The Latest Developments in Remote Sensing Technology for Oil Spill Detection

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Abstract

Oil spills are inherently dynamic in nature, as the oil is affected by the physical environment into which it is spilled and its own changing chemical composition. Prompt information about the location and extent of the spill are required to effectively direct spill countermeasures. When responding to major oil spills, there are requirements for both long-term and short-term information. In terms of remote sensing capabilities, the tactical or short-term needs have traditionally been addressed by airborne sensors. This paper will assess remote sensors for oil spill detection and review recent developments. This assessment will include a discussion of airborne and satellite-borne sensors, their inherent benefits and operational shortfalls. Satellite sensors have typically provided a strategic overview of marine oils spills. The state-of-the-art capabilities of several new space-borne sensors might provide responders with information that can be used in a tactical oil spill response role.

1 Introduction

Spills of oil and related petroleum products in the marine environment, be they large or small, can have serious biological and financial impacts. Once a spill occurs, the public and media rightfully demand that the location and extent of the oil spill be determined. It is in this context that remote sensing plays an increasingly important role in oil spill response efforts. Through the use of modern remote sensing instruments and systems, oil can now be monitored on the open ocean around the clock. With a timely knowledge of slick locations and movement, response personnel can more effectively plan countermeasures in an effort to mitigate the effects of the pollution. In recent years, there has been a strong interest in detection of illegal discharges, especially in view of the large seabird mortality associated with such discharges (Serra-Sogas et al., 2008).

In remote sensing, a sensor, other than the eye or conventional photography, is used to detect the target of interest at a distance. Remote sensing from an aircraft is still the most common form of tactical oil spill tracking. Historically, the most common forms of oil spill surveillance and mapping has involved simple still or video photography. There have been many advances in airborne oil spill remote sensors in recent times. The sensor themselves are becoming smaller, more sophisticated and much less expensive. These changes along with advances in computer processing capabilities have helped to transform the use of individual sensors into integrated multi-sensor operational systems.

Satellite remote sensing for oil spills has typically been employed in a strategic fashion. Recent advances in the capabilities of satellite sensors in terms of resolution and frequency of image capture are changing the perception of these sensors such that response personnel are now beginning to view them as potential tactical tools.

There have been several general reviews of oil spill remote sensing in the past decade, reference is made to those reviews here and readers are encouraged to consult them for specific details; Fingas and Brown 2005, 2007; Hengstermann and Robbe, 2008; Jha et al., 2008. These reviews provide details of the progress in oil spill remote sensing, and illustrate the advantages of certain specialized sensors for unique oil spill remote sensing circumstances. As no "magic bullet" sensor exists, private sector organizations are now focusing on producing integrated airborne remote sensor packages which provide a comprehensive overview of the spilled oil in a timely fashion with geo-referenced spill location information displaced in a graphical format.

2 Oil Spill Remote Sensing

Under many circumstances oil on the ocean's surface is not visible to the naked eye (Fingas et al., 1999). Other than the obvious situations of nighttime and fog, there exist many other situations where oil cannot be seen. A common situation is that of thin oil such as that which results from ship discharges or the presence of materials such as sea weed, ice and debris that mask oil presence. Often there are conditions on the sea that may appear like oil, when there is indeed not oil. These include wind shadows from land forms, surface wind patterns on the sea, surface dampening by submerged objects or weed beds, natural oils or biogenic material and oceanic fronts. In the case of large spills, the area may be too great to be mapped visually. All these factors dictate that remote sensing systems be used to assist in the task of mapping and identifying oil.

3 Optical Sensors

3.1 Visible

In the visible region of the electromagnetic spectrum (approximately 400 to 700 nm), oil has a higher surface reflectance than water, but shows limited nonspecific absorption tendencies. Oil generally manifests throughout the entire visible spectrum. Sheen shows up silvery and reflects light over a wide spectral region down to the blue. As there is no strong information in the 500 to 600 nm region, this region is often filtered out to improve contrast (O'Neil et al., 1983). Overall, however, oil has no specific characteristics that distinguish it from the background (Brown et al., 1996). Taylor studied oil spectra in the laboratory and the field and observed flat spectra with no useable features distinguishing it from the background (Taylor, 1992). Therefore, techniques that separate specific spectral regions do not increase detection capability. It has been found that high contrast in visible imagery can be achieved by setting the camera at the Brewster angle (53 degrees from vertical) and using a horizontally-aligned polarizing filter which passes only that light reflected from the water surface. This is the component that contains the information on surface oil (O'Neil et al., 1983).

