EVOLUTION OF OIL SLICK PATTERNS AS OBSERVED BY SAR OFF THE COAST OF WALES

Pablo Clemente-Colón, William Pichel, and
National Environmental Satellite, Data, and Information Service
National Oceanic and Atmospheric Administration, Washington, DC 20233, USA
phone: + 1 301 763 8231, fax: + 1 301 763 8020
pclemente nesdis.noaa.gov
http://manati.wwb.noaa.gov/oppt.html

Xiao-Hai Yan
Graduate College of Marine Studies, University of Delaware, Newark, DE 19716, USA
phone: + 1 302 831 3694, fax: + 1 302 831 1199
Xiao.Yan mvs.udel.edu
http://triton.cms.udel.edu/crs/crs.html

Abstract

Imagery from three different Synthetic Aperture Radar (SAR) spaceborne sensors were obtained over the coast of Wales, UK. These observations indicated the persistence of slick features associated with the grounding on February 15, 1996 of the Sea Empress tanker at the entrance of the Milford Haven estuary and the resulting massive oil spill that followed. RADARSAT, ERS-1, and ERS-2 SAR images revealed the evolution of these features from February 22 to February 26, 1996. The feature tracking Maximum Similarity Shape Matching method (MSSM) developed at the University of Delaware College of Marine Studies (CMS) was applied to the pair of ERS SAR images. MSSM calculated drift speeds of about 10 cm/s. Observations of the slick pattern evolution in the SAR imagery were compared to available reports of ground conditions. Deformation of the slick features was also evident in the SAR data throughout the five-day period.

Keywords: SAR, Oil Spill, Slick, Wales, Sea Empress

Introduction

Ocean features such as current fronts and eddies can be detected by visible, thermal, and Synthetic Aperture Radar (SAR) satellite sensors and can potentially be tracked by any of these systems if adequate temporal coverage relative to the movement and deformation of the feature exists. In particular, the detection by these sensors of ocean features associated with the presence of surface oil slicks has also been documented. Surface oil slicks produce changes in sun-glitter patterns that can be detected and mapped using the visible bands of remote sensing sensors such as the LANDSAT, SPOT and the NOAA Advanced Very High Resolution Radiometer (AVHRR) radiometers (Wald et al., 1984). Due to differences in the emissivity of oil and sea water, surface temperature differences can be developed to a level that will also make slick patterns detectable by satellite thermal sensors (Park et al., 1989; Stringer et al., 1992). Changes in the surface tension due to the presence of oil will tend to dampen the capillaries and short gravity waves that are responsible for most of the backscattered signal received by a SAR instrument. These relatively smoother areas will appear as darker or low backscatter regions in radar images (Goodman, 1990). The advantages of the SAR over AVHRR IR data are higher spatial resolution and the capacity to make observations both day and night and under cloud covered conditions.

The ability of SAR to detect oil slick features depends greatly on the wind conditions at the time of the observation. Low winds will not produce enough roughness over the unaffected sea surface to create sufficient contrast with the oil covered areas. On the other hand, very high winds will tend to destroy frontal features due to mixing and may create enough backscatter clutter to make it impossible to detect any oil covered areas. Wave action and tidal mixing can also greatly affect the development and detection of oil slicks. In spite of this, many cases of oil spill detection by spacecraft SAR have been documented since the launch of ERS-1 satellite.

The use of satellite data for ocean feature-tracking is becoming more and more commonly accepted as a valuable tool for applied and basic research (Vastano, 1995; Emery, 1985; Kelly and Strub, 1992; Yan et al., 1994; Breaker et al., 1992). The technology has been evolving from the early use of hardcopy satellite images to computer assisted analysis and more recently to automated feature recognition techniques such as the Maximum Shape-matching Method (MSSM) developed at the University of Delaware Center for Remote Sensing (Kuo and Yan, 1994).

The detection, mapping, and tracking of oil spills, in particular, is of critical importance in a wide range of emergency response activities after a major oil spill. This information, along with additional information on local environmental conditions and model output, can be used to devise protection responses and cleanup strategies. Knowing the extent and trajectory of an oil spill can increase the efficiency of the emergency response effort. The Exxon Valdez oil tanker spill on March 24, 1989 in Alaskan waters was the first major spill widely studied with the use of spacecraft visible and thermal remote sensing (Park et al., 1989; Stringer et al., 1992).

