Remote Sensing in Support of Oil Spill Response

Planning Guidance

API TECHNICAL REPORT 1144
SEPTEMBER 2013

AMERICAN PETROLEUM INSTITUTE

Special Notes

API publications necessarily address problems of a general nature. With respect to particular circumstances, local, state, and federal laws and regulations should be reviewed.

Neither API nor any of API's employees, subcontractors, consultants, committees, or other assignees make any warranty or representation, either express or implied, with respect to the accuracy, completeness, or usefulness of the information contained herein, or assume any liability or responsibility for any use, or the results of such use, of any information or process disclosed in this publication. Neither API nor any of API's employees, subcontractors, consultants, or other assignees represent that use of this publication would not infringe upon privately owned rights.

API publications may be used by anyone desiring to do so. Every effort has been made by the Institute to assure the accuracy and reliability of the data contained in them; however, the Institute makes no representation, warranty, or guarantee in connection with this publication and hereby expressly disclaims any liability or responsibility for loss or damage resulting from its use or for the violation of any authorities having jurisdiction with which this publication may conflict.

API publications are published to facilitate the broad availability of proven, sound engineering and operating practices. These publications are not intended to obviate the need for applying sound engineering judgment regarding when and where these publications should be utilized. The formulation and publication of API publications is not intended in any way to inhibit anyone from using any other practices.

Any manufacturer marking equipment or materials in conformance with the marking requirements of an API standard is solely responsible for complying with all the applicable requirements of that standard. API does not represent, warrant, or guarantee that such products do in fact conform to the applicable API standard.

Foreword

Nothing contained in any API publication is to be construed as granting any right, by implication or otherwise, for the manufacture, sale, or use of any method, apparatus, or product covered by letters patent. Neither should anything contained in the publication be construed as insuring anyone against liability for infringement of letters patent.

Suggested revisions are invited and should be submitted to the Director of Marine and Security, API, 1220 L Street, NW, Washington, DC 20005.

Contents

Tables

Attachments

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 of 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

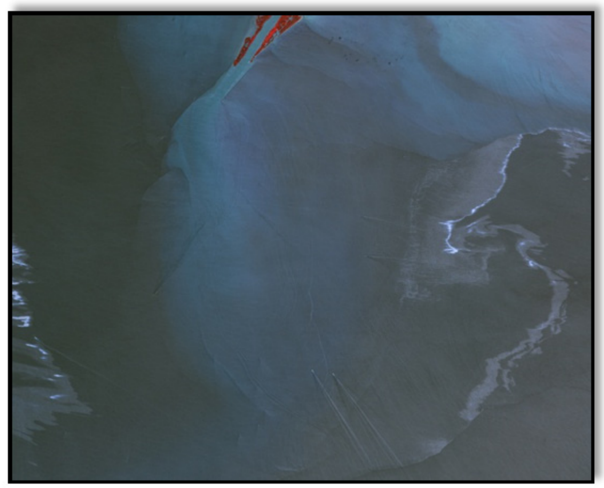
What Platforms Are Available?

- 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.

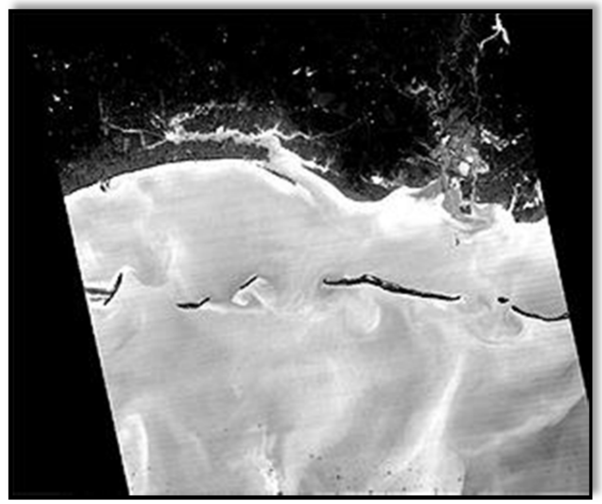
Thermal Infrared Sensors

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

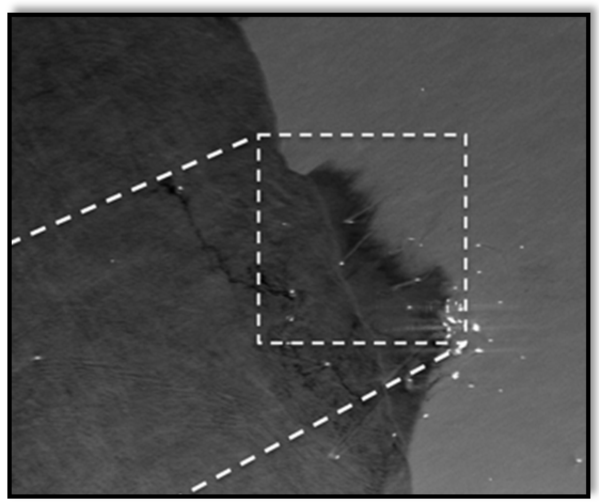
The active sensors discussed in this section include

- 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)

What Are the Pros?

- X-band radar provides real-time processing on the scene.
- The technology works day or night, under clear or cloudy conditions.

What Are the Cons?

- Most navigation radars are not configured for oil slick detection.
- The low altitude of the sensor limits the observable range of the field of view.
- X-band radar does not discriminate between thin or thick oil.
- The imagery is prone to false positives due to other sea-dampening phenomena (e.g., seaweed, wind shadows, and biogenic oils).
- The interpretation to discern the presence of oil is complex and requires a skilled expert.
- X-band radar cannot provide an estimate of slick thickness.

Additional Notes

- VV polarization is optimal.
  - HH polarization, the most commonly found and the most useful for marine navigation, is the poorest choice for oil detection.
  - The HH configuration is designed to minimize sea clutter, which is the feature of the image necessary to observe wave dampening (and the presence of oil).
- Most marine radars are not configured to observe the wave-dampening effect of floating oil.
- Care must be taken to locate those few commercially available marine radar systems that have been properly configured for oil slick detection.

Laser-Induced Fluorosensors

What Platforms Are Available?

- Aircraft systems

What Are They?

Laser-induced fluorosensors (LIF) are active sensors that provide their own energy source. Their performance does not require sunlight and is not affected by cloud cover. The energy from the system is absorbed by constituents in the oil that become electrically stimulated and produce a fluorescence. The sensors then detect the spectral signature specific to the oil being observed. Laser fluorosensors are the only remote sensors systems that provide the ability to discriminate between different types of oil and other materials that fluoresce.

How Do They Work?

Laser fluorosensors used in oil detection utilize a laser in the UV range. The laser illuminates the water surface, and a telescope is directed at the same field of view. When oil is present at the surface, the laser light is absorbed by constituents in the oil. These constituents then re-emit a portion of that light energy as fluorescent light. This returning light signal is transmitted to a sensor by way of the telescope, and the wavelength of the returning light is measured. Different materials (e.g., water, organic materials, oil, and chemicals) emit fluorescent light at different wavelengths, providing the ability to identify and discriminate among them. This analysis can be performed and recorded in real time.

When Are They Effective?

- Daylight hours and nighttime

When Are They Not Effective?

- Fog and weather conditions limit the transmission of laser and returning fluorescent light.
    - The extent of limitation by weather is determined by the power of the laser system.
- Altitude affects performance, and present systems may not be effective above 500 m.
- Because water surface roughness may backscatter returning light, surface dynamics can affect the imagery quality.

What Are the Pros?

- Laser fluorosensors enable real-time analysis.
- The technology discriminates oil from non-oil false positives.
- Laser fluorosensors may be able to provide slick measurements in both daylight and darkness.

What Are the Cons?

- The current technology is a large system and typically requires a dedicated aircraft.
- Aircraft mission altitude is determined by the power of the laser.
- Oil weathering produces additional complexities in analysis of the data.
- Laser fluorosensors cannot provide large aerial coverage due to their narrow beam width.

3.2.4 Multi-Band Integration

The discussion of multi-band integration includes:

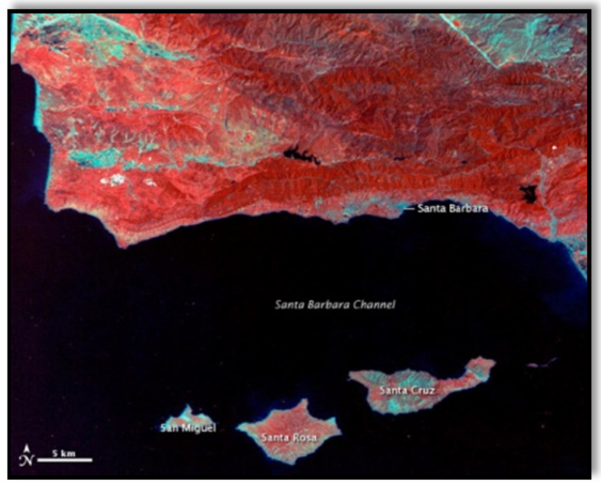
- Multispectral sensors
- Hyperspectral sensors

Multispectral Sensors

What Platforms Are Available?

- Aircraft systems
- Satellite systems

What Are They?



Landsat 2 MSS image of the Santa Barbara Channel Image created by Laura Rocchio using Landsat data provided by the United States Geological Survey.

Multispectral (MS) refers to passive sensors that measure reflected and/or emitted radiation in the UV, VIS, and IR wavelengths in a relatively small number of discrete spectral bands (4–50 spectral bands). While human vision is limited to visible light, multispectral sensors, or imagers, can collect data over a wider range of the EM spectrum and record the energy of a discrete number of spectral bands. MS sensors usually cover the VIS portion of the EM spectrum, in addition to the NIR and SWIR. Frequently, an MS platform will have a variety of different sensors onboard and therefore can collect data across the EM spectrum from the VIS to the TIR range.

How Do They Work?

All materials leave unique fingerprints across the EM spectrum, known as *spectral signatures*. A material's spectral signature is determined by how much energy is absorbed or reflected at a certain wavelength. Multispectral sensors are able to "view" objects within a wide range of the EM spectrum at discrete bandwidths. Consequently, the spectral signatures of an object can be used to identify the materials in the image. Because hydrocarbons have a distinct spectral signature, multispectral imaging can be utilized in determining the extent of oil, affected shorelines, and actionable areas of surface oiling with less occurrence of false detections.

What Are the Pros?

- Collection of data across multiple spectral ranges may reduce false positives.
- The potential exists for combining, or fusing, bands together into one image that can quantitatively measure oil thickness or provide other specialty data sets.

What Are the Cons?

- The more complex sensor systems may have longer turn-around times for producing usable data and images.
- Operators typically need greater technical specialization and training to operate the equipment.

Additional Notes

- MS 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 long-term series and high spatial resolution satellites are equipped with MS sensors.
- Several off-the-shelf aerial sensors are available for rapid deployment.

Hyperspectral Sensors

What Platforms Are Available?

- Aircraft systems
- Satellite systems

What Are They?

Hyperspectral sensors are passive sensors that collect data across the EM spectrum. While human vision is limited to visible light, hyperspectral imagers can collect data over a wider range of the EM spectrum and divide the energy into many more bands (>100 spectral bands). Although most hyperspectral sensors operate between the VIS and SWIR wavelengths, several sensors also collect data in the TIR range. Hyperspectral imaging differs from multispectral imaging in that it divides the image spectrum into much narrower spectral wave bands.

How Do They Work?

All materials leave unique fingerprints across the EM spectrum, known as *spectral signatures*. A material's spectral signature is determined by how much energy is absorbed or reflected at a certain wavelength. Hyperspectral sensors are able to "view" objects within a vast portion of the EM spectrum and at very small bandwidths. Consequently, the spectral signatures of an object can be used to identify the materials in the image. Because hydrocarbons have a distinct spectral signature, hyperspectral imaging can be utilized in determining the extent of oil, affected shorelines, and actionable areas of surface oiling with less occurrence of false detections.

What Are the Pros?

- Collection of data across multiple spectral ranges may reduce false positives.
- The potential exists for combining, or fusing, multiple bands together into one image that can quantitatively measure oil thickness or provide other specialty data sets.