Video cameras are often used in conjunction with filters to improve the contrast in a manner similar to that noted for still cameras. This technique has had limited success for oil spill remote sensing because of poor contrast and lack of positive discrimination. Despite this, video systems have been proposed as remote sensing systems (Bagheri et al., 1995). With new light-enhancement technology (low lux), video cameras can be operated even in darkness. Tests of a generation III night vision camera shows that this technology is capable of providing imagery in very dark night conditions (Brown et al., 2004a, 2005a).

New digital photography has enabled the combination of photographs and the processing of images. Locke et al. (2008) used digital photography from vertical images to form a mosaic of an area impacted by an oil spill. It was then possible to form a singular image and to classify oil types by color within the image. The area impacted by the spill can also be extracted. Nowadays there are a large number of digital cameras, both still and video which are low priced and are available commercially for airborne oil spill remote sensing. Imagery from digital cameras is often enhanced by the use of precise geo-referencing information available through the integration of GPS (Global Positioning Systems) position. The technology to directly overlay this digital imagery onto graphical information systems (GIS) in now commonplace.

The use of visible techniques in oil spill remote sensing is largely restricted to documentation of the spill because there is no mechanism for positive oil detection. Furthermore, there are many interferences or false alarms. Sun glint and wind sheens can be mistaken for oil sheens. Biogenic material such as surface seaweeds or sunken kelp beds can be mistaken for oil. Oil on shorelines is difficult to identify positively because seaweeds look similar to oil and oil cannot be detected on darker shorelines. In summary, the usefulness of the visible spectrum for oil detection is limited. It is, however, an economical way to document spills and provide baseline data on shorelines or relative positions.

3.2 Infrared

Oil, which is optically thick, absorbs solar radiation and re-emits a portion of this radiation as thermal energy, primarily in the 8 to 14 μm region. In infrared (IR) images, thick oil appears hot, intermediate thicknesses of oil appear cool and thin oil or sheens are not detected. The thicknesses at which these transitions occur are poorly understood, but evidence indicates that the transition between the hot and cold layer lies between 50 and 150 μm and the minimum detectable layer is between 10 and 70 μm (Fingas and Brown, 2005). The reason for the appearance of the "cool" slick is not fully understood. A plausible theory is that a moderately thin layer of oil on the water surface causes destructive interference of the thermal radiation waves emitted by the water, thereby reducing the amount of thermal radiation emitted by the water (Fingas and Brown, 2005). The cool slick would correspond to the thicknesses as observed above, because the minimum destructive thickness would be about 2 times the wavelength which is between 8 to 10 μm. This would yield a destructive onset of about 16 to 20 μm to about 4 wavelengths or about 32 to 40 μm. The destructive area is usually only seen with test slicks, which is explained by the fact that the more rapidly-spreading oil is more transparent than the remaining oil. The onset of the hot thermal layer would in theory then be at thicknesses greater than this or at about 50 μm.

Infrared devices can not detect emulsions (water-in-oil emulsions) under most circumstances (Bolus, 1996). This is probably a result of the high thermal conductivity of emulsions as they typically contain 70% water and thus do not show a temperature difference relative to the surrounding.

Most infrared sensing of oil spills takes place in the thermal infrared at wavelengths of 8 to 14 μm. Tests of a number of infrared systems show that spatial resolution is extremely important when the oil is distributed in windrows and patches, emulsions are not always visible in the IR, and cameras operating in the 3 to 5 μm range are only marginally useful (Hover, 1994). Night-time tests of IR sensors show that there is detection of oil (oil appears cold on a warmer ocean); however the contrast is not as good as during daytime (Hover, 1994; Grierson, 1998).

The relative thickness information in the thermal infrared can be used to direct skimmers and other countermeasures equipment to thicker portions of the slick. Oil detection in the infrared is not positive, however, as several false targets can interfere, including seaweeds, shoreline, and oceanic fronts (Brown et al., 1998). Infrared sensor technology is reasonably inexpensive, however, and is frequently the tool of choice for oil spill response personnel.