The Sea Empress oil tanker spill on February 15, 1996 off the coast of Wales was much larger than that of the Exxon Valdez spill in Alaska and has given us the first opportunity to study the evolution of a major spill using spaceborne SAR. Although, at least 12 scenes from three different SAR satellites were acquired between February 22 and March 17 (Bjerkelund, 1996), only three images were available for this study. The objectives of this paper are to apply the MSSM method to two of the spaceborne SAR images of the Wales oil spill and to study the potential use of spaceborne SAR for oil detection and tracking.

SAR Data

The ERS-1 and ERS-2 satellites are multi-sensor satellites operated by the European Space Agency (ESA). ERS-1 was launched on July 17, 1991 and almost four years later, ERS-2 was launched on April 21, 1995. The Active Microwave Instrument (AMI) aboard has a single SAR mode with a resolution of 25 m, a fixed incidence angle of 23 degrees at the center of the scene and 100 km swath. The Tromsø Satellite Satation (TSS) acquired and processed the SAR data over the southwest Wales region. Two full resolution images, for February 25 and 26, 1996, were available from ESA for this study. A third RADARSAT Standard Mode 1 SAR image of the region was produced from data acquired on February 22 by the Canada Centre for Remote Sensing (CCRS) and processed by RADARSAT International (RSI). This RADARSAT mode is analogus to the ERS-1/2 SAR with a resolution of 25 m. The image was available through the world wide web from the Canadian Space Agency (CSA) but at a much lower spatial resolution of about 300 m.

Sea Empress Oil Spill

The Sea Empress oil tanker ran aground off Saint Ann's Head, just outside the Milford Haven estuary in Wales, under gale-force winds of up to 40 knots and 10 ft waves conditions on February 15, 1996. At the time, it was transporting a cargo of 37.6 million gallons of medium to light crude oil to the Texaco refinery in Milford Haven, a major oil refinery and loading port in the UK. Unfortunately, the Milford Haven Estuary is also an important natural conservation area and forms part of the Pembrokeshire Coast

National Park, Britain's only marine wildlife sanctuary. In addition, Milford Haven is an important fishing port for lobster, crab, and mackerel fisheries.

After the initial grounding, around 1.7 million gallons were estimated to have spilled out of the tanker. On February 18, the tanker ran aground again with spill estimates jumping to about 9 million gallons. Thousands of gallons of dispersant were sprayed by aircraft to dissipate the increasing spill. By February 21, the estimated spill had jumped to 12 million gallons with gale winds and raging seas also reported. A NOAA AVHRR satellite image of the oil slick was taken at 08:08Z on February 21 at the Natural Environment Research Council (NERC) Dundee Satellite Receiving Station (DSRS) and made available by Richard Lucas, Regional Remote Sensing Centre, Geography Dept. University of Wales Swansea (Dyrynda and Symberlist, 1997). A combination of channels 2, 4, and 5 showed a long streak of oil spreading eastwards along the coast towards the Caldey Island. Southwesterly winds were credited with initially spreading much of the oil offshore but shifting winds throughout this period pushed large amounts of the crude toward the coastlines and into beaches from the Saint Brides Bay, north of Saint Ann's Head, to the Carmarthen Bay to the east. By February 26 oil sheen had been reported as far as the Lundy Island in the middle of the Bristol Channel, about 65 km SSE of Saint Ann's Head. Three weeks after the initial oil spill, persistent beach contamination from new oil coming ashore was being reported over beaches on the western Carmarthen Bay. The final official spill estimate for this disastrous event stands at 16 million gallons (72 thousands tonnes) of oil.

MSSM Analysys

The MSSM technique was used to derive velocity vectors from observed oil slick patterns on the ERS-1/2 SAR images. This method uses the concept of maximum similarity between features for which a centroid is calculated through a radius weighted mean. In theory, the features may have any shape and can not only translate but also rotate and suffer some deformation from one image another. Features are matched between the two images based on selectable confidence levels. Once this is done, the corresponding velocity vectors can be calculated and plotted for different parts of the feature. A more detail description of the method is presented in Kuo and Yan, 1994.

