Space-based surveillance and the role of SAR for operational oil slick detection and monitoring

S. Chesworth¹ & P. Engel²

¹RADARSAT International, United Kingdom  
²RADARSAT International, France

Abstract

Shipping accidents and the resulting catastrophic oil spills have received widespread public attention, illustrating the problems associated with vessel transportation and the subsequent degradation of the marine environment. However, these spills only make up a relatively small proportion of the total amount of oil pollution that occurs at sea. Large amounts of oil are deliberately released everyday through the discharge of bilge and ballast waters and these are going undetected. Also, leakages occur from oil platforms and pipelines adding to pollution. Many countries do not have the resources to effectively monitor more than a small proportion of their Exclusive Economic Zone (EEZ). This paper reviews past and current experiences of RADARSAT International and its partners using SAR data from RADARSAT-1 for operational monitoring of oil spills and the illegal and uncontrolled discharge of pollution. Case studies will be presented where SAR is used operationally for oil slick detection and oil spill monitoring by providing near real time target reports and image sub-scenes delivered electronically to the client. These current operations show that SAR is a valuable component to effective monitoring and response in conjunction with sea and aerial based surveillance. Important information about the ship can also be transmitted to the client showing synergy with vessel monitoring system providers (VMS), coastal radar operators, Coastguards, patrol craft and response teams. The next generation of SAR satellites is then reviewed which provisionally demonstrates the improvement of the new sensors for tactical operations and the vision of a global oil pollution control and deterrent system.
1 Principle of surveillance by satellite

Earth Observation satellites orbit the Earth at approximately 800km in altitude (RADARSAT-1, SPOT, Landsat, ENVISAT, RADARSAT-2, etc.), completing about 14 orbits a day with a sun-synchronous orbit geometry. Due to the satellite orbit geometry, each satellite revisits the same point on the Earth's equator once every orbit cycle. The cycle length varies between each satellite: 24 days for RADARSAT-1, 26 days for SPOT and 35 days for ERS or ENVISAT. A satellite's capability for a steerable beam mode and to alter the incidence angle for image acquisition allows an area on the Earth to be acquired more often than once an orbit cycle. For example, RADARSAT-1 can acquire imagery over the Mediterranean every one to three days (see Figure 1.).

![figure 1: RADARSAT-1 imaging modes. Modes used for oil pollution detection and monitoring are Wide Beam Mode (150km Swath Width) and ScanSAR Narrow (300km Swath Width).](image)

Satellite imaging sensors on-board a satellite can be either passive, such as SPOT, or the instruments can be active, such as the Synthetic Aperture Radar (SAR) used on RADARSAT-1. Passive optical sensors require sun illumination and cloud free skies to provide useful images. Active SAR sensors have the ability to acquire images regardless of cloud conditions, rain, smoke or illumination from the sun. Currently, satellites operate in the microwave range of the electromagnetic spectrum at approximately 5 cm or C-Band. Other satellites operating at different wavelengths, such as X-Band or L-Band, have been available in the past and will be in the future, however C-Band is seen as the most effective for ocean surveillance. Therefore active SAR sensors are operationally more effective for monitoring and surveillance, due to the limitations of passive optical sensors. In addition, satellite sensors have a much
larger swath width than typical airborne sensors, such as SLAR, and can potentially cover a much larger area of the ocean than aircraft.

Oil slicks have been identified on satellite images as far back as 1973 with the first ERTS-1 multi-spectral optical images [1]. However, not only do optical images require sun illumination, cloud and haze free conditions, but also the elevation of the sun can directly effect the detection of the oil slick. Radar is very sensitive to texture and water content. Oil dampens capillary waves and this produces a smoother ocean surface where the oil is present than the surrounding water. As the surface is smoother with the presence of oil, the amount of backscatter or radar return from the ocean surface is reduced. The texture is altered and the oil appears as an area of little or no return in the SAR image, which shows as dark patches or linear streaks compared to the rougher, brighter surrounding ocean surface.

The frequency of image acquisitions due to the orbiting constraints has been mentioned. Using one satellite may not provide the necessary frequency of acquisitions needed for operational monitoring. The combination of more than one satellite increases the number of passes available over an area of interest. ENVISAT was launched 1 March 2002 and it is expected that the satellite will become operational in September 2002. The utilisation of both RADARSAT and ENVISAT will allow Earth Observation to be a viable alternative to other, more traditional, surveillance methods. Over a 24 day period (the orbit cycle of RADARSAT) it is possible to achieve almost double the number of acquisitions using both satellites. For example, this would translate to approximately 45 passes of either RADARSAT or ENVISAT over the EEZ of Greece; 1 – 2 passes a day.

