

Remote Sensing in Support of Oil Spill Response

Planning Guidance

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Acronyms

µm	Micrometer(s)
AOI	Area of interest
API	American Petroleum Institute
AUV	Autonomous underwater vehicle
cm	Centimeter(s)
EM	Electromagnetic
FAA	Federal Aviation Administration
GHz	Gigahertz
GIS	Geographic Information System
HH	Horizontal transmit, horizontal receive
IAP	Incident Action Plan
ICS	Incident Command System
IR	Infrared
km	Kilometer(s)
kph	Kilometers per hour
LISST	Laser in situ scattering and transmissometry
LWIR	Long-wave infrared
m	Meter(s)
m/s	Meters per second
MS	Multispectral
MWIR	Mid-wave infrared
NIIMS	National Interagency Incident Management System
NIR	Near infrared
RRP	Rapid response product
SAR	Synthetic aperture radar
SLAR	Side-looking airborne radar
SME	Subject Matter Expert
SWIR	Short-wave infrared
TIR	Thermal infrared
TWG	Technical working group
UAV	Unmanned aerial vehicle
UV	Ultraviolet
VIS	Visible
VV	Vertical transmit, vertical receive

Remote Sensing in Support of Oil Spill Response Planning Guidance

Purpose of This Guide

This guide has been developed to introduce response personnel to oil spill remote sensing technology and to provide guidance on its effective incorporation into spill response operations. This document is not intended for use during an actual incident by those unfamiliar with the technology. The guide is intended as a resource in response planning prior to a spill event, as a tool for planning readiness exercises and drills, and as a reference for responders during exercises and drills.

In 2010, the American Petroleum Institute (API) established a technical working group (TWG) consisting of members from the oil industry, and members from federal and state governments, to assess the utility of remote sensing technology in oil spill response. During an initial workshop in early 2011, the Oil Sensing and Tracking TWG identified a need within the oil spill response community for guidance on implementation of remote sensing during an oil spill. Based on their discussions, the TWG initiated a project with the following key elements:

- Hold a series of workshops to identify and develop a deliverable that outlines current and emerging remote sensing technologies for oil spill response.
- Research detection capabilities to determine reliability and performance expectations.
- Identify technologies most reliable for indicating the greatest concentrations of oil on the water's surface in order to direct response operations and maximize collection.
- Develop a guidance document that evaluates sensing and tracking applications and technologies, and provides recommendations for their use in oil spill response.

What Is Remote Sensing?

Remote sensing refers to the acquisition of information about an object or phenomenon without making physical contact with the object. For this guide, the term refers to the use of a sensor to detect and classify oil and objects on water surfaces. Remote sensing technology is currently available in a variety of sensor and platform combinations, but this guide focuses primarily on those technologies that provide satellite and aerial imagery.

The science of oil spill remote sensing in the marine environment, below the surface of the water, is in the early stages of development. Although technology for subsurface oil detection and tracking exists, it has not been extensively tested or utilized in real-world scenarios. Therefore, it is not covered in this document.

Remote sensing in the arctic environment is not addressed in this guide due to the availability of other technical documents that focus specifically on the subject. Readers are encouraged to pursue guidance documents on arctic remote sensing that are currently being developed by the International Oil and Gas Producers Association.

How Should Remote Sensing Be Incorporated into Mission Support Planning for an Incident?

Mission support planning related to remote sensing should incorporate the following actions:

- Identify the anticipated mission and purpose of the remote sensing team.
- Define the area of interest (AOI) or the theater of operations for the incident.
- Describe the limits of the AOI both in terms of natural or cultural features and latitude and longitude coordinates.

Specific considerations for the remote sensing team to be addressed during an incident include:

- Staffing availability of trained expert aerial observers and image interpretation specialists.
- Quality assurance/quality control and standards enforcement (datum determination).
- Geospatial database management, data and information indexing and cataloguing.
- IT support and direct computer-to-computer access, wireless infrastructure capabilities.
- Supply needs and logistics.
- Support to and from country governments and local agencies.
- Support from commercial service providers.
- Digital data production and image processing resources.
- Dissemination procedures of raw data and interpreted data/imagery.
- Disclosure and release of information and data (e.g., to partners, industry groups, researchers, media, and the public).

What Steps Are Involved in Integrating Remote Sensing into Oil Spill Response?

This guide presents 5 steps for implementing a remote sensing/surveillance program during an oil spill response. It is suggested that readers review the steps to gain an understanding of the remote sensing process and to aid in the integration of remote sensing into spill response planning. The remainder of the guide has been organized to correspond with the following 5 steps:

1. Understand how remote sensing supports a response.
2. Establish the remote sensing team.
3. Determine the appropriate technology.
4. Deploy the technology.
5. Analyze and communicate the data.