The February 25 and February 26 images (figures 1 and 2, respectively) show several recognizable slick features from one image to the other. The effort concentrated over the Carmarthen Bay were a large slick pattern was observed in both images. A sub-image was cropped out for this region. Co- registration of the sub-images was done with an IDL/ENVI geometric transformation routine using selected coastline control "tie" points between the two sub-images. An adaptive Lee filter was used to reduce speckling and a median filter was then applied to further enhance some of the slick features. The sub-images were then sampled down by one third for final MSSM analysis. Edge detection and contrast enhancement were finally applied to binarize the image and better define slick boundaries.

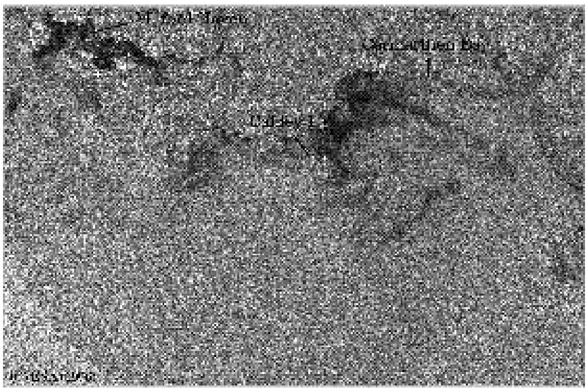

Figure 1: ERS-1 SAR image acquired on February 25,1996 at 22:24 UTC. Darker areas represent lower backscatter returns caused by the presence of a large oil slick on the Carmarthen Bay .

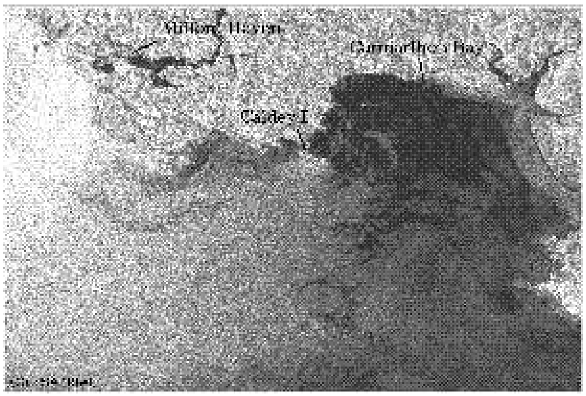

Figure 2: ERS-1 SAR image acquired on February 26,1996 at 22:24 UTC. Darker areas represent lower backscatter returns caused by the presence of a large oil slick on the Carmarthen Bay .

Results

The SAR images used in this project represent the first time that the evolution of a slick feature from a major oil spill has been observed throughout several days and by multiple spacecraft SAR instruments. The RADARSAT image of the spill available from CSA indicates very low backscatter over the western Carmarthen Bay, relative low backscatter also to the south and to the west along the coast, and a bright region over the eastern Bay. The bright region indicates that eastern Bay areas were not yet impacted by the spill as of February 22. The low backscatter regions indicate general oil contamination with the most intense slicks hogging the western Carmarthen Bay coastline and rapidly advancing further into the Bay as suggested by the AVHRR observations of the previous day. Available meteorological information can help explain the observed distribution of the oil slick. Hourly data for February 21 and 22 from the weather buoy 62303 located just southwest of the Carmarthen Bay at 51.5N, 49.0W, show persistent strong winds between 8 and 20 knots in a west northwest direction throughout those days. Further advance of the oil slick into the Carmarthen Bay is evident in the ERS-1 image for February 25 with some of the low backscatter filaments extending more than half way into the eastern Bay. The observed drift appears to be related to a relaxation in wind speed and a change in the wind direction toward the southeast earlier that day. The filaments extend even further on February 26 reaching the eastern Bay. The drift and dispersion of the slick pattern in the Carmarthen Bay during the 24 hours between the February 25 and 26 images was more rapid than during the 3 days between the February 22 and 25 observations. This fast spreading of the slick over most of the bay is probably due to a combination of the reported airborne spraying of thousands of gallons of dispersant over the Carmarthen Bay on February 25 (SOUTHERNAIR, 1996) and very rapidly shifting winds throughout the day.