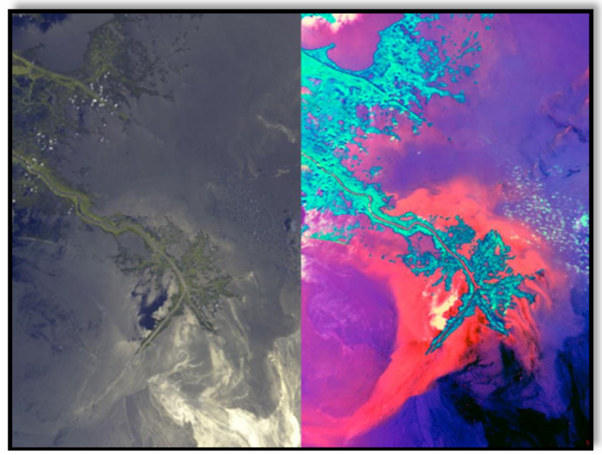
What Are the Cons?

- The more complex sensor systems may require longer turn-around times for producing usable data and images. Because hyperspectral sensors generate such a large volume of data, their ability to provide near real-time data and images is severely limited.
- Hyperspectral sensor operators typically need greater technical specialization and training to operate the equipment.

Additional Notes

- An extensive volume of data is generated, and post-processing data can be time consuming. Final image products cannot be provided in near real time based on the large size of files and status of the current technology.

3.2.5 Multi-Sensor Integration



Multiple cameras on JPL's MISR instrument on NASA's Terra spacecraft. NASA/GSFC/LaRC/JPL MISR Team.

What Platforms Are Available?

- See descriptions for the individual sensors.

What Are They?

Integrated multi-sensor platforms are combined sensor packages. Commercially operating paired systems include the following:

- UV and TIR
- X-band radar and IR camera
- SAR, SLAR, IR, UV, microwave radiometer, LIF, and VIS
- Digital MS, TIR, and VIS
- MS and IR

The combinations of sensors depend on the capabilities of the organization and the typical day-to-day utilization of the sensor packages.

What Are the Pros?

- Use of multiple sensors may reduce false positives.
- See descriptions for the individual sensors.

What Are the Cons?

- Results must be integrated in a timely manner to be useful.
- See descriptions for the individual sensors.
- Some paired sensors may not possess the same exact field of view, which adds to the complexity of integrating their outputs.

Additional Notes

Most currently utilized platforms fall under this category.

4.0 Deploy the Technology

One reason that remote sensing is such a useful tool for oil spill response is that its technology can be deployed on a variety of platforms. Depending on the size, timing, and location of an incident, different types of data can be gathered from different platforms. This section covers the following major types of platforms currently utilized for remote sensing:

- Satellite systems

- Aircraft systems
- Unmanned aerial vehicles
- Tethered balloon systems
- Surface vessels

4.1 Satellite Systems

What Are They?

As the name implies, satellite systems are spaceborne platforms that host a variety of sensors. Many civilian satellites have been acquiring and archiving imagery for nearly 40 years. Imagery from systems such as LANDSAT, SPOT, IKONOS, RadarSAT, and others are available—along with newer systems such as Pleiades, RapidEye, WorldView2, and GeoEye.

How Do They Work?

A satellite's field of view is determined by its nadir angle and altitude. In some cases, multiple passive or active tasking opportunities are obtainable each day from individual commercial satellite vendors. By leveraging all of these imaging opportunities in an organized manner, it is possible to achieve multi-temporal coverage approaching that of persistent surveillance. Data gathered by the satellite platform are transmitted to teams on the ground, who then process and interpret the data to produce actionable intelligence. The newer satellite systems have spatial resolutions as low as 50 cm, and systems like these can revisit a specific target daily. Multiple SAR systems are currently in orbit. A single MS image from a commercial satellite could cover 300 square km, with better than 0.5 m resolution. When imaging off nadir, the same MS imaging satellite can acquire 10,000 square km, with resolution that is still adequate for most response needs. A significant constellation of commercial MS imaging satellites is available, assuring multiple passes per day, weather permitting. In support of a declared emergency, satellite imagery may be tasked with as little notice as 90 minutes.

What Are the Pros?

- Satellite systems can potentially cover a large area in a short period of time.
- Data may potentially be transmitted via the internet almost immediately.
- Many radar satellites are useful in detecting large offshore spills and spotting anomalies.
- Some operational commercial satellites can be tasked to respond to emergencies within a range of 90 minutes to 4 hours.

What Are the Cons?

- The timing and frequency of overpasses by satellite systems may not be optimal for the situation.
- Clear skies are needed to perform optical work.
- The probability of detecting oil may be low.

- Developing algorithms to highlight oil slicks is difficult.
- Extensive time may be required to convert data into actionable information. In some situations, data can be collected in hours; when bounded by different situational factors, however, actionable information may take days.

Additional Notes

- In past spill response events, when the position of the oil was already known, processing the satellite data to actually "see" the oil frequently took several weeks.
- The ability to detect oil may be a complex function of conditions, oil types, and view angles.
- To be successful, these techniques generally rely on ancillary data, such as suspected position or other satellite data.

4.2 Aircraft Systems

What Are They?

Various models of planes can be tasked to deploy observers and specialized observation equipment. Aircraft have a much better chance of finding and tracking oil, compared to some other systems, due to their ability to change direction, altitude, and course when needed.

How Do They Work?

Remote sensing equipment is loaded into locally available or pre-identified aircraft. For open ocean spills, there is less need for rapid changes in flying speed, direction, and altitude. In these instances, low-altitude, fixed-wing aircraft have been shown to be the most effective platform. In near-shore waters, the flexibility of helicopters is beneficial when considering the intricacies of coastlines (e.g., cliffs, barrier islands, extensive bays, and estuaries).

What Are the Pros?

- Large areas can be surveyed in a relatively short time frame.
- Aircraft are usually available on short notice and can be more cost effective.
- Most types of remote sensors can be deployed on aircraft.
- Multiple sensor types may be deployed from a single aircraft.
- Aircraft usually have multiple navigation aids that can assist in pinpointing locations.

What Are the Cons?

- Weather and daylight/darkness must be suitable for the type of aircraft and sensors being utilized.
    - Safety margins for operation need to be determined and adhered to.
    - Regional flight rules may dictate operating conditions for aircraft (e.g., visual flight rules).

- It is almost necessary to have remote sensing equipment in a “universal” package that can be deployed on any type of aircraft.
    - Specifications of a remote sensing package are needed prior to locating the appropriate aircraft, and the air speed operational parameters (if any) of the remote sensing equipment.
    - Some equipment may require that an operator, or operators, be present on the aircraft.
- Some remote sensing equipment is too bulky and can be used only from the dedicated aircraft on which it is installed.
- The remote sensing operation must be coordinated with other aircraft activities (e.g., overflight, dispersant, and observer).
- The remote sensing package must have the necessary method of data capture and communications that can relay information to the command center from the aircraft.
    - Some remote sensing packages have self-contained data capture that must be downloaded after the flight, which can delay interpretation and use of the data.

Additional Notes

- Safety considerations are paramount, and the aircraft pilot should be consulted on all aspects of the intended remote sensing operation—prior to engagement and before departure.
- Those taking part in a flight should be thoroughly briefed beforehand on the safety features of the aircraft and procedures to be followed in the event of an emergency.
- Suitable protective equipment, such as life jackets and ear protection, must be used.

4.3 Unmanned Systems

The discussion of unmanned systems includes:

- Unmanned aerial vehicles
- Tethered balloon systems

Unmanned Aerial Vehicles

What Are They?

Unmanned aerial vehicles (UAVs) are a relatively new option for deploying remote sensors. UAVs come in two types: fixed wing and rotary wing. They have been used extensively in the military/intelligence community for several years. The technology has been restricted from civilian use by the Federal Aviation Administration (FAA) due to safety concerns, but the FAA is developing a commercialization strategy to address this.

How Do They Work?

UAVs come in all shapes and sizes—from long-range, high-endurance models to small, human-portable UAVs with ranges of a few miles. A large UAV offers outstanding performance and capability (carrying

VIS, IR, and SAR sensors), but at a high cost ($20–$30 million per unit). A family of smaller, lighter UAVs offers a more balanced approach between capabilities and costs for oil spill response. These UAVs are propelled by gasoline-powered engines, are capable of programmed or manually controlled flight, and require minimal space for launch and recovery. UAV systems generally include a ground station used to program missions; make in-flight adjustments; and receive, process, display, and potentially disseminate real-time imagery and imagery products. The smaller UAVs can be packaged with their ground station to fit into a mid-sized sport utility vehicle, and they typically involve relatively simple assembly and user-friendly operation. Operational sensor packages that are small enough to meet payload restrictions for small UAVs include panchromatic (VIS) and IR imagers.

What Are the Pros?

- UAVs can fly lower than aircraft and generate imagery of high spatial resolution.
- UAVs can fly below low clouds, removing that obstruction from the field of view.
- The cost of some UAVs is significantly lower than the cost of some other platforms.
- Launch and recovery requirements help UAVs reach some places inaccessible to other aircraft.
- UAVs can be deployed rapidly.
- UAVs are less noisy, smaller, and less intrusive than manned aircraft.

What Are the Cons?

- Payload capacity limits the sensors currently available for operations.
- In the United States, current FAA regulations heavily restrict the use of commercial UAVs.
- Some UAVs are limited by government regulations to “line-of-sight” operations.
- Slow speeds and short-duration flights may limit the amount of data collected.

Additional Notes

- The ability of UAVs to capture, process, and integrate imagery from multiple sensors increases the utility and timeliness of obtaining useable event intelligence.
- On some systems, quantified information can be directly downloaded, processed, analyzed, and web-served to the command and control or response assets.

Tethered Balloon Systems (Aerostats)

What Are They?

Tethered balloon systems are lighter-than-air, balloon-like systems that can be deployed from ships or other marine- or land-based attachment points. The large size and weight-carrying capacity of some systems allow them to support a broad range of sensors that will greatly extend the operational observation capabilities of response assets. Co-registered visible, thermal, and other spectral sensors can greatly enhance the ability to provide quantifiable information to event responders by viewing an area several miles around the platform, depending on the operational height of the balloon.

How Do They Work?

These systems are intended to function in a manner similar to planes with aerial observers. A variety of sensor types may be attached to a helium-filled balloon using a tether and winch system attached to a platform. The sensor can be wirelessly controlled from a computer and deck station on the platform. It transmits a signal wirelessly back to the mother ship and surrounding vessels. The balloons are generally powered by a battery with an expected duration of 24 hours, and there may be an option for using a wire to transmit power and signal to and from the camera. High winds and other intense weather conditions can restrict the effectiveness of these systems.

What Are the Pros?

- Balloons are relatively low cost.
- Balloons can fly below low clouds, removing that obstruction from the field of view.
- A tethered balloon increases the height of observation, compared to boat-based observers.
- Balloons can be deployed from a moderate-size ship.
- Balloons transmit pictures wirelessly.
- Balloons can operate 24 hours per day, with few weather limitations.
- Balloons are not subject to the FAA regulations that limit the use of UAVs.

What Are the Cons?

- Operating the system to its full capability can require extensive training.
- High winds can degrade the system's capabilities.
- Obtaining adequate volumes of helium for larger balloons may be difficult in some areas.

Additional Notes

- Tethered balloons must operate under the FAA regulations found in 14 CFR Part 101. This regulation covers operating limitations, notices, lighting and marking, and other requirements.
- Tethered balloon systems may provide a tool for resource management, allowing task force leaders to observe other vessels within the task force and check for positioning and adherence to tasks.
- The tethered balloon may also be used to develop a communication relay system by carrying repeating equipment.
- The majority of the costs for these platforms are associated with the sensor/camera system.
- If deployed more than 5 miles from an airport and below 500 feet, a permit is not required.

4.4 Surface Vessels

What Are They?

Remote sensing devices used on surface vessels direct response assets to actionable oil on the water. The platforms are comprised of ships, boats, barges, and buoys. Any number of sensors can be deployed that may increase the interface with floating or subsurface oil. Examples include visual observations, radar systems, and thermal sensors. Trained observers on these vessels also can verify the presence of oil and direct resources in removing oil from the surface of the water.