1.0 Understand How Remote Sensing Supports a Response

Aerial surveillance and remote sensing are recognized as a critical part of oil spill response operations. The success of most spill response operations is directly linked to effective aerial surveillance and effective use of various remote sensing sensors. In the early stages of a response, typical objectives for remote sensing systems are to:

- Provide situational awareness at the source.
- Assist in determining the extent of the release.
- Provide information related to selecting appropriate recovery methods.

As an incident progresses, the demands on a surveillance program increase, and the program often divides into a tactical and a strategic role. The tactical role includes support to response operations such as mechanical recovery, application of dispersants, controlled in situ burning, and shoreline assessments. The strategic role is focused on providing a synoptic overview of the overall extent of the release, identifying resources at risk, and gathering information to assist with prediction or trajectory modeling efforts.

Various remote sensors and technologies are deployed to detect and track oil. The sensors, which are often combinations of different types of sensors, support both tactical and strategic missions. Due to the dynamic nature of most incidents, the timeliness of delivering data from these sensors is critical. Slow delivery and complex processing of remote sensing data may lead to delays in tactical operations or misinterpretation of oil location when response assets are deployed. Therefore, rapid distribution of analyzed and interpreted images and associated data are critical for responders at both the tactical and strategic level to support operational decisions.

2.0 Establish the Remote Sensing Team

Supplying accurate and timely information to responders, as well as to the public and their political leadership, is an essential function of a well-trained remote sensing team. Because the value of remote sensing data is greatly diminished by delays between its receipt and the production of actionable intelligence, the availability of well-trained staff able to quickly and accurately integrate multiple sources of information is critical to leveraging remote sensing tools during an oil spill response. This section discusses the role of the remote sensing team within the Incident Command System (ICS), the potential need for a Remote Sensing Subject Matter Expert (SME), and the SME's roles and responsibilities.

2.1 What Is the Role of the Remote Sensing Team Within the Incident Command System?

ICS is the fundamental command and control organizational structure of an emergency response team within the United States and in other parts of the world. Assignment of a remote sensing team within the ICS—as well as a clear definition of the team's roles and responsibilities—is necessary to effectively

integrate remote sensing into spill response planning. Additional information on the ICS and the National (U.S.) Interagency Incident Management System (NIIMS) can be found at:

http://www.osha.gov/SLTC/etools/ics/ics_tasks.html

<http://www.fema.gov/incident-command-system>

Within the ICS structure, the remote sensing team is typically assigned to the Planning Section and reports to the Situation Unit Leader. Air Operations, the team responsible and accountable for the safe operation and tracking of aircraft (or platforms), typically operate out of the Operations Section. Depending on the size and extent of the spill event, the remote sensing team may be comprised of a single individual or a group of specialists led by an experienced manager. Certain larger-scale oil spill incidents may require a Remote Sensing SME with specialized knowledge and expertise to locate, track, and display the location of released or spilled oil in a manner useful to the end user. The end user may include organizational command and control roles (i.e., the Situation Unit Leader, in addition to command and general staff), responders in the field, the media, and the general public. The responsibilities of the remote sensing team are divided by role and are described below.

2.1.1 What Are the Responsibilities of the Remote Sensing Team Manager?

The Remote Sensing Team Manager would be responsible for the following actions:

- Determine desired end products, assist in production, manage delivery deadlines, and conduct briefings as necessary.
- Coordinate, prioritize, and supervise remote sensing tasks to ensure that production standards and the requirements of internal and external organizations and agencies are met.
- Develop and maintain appropriate ICS forms and information for the Planning Chief.
- Perform various administrative tasks, including development of the scope of work and other planning efforts, generation of reports, recordkeeping, inventory tracking, and determining communication and resource procurement requirements.

2.1.2 What Are the Responsibilities of the Remote Sensing Team Specialist?

The Remote Sensing Team Specialist would report to the Remote Sensing Team Manager and would be responsible for the following actions:

- Generate maps and other products.
- Operate the remote sensing technology and software.
- Interpret acquired data.
- Develop and update databases.
- Perform various administrative tasks, including assembling data and deliverables, documenting team activities, transferring data and images, maintaining printing and plotting equipment, and maintaining remote sensing hardware needed for rapidly deployed surveillance kits (i.e., *go-kits*).

2.1.3 What Are the Responsibilities of the Remote Sensing Subject Matter Expert?

If a Remote Sensing SME is required for an incident, the SME role would include the role and duties of the Remote Sensing Specialist. The SME would provide technical guidance. The SME would assist in tasking and data acquisition via all necessary means (satellite imagery, air or surface instrument imagery, and subsea instrument imagery), determining the scope and requirements for technical presentations, and determining the presentation style and format that best communicate the situation and status of the incident for the intended audience. The SME also would be responsible for the following actions:

- Assist with planning remote sensing missions, including selection of sensors and platforms.
- Interpret imagery collected and assemble the support staff to support timely interpretation of images.
- Provide technical expertise and advice to command and general staff as needed.
- Attend meetings and briefings to clarify and help to resolve technical issues related to remote sensing.
- Provide expertise during development of the Incident Action Plan (IAP) and other reports and plans.
- Work with the Safety Officer and the Air Operations staff within the Operations Section to minimize unsafe work practices.
- Work closely with the Liaison, Community Relations, and Operations Sections to help facilitate product interpretation and understanding among stakeholders and special interest groups (e.g., the media and the public).
- Attend press briefings or town hall meetings to clarify technical issues.
- Work with the Operations Section to monitor the success of the executed surveillance activities.
- Research technical issues and provide findings to decision makers.
- Troubleshoot technical problems and provide advice on their resolution.