SAR satellites record two types of data parameters. Firstly, the time it takes for the radar signal to travel from the satellite to the ground and back again. Secondly, the energy of the return signal which is a measure of the object or feature on the Earth reflecting the signal. For this reason the unprocessed data is in a complex format which requires a SAR processor to produce radar images. The SAR processor creates a georeferenced radar image using the satellite positional data and the platform attitude information during the processing stage. Satellite images are usually created to a proprietary format, such as CEOS for RADARSAT. An image processing software is then required to view the image and this software acts as a post processing software tool or image analysis system. The image processing software can extract the desired information such as the presence of an oil slick, the longitude and latitude, the probability of the feature being an oil slick and any other ancillary information that may be important to the client. The time it takes to process an image can vary depending on the hardware and software configuration, but typically this can take 15 - 20 minutes for a RADARSAT ScanSAR scene using the latest dedicated hardware SAR processors. The analysis on an image may take an additional 30 minutes.
2 The role of ground receiving stations

In the absence of a local ground receiving station, images are recorded on-board the satellite using either tape recorders in the case of RADARSAT-1, or solid state recorders in the case of RADARSAT-2 or ENVISAT. The images are then downlinked when the satellite passes over a 'Master' ground receiving station, such as the Canadian Data Processing Facility for RADARSAT-1. Using the recorders adds time to the point at which an image is ready for interpretation; from the point at which acquisition takes place to the point where the image is processed. The time difference will depend on where the satellite acquires the image and the time it takes for the satellite to pass over the 'Master' station. This time may be in the order of 3 – 4 hours between acquisition and downlink, sometimes up to 6 or 7 hours.

The presence of a local ground receiving station allows real time downlinking of the data during acquisition. Therefore, a local ground receiving station can dramatically reduce the time it takes between acquisition to the provision of information about possible oil slicks. With the implementation of correct procedures at the local ground receiving station, oil slick information could be available within 1 hour of acquisition of the image; this time is also dependant on the processor configuration (see Figure 2). This time is usually sufficient for the local authorities or law enforcement to act and verify the presence of the oil slick through their own operational assets, such as aircraft or patrol vessels, and to help identify the responsible rogue vessels.

Additionally, a local ground station's presence within a country can provide confidentiality of the information derived from the SAR imagery. The link between a ground receiving station can be direct without the intervention of third parties, such as commercial satellite operators or value-adding companies.

![Diagram](image_url)

Figure 2: Timeline to output Near Real Time information from a local ground receiving station.
3 Feature detection by SAR

As stated previously, SAR measures the surface roughness or texture of the area being imaged where oil on the sea surface appears smooth and shows as a dark area on the resulting image. However, for oil to dampen the waves there must be enough wind to generate waves for the oil to have a significant dampening effect. Additionally, the waves cannot be too large otherwise the dampening effect of the oil is insignificant to cause a change in surface roughness or the surface slick may become broken and overwashed. Therefore there is an optimum window for the detection of oil on the ocean surface. This window is approximately 3 – 12 m/s, although Tromsø Satellite Station has reported the detection of an oil slick at up to 18 m/s wind speed.

Dark areas on the image may also result from phenomena other than oil resulting in false positives. Wind effects resulting from topography or other wind phenomena may create calm areas on the ocean surface, which may also appear dark. Algae blooms, natural sheen, local upwelling or natural hydrocarbon seeps may also dampen capillary waves. Consequently, a trained operator who has knowledge of the local prevailing winds as well as knowledge of other influencing factors must perform image interpretation. The new generation of SAR satellites, RADARSAT-2 and ENVISAT, have enhanced polarimetric capabilities and this may aid the identification of oil against false positives.

Figure 3: Dark patches on a RADARSAT-1 image not resulting from oil pollution, upper right corner.