How Do They Work?

Surface vessels are very agile and can be maneuvered to locate oil. Observation instruments are often mounted on the highest point on the vessel to provide the maximum viewing distance. Manned vessels can be maneuvered to find and remain in oil, based on data from the sensing instruments.

What Are the Pros?

- Surface vessels have increased interface with the thickest oil based on remote sensing data and visual means.
- Surface vessels are versatile and can be maneuvered to remain in actionable oil.
- Instrumentation and sensors can easily be changed to meet needs and weather conditions.
- The probability of detecting oil is very high.
- Human presence on manned vessels enables the presence of oil to be validated by visual means.
- Surface vessels can provide a much longer “time on station” (e.g., hours to days) in the area of intent for observations grouped with other platforms.

What Are the Cons?

- Surface vessels are limited to small coverage areas in the immediate vicinity of the vessel.
- Surface vessels have limited usefulness in high seas due to sensor movement at the high point of the vessel.

Additional Notes

- Surface vessels with appropriate sensors can locate and remove oil from the water’s surface, and they can track oil on the surface or subsurface.
- Appropriate use of sensors can place removal equipment into the thickest oil, increasing the interface and achieving the best collection results.
- The ability to detect oil may be a complex function of sea state and conditions, oil types, and sensor view angles.

5.0 Analyze and Communicate the Data

Once the remote sensing technology has been selected and deployed, it will acquire data in the chosen manner and transmit it to the remote sensing team. The remote sensing team is then responsible for processing and interpreting the acquired data, integrating it with other data sources, and producing a usable product that can effectively communicate the information to the appropriate parties. Often the collected data and images are integrated into a Geographic Information System (GIS) for analysis and displayed in the incident command center on a Common Operating Picture (COP) system.

Several steps must occur to ensure that the remote sensing data are communicated accurately. This section discusses the following steps and the responsibilities of the remote sensing team:

- Image acquisition, analysis, and interpretation
- Data integration and exploitation
- Internal and external data communication

5.1 How Are Images Acquired, Analyzed, and Interpreted?

The first step in the data communication process is to acquire and process data set(s) into imagery products, which are then interpreted by SMEs. Details of the acquisition, processing, and interpretation steps include, but are not limited to:

- Determine the appropriate sensors and platforms necessary to most effectively respond to the event.
- Task the appropriate satellite, aircraft, and/or marine vessels, as well as remote sensing service providers to deploy the technology.
- Acquire and download the data.
    - The time for these processes varies significantly, depending on the type of sensor and platforms used, and on the size of the images acquired.
- Process, analyze, and interpret the data.
    - Pre-processing or initial processing is a mandatory step when interpreting remote sensing data. Sensor calibration, atmospheric corrections, georectification, and orthorectification must be completed to prevent inaccuracies in the products.
    - Only after initial image processing should the EM signals be analyzed. The scope of the analysis depends on the data type (band ratios, spectral unmixing, textural, or backscatter analysis).
    - Once data are processed, the imagery and products should be interpreted by an SME. Single images or datasets are useful by themselves, but often the most useful information is obtained when multiple images and data types are fused. During integration of multiple sources of data, it is important to use common data formats in order to allow fusion of different sensors and reproduction of various types of outputs (e.g., maps and mosaics).

- Timely image enhancement and information extraction are key components of the tactical advantage of remote sensing data. Because data are acquired at different rates, it is necessary to distinguish between critical processes and more complex tasks that can be completed when time permits. For example, high temporal resolution sensors like SAR produce images with a lower spatial resolution, but their high acquisition rate allows them to track the trajectory of an event. As this type of data is particularly useful, these images should be analyzed as they are acquired, while a more time-consuming hyperspectral analysis may be conducted when time permits.

- During this stage it is vital that the data interpretation be conducted by a trained and experienced SME. The ability of the SME to clearly understand the data and effectively convey what the EM signal represents is imperative to successful remote sensing data communication.

5.2 What Are Data Integration and Exploitation?

The second step in the data communication process is integration of the data to form all-source intelligence products (remote sensing, GIS, field observation, and other human assets). Timely all-source intelligence is critical to successfully managing an operational event, as extensive delays between recognizing a reconnaissance requirement and delivery of actionable information can lead to delays in tactical operations.

Although actual imagery is sometimes essential for a responder to visualize the environment, it is more important to receive accurate information. Quantifiable, geographically accurate information that is capable of determining where and when to deploy appropriate response assets is crucial for an effective response. Therefore, it is necessary to create and deliver rapid response products (RRPs), in near real time, to the response facility.

GIS is an ideal tool because it ensures that all data are in the same coordinate system. GIS also allows users to add new data as collected (including remote and field-based observations), edit response maps, and turn layers on and off (including imagery, maps, areas of interest, and vectors). Products can be viewed in a detailed output or in a more generic output, such as PDF. The products can be delivered to responders in the field on electronic tablets or cell phones, where responders also can update the working file with field observations. The products can also be directly integrated into aircraft or other platforms.

5.3 How Are the Data Communicated?

The final step in the data communication process is sharing of the remote sensing products to supply information both internally and externally. To ensure that supplied information is accurate, the SME analyzing the data must clearly define what the products represent. For example, if a map is produced from an SAR image and it is not possible to distinguish the thickness of the oil, those facts must be apparent in the RRP. The data used to generate the product, along with the processes and analyses completed, also need to be noted and stored, in addition to any areas of uncertainty.

It is the responsibility of the SME to clearly and precisely transfer the data, product, and information to the appropriate unit leaders within the response team. Those leaders are then responsible for distributing the information to the public and the command center. The SME should be available to answer any questions that arise about the data, the generation of the products, or the products themselves.

6.0 Beyond the 5 Steps

The 5-step process detailed in this guide will aid responders in integrating remote sensing into response operations. It is essential to remember, however, that maintaining readiness directly affects the success of a response plan during an actual spill event.

Spill response readiness must be actively managed to ensure that the capabilities, technology, infrastructure, and logistics are in place and that they are sustained, ready, and continuously improved. Therefore, a remote sensing program should be included in response plans and implemented in readiness exercises and drills in order to be effective during an actual spill event. Oil spill response plans should contain a specific reference to remote sensing, including available resources, processes, and staff to support a response.

As stated above, maintaining readiness includes staying abreast of advances in technology. This guide includes detailed information on existing sensors and platforms, but numerous research and development projects are continually underway—to advance and refine current technology, and to conceptualize and test novel sensors and methods. It is therefore important to periodically review new innovations in remote sensing and to update response planning accordingly. A number of ongoing remote sensing research and development projects are listed in Appendix A. This list includes information on the particular technology being researched and links to the program websites. Appendix A also contains a listing of published, peer-reviewed papers and "Lessons Learned" documents related to remote sensing use during previous oil spill response operations.

Attachment A

Surveillance Technologies for Oil Spill Response: An Assessment of Current Research and Emerging Trend

Surveillance Technologies for Oil Spill Response

Current Research and Emerging Trends

Cardno ENTRIX

Shaping the Future

Table of Contents

Appendices

Figures

Acronyms

API	American Petroleum Institute
Dialog	The Dialog® Service
DWH	Deepwater Horizon
GIS	Geographic Information System
GoMRI	Gulf of Mexico Research Initiative
R&D	Research and Development
RS TWG	Remote Sensing Technical Work Group
SAR	Synthetic Aperture Radar
U.S.	United States

1 Introduction

Releases of oil in the marine environment are difficult to detect, monitor, and track due to the dynamic nature of the open ocean and the likelihood that the release will occur in a remote location. Thus, responding to these events requires mobile, rapidly deployed, and highly specialized equipment. Remote sensing tools that utilize a range of wavelengths on the electromagnetic spectrum are currently used during oil spill response operations to detect, track, and monitor oil releases. Remote sensing data can provide crucial information regarding the location and extent of spilled oil and potentially impacted areas to aid oil spill responders in directing both tactical operations and synoptic assessment during a response.

Historically, oil spill response and surveillance has been conducted with manned aerial surveys via helicopter or fixed wing aircraft, with satellite imagery providing broad-scale data over large areas. Recent advances in aerial surveillance systems and their broadening availability on the commercial market has introduced an array of remote sensing systems that utilize electromagnetic sensors deployed from a variety of platforms to detect, track, and monitor oil. The sensors can be classified as either passive or active, and both rely on differences in the reflectance or emissive spectra of objects to differentiate oil and other objects from surrounding waters. While these differences can be measured during both daytime and nighttime operations, the natural weathering processes of oil (evaporation, emulsification, and dispersion) influence its detectability by remote sensing systems (Brekke 2005).

Though potential technological capabilities exist, their use in spill response and surveillance is still in its nascent stages due to the unique requirements and complexities of oil spill response. Inclement weather and elevated wave activity during data collection can inhibit imagery, and a majority of systems are subject to false positive identification of oil on the ocean surface. Additionally, while software is improving, post-processing of some remote sensing data can be a lengthy effort. Finally, field testing and optimization of laboratory developed systems is challenging due to the unpredictable nature of spill events, the availability of “real world” settings to test and evaluate systems, and the regulations restricting controlled releases; thereby limiting opportunities to fully integrate and test equipment.

On-going research is aimed at enhancing the capabilities and practical applications of existing tools, developing new solutions to complex spill scenarios, and testing the efficacy of both new and existing technologies. Recent oil spills around the globe have also lead to the publication of “Lessons Learned” documents that include an analysis of the results of remote sensing use during oil spill response, as well as the publication of a significant number of peer-reviewed scientific papers discussing remote sensing research theories, results, and applications of existing and developing technologies.

In the summer of 2012, the American Petroleum Institute’s (API) Remote Sensing Technical Work Group (RS TWG) contracted Cardno ENTRIX to research and compile available information on published, peer-reviewed papers relating to remote sensing technology; “Lessons Learned” documentation from oil spills where remote sensing was used during response operations; and current and on-going remote sensing research and development (R&D) programs. From this investigation the RS TWG sought to acquire an overview of the global remote sensing “state of knowledge”, remote sensing technology needs identified during recent spill events, and emerging trends in remote sensing R&D. A global search was conducted using online resources including Google Scholar and The Dialog® Service (Dialog), a database of scientific, technical, and business publications. Per the RS TWG’s request, only Lessons Learned and peer-reviewed papers published in the past 12 years were considered. Results of the research were compiled into three spreadsheets that are provided in Appendices A, B, and C. This report is an effort to summarize results of this research effort.

2 Peer-Reviewed Remote Sensing Papers

Cardno ENTRIX staff performed a global search for peer-reviewed papers relating to remote sensing theory, research, and/or testing. The search was conducted using Google Scholar and Dialog. A total of 75 papers were located and their information added to the "Remote Sensing Peer-Reviewed Papers" spreadsheet provided in Appendix A. Only papers published between the years 2000 and 2012 were considered for inclusion. A far greater number of papers were discovered during this search than were recorded, as the researchers were instructed to limit the number of entries to a cross-section of the available documents. A summary of the results compiled in the spreadsheet are discussed in this section.

Upon review of the spreadsheet entries, it can clearly be seen that sensors mounted from satellite platforms are the most frequent subject of the papers (Figure 2-1). Synthetic aperture radar (SAR) sensors are particularly frequent across all platforms (Figures 2-2, 2-3, and 2-4), appearing in 60 of the 75 entries, and maintaining a steady rise in publication rate that peaks in 2011 (Figure 2-5). In fact, the total publication rate during the 12 year period peaked in 2011 across all subjects (Figure 2-5). The majority of the 2011 papers were published in the United States (U.S.), and a review of their abstracts established that the sudden uptick in publication was directly related to the use of remote sensing technology during the 2010 Deepwater Horizon (DWH) Incident. See Figure 2-1 for a breakdown of publications per platform, Figures 2-2 through 2-4 for a breakdown of articles per sensor type for a particular platform, and Figure 2-5 for a breakdown of publications per sensor type for each year in the 12 year period.