3.0 Determine the Appropriate Technology

Although a range of airborne and spaceborne sensors are currently available from both the private and government sectors, each sensor and platform combination contains a balance between utility and availability. For example, synthetic aperture radar (SAR) can image through clouds and requires no solar illumination, but it cannot identify materials on the water's surface based on their spectral characteristics and often does not provide a unique quantitative solution. As a result, most successful applications of remote sensing technology require the combination of several sensors and data sets to satisfactorily address the unique situation at hand.

This section discusses the process for determining the appropriate remote sensing technology for a specific response situation and describes the existing sensors and platforms available at the time of this document's publication.

3.1 How Are Remote Sensors Classified?

Sensors used for traditional remote sensing are classified as passive or active. Passive sensors detect natural radiation emitted or reflected by the objects being observed. Reflected sunlight and thermal emissions are the most common sources of electromagnetic (EM) energy measured by passive sensors. These remote sensing systems utilize a variety of detectors that are sensitive to wavelengths spanning the optical (i.e., visible) range of the EM spectrum to the thermal infrared (TIR) range of the EM spectrum. These passive imaging sensors rely on external sources of energy that are reflected or emitted from objects on the ground to a detector sensitive to specific wavelengths.

Active sensors first emit a pulse of EM energy and then measure the signal reflected back to the sensor. RADAR and LiDAR are examples of active remote sensing systems.

Remote sensing systems are also classified by the resolution of the system. Three major types of resolutions dictate how effective a system will be for a response event: temporal, spatial, and spectral. Temporal resolution is used to describe how frequently data are gathered, spatial resolution describes the ground representation for a particular data set, and spectral resolution reflects the number and bandwidth of discrete bands in which data are collected. Systems that obtain imagery from distances closer to a surface may provide better spatial resolution of a smaller area of view, while systems acquiring imagery from greater distances typically provide poorer spatial resolution of a much larger area of view. Most satellite or high-altitude systems may be useful for initial detections of medium-sized spills or mapping of larger spills. Shoreline assessment and detection of small spills, especially those near coastal areas, usually require the higher resolution that lower altitude systems may provide.

Aerial remote sensing systems are typically designed to look vertically downward (toward the nadir [*nadir* is the point directly above the location]). The majority of remotely sensed imagery used for mapping and environmental remote sensing is obtained with a vertical sensor—one that records an image with a downward-viewing angle of less than 3 degrees. The viewing angle of an oblique image is tilted upward toward the horizon, and the images are typically taken with hand-held, digital, single-reflex cameras or sensors mounted within gimbals.

In order to determine the appropriate imaging system to use in an event, one must first understand how EM energy interacts with oil in different areas of the EM spectrum. Sensors are categorized according to the EM wavelength (in micrometers [μm]) that the sensor detects:

- Ultraviolet (UV at 0.1–0.4 μm).
- Visible (0.4–0.7 μm).
- Near infrared (NIR at 0.74–1.4 μm).
- Short-wave infrared (SWIR at 1.4–3.0 μm).
- Thermal infrared (TIR at ~ 3.0–14.0 μm). TIR can be sub divided into two groups:
 - Mid-wave infrared (MWIR/MIR at 3.0–5.0 μm ; some heat sensitivity).
 - Long-wave infrared (LWIR at 8.0–14.0 μm ; good heat sensitivity).
- Microwave (~1.0–30.0 μm).

3.2 What Is the Appropriate Tool for the Mission?

As each sensor has different capabilities and produces different image products, it is important to consider the goal of the remote sensing mission and the existing conditions of the situation when selecting a sensor for a particular spill event. For example:

- What is the mission?
 - Determining the location and extent of the oil slick?
 - Mapping the oil's potential trajectory?
 - Monitoring the effectiveness of mitigation efforts?
- What are the conditions?
 - Will the sensor be deployed at night or during the day?
 - Is it raining or foggy?
 - Is the sea calm or rough?

After determining the specific spill reconnaissance mission and its conditions, sensors can be compared for applicability. Table 4-1 provides a useful tool to aid in selection of an appropriate sensor for use during a mission, and it identifies the information responders can expect to obtain.