3.3 Ultraviolet

Ultraviolet sensors can be used to map sheens of oil as oil slicks display high reflectivity of ultraviolet (UV) radiation even at thin layers (<0.1 μm). Overlaid ultraviolet and infrared images are often used to produce a relative thickness map of oil spills. Ultraviolet data are also subject to many interferences or false images such as wind slicks, sun glints, and biogenic material. Since these interferences are often different than those for infrared sensing, combining IR and UV can provide a more positive indication of oil than using either technique alone.

4 Laser Fluorosensors

Laser fluorosensors are active sensors that take advantage of the fact that certain compounds in petroleum oils absorb ultraviolet light and become electronically excited. This excitation is rapidly removed through the process of fluorescence emission, primarily in the visible region of the spectrum. Since very few other compounds show this tendency, fluorescence is a strong indication of the presence of oil. Natural fluorescing substances, such as chlorophyll, fluoresce at sufficiently different wavelengths than oil to avoid confusion. As different types of oil yield slightly different fluorescent intensities and spectral signatures, it is possible to differentiate between classes of oil under ideal conditions (Brown et al., 2002a,b, 2003a,b, 2004a,b; 2005a; Hengstermann and Reuter, 1990; Samberg, 2007).

Most laser fluorosensors used for oil spill detection employ a laser operating in the ultraviolet region of 300 to 355 nm (Brown et al., 2003a). The fluorescence response of crude oil ranges from 400 to 650 nm with peak centers in the 480 nm region.

Another phenomenon, known as Raman scattering, involves energy transfer between the incident light and the water molecules. When the incident ultraviolet light interacts with the water molecules, Raman scattering occurs. The water molecules absorb some of the energy as rotational-vibrational energy and emit light at wavelengths which are the sum or difference between the incident radiation and the vibration-rotational energy of the molecule. The Raman signal for water occurs at 344 nm when the incident wavelength is 308 nm (XeCl laser). The water Raman signal is useful for maintaining wavelength calibration of the fluorosensor in operation, but has also been used in a limited way to estimate oil thickness, because the strong absorption by oil on the surface will suppress the water Raman signal in proportion to thickness (Piskozub et al., 1997). The point at which the Raman signal is entirely suppressed depends on the type of oil, since each oil has a different absorption coefficient. The Raman signal suppression has led to estimates of sensor detection limits of about 0.05 to 0.1 μm (Goodman and Brown, 2005).

Laser fluorosensors have significant potential as they may be the only means to discriminate between oiled and unoiled seaweeds and to detect oil on different types of beaches. Tests on shorelines show that this technique has been very successful. Work has been conducted on detecting oil in the water column such as occurs with the product, Orimulsion (Brown et al., 2002b, 2003a, b). The fluorosensor is also the only reliable means of detecting oil in certain ice and snow situations.

5 Radar Sensors

5.1 SAR and SLAR

Capillary waves on the ocean reflect radar energy, producing a "bright" image known as sea clutter. Since oil on the sea surface dampens some of these capillary waves, the presence of an oil slick can be detected as a "dark" sea or one with an absence of this sea clutter. Unfortunately, oil slicks are not the only phenomena that are detected in this way. There are many interferences or false targets, including fresh water slicks, wind slicks (calms), wave shadows behind land or structures, seaweed beds that calm the water just above them, glacial flour, biogenic oils, and whale and fish sperm (Gens, 2008). As a result, radar can be ineffective in locations such as Prince William Sound, Alaska where dozens of islands, fresh water inflows, ice, and other features produce hundreds of such false targets. Despite these limitations, radar is an important tool for oil spill remote sensing because it is the only sensor that can be used for searches of large areas and it is one of the few sensors that can "see" at night and through clouds or fog.

The two basic types of radar that can be used to detect oil spills are Synthetic Aperture Radar (SAR) and Side-Looking Airborne Radar (SLAR). The latter is a less expensive technology, which uses a long antenna to achieve spatial resolution. Synthetic aperture radar uses the forward motion of the aircraft to synthesize a very long antenna, thereby achieving very good spatial resolution, which is independent of range, with the disadvantage of requiring sophisticated electronic processing. While inherently more expensive, the SAR has greater range and resolution than the SLAR. In fact, comparative tests show that SAR is vastly superior (Brown and Fingas, 2003b). SLAR has predominated airborne oil spill remote sensing, primarily because of the lower sensor cost (Zielinski and Robbe, 2004; Dyring and Fäst, 2004).