While the majority of papers published during the peak year originated in the U.S., Italy has produced a slightly greater number across the overall period of research, with Greece and China closely following these two countries. It was not possible to determine the funding source for every publication, and as such many in the spreadsheet are marked as "unknown". However, from those that were able to be determined, the greatest number were funded by the European Commission and published by its Joint Research Centre. The National Aeronautics and Space Administration (NASA) follows a close second, with some papers published directly by the agency and the remaining funded through NASA grants to other institutions. See Appendix A for the full listing of papers, which includes information on platform and sensor type, funding source, author, etc.

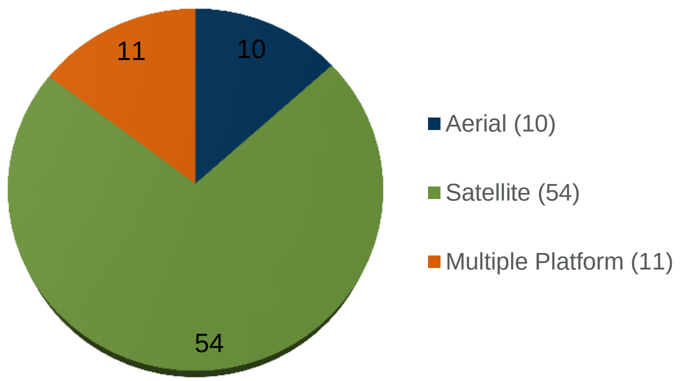


Figure 2-1 Total Publications per Platform

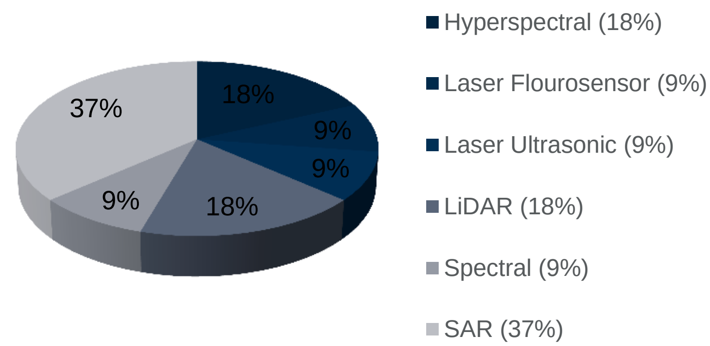


Figure 2-2 Aerial Platform Publications per Sensor (%)

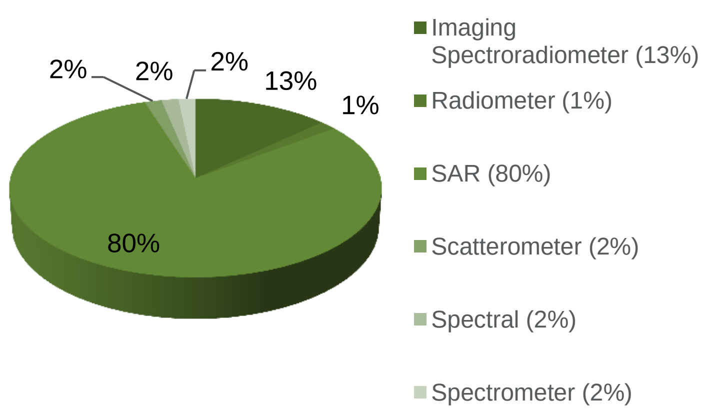


Figure 2-3 Satellite Platform Publications per Sensor (%)

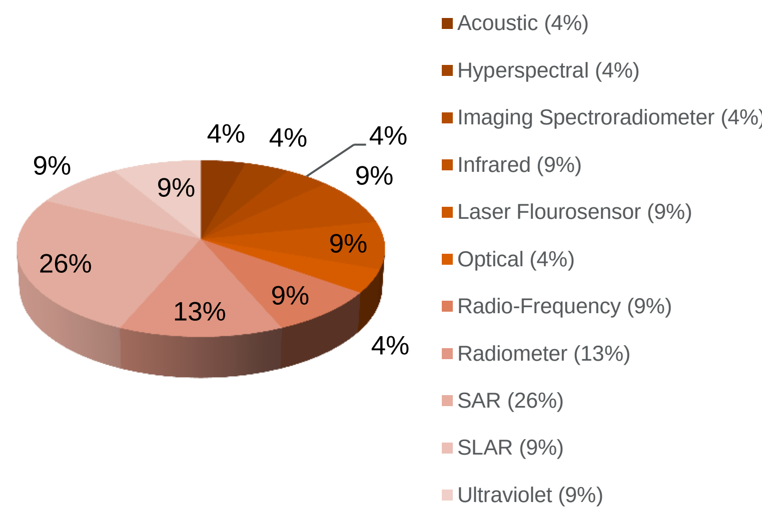


Figure 2-4 Multiple Platform Publications per Sensor (%)

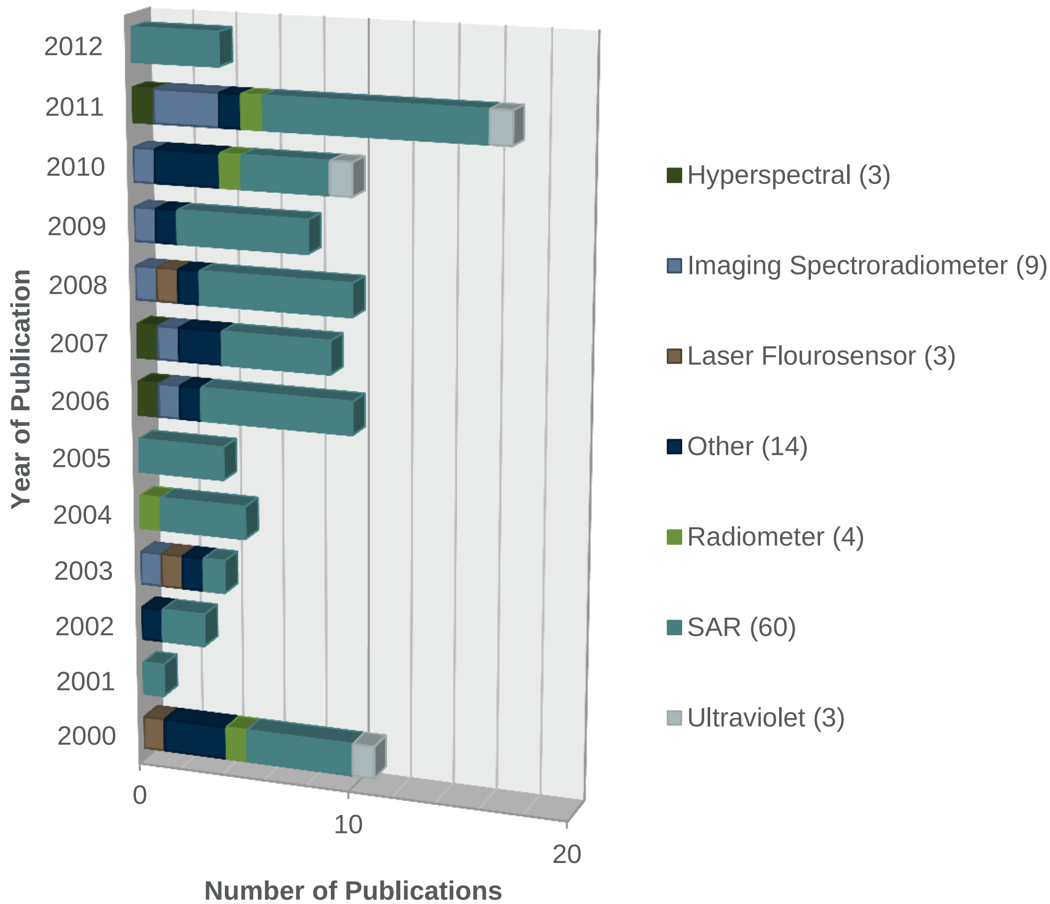


Figure 2-5 No. of Publications per Sensor Type per Year (2000 – 2012)[*] [†]

[*] "Other" is defined as those sensors that appear as the subject of two or fewer papers. Those sensors include: acoustic, infrared, laser ultrasonic, LiDAR, optical, radio-frequency, scatterometer, SLAR, spectral, and spectrometer.

[†] The total number of publications in this figure is greater than 75 because the tally includes each sensor defined as the subject of a paper, and some papers discussed multiple sensors.

3 Lessons Learned from Recent Oil Spills

Cardno ENTRIX staff performed a global search for oil spill response Lessons Learned that included a discussion of remote sensing use. The search was conducted using online resources. A total of six documents were located and their information added to the "Lessons Learned from Recent Oil Spills" spreadsheet provided in Appendix B. Only documents published between the years 2000 and 2012 were considered for inclusion. Significantly fewer Lessons Learned documents were discovered as compared to the peer-reviewed papers, and all but one of the Lessons Learned documents found were published in the U.S. It should not be assumed that these results are inclusive of all relevant documents published during the 12 year period, as the search methods may have influenced or restricted the results. Highlights of the Lessons Learned compiled in the spreadsheet are discussed in this section.

3.1 Highlights of the Lessons Learned Documents

Recent Experience from Multiple Remote Sensing and Monitoring to Improve Oil Spill Response Operations (Jensen et al. 2008) described a two-day oil-on-water exercise conducted in the North Sea in 2006 by the Norwegian Clean Seas Association for Operating Companies (NOFO). NOFO performed a controlled release of oils and then field tested a variety of remote sensing technology on the resulting eight slicks. NOFO noted the following conclusions:

> Fog interfered with high quality data collection from the infrared camera, microwave radiometer, and laser flourosensor.

> Radar sensors on all platforms provided useful data.

> A number of remote sensing tools are available, but no single tool can satisfy all spill response needs. Sensors need to be combined for efficiency and flexibility or situation.

> High speed internet and connections between vessels is essential for distribution.

Joint Industry Oil Spill Preparedness and Response Task Force: Draft Industry Recommendations to Improve Oil Spill Preparedness and Response (Oil Spill JITF 2010) described the use of a variety or remote sensing technology during the 2010 Deepwater Horizon (DWH) incident and provided a summary of findings and recommendations for future use.

> Findings:
  - Skilled aerial observers provided most reliable data.
  - Optical, infrared, and side-looking airborne radar proved successful when operators were properly trained.
  - Satellite imagery was useful in tracking oil transport.
  - Remotely operated vehicles successfully monitored deep water oil plumes.

> Recommendations:
  - Subsurface remote sensing methodology needs to be developed, including technology that can produce 3D maps of plumes and currents.
  - Standardized protocols for trajectory modeling using remote sensing data need to be developed.
  - Standardized surface tracking system needs to be developed.
  - Standardized R&D parameters, protocols and training need to be developed for the use of aerial platforms.

- Program should be implemented to adopt satellite systems.
- Surface and subsurface remote sensors that can provide data on oil concentration and fate should be investigated.
- Investigations should be conducted to determine whether satellite imagery can be used to direct response operations.
- Investigations should be conducted to determine whether hyperspectral image analysis can be combined with other sensor data.
- Investigations should be conducted to determine whether flourometers can be modified to extend the range of volume of water sampled.

The Effectiveness of Using MODIS Products to Map Sea Surface Oil (Innman and Easson 2010) describes the use of Moderate Resolution Imaging Spectroradiometer (MODIS) imagery to monitor and track oil during the DWH incident. The document noted the following conclusions:

> Publicly available MODIS products were less effective at mapping oil than other methods used during the response.

> Satellite imagery was not as accurate as some other methods, but was still found to be a viable resource.

> Combinations of resources were very effective at mapping oil and were also found to be economical.

> Sun glint on true color imagery was found to be the most consistent method for detecting oil.

Lessons Learned in Emergency Remote Sensing and BP Response during Deepwater Horizon (Nir and Shechter 2011) describes the use of the Icaros Digital Mapper-200 aerial photography system during the DWH incident. The document noted the following conclusions:

> It is important to evaluate the capabilities of a technology during the planning phase to maximize its efficient use.

> Having infrastructure for spatial data in place prior to an event is important to the success of response mapping.

> Resulting data sets are large, and when frequently collected they require proper management.

> Integrating data sets across multiple platforms proved difficult.