Table 4-1 Selection of the Appropriate Tool for Marine Spill Response Missions

Mission	Appropriate Sensor(s)	Derived Information
Initial and Ongoing Synoptic and Tactical Situational Awareness, Spill Tracking, and Monitoring	1. Visual observation 2. Multispectral imaging 3. Thermal imaging 3. Synthetic aperture radar 4. Side-looking airborne radar	▪ Extent of spill at time X ▪ Location and condition of personnel, resources, and assets at time X ▪ Indication of areas of information uncertainty (which areas were not covered by mission or sensor at time X) ▪ Indication of areas of information certainty (which areas were covered by mission or sensor at time X) ▪ Direction of slick movement ▪ Mission route
Spill Trajectory Modeling	1. Synthetic aperture radar 2. Visual observations (with or without multispectral imaging support) 3. Side-looking airborne radar 4. Multispectral imaging 5. Thermal imaging	▪ Extent of spill at time X ▪ Direction of slick movement ▪ Indication of areas of information uncertainty (which areas were not covered by mission or sensor at time X) ▪ Indication of areas of information certainty (which areas were covered by mission or sensor at time X) ▪ Observable meteorological conditions at time X ▪ Sea state at time X

Table 4-1 Selection of the Appropriate Tool for Marine Spill Response Missions

Mission	Appropriate Sensor(s)	Derived Information
Reconnaissance and Tactical Planning	1. Visual observations (with or without multispectral imaging support) 2. Multispectral imaging 3. Thermal imaging	▪ Condition of objects or areas of interest at time X ▪ Identification of hazards or other topics of interest per mission objectives ▪ Topographical and environmental context of objects or area of interest (AOI) at time X ▪ Target confirmation (eliminating false positives from other sensors) ▪ Mission route
Command and Control	1. Visual observations (with or without multispectral imaging support)	▪ Condition of objects or AOI at time X ▪ Identification of hazards or other topics of interest per mission objectives ▪ Topographical and environmental context of objects or AOI at time X ▪ Mission route
Spill Volume Estimation	1. All available surveillance data are used, though primarily for determining the areal component of the volume estimate. Thickness is poorly quantified by remote sensing techniques.	▪ Visual appearance of slick or sub-slick at time X ▪ Weathered state assessment of slick or sub-slick at time X ▪ Estimate of relative thickness of different sub-slicks ▪ Estimate of coverage (% distribution) ▪ Location of slick or sub-slick at time X ▪ Extent of slick or sub-slick at time X
Determining “Best” Recovery Method	1. Visual observations (with or without multispectral imaging support) 2. Multispectral imaging 3. Thermal imaging	▪ Visual appearance of slick or sub-slick at time X ▪ Weathered state assessment of slick or sub-slick at time X ▪ Location of slick or sub-slick at time X ▪ Extent of slick or sub-slick at time X ▪ Location and condition of personnel, resources, and assets at time X in relation to the slick or sub-slick ▪ Mission route
Monitoring Dispersant Efficacy (Spotting)	1. Visual observations (with or without multispectral imaging support) 2. Multispectral imaging 3. Thermal imaging	▪ Extent, location, and visual appearance of sprayed slick or sub-slick before application of dispersant at time X ▪ Extent, location, and visual appearance of slick or sub-slick after dispersant application at indicated time intervals ▪ Mission route
Maximizing Volume of Recovered Oil (Skimming)	1. Visual observations (with or without multispectral imaging support)	▪ Extent, location, and orientation (bearing or heading) of recoverable oil at time X ▪ Location and condition of personnel, resources, and assets at time X in relation to the recoverable oil ▪ Mission route
Management and Monitoring of In-Situ Burning	1. Visual observations (with or without multispectral imaging support) 2. Multispectral imaging 3. Thermal imaging	▪ Location of burn ▪ Footprint of burn at time X ▪ Location of staff, resources, and assets at time X ▪ Mission route

Table 4-1 Selection of the Appropriate Tool for Marine Spill Response Missions

Mission	Appropriate Sensor(s)	Derived Information
Public Interest and Public Relations	1. All available surveillance data are used.	▪ The essential information elements for the public interest and public relations use cases are similar to those for ongoing situational awareness, spill tracking and monitoring, and reconnaissance and planning. ▪ The information presented is succinct, clear, and self-interpreting to the extent that any media interpretation or commentary cannot misstate the actual facts that are presented in the distributed product. ▪ Surveillance and imagery intelligence data presented to the public or the media must be accompanied with factual and correct information about the product, as well as what is shown and what cannot be inferred from the data. ▪ Within the constraints of a safe and effective response, this information must be made available freely, rapidly, and as widely as possible. ▪ For significant spills, ensure that the responsible party has information dominance in the social media domain.
Detection and Monitoring of Submerged Oil Mats	1. Visual observations (with or without multispectral imaging support) 2. Multispectral imaging	▪ Visual appearance of shoreline or AOI at location Y at time X ▪ Size and appearance of foreign objects, damage and oil substance, and hazards at location Y at time X ▪ Location and condition of personnel, resources, and assets at time X in relation to the area imaged ▪ Mission route
Shoreline Categorization and Assessment	1. Visual observations with multispectral imaging support	▪ Visual appearance of shoreline or AOI at location Y at time X ▪ Size and appearance of foreign objects, impact assessment and oil substance, and hazards at location Y at time X ▪ Location and condition of personnel, resources, and assets at time X in relation to the area imaged ▪ Mission route

Detailed descriptions of each sensor referenced in Table 4-1 are included throughout the remainder of this section. Sensor types are organized into the following categories:

- Visual observation
- Passive sensors
- Active sensors
- Multi-band integration
- Multi-sensor integration

Descriptions of available platforms identified for each sensor technology are included in Section 4.0.

