3 Conclusions

This study shows the potential of low noise airborne SAR, even at L-band, for tracking the transport and weathering of mineral oil slicks from natural seeps or anthropogenic sources. The series of images at < 1-hour repeat interval is of particular value in determining the origin of oil at an extended distance from the source. This is demonstrated by the earlier images in the time series in Figure 2, which show the oil from the southern slick, which originated at the TE site, being entrained into a nearshore current that moves it in nearly the opposite direction from its original direction moving away from the source. Without the series of images this would have not been apparent from a later image alone. The series also shows that concentrated oil forms smaller slicks that continue to be transported on the surface after separating from the main continuous slick.

With adaptive flight planning and on-board imaging capability, this technology could be used to track an oil slick as it comes ashore to determine potential locations where there is longer-term impact to the environment. Future work will involve evaluating additional parameters and images, including data acquired in other UAVSAR flights in which the Taylor slick was imaged, to better track weathering and transport and to track for a longer period of time the emulsions that appear to persist near the Louisiana shore.

4 Acknowledgements

The authors thank Anthony Doulgeris for use of his EPFS segmentation code to generate the oil slick mask. This research was carried out in part at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the U.S. National Aeronautics and Space Administration (NASA). The research was also funded in part by the Centre for Remote Sensing and Forecasting for Arctic Operations (CIRFA) under the Research Council of Norway (RCN) grant no. 237906. The UAVSAR data are courtesy of NASA/Jet Propulsion Laboratory and are openly available through the Alaska Satellite Facility (http://asf.alaska.edu).

5 References

[1] www.bonnagreement.org, The Bonn Agreement Oil Appearance Code.

[2] W. Alpers, B. Holt, K. Zeng, "Oil spill detection by imaging radars: Challenges and pitfalls," in *Remote Sensing of Environment, 201, 133-147, 2017.*

[3] B. Minchew, C. E. Jones, B. Holt, "Polarimetric Analysis of Backscatter From the Deepwater Horizon Oil Spill Using L-Band Synthetic Aperture Radar," in *IEEE Transactions on Geoscience and Remote Sensing*, *50*(10), 3812-3830, 2012.

[4] S. Angelliaume, P. Dubois-Fernandez, C.E. Jones, B. Holt, B. Minchew, E. Amri and V. Miegebielle, "SAR Imagery for Detecting Sea Surface Slicks: Performance Assessment of Polarization-Dependent Parameters," *IEEE Transactions on Geoscience and Remote Sensing*, 2018, doi: 10.1109/TGRS.2018.2803216.

[5] V. Wismann, M. Gade, W. Alpers and H. Huhnerfuss, "Radar signatures of marine mineral oil spills measured by an airborne multi-frequency radar," in *Int. J. Remote. Sens.* 19, 3607-3623, 1998.

[6] M. M. Espeseth, S. Skrunes, C. E. Jones, C. Brekke, B. Holt, A. P. Doulgeris, "Analysis of Evolving Oil Spills in Full-Polarimetric and Hybrid-Polarity SAR," in *IEEE Transactions on Geoscience and Remote Sensing* , *55*(7), 4190-4210, 2017.

[7] C. E. Jones, M. Espeseth, B. Holt, C. Brekke, S. Skrunes, 'Characterization and discrimination of evolving mineral and plant oil slicks based on L-band synthetic aperture radar (SAR)," in *SAR Image Analysis, Modeling, and Techniques XVI*, ed. C/ Notarnicola, S. Paloscia, N. Pierdicca, E. Mitchard, Proc. of SPIE Vol. 10003, 100030K, 2016.

[8] S. Skrunes, C. Brekke, C. E. Jones, B. Holt, "A multisensor comparison of experimental oil spills in polarimetric SAR," in *IEEE JSTARS, 9*(11), 4948-4961, 2016.

[9] S. Asl, J. Amos, P. Woods, O. Garcia-Pineda, I. MacDonald, "Chronic, anthropogenic hydrocardbon discharges in the Gulf of Mexico," in *Deep-Sea Research II, 129*, 187-195, 2016.

[10] M. Fingas, B. Fieldhouse, "Studies on water-in-oil products from crude oils and petroleum products," in *Marine Pollution Bulletin, 64*, 272-283, 2012.

[11] A. P. Doulgeris and T. Eltoft, "Scale mixture of Gaussian modelling of polarimetric SAR data,," *EURASIP Journal on Advances in Signal Processing*, *8*, Jan. 2010.

[12] A. P. Doulgeris, "A simple and extendable segmentation method for multi-polarisation SAR images," in *POLINSAR, Frascati*, 2013.