> Information sharing via a Geographic Information System (GIS) with the public is expected to become increasingly popular.

Operational Utilization of Aerial Multispectral Remote Sensing during Oil Spill Response: Lessons Learned During the Deepwater Horizon (MC-252) Spill (Svejkovsky et al. 2012) describes the use of Ocean Imaging (OI) Corp.'s multispectral oil mapping system during the DWH incident. The document noted the following conclusions:

> Imagery products from a combination of sensors can provide information useful for a variety of different response activities.

> The ability to create GIS-compatible maps of oil thickness classes is an important new asset that works well in combination with SAR and SLAR data.

> Aerial imagery can provide permanent documentation of oil spill patterns and events for uses beyond the immediate clean-up.

> Aerial system imaging of spills is limited by sun angles and camera field of view. Aerial observation surveys completed by trained observers are likely to remain the most time and cost-effective option.

> Oil characterizations from aerial imaging was useful for offshore and shoreline response activities, but lightly oiled vegetation areas was difficult or impossible to detect.

> Due to the relative novelty of the technology, some of the aerial multispectral products were underutilized during the response as some responders lacked the proper means to use or incorporate the data into other processes. Therefore satellite and aerial remote sensing needs to be included in response planning and rehearsal exercises to prepare for use during a response.

State of the Art Satellite and Airborne Marine Oil Spill Remote Sensing: Application to the BP Deepwater Horizon Oil Spill (Leifer et al. 2012) describes the use of a variety of remote sensing systems during the DWH incident and provides an assessment of their relative efficacy. The document noted the following conclusions:

> The AVIRIS hyperspectral approach used to quantify oil thickness played an important role and provided results that were unattainable with previous technology.

> Remote sensing products with rapid turnaround time were critical to supporting decision-making during the spill. Products with lengthy processing times were not generally useful during the spill, but provided value during post-spill activities.

> It is necessary to increase oil spill science research before another large spill occurs; particularly into graduating technologies from R&D to operational readiness.

3.2 Common Factors and Conclusions

Though a relatively small number of Lessons Learned documents were discovered during the search process, it is apparent from the highlights in Section 3.1 that they share many common elements. All of the Lessons Learned documents were published between 2008 and 2012 and were generally produced by and for industry organizations and/or government agencies. Five of the six documents were written in response to the DWH Incident and were published in the U.S. While each of the Lessons Learned document provides unique conclusions, some recurring themes and ideas can be discerned among them:

> A system or product that combines a variety of sensors and/or data would provide the most utility across the greatest number of response activities. More research should be conducted to design new or improve current combined sensor technology.

> Satellite imagery provided valuable data during response operations. Satellite acquisition processes and satellite technology capabilities should be investigated further.

> The sharing of remote sensing data via GIS not only within response groups, but also with the media and public, proved to be a useful tool. This process should be refined and included in response planning.

> Though many new technologies provided useful and unique data, aerial observation surveys remain one of the most practical and effective methods for surveillance of a large spill.

> More R&D into remote sensing technology for spill response needs to be conducted in general, but technologies currently in the developmental stages need to be field-ready before the next large spill.

> Both novel and established remote sensing technologies provided a wide range of valuable data, but were not always utilized due to an overabundance of the data or a lack of means to employ it. Therefore the process of remote sensing itself, as well as the application of resultant data, during a spill response needs to be established and included in future planning efforts.

4 Oil Spill Research and Development Programs

Cardno ENTRIX staff performed a global search for oil spill remote sensing R&D programs. The search was conducted using online resources. A total of 15 programs were investigated and their information added to the “Current Oil Spill Research and Development Programs” spreadsheet provided in Appendix C. Only those programs that were on-going or up-coming at the time of the search were considered. It should not be assumed that these results are inclusive of all existing relevant programs, as the search methods may have influenced or restricted the results. A summary of the results compiled in the spreadsheet are discussed in this section.

It is evident that some of the R&D programs align with the remote sensing needs established in the Lessons Learned documents, particularly those pertaining to improving the use of satellite imagery and developing systems to more efficiently utilize acquired data. However, it is also apparent that not every need established is under development in these programs and many are beyond their scope entirely. All current R&D programs listed in the spreadsheet were initiated between 2010 and 2012. The sensor types under research are widely varied, though the platforms are most frequently identified as either aerial or satellite. A majority of the programs are being conducted in the U.S. through government agency grants and in the United Kingdom by the OGP. The U.S.-based programs most often pertain to research in the Gulf of Mexico and many are funded by the Gulf of Mexico Research Initiative (GoMRI) that was created as a direct result of the DWH incident. These programs are heavily focused on remote sensing for coastal ecosystems including mapping system advancements, spill trajectory and landfall predictions, and ground-truthing collected data. Though the DWH Incident seems to have driven a number of the current programs in place, there are many directed in other areas of research outside the Gulf of Mexico. For example, the European Commission is funding two separate programs aimed at developing systems for integrating various remote sensing data to improve future spill response operations. Other programs are requests for general remote sensing technology research, but approximately one third of the total programs are directed at improving remote sensing of oil in ice with a particular focus on the Arctic region.

5 Conclusions and Emerging Trends

The field of oil spill remote sensing and surveillance has seen significant advances in platform availability and field applications in recent years. There are a suite of sensors currently available, and continued development and integration of new technologies are expected to continue. A primary challenge to the development and integration of these technologies is bringing a laboratory tested technology to field readiness status, due to limited opportunities to test the systems. The response to a spill event is not an appropriate time for field tests, as the primary objective of remote sensing during spill response is data collection towards control and mitigation of the event. Thus, response activities have a bias toward established and proven technologies, while emerging technologies struggle for real-time field trial opportunities. However, the DWH Incident provided an opportunity to test new approaches under real conditions. As a result of the DWH response it was realized that, despite some limitations, remote sensing technologies such as hyperspectral, infrared, and SAR imagery can provide valuable information to response personnel. As a result of these activities, recommendations for future R&D have been identified and funding dedicated to advancing the field of remote sensing surveillance.

While data resultant from the DWH Incident has established specific paths forward in the region, the field as a whole has seen a similar shift towards the same objectives. Following the development and application of remote sensing technologies throughout the 1990s and early 2000s, global research has shifted to the next phases of technological advancement. These emerging trends include the development of new sensors, such as laser fluorosensors, which have an increased ability to differentiate oil types, oil thickness, and oiled vs. non-oiled materials (Samberg 2007, Jha 2008, Dassenakis 2012). Along this line, there is a focus on the integration of multiple sensors in order to maximize the unique features of each sensor (Shcherbak 2008, Streett 2011). Using multiple satellite-borne sensors and taking advantage of data collected from different wavelengths (visible, infrared and microwave) on different spatial and temporal scales, researchers developed an approach for daily monitoring and detection of the Black Sea (Shcherbak 2008). The integration of multiple data streams can provide a more comprehensive dataset that reduces false positives in comparison to the use of a single data stream. Perhaps the strongest trend in recent remote sensing research is the development of classification algorithms to allow automated detection of surface oil for large-scale monitoring efforts (Karantzalos 2008, Grimaldi 2011, Liu 2011). This developing automation strives to reduce false positives through multi-phase classification of imagery data and is designed to allow early detection using global satellite data and advanced computer algorithms (Brekke 2008, Ferraro 2010, Akar 2011, Grimaldi 2011). To date, these automated classification systems have been able to differentiate oil slicks from ‘look-alikes’ (false positives) with 80 to 95% accuracy (Topouzelis 2009, Akar 2011, Chen 2011). Thus, the emerging trends of global research align with the lessons learned from DWH and emphasize common themes for moving forward in remote sensing technology: continued multi-sensor integration, better resolution of oil type and volume, automated classification algorithms that reduce false positives and decrease data processing time.

6 Literature Cited

Akar, S., M. L. Suzen, N. Kaymakci. 2011. Detection and object-based classification of offshore oil slicks using ENVISAT-ASAR images. Environmental Monitoring and Assessment. 183:409-423.

Brekke, C., A. H. S. Solberg. 2005. Oil spill detection by satellite remote sensing. Remote Sensing of Environment. 95:1-13.

Brekke, C., A. H. S. Solberg. 2008. Classifiers and Confidence Estimation for Oil Spill Detection in ENVISAT ASAR Images. IEEE Geoscience and Remote Sensing Letters. 5(1):65-69.

Chen, P., H. Zhou, X. T. Wang. 2011. Oil Spills Identification in SAR Image Using Mahalanobis Distance. Advanced Materials Research. 466-467:246-250.

Grimaldi, C. S. L., I. Coviello, T. Lacava, N. Pergola, V. Tramutoli. 2011. A new RST-Based Approach for Continuous Oil Spill Detection in TIR Range: The Case of the *Deepwater Horizon* Platform in the Gulf of Mexico. Monitoring of Marine Oil. Monitoring and Modeling the *Deepwater Horizon* Oil Spill: A Record-Breaking Enterprise, Geophysical Monograph Series. 195:19-31.

Joint Industry Oil Spill Preparedness and Response Task Force (Oil Spill JITF). 2010. Draft Industry Recommendations to Improve Oil Spill Preparedness and Response. Sept. 3, 2010.

Karantzalos, K. and D. Argialas. 2008. Automatic detection and tracking of oil spills in SAR imagery with level set segmentation. Internation Journal of Remote Sensing. 29(21):6281-6296.

Liu, P., X. Li, J. J. Qu, W. Wang, C. Zhao, W. Pichel. 2011. Oil spill detection with fully polarmetric UAVSAR data. Marine Pollution Bulletin. 62(12):2611-2618.

Nir, A., and E. B. Shechter. 2011. Lessons Learned in Emergency Remote Sensing and BP Response During Deepwater Horizon. ASPRS 2011 Annual Conference. Milwaukee, WI. May 1-5, 2011.

Samberg, A. 2007. The state-of-the-art of airborne laser systems for oil mapping. Canadian Journal of Remote Sensing. 33(3):143-149.

Schcherbak, S. S., O. Y. Lavrova, M. I. Mityagina, T. Y. Bocharova, V. A. Krovotyntsev, and A. G. Ostrovskii. 2008. Multisensor satellite monitoring of seawater state and and oil pollution in the northeastern coastal zone of the Black Sea. International Journal of Remote Sensing. 29(21):6331-6345.

Streett, D. 2011. NOAA's Satellite Monitoring of Marine Oil. Monitoring and Modeling the *Deepwater Horizon* Oil Spill: A Record-Breaking Enterprise. Geophysical Monograph Series. 195:9-18.

Svejkovsky, J., W. Lehr, J. Muskat, G. Graettinger, and J. Mullin. 2012. Operational Utilixation of Aerial Multispectral Remote Sensing during Oil Spill Response: Lessons Learned During the Deepwater Horizon (MC-252) Spill. Photogrammetric Engineering and Remote Sensing. 78:1089 – 1102.

Topouzelis, K., D. Stathakis, V. Karathanassi. 2009. Investigation of genetic algorithms contribution to feature selection for oil spill detection. International Journal of Remote Sensing. 30(3):611-625.