3.2.1 Visual Observation

What Platforms Are Available?

- Aircraft systems

What Is It?

Aerial visual observation uses the human eye as the primary sensor. Because it is one of the simplest sensing techniques and its platforms can be rapidly deployed, visual observation often serves as the backbone of a surveillance program during a response. Trained observers can provide interpretation of visual oil signatures as well as spatial patterns related to appearance and relative thickness. Aerial visual observation can be used in both a preventive (prior to an environmental event) and a reactive (during a response) mode, and is typically one of the first types of surveillance data received.

How Does It Work?

A trained observer is deployed on an aircraft to make visual observation from a window or specialized viewing port. Observers often are deployed with a go-kit that includes technical guides, communication equipment (radio, cell phone, or satellite phone), global positioning system (GPS), and a digital camera or video recorder capable of recording geo-reference data (e.g., latitude/longitude, compass direction, and altitude). The trained observer interprets observations and records them manually and/or electronically.

When Is It Effective?

- Daylight hours
- Relatively calm weather environments

When Is It Not Effective?

- Nighttime (typically not deployed at night for safety reasons and a lack of visibility)
- During rough weather
 - Due to safety restrictions on launching aircraft or other manned platforms
 - Because accurate observations are difficult when the water surface is highly disturbed
- An untrained aerial observer may report false positives (i.e., mistaking other features for oil)

What Are the Pros?

- Trained observers can verbally communicate observations to tactical resources in the field or back to a centralized command center in real time.
- Trained observers are one of the simplest of sensors; they are very effective at the mission.
- Trained observers often can be deployed rapidly, before other electronic sensors are available.
- Visual observation allows for interpretation at the same time as observation.

What Are the Cons?

- Untrained observers can be prone to false positives (e.g., algae blooms, seaweed, wind shadows, and biogenic oils).
- Safety concerns are related to operation of manned aircraft.
- Relative thickness estimates are qualitative and subjective.
- Observer fatigue is a factor.

3.2.2 Passive Sensors

The following passive sensors are discussed in this section:

- Visible (VIS), NIR, and SWIR sensors
- TIR sensors

Visible, Near Infrared, and Short-Wave Infrared Sensors

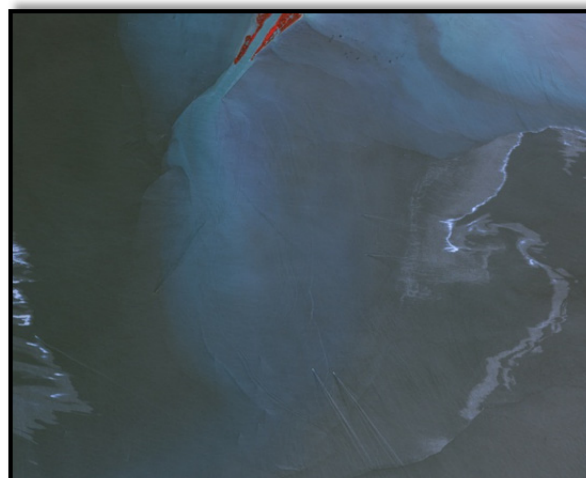
What Platforms Are Available?

- Aircraft systems
- Satellite systems

What Are They?

Passive optical sensors measure reflected radiation in the VIS range; NIR and SWIR sensors detect reflected energy from objects at the given wavelengths.

- VIS sensors detect reflected light in multiple bands in the EM spectrum that are visible to the human eye (0.4–0.74 μm).
- NIR sensors (0.74–1.4 μm) detect reflected light in a range not visible to the human eye.
- SWIR sensors (1.4–3.0 μm) detect reflected light in a range not visible to the human eye.



NASA Earth Observatory image created by Jesse Allen and Robert Simmon, using data provided courtesy of NASA/GSFC/METI/ERSDAC/JAROS, and U.S./Japan ASTER Science Team.

How Do They Work?

In the VIS spectral range, imagery is normally displayed in “true color.” Images displayed in true color capture the nearest approximation of what a human observer might view directly; therefore, detecting oil in VIS imagery is similar to how a spotter would detect oil from the air. In this case, oil would be detected on the water’s surface (as it would be by a spotter), by color. Under some circumstances, the visual color of the oil on the water can be used to estimate the relative thickness of the oil.