Experimental work on oil spills has shown that X-band radar yields better data than L- or C- band radar. It has also been shown that vertical antenna polarizations for both transmission and reception (V,V) yield better results than other configurations (Fingas and Brown, 2005). The ability of radar to detect oil is limited by sea state. Sea states that are too low will not produce enough sea clutter in the surrounding sea to contrast to the oil and very high seas will scatter radar sufficiently to block detection inside the troughs. Indications are that minimum wind speeds of 1.5 m/s (~3 knots) are required to allow detection and a maximum wind speed of 6 m/s (~12 knots) will again remove the effect (Hühnerfuss et al., 1996). This limits the environmental window of application of radar for detecting oil slicks. Gade et al., (1996) studied the difference between extensive systems from a space-borne mission and a helicopter-borne system. They found that at high winds, it was not possible to discriminate biogenic slicks from oil. At low wind speeds, it was found that images in the L-band showed discrimination. Under these conditions the biogenic material showed greater damping behaviour in the L-band. Okamoto et al., (1996) studied the use of ERS-1 using artificial oil (oleyl alcohol) and found that an image was detected at a wind speed of 11m/s, but not at 13.7 m/s.

In summary, radar optimized for oil spills is useful in oil spill remote sensing, particularly for searches of large areas and for night-time or foul weather work. The technique is highly prone to false targets, however, and is limited to a narrow range of wind speeds.

6 Slick Thickness Determination

There has long been a need to measure oil slick thickness, both within the oil spill response community and among academics in the field. There are presently no reliable methods, either in the laboratory or the field, for accurately measuring oil-on-water slick thickness. The ability to do so would significantly increase understanding of the dynamics of oil spreading and behaviour. Knowledge of slick thickness would make it possible to determine the effectiveness of certain oil spill countermeasures including dispersant application and in-situ burning. Indeed, the effectiveness of individual dispersants could be determined quantitatively if the oil remaining on the water surface following dispersant application could be accurately measured (Goodman and Fingas, 1988; Jensen et al. 2008).

6.1 Specific Thickness Sensors

The suppression of the water Raman peak in laser fluorosensor data has not been fully exploited or tested. This technique may work for thin slicks, but not necessarily for thick ones, at least not with a single excitation frequency. Attempts have been made to calibrate the thickness appearance of infrared imagery, but also without success. It is suspected that the temperatures of the slick as seen in the IR are highly dependent on oil type, sun angle, and weather conditions. If so, it may not be possible to use IR as a calibrated tool for measuring thickness. As accurate ground-truth methods do not exist, it is very difficult to calibrate existing equipment (Brown et al., 2006). Several attempts have been made to measure thickness by using visible spectral imaging. As there is no visual indication other than the rainbow sheen area around 0.8 μm, these efforts are wasted (Fingas et al., 1999; Svejkovsky et al., 2008).

The only sensor which has been proven capable of accurately measuring the absolute thickness of an oil slick on water from an airborne platform is the Laser Ultrasonic Remote Sensing of Oil Thickness (LURSOT) sensor. The LURSOT sensor consists of three lasers, one of which is coupled to an interferometer to accurately measure oil thickness (Brown et al., 1997, 2001b, 2005b; 2006; Brown and Fingas, 2003c). The sensing process is initiated with a thermal pulse created in the oil layer by the absorption of a powerful CO_2 laser pulse. Rapid thermal expansion of the oil occurs near the surface where the laser beam was absorbed, which causes a step-like rise of the sample surface as well as an acoustic pulse of high frequency and large bandwidth (~ 15 MHz for oil). The acoustic pulse travels down through the oil until it reaches the oil-water interface where it is partially transmitted and partially reflected back towards the oil-air interface, where it slightly displaces the oil's surface. The time required for the acoustic pulse to travel through the oil and back to the surface again is a function of the thickness and the acoustic velocity of the oil. The displacement of the surface is measured by a second laser probe beam aimed at the surface. Motion of the surface induces a phase or frequency shift (Doppler shift) in the reflected probe beam. This phase or frequency modulation of the probe beam can then be demodulated with an interferometer. The thickness can be determined from the time of propagation of the acoustic wave between the upper and lower surfaces of the oil slick. This is a very reliable means of studying oil thickness and has great potential. This technology was developed by a consortium of agencies including Imperial Oil, Environment Canada, and the United States Minerals Management Service. Laboratory tests have confirmed the viability of the method and a test unit has been flown to confirm its operability (Brown et al., 2006).