APPENDIX

A

PEER-REVIEWED REMOTE SENSING PAPERS SPREADSHEET

Peer Reviewed Remote Sensing Papers

Platform	Sensor	Geographical Area of Study	Areal Extent of Study	Institution	Country	Funding Source	Article Title	Principal Investigator/ Author	Contact Information	Co-Authors (if any)	Year	Source	Publication Type	Abstract	Keywords	Link to Website	No. of Citations	Copyright Issues?
Aerial	Laser Fluorosensors	N/A	N/A	Environment Canada	Canada	Environment Canada	Review of the Development of Laser Fluorosensors for Oil Spill Application	Brown, Carl (Environment Canada)	carl.brown@ec.gc.ca	Fingas, Merv (Environment Canada)	2003	Marine Pollution Bulletin	Journal - news, comment, reviews and research reports	As laser fluorosensors provide their own source of excitation, they are known as active sensors. Being active sensors, laser fluorosensors can be employed around the clock, in daylight or in total darkness. Certain compounds, such as aromatic hydrocarbons, present in petroleum oils absorb ultraviolet laser light and become electronically excited. This excitation is quickly removed by the process of fluorescence emission, primarily in the visible region of the spectrum. By careful choice of the excitation laser wavelength and range-gated detection at selected emission wavelengths, petroleum oils can be detected and classified into three broad categories: light refined, crude or heavy refined. This paper will review the development of laser fluorosensors for oil spill application, with emphasis on system components such as excitation laser source, and detection schemes that allow these unique sensors to be employed for the detection and classification of petroleum oils. There have been a number of laser fluorosensors developed in recent years, many of which are strictly research and development tools. Certain of these fluorosensors have been ship-borne instruments that have been mounted in aircraft for the occasional airborne mission. Other systems are mounted permanently on aircraft for use in either surveillance or spill response roles.	laser fluorosensor; oil detection; active sensors	http://www.sciencedirect.com/science/article/pii/S0025326X03002133	6	None - PDF provided on disk
Aerial	LURSOT (Laser-ultrasonic remote sensing of oil thickness)	N/A	N/A	Environment Canada	Canada	Environment Canada	Development of Airborne Oil Thickness Measurements	Brown, Carl (Environment Canada)	carl.brown@ec.gc.ca	Fingas, Merv (Environment Canada)	2003	Marine Pollution Bulletin	Journal - news, comment, reviews and research reports	A laboratory sensor has now been developed to measure the absolute thickness of oil on water slicks. This prototype oil slick thickness measurement system is known as the laser-ultrasonic remote sensing of oil thickness (LURSOT) sensor. This laser opto-acoustic sensor is the initial step in the ultimate goal of providing an airborne sensor with the ability to remotely measure oil-on-water slick thickness. The LURSOT sensor employs three lasers to produce and measure the time-of-flight of ultrasonic waves in oil and hence provide a direct measurement of oil slick thickness. The successful application of this technology to the measurement of oil slick thickness will benefit the scientific community as a whole by providing information about the dynamics of oil slick spreading and the spill responder by providing a measurement of the effectiveness of spill countermeasures such as dispersant application and in situ burning. This paper will provide a review of early developments and discuss the current state-of-the-art in the field of oil slick thickness measurement.	oil slick; thickness measurement; opto-acoustic	http://www.sciencedirect.com/science/article/pii/S0025326X03002030	15	None - PDF provided on disk
Aerial	Synthetic Aperture Radar	Tropical Atlantic	N/A	NASA	USA	NASA	Studies of the Deepwater Horizon Oil Spill with the UAVSAR Radar	Jones, Cathleen E.	cathleen.jones@jpl.nasa.gov	Minchew, B. Holt, B. S. Hensley, S.	2011	Monitoring and Modeling the Deepwater Horizon Oil Spill: A Record-Breaking Enterprise [Geophysical Monograph Series, Vol. 195]	Scientific journal	On 22–23 June 2010, the Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR) L band radar imaged the Deepwater Horizon oil spill and the effects of oil that was transported within the Gulf of Mexico. We describe the campaign and discuss the unique contributions of the UAVSAR radar to the study of the detection, migration, and impact of oil from the spill. We present an overview of UAVSAR data analyses that support the original science goals of the campaign, namely, (1) algorithm development for oil slick detection and characterization, (2) mapping of oil intrusion into coastal wetlands and intercoastal waterways, and (3) ecosystem impact studies. Our study area focuses on oil-affected wetlands in Barataria Bay, Louisiana. The results indicate that fine resolution, low-noise, L band radar can detect surface oil-on-water with sufficient sensitivity to identify regions in a slick with different types of oil/emulsions and/or oil coverage; identify oil on waters in inland bays and differentiate mixed/weathered oil from fresh oil as it moves into the area; identify areas of potentially impacted wetlands and vegetation in the marshes; and support the crisis response through location of compromised booms and heavily oiled beaches.	oil slick detection and characterization, mineral oil slicks, Louisiana wetland ecosystem, POLSAR	http://www.agu.org/books/gm/v195/2011GM001113/2011GM001113.shtml	5	None - PDF provided on disk - need book
Aerial	Synthetic Aperture Radar	Tropical Atlantic	N/A	California Institute of Technology	USA	NASA	High Resolution Radar for Response and Recovery: Monitoring Containment Booms in Barataria Bay	Jones, Cathleen E. (California Institute of Technology. Jet Propulsion Lab)	cathleen.jones@jpl.nasa.gov	Davis, Bruce A. (Dept. of Homeland Security, Science and Technology)	2011	Photogrammetric Engineering and Remote Sensing	Open Access Journal	None	SAR, oil spill. Remote sensing	http://digital.ipcprintservices.com/publication/?i=58986&p=8	1	Yes - can share with CCC license

Peer Reviewed Remote Sensing Papers

Platform	Sensor	Geographical Area of Study	Areal Extent of Study	Institution	Country	Funding Source	Article Title	Principal Investigator/ Author	Contact Information	Co-Authors (if any)	Year	Source	Publication Type	Abstract	Keywords	Link to Website	No. of Citations	Copyright Issues?
Aerial	Airborne Spectral Photometric Environmental Collection Technology	Tropical Atlantic	N/A	The Aerospace Corp. Dynamic Corp. National Geospatial-Intelligence Agency TASC, Inc.	USA	USEPA	Airborne Remote Sensing for Deepwater Horizon Oil Spill Emergency Response	Kroutil, Robert T. (Dynamac Corp.)	N/A	Shen, Sylvia S. (The Aerospace Corp.) Lewis, Paul E. (National Geospatial-Intelligence Agency) Miller, David P. (TASC, Inc.) Cardarelli, John (USEPA) Thomas, Mark (USEPA) Curry, Timothy (USEPA) Kudaraskus, Paul (USEPA)	2010	Proceedings SPIE	Conference Paper	On April 28, 2010, the Environmental Protection Agency's (EPA) Airborne Spectral Photometric Environmental Collection Technology (ASPECT) aircraft was deployed to Gulfport, Mississippi to provide airborne remotely sensed air monitoring and situational awareness data and products in response to the Deepwater Horizon oil rig disaster. The ASPECT aircraft was released from service on August 9, 2010 after having flown over 75 missions that included over 250 hours of flight operation. ASPECT's initial mission responsibility was to provide air quality monitoring (i.e., identification of vapor species) during various oil burning operations. The ASPECT airborne wide-area infrared remote sensing spectral data was used to evaluate the hazard potential of vapors being produced from open water oil burns near the Deepwater Horizon rig site. Other significant remote sensing data products and innovations included the development of an advanced capability to correctly identify, locate, characterize, and quantify surface oil that could reach beaches and wetland areas. This advanced identification product provided the Incident Command an improved capability to locate surface oil in order to improve the effectiveness of oil skimmer vessel recovery efforts directed by the US Coast Guard. This paper discusses the application of infrared spectroscopy and multispectral infrared imagery to address significant issues associated with this national crisis. More specifically, this paper addresses the airborne remote sensing capabilities, technology, and data analysis products developed specifically to optimize the resources and capabilities of the Deepwater Horizon Incident Command structure personnel and their remediation efforts.	Airborne Spectral Photometric Environmental Collection Technology, infrared spectroscopy, multispectral infrared imagery	http://proceedings.spiedigitallibrary.org/proceeding.aspx?articleid=723248	1	Yes - Article available for purchase
Aerial	Fluorescent Lidar Passive Hyperspectral Imager	Temperate Northern Atlantic	N/A	AS Laser Diagnostic Instruments GET/ENST-Gretagne SAS ActiMar	France	RITMER programme of the French Ministry of Research (DETECSUIV) European Union	Detection and Mapping of Oil Slicks in the Sea by Combined Use of Hyperspectral Imagery and Laser-Induced Fluorescence	Lennon, Marc (SAS ActiMar/GET/ENST-Gretagne)	maarc.lennon@actimar.fr	Babichenko, Sergey (AS Laser Diagnostic Instruments) Thomas, Nicolas (SAS ActiMar) Mariette, Vincent (SAS ActiMar) Mercier, Grégoire (GET/ENST-Gretagne) Lisin, Aleksei (AS Laser Diagnostic Instruments)	2006	EARSeL eProceedings	Open Access Journal	The demand for efficient detection, mapping and volume estimation of oil pollution in the sea is growing. Reliable observation tools are required to support monitoring flights against sea pollutions and to provide guidance for maritime and airborne means of fighting such occurrences. The present pilot projectaimed at the evaluation of the combined use of airborne passive Hyperspectral Imagery (HI) and Laser Induced Fluorescence (LIF) technologies for remote sensing of oil spills in the sea. The passive hyperspectral imager (CASI-2) and the Fluorescent Lidar System (FLS-AU) have been installed onboard a fixed-wing aircraft (Cessna 404). Test flights have been carried out over controlled simulated oil pollution at sea off the coast of Brittany, France, in May 2004. CASI data allowed very high spatial resolution (1 and 2 metres) slick maps to be produced, and the polluted surface to be estimated. LIF spectra acquired by FLS-AU allowed oil slick thickness to be locally estimated with approximate spatial resolution of 25 metres along the flight track. The data fusion procedure proved to be consistent with the radiative transfer model over a polluted water area including a thin layer of oil, and allowed a high resolution (1 metre) thickness map to be computed. As a result of the studies the location, extents, and volume of the oil spilled were estimated from the maps. A critical study of the methodology used and a discussion on the precision reached by the quantitative estimates is proposed. The ways towards the design of an operational system including both passive and active airborne optical sensors for supporting recovering operations are discussed.	hyperspectral, laser-induced fluorescence, oil spill survey	http://www.eproceedings.org/static/vol05_1/05_1_lennon1.html	19	None - PDF provided on disk
Aerial	Synthetic Aperture Radar	Tropical Atlantic	N/A	Beihang University George Mason University NOAA Ocean University of China	USA	NOAA	Oil-Spill Detection with Fully Polarimetric UAVSAR Data	Liu, P. (Ocean University of China)	Xiaofeng.Li@noaa.gov	Li, X (IMSG at NOAA/NESDIS) Qu, J. J. (ESTC, George Mason University) Wang, W. (Beihang University) Zhao, C. (Ocean University of China) Pichel, W. (OAA/NESDIS/STAR)	2011	Marine Pollution Bulletin	Journal - news, comment, reviews and research reports	In this study, two ocean oil spill detection approaches based on four scattering matrices measured by fully polarimetric synthetic aperture radar (SAR) are presented and compared. The first algorithm is based on the co-polar correlation coefficient, ρ, and the scattering matrix decomposition parameters, Cloud entropy (H), mean scattering angle (α) and anisotropy (A). While each of these parameters has oil spill signature in it, we find that combining these parameters into a new parameter, F, is a more effective way for oil slick detection. The second algorithm uses the total power of four polarimetric channels image (SPAN) to find the optimal representation of the oil spill signature. Otsu image segmentation method can then be applied to the F and SPAN images to extract the oil slick features. Using the L-band fully polarimetric Uninhabited Aerial Vehicle - synthetic aperture radar (UAVSAR) data acquired during the 2010 Deepwater Horizon oil spill disaster event in the Gulf of Mexico, we are able to successfully extract the oil slick information in the contaminated ocean area. Our result shows that both algorithms perform well in identifying oil slicks in this case.	oil spill detection, polarimetric, UAVSAR	http://www.sciencedirect.com/science/article/pii/S0025326X11005248	2	None - PDF provided on disk