The strength of the oil signal in the NIR and SWIR band is a function of several factors (e.g., the amount of oil, the surface area of oil in relation to the spatial resolution of the sensor, the light availability for reflection, and the solar and sensor angle). Recent technology advances are making these types of sensors readily available for use in oil spill surveillance.

When Are They Effective?

- Daylight hours (VIS, NIR)
- Daylight hours to dusk (SWIR)
- Sea states between calm and rough (calm = flat seas and no wind; rough = seas ~2 meters [m] and winds ~35 kilometers per hour [kph] [approximately 19 knots])
- Clear skies with limited cloud cover (VIS, SWIR)
- Hazy or foggy conditions (SWIR)

When Are They Not Effective?

- Nighttime
- Very rough seas
- Significant cloud or fog conditions

What Are the Pros?

- The technology has been used successfully during oil spills for decades.
- A variety of commercial and government sensors are available for use on both aerial and satellite platforms.

What Are the Cons?

- Optical sensors can be used only in daytime and are limited by cloud cover.
- False positives (oil look-alikes) can be common from seaweed, wind and cloud shadow, and sun glint.
- There can be long delays between satellite or aircraft tasking and final delivery of an interpreted product.

Additional Notes

- Although most sensors currently have difficulty detecting relative oil thickness, ongoing research is being conducted to determine whether it may be possible through greater analyses on spectral data and the potential for fusing different sensor images.
- Sensors typically are flown on satellites with variable spatial, spectral, and temporal resolutions, which likely require a combination of different sensors for the most effective result.
- Several off-the-shelf aerial sensors for aircraft are available for rapid deployment.
- Several long-term series and high spatial resolution satellites are equipped with optical sensors.

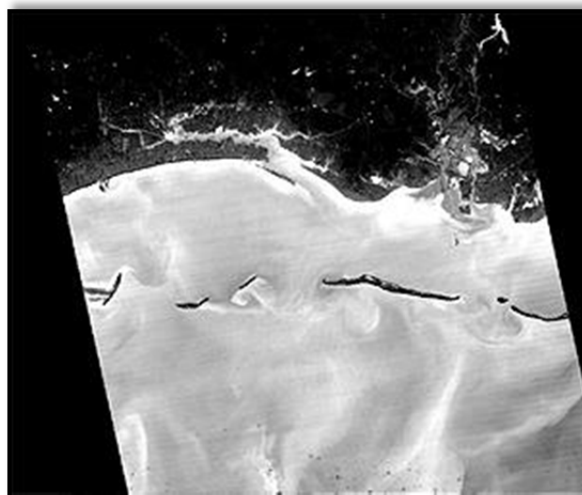
Thermal Infrared Sensors

What Platforms Are Available?

- Aircraft
- Satellite
- Handheld

What Are They?

TIR sensors are passive sensors that detect thermal radiated energy (radiance) between 3.0 and 14.0 μm . Radiated energy between 3.0 and 8.0 μm is defined as MWIR, and between 8.0 and 15.0 μm as LWIR. Currently, most TIR remote sensing of oil spills takes place at wavelengths of 7.0–14.0 μm .



Night Infrared View of Gulf Oil Spill NASA/GSFC/METI/ERSDAC/JAROS, and U.S./Japan ASTER Science Team.

How Do They Work?

Two significant properties can be used to discriminate oil from water in the TIR wavelengths: emissivity and temperature. *Emissivity* is the ratio of emittance from an object to the emittance by a black body (an object that absorbs and emits all radiation) at the same temperature. Emissivity describes the actual absorption and emission properties of an object. Since oil has a slightly lower TIR emissivity than sea water, it emits less radiation at the same temperature. Therefore, when converting data from radiance (the value measured by a sensor) to temperature, the oil will appear cooler. This technique is used to distinguish oil in night imagery.

The difference in oil's emissivity, heat capacity, and thermal conductivity compared to the surrounding water also allows for remote detection using TIR sensors/imagery. Oil often retains more heat than sea water when exposed to an IR source like the sun. Therefore, oil will have a higher temperature than the surrounding sea water. This technique can be used only during the day or early evening when oil has been exposed to solar heat.

The ability to distinguish oil in TIR images depends on many variables, including relative oil thickness and time of day. In addition, a number of natural phenomena in the open ocean can appear to be oil slicks in TIR imagery, such as sea grass and oceanic fronts. TIR imagery and other spectral bands are often acquired concurrently and then electronically fused to more accurately delineate the extent and relative thickness of an oil slick. This complexity illustrates the need for expert interpretation.

When Are They Effective?

- Day and night with clear skies

When Are They Not Effective?

- Rough weather
- Degraded performance for oil-water emulsions (because there is little temperature difference between oil that is heavily diluted in water and the surrounding water)

What Are the Pros?

- TIR sensors can detect oil on water during day or night due to temperature variations between the two bodies.
- The technology is mature. A wide range of commercially available sensors are used by responders.
- Relative thickness information can be used to direct skimmers and other countermeasure equipment to thicker portions of a slick.