Oil slicks resulting from the discharge of bilge or ballast waters appear as long linear shapes, such as in Figure 4. Oil may be released or leak from oil platforms and these shapes start to take on a sinuous shape resulting from the influence of
currents or wind, Figure 5. Bright targets on the image and ocean surface can indicate vessels or oil platforms, due to the strong return of the signal resulting from the structure and shape of the object and the metallic construction. Ships, which are moving, often create wakes. If the resolution of the image is appropriate for the sea conditions and the incidence angle is sufficiently vertical, it is possible to view this wake on the SAR image. An estimate of vessel speed can then be calculated, Figure 6.

SAR satellites cannot measure the thickness or type of slick, as it is the dampening effect of the oil on the ocean surface that is being sensed. It is possible to infer some information relating to the slick if the environmental conditions are known. The higher density and higher viscosity of the oil will hinder the spreading of the slick. Under high sea states a thicker, more cohesive slick may result from heavier oil [2].

Satellites can also provide auxiliary environmental information that is useful for oil spill monitoring and response. Wind direction and speed can be extracted from SAR images [3] [4] [5], as well as current velocity measurements [6], providing an aid to slick propagation and modelling. It is important to note that the SAR-derived wind and current fields do not require additional imagery, since the wind information can be extracted from the same set of images that are used for ship and oil spill detection.

Figure 4: Oil slick from a vessel. The source vessel can been seen in the original image. Image courtesy of QinetiQ Ltd. Left image.

Figure 5: Oil slicks from oil platforms, Gulf of Mexico. Right image.
Calculation of the vessel speed, by measuring the vessel displacement from the wake (doppler effect) using the relationship:

\[ V_{\text{ship}} = V_S \Delta x / (R \cos(\phi)) \]

Where \( V_{\text{ship}} \) is the ship velocity, \( V_S \) is the satellite orbit speed, \( \Delta x \) is ship displacement from its wake, \( R \) is the slant range, and \( \phi \) is the angle between the ship velocity vector and the SAR look-direction.

4 Synergy with other control operations

RADARSAT International and the Canadian Space Agency has undertaken and validated ship positional information with information derived from Vessel Monitoring Systems (VMS). VMS provides the position of registered vessels that carry a transponder, which gives away the position of the boat at regular intervals. SAR imagery is able to detect almost all vessels operating in an area of interest, subject to beam mode, incidence angle and wind speed. The ship positions provided by the VMS are correlated with the ship locations given by the SAR satellite at the time of overpass. By simple subtraction between the SAR vessel positions and the VMS vessel positions, the VMS operator is able to distinguish and select non-registered vessels and communicate the coordinates to the law enforcement agency or coastguard. The communication may take the form of a text file, which can be faxed or emailed immediately. Text files can be readily ingested into existing software's for display and analysis with other information sources (Figure 7). A cron job, or script, can be set up to detect incoming files and import directly into the law enforcement's vessel monitoring system. Text files are only a few kilobytes in size and rapid dissemination of the
information can be achieved rather than attempting to transfer imagery, which can be in the order of 150MB. However, if the coastguard required to verify what the vessels appearance looked like on the SAR imagery, image chips or sub-scenes of the vessels can be hosted in a web environment for remote inspection and verification. Such fast dissemination allows for re-routing of other surveillance craft, such as patrol vessels or aircraft, where the operational costs of these assets are much higher than the use of satellite surveillance on a routine basis. Satellite information may also be used to generate statistics over time, which can be used to refine mission planning of aircraft and vessel patrol.

Figure 7: Graph and text output of FL4DARSAT detected vessels, Strait of Bosphorus. Processed by Satlantic using the Ocean Monitoring Workstation.

4.1 Synergy with coastal radar operations

The interest of radar coastal operators for the R4DARSAT data and system results from various limitations of the coastal radar. High Frequency Short Wave Radar resolution cells decrease with the range from the shore (beyond 100 nautical miles), slow moving ships and near shore vessels are invisible to HF Radar. Shore based radar, or Vessel Tracking Systems (VTS), by comparison have a more limited range from shore, in the order of 50 nautical miles. However, VTS is able to detect most vessels within its range.

R4DARSAT is able to provide the positions of vessels beyond the range of the radar, enabling vessels to be 'queued' prior to detection by the shore based radar as well as providing vessel positions that are stationary or slow moving in the
area. RADARSAT International is currently providing RADARSAT Data to the Canadian Coastguard for vessel positions to be integrated in their Vessel Traffic Operations Support System, VTOSS, Figure 8. Vessel positions are extracted from the RADARSAT imagery and imported into the VTOSS system, together with other information such as the heading and speed where available. In addition, other information about the vessel from the SAR imagery can be recorded, such as whether a slick is present in the vicinity of the vessel.