Peer Reviewed Remote Sensing Papers

Platform	Sensor	Geographical Area of Study	Areal Extent of Study	Institution	Country	Funding Source	Article Title	Principal Investigator/ Author	Contact Information	Co-Authors (if any)	Year	Source	Publication Type	Abstract	Keywords	Link to Website	No. of Citations	Copyright Issues?
Aerial	Synthetic Aperture Radar	Tropical Atlantic	N/A	California Institute of Technology, Jet Propulsion Laboratory	USA	NASA	Polarimetric Analysis of Backscatter from the Deepwater Horizon Oil Spill Using L-Band Synthetic Aperture Radar	Minchew, Brent (California Institute of Technology, Seismological Laboratory)	bminchew@gps.caltech.edu	Jones, Cathleen (California Institute of Technology, Jet Propulsion Laboratory) Holt, Benjamin (California Institute of Technology, Jet Propulsion Laboratory)	2012	IEEE Transactions on Geoscience and Remote Sensing	Open Access Journal	We analyze the fully-polarimetric Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR) data acquired on June 23, 2010, from two adjacent, overlapping flight tracks that imaged the main oil slick near the Deepwater Horizon (DWH) rig site in the Gulf of Mexico. Our results show that radar backscatter from both clean water and oil in the slick is predominantly from a single surface scatterer, consistent with the tilted Bragg scattering mechanism, across the range of incidence angles from 26^{circ} to 60^{circ}. We show that the change of backscatter over the main slick is due both to a damping of the ocean wave spectral components by the oil and an effective reduction of the dielectric constant resulting from a mixture of 65–90% oil with water in the surface layer. This shows that synthetic aperture radar can be used to measure the oil volumetric concentration in a thick slick. Using the $hbox{H/A}/alpha$ parameters, we show that surface scattering is dominant for oil and water whenever the data are above the noise floor and that the entropy (H) and $alpha$ parameters for the DWH slick are comparable to those from the clean water. The anisotropy, A, parameter shows substantial variation across the oil slick and a significant range-dependent signal whenever the backscatter in all channels is above the instrument noise floor. For slick detection, we find the most reliable indicator to be the major eigenvalue of the coherency matrix, which is approximately equal to the total backscatter power for both oil in the slick and clean sea water.	oil spill, radar polarimetry, synthetic aperture radar	http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=6166389&url=http%3A%2F%2Fieeexplore.ieee.org%2Fiel5%2F36%2F4358825%2F06166389.pdf%3Farnumber%3D6166389	1	Yes - can share with CCC license
Aerial	Hyperspectral Lidar	N/A	N/A	AVAPROedu	Canada	AVAPROedu	State-of-the-Art of Airborne Laser Systems for Oil Mapping	Samberg, Andre (AVAPROedu)	info@AVAPROedu.com	N/A	2007	Canadian Journal of Remote Sensing	Scientific journal	Since the beginning of the 21st century, there has been an increasing interest in merging data acquired simultaneously by lidar and hyperspectral sensors. There are two major reasons for this interest. First, a laser works as an artificial light source that expands the operating range of optical remote sensing systems. Second, a hyperspectral detector is adjusted to specific spectral feature(s) of the scene due to the operating wavelength(s) of the laser light source. This simplified approach allows us to ignore extra information coming from a passive hyperspectral sensor and therefore greatly speeds up the decision-making process. This study was motivated by the absence of sufficient information about active optical remote sensing means in the literature, which is widely used in remote sensing education and image interpretation. This paper provides an overview of the state-of-the-art of airborne laser systems for oil mapping.	airborne laser systems, active optical remote sensing, laser-induced fluorescence	http://pubs.casi.ca/doi/abs/10.5589/m07-021	2	Yes - can share with CCC license
Aerial	Various	Temporate Northern Atlantic	N/A	Katholieke Universiteit Leuven, Laboratory of Aquatic Ecology Management Unit of the North Sea Scheldt Estuary Mathematical Models	Belgium	Uknown	Aerial Surveillance of Operational Oil Pollution in Belgium's Maritime Zone of Interest	Volckaert, F.A.M. (Katholieke Universiteit Leuven)	filip.volckaert@bio.kuleuven.ac.be	Kayens, G. (Katholieke Universiteit Leuven) Schallier, R. (Management Unit of the North Sea and Scheldt Estuary Mathematical Models) Jacques, T. G. (Management Unit of the North Sea and Scheldt Estuary Mathematical Models)	2000	Marine Pollution Bulletin	Journal - news, comment, reviews and research reports	Belgium's Maritime Zone of Interest (BMZI), including the Belgian Territorial Sea, Belgian Continental Shelf, and Bonn Agreement Zone of Multilateral Responsibility, were regularly surveyed by remote-sensing aircraft for the presence of operational oil spills between 1991 and 1995. Simultaneously wind speed and direction were recorded; wave height was obtained from the literature. In total, 228 spills of various sizes, volumes and origins were analysed by means of univariate statistical analysis. We documented that the observed oil spills were generally elongate, narrow and thin, that spill dimensions were interrelated, and that wind speed and wave height affected these dimensions. A major fraction of the total variation however could be attributed to slick thickness. Spills found outside the Traffic Separation Scheme (TSS) tended to be smaller in surface area but showed no significant difference in average volume. Thus, the source of the spill more so than the hydrodynamics of the sea determined the characteristics of the spill. Given the impact of oil spills on marine life, continuous attention should be paid to monitoring and pollution control measures in the BMZI.	aerial surveillance; Bonn agreement; North Sea; oil pollution; statistics; Tra Separation Scheme	http://www.sciencedirect.com/science/article/pii/S0025326X00000564	15	None - PDF provided on disk
Aerial Marine Vessel Satellite	Optical Synthetic Aperture Radar Thermal imaging radiometer Ultraviolet to visible hyperspectral imaging radiometer Visible high dynamic range context imager	Tropical Atlantic	N/A	Unknown (paper availabile in book, not yet received)	USA	Unknown	Absolute Airborne Thermal SST Measurements and Satellite data Analysis from the Deepwater Horizon Oil Spill	Good, W.S.	N/A	Warden, R. Kaptchen, P. F. Finch, T. Emery, W. J. Giacomini, A.	2011	Monitoring and Modeling the Deepwater Horizon Oil Spill: A Record-Breaking Enterprise [Geophysical Monograph Series, Vol. 195]	Scientific journal	Rapid assessment and continuous monitoring was critical to addressing the changing conditions in response to the Deepwater Horizon oil spill. Airborne, satellite, shipborne, and underwater sensors were all used with data being assimilated as actionable reports. To assist with the recovery effort and evaluate the utility of new sensors for oil spill response, Ball Aerospace sent a team of scientists and engineers to the Gulf in July 2010. The team deployed on a Twin Otter aircraft with a suite of sensors including a thermal imaging radiometer, UV to visible hyperspectral imaging radiometer, and a visible high dynamic range context imager. All three sensors were operated at the same time with overlapping fields of view to assist with targeting and characterization of the oil. Data was also gathered from satellite synthetic aperture radar (SAR) and optical sensors during the same time and analyzed to determine additional capabilities from these sources. The UV and thermal imaging capabilities demonstrated were unique when compared with other airborne sensors flown over the spill. In the optical spectral range, imagery from the WorldView 2 satellite operated by DigitalGlobe was utilized, while SAR imagery was collected by the TerraSAR-X, COSMO-SkyMed (also X-band), and the Envisat Advanced SAR (ASAR, C-band). This combination of optical and radar imagery proved very useful in being able to map oil features on the surface of the Gulf of Mexico. Results of the thermal measurements are presented along with a discussion of the other sensor data used to further characterize the spill.	oil spill, SST, thermal IR, hyperspectral	http://www.agu.org/books/gm/v195/2011GM001114/2011GM001114.shtml	1	None - PDF provided on disk - need book

Peer Reviewed Remote Sensing Papers

Platform	Sensor	Geographical Area of Study	Areal Extent of Study	Institution	Country	Funding Source	Article Title	Principal Investigator/ Author	Contact Information	Co-Authors (if any)	Year	Source	Publication Type	Abstract	Keywords	Link to Website	No. of Citations	Copyright Issues?
Aerial Satellite	Synthetic Aperture Radar	Temperate Northern Atlantic	N/A	Norwegian Defence Research Establishment University of Oslo, Dept. of Informatics	Norway	Norwegian Defence Research Establishment	Classifiers and Confidence Estimation for Oil Spill Detection in ENVISAT ASAR Images	Brekke, Camilla (Norwegian Defence Research Establishment)	Camilla.Brekke@ffi.no	Solberg, A.H.S. (University of Oslo)	2008	IEEE Geoscience and Remote Sensing Letters	Open Access Journal	An improved classification approach is proposed for automatic oil spill detection in synthetic aperture radar images. The performance of statistical classifiers and support vector machines is compared. Regularized statistical classifiers prove to perform the best on this problem. To allow the user to tune the system with respect to the tradeoff between the number of true positive alarms and the number of false positives, an automatic confidence estimator has been developed. Combining the regularized classifier with confidence estimation leads to acceptable performance.	classification, oil spills	http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=4378189&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D4378189	12	Yes - can share with CCC license
Aerial Satellite	Various	Temperate Northern Atlantic Eastern Mediterranean Sea	N/A	University of Athens	Greece	IUPAC Chemistry and the Environment Division	Remote sensing in coastal water monitoring: Applications in the eastern Mediterranean Sea (IUPAC technical report) [Chapter 10: Remote Sensing Monitoring of Oil Spills: Sensors and Case Studies]	Dassenakis, Manos (University of Athens)	edasenak@chem.uoa.gr	Paraskevopoulou, Vasiliki (University of Athens) Cartalis, Constantinos (University of Athens) Adaktilou, Nektaria (University of Athens) Katsiabani, Katerina (University of Athens)	2012	Pure and Applied Chemistry	Scientific journal	Remote sensing/satellite observation of land and oceans is a field of research that was developed during the second half of the 20th century, and its importance is widely recognized because of the amount of information it can provide to the scientific community and the general public. The outcomes of remote sensing/satellite observation can be used to address and study significant aspects of environmental concern, such as habitat destruction, environmental degradation, forest fires, oil spills, and climate change. There is continuous improvement of the methods and means of remote sensing observations in order to achieve more accurate and useful information. The main advantage is the possibility of observing large areas, and the main disadvantage is that it can observe only the water and land surface. The present paper is an effort to review the technologies used in remote sensing and the general applications in a comprehensive manner addressed to scientists who do not specialize in this area of research. Furthermore, this paper reviews case studies/applications in the Mediterranean Sea, an area affected by various polluting activities (industrial cities, agriculture, shipping, etc.) that should be continuously monitored so that the coastal countries are able to successfully manage this sensitive environment.	chlorophyll; coastal management; eutrophication; IUPAC Chemistry and the Environment Division; Mediterranean Sea; oil spills; remote sensing	http://pac.iupac.org/publications/pac/pdf/2012/pdf/8402x0335.pdf	0	None - PDF provided on disk
Aerial Satellite	Side-looking Airborne Radar Synthetic Aperture Radar	North East Atlantic	N/A	Joint Research Centre	Italy	European Commission	Long Term Monitoring of Oil Spills in European Seas	Ferraro, G. (Joint Research Centre)	guido.ferraro@jrc.it	Meyer-Roux, S. (Joint Research Centre) Muellenhoff, O. (Joint Research Centre) Pavliha, M. (University of Ljubljana) Svetak, J. (University of Ljubljana) Tarchi D. (Joint Research Centre) Topouzelis, Konstantinos (Joint Research Centre)	2009	International Journal of Remote Sensing	Open Access Journal	Accidental pollution at sea can be reduced but never completely eliminated; however, deliberate illegal discharges from ships can indeed be reduced by the strict enforcement of existing regulations and the control, monitoring and surveillance of maritime traffic. Despite this, operational oil discharges are common and represent the main source of marine pollution from ships. To analyse this problem, the Joint Research Centre (JRC) of the European Commission has focused its attention on the need to monitor in the long term sea-based oil pollution. This research aims, in particular, to map the oil spills, to identify the hot spots and to define the trends in all European seas. For this reason, JRC has collected all relevant data concerning sea-based oil pollution from different actors and archives. For the North and Baltic seas, data from aerial surveillance were used and, for this reason, all oil spills are real and confirmed. Conversely, the data for the Mediterranean and the Black Sea derive from oil spills detected by JRC in low resolution SAR (Synthetic Aperture Radar) satellite images from archives. For the Mediterranean and the Black Sea, these data represent the only source to draw some preliminary conclusions on marine oil pollution. This paper presents for the first time a comprehensive view of the long term monitoring of sea-based oil pollution in all the seas around Europe. The key conclusion of this study is that, if the data analysed are not homogenous, operational pollution in the seas around Europe seems to be slightly decreasing.	illegal discharges from ships, oil spill trends	http://www.tandfonline.com/doi/abs/10.1080/01431160802339464#preview	12	Yes - can share with CCC license
Aerial Satellite	Acoustic Infrared/Ultraviolet Laser Flourosensor Radio-frequency Radar	N/A	N/A	Emergencies Science Division, Environment Canada	Canada	Environment Canada	A Review of the Status of Advanced Technologies for the Detection of Oil in and with Ice	Fingas, Merv (Environment Canada)	fingas.merv@etc.ec.gc.ca	Brown, Carl (Environment Canada)	2000	Spill Science & Technology Bulletin	Journal - news, comment, reviews and research reports	Remote sensors for application to oil in ice and oil with ice are assessed. Radio-frequency methods to detect oil in ice depend on the difference in dielectric properties between oil and water. Freshwater ice is relatively transparent to frequencies below about 200 MHz. Despite extensive theoretical studies, there is a lack of experimental evidence to support the notion that radio-frequency methods have potential. Acoustic methods for the detection of oil in ice show promise. Regular metal inspection equipment is capable of detecting oil layers under ice. Oil propagates shear waves and detection methods based on this unique property are capable of identifying oil in ice. One unit has been built and tested in the field based on this principle. Oil with ice detection is a well developed technology. A common sensor is an infrared camera or an IR/UV (infrared/ultraviolet) system. The inherent weaknesses include the inability to discriminate oil on beaches, among weeds or debris. The laser fluorosensor is a most useful instrument because of its unique ability to identify oil on backgrounds that include water, soil, ice and snow. It is the only sensor that can positively discriminate oil on most backgrounds. Radar offers the only potential for large area searches and foul weather remote sensing, however, there is little potential to detect oil in the immediate vicinity of ice. A major weakness of radar is that it is limited to operation over seas with winds of about 2–8 m/s. Equipment operating in the visible region of the spectrum, such as cameras and scanners, is useful for documentation or providing a basis for the overlay of other data. It is not useful beyond this because oil shows no spectral characteristics in the visible region that can be used to discriminate oil.	spilled oil remote sensing; ice; IR; UV; radar; laser fluorosensor; visible spectrum	http://www.sciencedirect.com/science/article/pii/S1353256101000561	13	None - PDF provided on disk
Aerial Satellite	Advanced Very High Resolution Radiometer Synthetic Aperture Radar	Temporate Northern Atlantic	N/A	Instituto Español de Oceanografía (IEO)	Spain	Ministry of Science and Technology of Spain (postdoctoral contract RAMON Y CAJAL)	Prestige Oil Spill and Navidad Flow	Garcia-Soto, C. (Instituto Espan‹ol de Oceanografia)	carlos.soto@st.ieo.es	N/A	2004	Journal of the Marine Biological Association of the UK	Scientific journal	The spread of the oil spill from the tanker 'Prestige' was analysed in relation to the occurrence of the exceptional 2002/2003 Navidad using airborne and AVHRR satellite measurements. Altimeter-derived geostrophic velocity and Envisat ASAR observations were also used to investigate the structure of this Cantabrian extension of the poleward current around Iberia.	tanker ships, ship illegal discharges	http://journals.cambridge.org/action/displayAbstract?fromPage=online&aid=210539	33	Yes - can share with CCC license