What Are the Cons?

- TIR sensors cannot detect thin oil sheens.
- TIR sensors require good visibility, with no fog or haze; cloudy conditions can limit the effectiveness of MWIR and LWIR.
- The imagery typically needs to be interpreted by a trained remote sensing specialist prior to distribution of the data, potentially adding significant delay from collection to useful dissemination of the data.
- Natural phenomena, such as biogenic oils (kelp beds), boat wakes, and river outflows, may appear to be oil slicks and result in false positives.

Additional Notes

- Expert interpretation is needed to differentiate between naturally occurring thermal differentiations in water.

3.2.3 Active Sensors

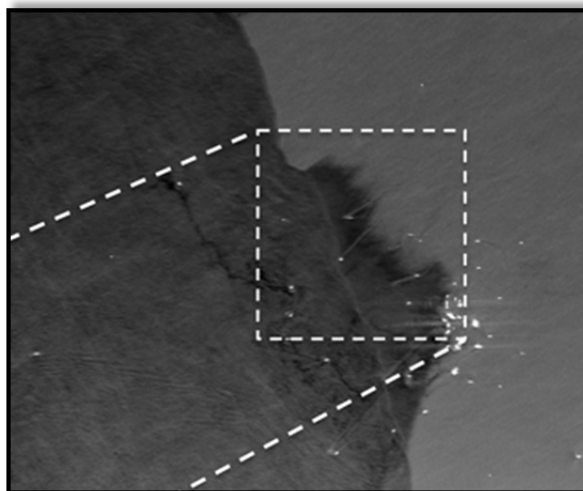
The active sensors discussed in this section include

- SAR
- SLAR
- X-band (marine navigation) radar
- Laser-induced fluorosensors

Synthetic Aperture Radar

What Platforms Are Available?

- Aircraft systems
- Satellite systems
- Ship-based systems



NASA UAVSAR image of the Deepwater Horizon Oil Spill.
Courtesy NASA/JPL-Caltech.

What Is It?

SAR is an active sensor that provides its own microwave energy source and records how much of an emitted signal is returned to the sensor. The presence of oil is detected by textural discrimination, as natural sea roughness is greater than surface areas with oil. Current systems operate in frequencies that provide capabilities for both terrestrial and marine event response.

How Does It Work?

When an SAR system sends radar signals toward the sea surface, the energy is reflected back to or away from its receiving antenna—or a combination of the two (scattered). How the energy interacts with the sea surface is governed mostly by its roughness. Wind-generated capillary waves are dampened by oil's higher surface tension; therefore, the sea surface is smoother when oil is present. Smoother surfaces reflect the impinging radar signal away from the radar's receiving antenna. In the resulting imagery, this appears as a "dark" patch of low spectral reflectance (low backscatter). Where the sea surface is rougher (no oil is present), wave facets generally reflect a greater portion of the energy back to the receiving antenna. In resulting imagery, these appear as "bright" patches of high spectral reflectance (high backscatter). Experts can then interpret the location of oil on the sea surface based on the bright and dark patches in the imagery. In either very calm or more extreme (higher energy) wave conditions, this capillary wave-dampening effect is reduced or eliminated.

When Is It Effective?

- Most mild sea states (between 0.2 and 1 m)
- Daylight hours and nighttime
- Cloud, rain, or fog conditions

When Is It Not Effective?

- Very calm seas, with wind speeds less than 5.5 kph (approximately 3 knots)
- Very rough seas, with wind speeds greater than 22.5 kph (approximately 12 knots)

What Are the Pros?

- SAR works day or night, under clear or inclement weather conditions.
- Little data processing time is required.
- The technology has been successfully used during oil spills for decades.
- SAR is readily available as both airborne and satellite systems, from both private and government sources.
- SAR imagery provides spatial resolution superior to SLAR imagery by simulating a longer antenna length through signal processing.

What Are the Cons?

- The interpretation to discern oil is complex and requires a skilled expert.

- The imagery is prone to false positives due to other sea-dampening phenomena (e.g., seaweed, wind shadows, and rain).
- SAR does not discriminate between thin or thick oil.
- SAR is difficult to use in areas cluttered with wind shadows (e.g., an area with a high concentration of small islands).

Additional Notes

- When tasking aircraft, keep in mind that the image swath is to the side of (or both sides of) the flight path and not directly beneath the aircraft.
- Resolutions for satellite systems range from 1 to 100 m, with swath widths ranging from 5 to 500 kilometers (km)
- Aerial platform SAR resolutions vary with aircraft altitude but are generally as fine as, or finer than, the highest satellite resolutions.
- Polar orbiting satellites produce more frequent repeat coverage at higher latitudes than at the equator.
- Optimal polarization is VV (vertical transmit, vertical receive), although some studies indicate that the difference between HH (horizontal transmit, horizontal receive) and VV can help discriminate oil slicks from biogenic oil slicks.
- The most commonly found frequency bands for imaging radar include the following:
 - X-band, 8–12 Gigahertz (GHz) (2.5–3.75 centimeters [cm])
 - C-band, 4–8 GHz (3.75–7.5 cm)
 - L-band, 1–2 GHz (15–30 cm)
 - P-band, 0.2998– 0.999 GHz (30–100 cm)
- C-band radar is generally regarded as the best frequency for oil slick detection.