7 Integrated Airborne Sensor Systems

Increasingly, a number of different types of airborne oil spill remote sensors are being consolidated into sensor systems. The reason for this integration is to take advantage of the different information provided by each of the specific sensors and combine the information to provide a more complete and comprehensive information product. Although each of the individual sensors has specific inherent weaknesses such as false detections, these false detections are often different for each sensor type, hence a consolidation of information can help resolve and remove some of the uncertainties that exist from a single data source. Furthermore, additional information such as the relative thickness of the oil slick can be deduced from the overlaying of imagery from several sensor types. Although the absolute thickness of an oil slick remains the subject of continued research and scientific opinion, the ability to locate the thicker portions of the slick is essential in terms of operational spill cleanup and response. In addition to the integration of a number of remote sensors into a sensor system, information from other sources such as marine vessel traffic surveillance systems (i.e., automatic identification system, AIS) can be integrated and can play an essential role in identifying the source of the marine pollution.

Two commercially available airborne marine oil spill remote sensing systems are the MEDUSA (Optimare 2009) and the MSS 6000 (Swedish Space Corporation 2009). MEDUSA incorporates a number of sensor technologies such as laser fluorosensors, infrared/ultraviolet line scanners, forward-looking infrared sensors, microwave radiometers, side-looking airborne radar systems and camera systems, as well processing software into a flexible real-time data acquisition and processing system. The data from the various sensors are geo-referenced and fused with information from AIS and marine surveillance radars into a GIS-based display output format. The processing software is known as the Oil Spill Scene Analysis System (OSSAS) and allows for the extraction of features such as the area of oil coverage including areas of intermediate and thicker portions of the slick. The MSS 6000 Maritime Surveillance System is comprised of a flexible suite of sensors such as side-looking airborne radar systems, infrared/ultraviolet line scanners, forward-looking infrared sensors, laser fluorosensors, microwave radiometers, and camera systems, along with data processing and mission management software in order to perform the oil spill remote sensing surveillance task. The MSS 6000 also focuses on sensor integration and includes AIS and marine search radar inputs. All sensor data, imagery, slick targets, vessels etc. are annotated using navigation data from a single source to form an integrated part of a Geographic Information System (GIS). Both the MEDUSA and MSS 6000 can distribute their data in near-real time via direct downlink or satellite communications to vessels or shore-based communications centers. A large number of maritime nations are now employing integrated airborne sensor systems (Armstrong et al., 2008; Brown and Fingas 2005)

8 Satellite Remote Sensing

The use of optical satellite remote sensing for oil spills has been attempted several times (Fingas and Brown, 2007).

There are several problems associated with relying on satellites operating in optical ranges, for oil spill remote sensing. The first is the timing and frequency of overpasses and the absolute need for clear skies to perform optical work. The chances of the overpass and the clear skies occurring at the same time give a very low probability of seeing a spill on a satellite image. This point is well illustrated in the case of the EXXON VALDEZ spill (Noerager and Goodman, 1991). Although the spill covered vast amounts of ocean for over a month, there was only one clear day that coincided with a satellite overpass, and that was on April 7, 1989. Another disadvantage of satellite remote sensing is the difficulty in developing algorithms to highlight the oil slicks and the long time required to do so. For the EXXON VALDEZ spill, it took over two months before the first group managed to "see" the oil slick in the satellite imagery, although its location was precisely known.

Recently, IR data from satellite has been used to map the land-based oil pollution in Kuwait (ud din et al., 2008). It was found that the old hydrocarbon-contaminated areas showed as much as 10°C difference from the surrounding land. Ground-truthing was used extensively in compiling the data.

Radar satellites, including ERS-1 and -2, RADARSAT-1, and ENVISAT, have demonstrated usefulness for detecting large offshore spills and for spotting anomalies (Brown and Fingas, 2001a, b; Brown et al., 2002c).

Table 1. Current Satellite-borne SAR Sensors (adapted from Topouzelis, 2008)

Satellite (Sensor)	Launch Date	Owner/Operator	Band
ERS-2	1995	ESA	C
RADARSAT-1	1995	CSA	C
RADARSAT-2	2007	CSA/MDA	C
ENVISAT (ASAR)	2002	ESA	C
ALOS (PALSAR)	2006	JAXA	L
TerraSAR-X	2007	DLR	X
Cosmos Skymed-1/2	2007	ASI	X

ASI – Italian Space Agency, CSA – Canadian Space Agency, DLR – German Aerospace Center, ESA – European Space Agency, JAXA – Japan Aerospace

Exploration Agency, MDA – MacDonald Dettwiler and Associates Ltd.