Figures 3 shows the output obtained from MSSM analysis with the calculated vectors plotted over the February 25 ERS-1 Carmarthen Bay sub-image. The elongated feature extending into the eastern Bay is the most identifiable feature after a large amount of slick dispersion occurred between the two days. The velocity vectors were computed and plotted by the MSSM program and represent speeds of 12.6 (label 1), 10.8 (label 2), 8.9 (label 3), and 8.1 ± 0.45 cm/s (label 4).

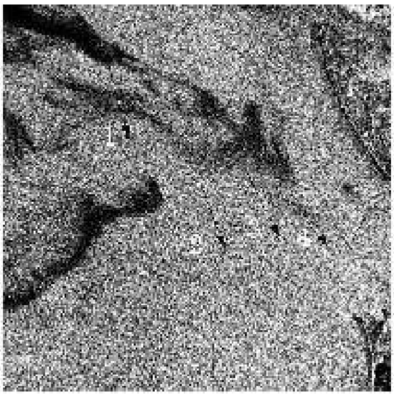

Figure 3: MSSM velocity vectors output for the elongated oil slick pattern on Carmarthen Bay superimposed on ERS-1 SAR sub-image for February 25, 1996. The vectors represent the displacement of the pattern between 22:24 UTC, February 25 and 22:24 UTC, February 26, 1996.

These velocity vectors show a southeastward drift of the pattern which is consistent with the visual inspection of the images. It is obvious that different parts of the slick drifted at different rates and that large deformation of the overall shape of the slick occurred in one day. Velocity vectors from other features on the south and western side of the slick pattern (not shown) indicated a generally slower southward drift with an averaged magnitude of 3.79 cm/s. The much faster southeastward drift of the northeastern part of the slick pattern again reflects significant deformation of the slick as it evolved. In general, the estimates from MSSM appear to be reasonable. ERS-1/2 SAR coverage of the region extending from the southern Carmarthen Bay to the Bristol Channel during February 25 and 26 is shown in figure 4. These data show that some of the slick actually drifted even faster reaching as far south as the Lundy Island in the Bristol Channel.

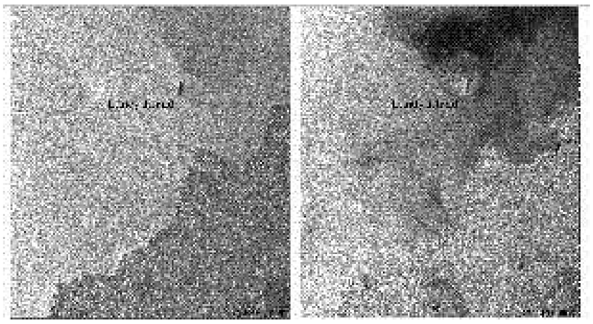

Figure 4: ERS-1(left) and ERS-2 (right) SAR images of the region extending from the southern Carmarthen Bay to the Bristol Channel on February 25 and 26, 1996, respectively. Darker filaments observed on February 26 represent

lower backscatter returns associated with oil slicks reaching the Bristol Channel.

Conclusions

The evolution of an oil slick pattern resulting from one of Britain's largest oil spills was observed using spacecraft SAR imagery. Much of the low backscatter patterns observed in three images acquired by RADARSAT, ERS-1, and ERS-2 satellites were consistent with reported ground conditions. In particular, a persistent oil slick pattern was observed between February 22 and February 26. This pattern was observed to drift from the western Bay, where many heavily polluted beaches were found, into the eastern Bay during the observing period. Evidence of slicks as far as 65 km south of the initial spill location was also shown.

The MSSM feature tracking technique developed at the Center for Remote Sensing, University of Delaware was used. The exercise demonstrated the possibility of using feature tracking techniques on spaceborne SAR images of oil slick features. In general, frequent observations of the oil slick patterns are desirable and would allow for better tracking under rapidly changing conditions. The high resolution SAR data can provide for good delineation of features and should allow for accurate estimates of oil slick drifts.

Acknowledgement

This study was partially supported by NSF under grant OCE-9453499, and by NOAA Sea Grant under grant NA56RG0147. ERS-1 and ERS-2 SAR data was provided by the European Space Agency under the National Ice Center ERS-1/2 Proposal.

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Keywords: ESA European Space Agency - Agence spatiale europeenne, observation de la terre, earth observation, satellite remote sensing, teledetection, geophysique, altimetrie, radar, chimique atmospherique, geophysics, altimetry, radar, atmospheric chemistry