Side-Looking Airborne Radar

What Platforms Are Available?

- Aircraft systems

What Is It?

Side-looking airborne radar (SLAR) is an active sensor that provides its own energy source, similar to SAR systems. Therefore, it does not require sunlight and is not affected by cloud cover. It differs from SAR in that its spatial resolution is restricted in part by the length of the physical antenna mounted on the platform (i.e., the side of the aircraft). SLAR imagery is used to detect the presence of oil on the water's surface by texturally discriminating between natural sea surface roughness and local areas dampened by surface oil slicks.

How Does It Work?

When an SLAR system sends radar signals toward the sea surface, the energy is reflected back to or away from its receiving antenna—or a combination of the two (scattered). How the energy interacts with the sea surface is governed mostly by its roughness. Wind-generated capillary waves are dampened by oil's higher surface tension; therefore, the sea surface is smoother when oil is present. Smoother surfaces reflect the impinging radar signal away from the radar's receiving antenna. In the resulting imagery, this appears as a dark patch of low spectral reflectance (low backscatter). Where the sea surface is rougher (no oil is present), wave facets generally reflect a greater portion of the energy back to the receiving antenna. In resulting imagery, these appear as bright patches of high spectral reflectance (high backscatter). Experts can then interpret the location of oil on the sea surface based on the bright and dark patches in the imagery. In either very calm or more extreme (higher energy) wave conditions, this capillary wave-dampening effect is reduced or eliminated.

When Is It Effective?

- Sea states between 0.2 and 1 m
- Daylight hours and nighttime
- Cloud, rain, or fog conditions

When Is It Not Effective?

- Very calm seas, with wind speeds less than 5.5 kph (approximately 3 knots)
- Very rough seas, with wind speeds greater than 22.5 kph (approximately 12 knots)

What Are the Pros?

- Little data processing time is required.
- SLAR performs day or night, under clear or cloudy conditions.
- The technology has been successfully used during oil spills for decades.
- SLAR is readily available.

What Are the Cons?

- The range resolution is altitude dependent. At higher altitudes, the sensor sees a larger area but at a lower resolution.
- Interpretation of true oil is complex.
- SLAR does not discriminate between thin or thick oil.
- The imagery is prone to false positives due to other sea-dampening phenomena (e.g., seaweed and wind shadow).
- The technology is difficult to use in areas cluttered with wind shadows (e.g., an area with a high concentration of small islands).

Additional Notes

- SLAR is found only on aircraft, not on satellites.
- When tasking aircraft, keep in mind that the image swath is to the side of (or both sides of) the flight path and not directly beneath the aircraft.
- VV polarization is the optimal configuration.

X-Band (Marine Navigation) Radar

What Platforms Are Available?

- Marine surface vessels

What Is It?

Although X-band radar is used on marine surface vessels primarily for navigation purposes, the systems can be reconfigured to maximize sea clutter in order to observe the reduction of return signals associated with calmer areas. Like all radar systems, they are active sensors that provide their own energy source. Therefore, no sunlight is required to operate, and X-band radar is not affected by cloud cover.

X-band radars are available from numerous marine platforms, but the vast majority of these systems are not designed to highlight the wave-dampening effect of oil. Some commercially available marine navigation radars have been modified through changes in processing and/or hardware to better serve this purpose.

How Does It Work?

When X-band radar sends radar signals toward the sea surface, the energy is reflected back to or away from its receiving antenna—or a combination of the two (scattered). How the energy interacts with the sea surface is governed mostly by its roughness. Wind-generated capillary waves are dampened by oil's higher surface tension; therefore, the sea surface is smoother when oil is present. Smoother surfaces reflect the impinging radar signal away from the radar's receiving antenna. In the resulting imagery, this appears as a dark patch of low spectral reflectance (low backscatter). Where the sea surface is rougher (no oil is present), wave facets generally reflect a greater portion of the energy back to the receiving antenna. In resulting imagery, these appear as bright patches of high spectral reflectance (high backscatter). Experts can then interpret the location of oil on the sea surface based on the bright and dark patches in the imagery. In either very calm or more extreme (higher energy) wave conditions, this capillary wave-dampening effect is reduced or eliminated.

When Is It Effective?

- Sea states between 0.2 and 1 m
- Daylight hours and nighttime
- Cloud, rain, or fog conditions

When Is It Not Effective?

- Very calm seas, with wind speeds less than 5.5 kph (approximately 3 knots)
- Very rough seas, with wind speeds greater than 22.5 kph (approximately 12 knots)