RADARSAT is an ideal complement to associate oil slicks to vessels registered on the log of coastal radar operators. The identification of vessels within and beyond the range of the coastal radar is becoming ever more important for national security and surveillance. Not only is it important to reduce the amount of pollution entering the ocean environment, but since the unfortunate events of September 11 2001, it is now necessary to report the arrival of a vessel on the shores of Canada or the United States 96 hours in advance. This can only be achieved by incorporating other surveillance methods, and space based surveillance from satellites is proving a cost effective and important tool.

Figure 8: Canadian Coastguard VTOSS system integrating vessels detected by Sofrelog system, dead reckoning vessels and RADARSAT detected vessels. 'Right clicking' on a vessel in the above graphic, shows the attributes of one of the RADARSAT identified vessels: longitude, latitude, course, speed and environmental risk, i.e. no oil slick detected. Graphic courtesy of The Canadian Coastguard.
5 The set-up of a maritime oil pollution and control deterrent system

 Authorities involved in maritime law enforcement should take advantage of the assets available from Earth Observation Technology. The application is now mature enough and is fully operational. Synergies presented in this paper are already in effect in Northern Europe, North America and also several other countries around the world. Earth Observation is not capable of providing all the information required, but it is shown that space based surveillance can improve the success rate for routine and tactical maritime operations. The key aspect of using SAR and satellite surveillance is the institutional linkage that needs to be established between the ground receiving station to the Coastguard or Navy.

If VMS information is available, the list of detected vessels should be correlated to the satellite-derived information in order to distinguish unregistered or unidentified vessels, which may correspond to illegal fishing vessels, for example. The final list of unidentified vessels is then sent to the pilots of the patrol vessel or aircraft for further verification. In the same manner, detection of oil slicks can be correlated with the presence of ships detected by shore based radar.

Once routine surveillance by satellite is launched, the knowledge that an EEZ or maritime area is monitored by various means, including SAR satellites, is spread amongst ship captains. The general public can grossly misunderstand the capabilities of surveillance and satellite systems thanks to Hollywood’s films over recent years, such as Enemy of the State and the James Bond movies. This can be used to the law enforcement’s advantage to act as a deterrent. A careful publicity strategy can be implemented by the Coastguard to promote the use of surveillance to vessels and employees operating in the area. Over time, the frequency of intentional pollution will decrease and the goal of a deterrent strategy is reached.

A possible strategy to start surveillance and deterrence is to acquire intensively over key areas for a set period of time, for example 6 months. During this period, publicity is made about the surveillance and the results of the campaign. The rogue captains who continually pollute the seas are then aware of the monitoring strategy and consequently stop for a fear of being caught, resulting in a decrease in pollution. Satellite acquisition campaigns can be implemented in two ways: (i) correlate the aircraft flights or vessel sorties with the satellite passes, operating together simultaneously, or (ii) use the satellite to acquire imagery in areas where the aircraft are not flying. The success of the deterrent and control strategy will be the routine implementation of the surveillance based on the synergy of the various assets.

It is worth noting that RADARSAT International is currently working with a number of oil companies to take advantage of RADARSAT and other EO
sensors’ capabilities to monitor oil slicks and provide environmental and ecological information about the region. The objective is to prove that the oil platforms and vessels are not the source of pollution and are not responsible for ecological damage to the marine environment and coastline.

6 Conclusion

In this paper, the use of SAR imagery to detect oil slicks and vessels has been reviewed. It has been shown that there is great synergy with space-based surveillance and current tools in use by law enforcement authorities. The utilisation of just one satellite is often not sufficient to provide the acquisition frequency needed for effective surveillance. RADARSAT International now offers its clients multi-SAR surveillance capabilities based on the recent launch of ENVISAT. The number of satellites will increase over the coming years with RADARSAT-2 (2003), RADARSAT-3 (2005) and ALOS (2006), thereby forming a constellation being capable of frequent acquisitions and quick response times. The continuity of data and the investments made will be secure for the next decade and beyond. This will increase, as Earth Observation becomes more and more available to the operational users.

References


RADARSAT Data © copyright Canadian Space Agency/Agence Spatiale Canadienne – All rights reserved - Distributed by Radarsat International Inc.