In recent years there have been a number of new satellite-borne SAR sensors launched, see Table 1. While one of these sensors, RADARSAT-2, operates in the traditional C-band, TerraSAR-X and Cosmos Skymed operate in the X-band, while the PALSAR sensor on ALOS operates in the L-band. As noted above, X-band is the preferred band for oil spill remote sensing in terms of Bragg scattering. All four of these new SAR satellites have polarimetric imaging modes (some are experimental vs. operational modes) and much higher spatial resolution (down to 3 m) which may have application for oil spill remote sensing. RADARSAT-2, like its predecessor is an operational commercial satellite that can be tasked to respond to emergency situations like major oil spills. The time required to task RADARSAT-2 in emergency mode is now 4 hours, which is a large improvement from the 12 hours required to task its predecessor. As noted above V,V polarization provides a superior clutter to noise ratio (CNR) over H,H polarization for oil spill detection. RADARSAT-2 is fully polarimetric and there is interest in investigating whether a dual channel ScanSAR mode utilizing V,V/V,H polarizations will work for oil and ship detection respectively as part of the Integrated Satellite Tracking of Pollution (ISTOP) program (DeAbreau et al., 2006). The increased number of SAR satellites plus the plans to operate constellations of small satellites like Cosmos (Constellation of Small Satellites for Mediterranean basin Observation) will provide increased temporal coverage with revisit times down to a few hours in some circumstances. The opportunity for increased frequency of image collection should prove useful to the oil spill response community.

9 Future Trends

Advances in sensor technology will continue to drive the use of remote sensors as operational oil spill response tools in the future. Thermal infrared detectors that offer high sensitivity are in the marketplace. This improvement not only reduces the size and complexity of the sensor, but also the cost. In order to significantly increase the use of laser-based sensors such as fluorosensors, a reduction in the size and energy consumption of lasers utilized in these systems is required. This will require advances in solid-state laser technology, in particular diode-pumped solid-state lasers. Smaller and more energy efficient sensors will allow for their installation in smaller, more economical aircraft which are within the budget of many more regulatory agencies and maritime countries. Rapidly improving computer capabilities will allow for true real-time processing. At the present time and for the foreseeable future, there is no single “Magic Bullet” sensor that will provide all the information required to detect, classify, and quantify oil in the marine and coastal environment.

As the technology in remote-controlled systems such as Unmanned Aerial Vehicles (UAVs) evolves, it is possible to employ such technology in oil spill remote sensing. First efforts in the deployment of remote-controlled sensing aircraft have posted success and will, no doubt, be expanded in the future (Allen and Walsh, 2008).

10 Conclusions

In order to respond effectively to major marine oil spills, it is recommended that one employs a combination of airborne and satellite-borne sensor systems. Improvements in the resolution of satellite-based systems, particularly SAR systems combined with the increased number of such systems and the ability to steer them to image the area of the oil spill will lead to their increased use in a tactical role. Being capable of imaging vast areas of the open ocean will ensure that satellite-borne sensors will also continue to be used in a strategic manner. There are a number of commercially available airborne sensor systems which provide near real-time information on oil slick location and indications of thicker areas of the pollution in an easily interpretable graphical manner. These airborne sensor systems are currently being employed by a large number of maritime nations in conjunction with satellite-based sensor systems.

Historically satellite sensors suffered from problems of low resolution and the low frequency of scene observation. These inadequacies are now being addressed by higher resolution systems with multiple imaging modes and the ability to steer the sensor to look in the direction of the target of interest. There are an increasing number of satellite-borne SAR and optical sensors, some of which currently or soon will operate in constellations to provide increased coverage of the earth's surface. These enhanced capabilities will allow for the possible use of these sensors in a tactical mode of operation. In spite of these increased capabilities, there remains an essential role for airborne oil spill remote sensing platforms. The ability to collect and deliver real-time oil slick location information will ensure the continued use of airborne systems in spite of their high operational costs.

If this type of real-time oil spill remote sensing information can be made available to response crews in a short enough timeframe following a spill incident, the information can be used to mitigate the potentially disastrous effects of a major oil spill on the marine ecosystem.

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