Peer Reviewed Remote Sensing Papers

Platform	Sensor	Geographical Area of Study	Areal Extent of Study	Institution	Country	Funding Source	Article Title	Principal Investigator/ Author	Contact Information	Co-Authors (if any)	Year	Source	Publication Type	Abstract	Keywords	Link to Website	No. of Citations	Copyright Issues?
Aerial Satellite	Laser fluorosensors [Scanning Laser Environmental Airborne Fluorosensor (SLEAF)]	N/A	N/A	University of Calgary Western Washington University	Canada USA	GEOIDE NCE NSERC	Advances in Remote Sensing for Oil Spill Disaster Management: State-of-the-Art Sensors Technology for Oil Spill Surveillance	Jha, Maya Nand (Department of Geomatics Engineering, University of Calgary)	gao@geomatics.ucalgary.ca	Levy, Jason (Western Washington University, Disaster Reduction and Emergency Planning) Gao, Yang (Department of Geomatics Engineering, University of Calgary)	2008	Sensors	Open Access Journal	Reducing the risk of oil spill disasters is essential for protecting the environment and reducing economic losses. Oil spill surveillance constitutes an important component of oil spill disaster management. Advances in remote sensing technologies can help to identify parties potentially responsible for pollution and to identify minor spills before they cause widespread damage. Due to the large number of sensors currently available for oil spill surveillance, there is a need for a comprehensive overview and comparison of existing sensors. Specifically, this paper examines the characteristics and applications of different sensors. A better understanding of the strengths and weaknesses of oil spill surveillance sensors will improve the operational use of these sensors for oil spill response and contingency planning. Laser fluorosensors were found to be the best available sensor for oil spill detection since they not only detect and classify oil on all surfaces but also operate in either the day or night. For example, the Scanning Laser Environmental Airborne Fluorosensor (SLEAF) sensor was identified to be a valuable tool for oil spill surveillance. However, no single sensor was able to provide all information required for oil spill contingency planning. Hence, combinations of sensors are currently used for oil spill surveillance. Specifically, satellite sensors are used for preliminary oil spill assessment while airborne sensors are used for detailed oil spill analysis. While satellite remote sensing is not suitable for tactical oil spill planning it can provide a synoptic coverage of the affected area.	oil spill surveillance, disaster management, contingency planning, remote sensing, space-borne sensors, airborne sensors	http://www.mdpi.com/1424-8220/8/1/236	36	None - PDF provided on disk
Aerial Satellite	Radiometics	N/A	N/A	Radiophysical Research Institute	Russia	Uknown	Radiometric Methods of Remote Sensing of Oil Spills on Water Surfaces	Krotikov, V.D. (Radiophysical Research Institute)	N/A	Mordvinkin, I. N. (Radiophysical Research Institute) Pelyushenko, A. S. (Radiophysical Research Institute) Pelyushenko, S. A. (Radiophysical Research Institute) Rakut, I. V. (Radiophysical	2002	Radiophysics and Quantum Electronics	Scientific journal	We present a comparative analysis of radiometric methods of remote sensing aimed at detecting and monitoring the parameters of oil spills on water surfaces. We consider the method of radio-brightness polarization contrasts and present the results of measuring the oil-film thickness on water, obtained using a two-frequency polarization radiometer with operating frequencies 12.2 and 34 GHz. The radiometric methods of radio-brightness contrasts and frequency scanning applied to the problems of remote sensing of oil-spill parameters are compared.	passive-radiometry; oil-film thickness	http://www.springerlink.com/content/q901mn03hd01ek3y/	1	None - PDF provided on disk
Aerial Satellite	Synthetic Aperture Radar	N/A	N/A	Centre for Environment, Fisheries and Aquaculture Science ECIMAT IDAEA-CSIC IEO IIM-CSIC Norwegian Institute for Water Research Plymouth Marine Laboratory	Spain	Defra Research Council of Norway MICINN	Post-Incident Monitoring to Evaluate Environmental Damage from Shipping Incidents: Chemical and Biological Assessments	Radović, Jagoš R. (IDAEA-CSIC)	josep.bayona@idaea.csic.es	Rial, Diego (IIM-CSIC) Lyons, Brett P. (CEFAS) Harman, Christopher (NIVA) Viñas, Lucia (IEO) Beiras, Ricardo (ECIMAT) et al.	2012	Journal of Environmental Management	Scientific journal	Oil and chemical spills in the marine environment are an issue of growing concern. Oil exploration and exploitation is moving from the continental shelf to deeper waters, and to northern latitudes where the risk of an oil spill is potentially greater and may affect pristine ecosystems. Moreover, a growing number of chemical products are transported by sea and maritime incidents of hazardous and noxious substances (HNS) are expected to increase. Consequently, it seems timely to review all of the experience gained from past spills to be able to cope with appropriate response and mitigation strategies to combat future incidents. Accordingly, this overview is focused on the dissemination of the most successful approaches to both detect and assess accidental releases using chemical as well as biological approaches for spills of either oil or HNS in the marine environment. Aerial surveillance, sampling techniques for water, suspended particles, sediments and biota are reviewed. Early warning bioassays and biomarkers to assess spills are also presented. Finally, research needs and gaps in knowledge are discussed.	Aerial surveillance; Sampling; Fingerprinting; Biomarkers; Bioassays	http://www.sciencedirect.com/science/article/pii/S0301479712002393	0	None - PDF provided on disk
Aerial, Satellite	Advanced Very High Resolution Radiometer Moderate Resolution Imaging Spectroradiometer Side-Looking Airborne Radar Ultraviolet Visible Infrared	N/A	N/A	University of Delaware	USA	NASA (EPSCoR Program at the University of Delaware) NOAA (Sea Grant NA10OAR4170084)	Tracking Oil Slicks and Predicting their Trajectories Using Remote Sensors and Models: Case Studies of the Sea Princess and Deepwater Horizon Oil Spills	Klemas, Victor (University of Delaware)	Victor Klemas klemas@udel.edu College of Earth Ocean and Environment, University of Delaware Newark, DE 19716, USA	N/A	2010	Journal of Coastal Research	Open Access Journal	Oil spills can harm marine life in the oceans, estuaries, and wetlands. To limit the damage by a spill and facilitate cleanup efforts, emergency managers need information on spill location, size and extent, direction and speed of oil movement, and wind, current, and wave information for predicting oil drift and dispersion. The main operational data requirements are fast turn-around time and frequent imaging to monitor the dynamics of the spill. Remote sensors on satellites and aircraft meet most of these requirements by tracking the spilled oil at various resolutions, over wide areas, and at frequent intervals. They also provide key inputs to drift prediction models and facilitate targeting of skimming and booming efforts. Satellite data are frequently supplemented by information provided by aircraft, ships, and remotely controlled underwater robots. The Sea Princess tanker grounding off the coast of Wales and the explosion on the Deepwater Horizon rig in the Gulf of Mexico provide good examples for studying the effectiveness of remote sensors during oil-spill emergencies.	oil spills; oil remote sensing; tracking oil spills; oil spill response; remote sensing	http://www.jcronline.org/doi/abs/10.2112/10A-00012.1	4	None - PDF provided on disk

Peer Reviewed Remote Sensing Papers

Platform	Sensor	Geographical Area of Study	Areal Extent of Study	Institution	Country	Funding Source	Article Title	Principal Investigator/ Author	Contact Information	Co-Authors (if any)	Year	Source	Publication Type	Abstract	Keywords	Link to Website	No. of Citations	Copyright Issues?
Satellite	Medium Resolution Imaging Spectrometer Moderate Resolution Imaging Spectroradiometer Synthetic Aperture Radar (Advanced)	Temperate Northern Atlantic	N/A	University of Bari The Institute of Intelligent Systems for Automation	Italy	National Research Council	Exploiting Sunglint Signatures from MERIS and MODIS Imagery in Combination to SAR Data to Detect Oil Slicks	Adamo (University of Bari/Institute of Intelligent Systems for Automation, National Research Council) Carolis Pasquale Pasquariello (Institute of Intelligent Systems for Automation, National Research Council)	Maria Adamo Via Amendola, 122/D 70126 Bari, Italy Ph.: +39 080 5929437 Fax: +39 080 5929460 Email:adamo@ba.issia.cnr.it	N/A	2007	Envisat Symposium 2007	Conference Paper	SAR spaceborne capability to detect marine oil spills through the damping of wind generated short gravitycapillary waves has been extensively demonstrated during the past years. In contrast, it has not yet been found any suitable method which exploits VIS/NIR imagery supporting SAR observations. To this end, we propose the use of MODIS and MERIS images acquired in sunglint conditions to reveal smoothed regions such as those affected by oil pollution. The underlying physical mechanism is based on the modification of the surface slopes distribution composing the roughened sea due the action of mineral oils. The methodology is demonstrated for a case study in the Mediterranean Sea where spills were detected by ASAR imaging.	oil spill; SAR; MODIS; MERIS; sunglint	http://envisat.esa.int/envisatsymposium/proceedings/posters/3P14/463602ad.pdf	N/A	None - PDF provided on disk
Satellite	Synthetic Aperture Radar	Temperate Northern Atlantic	436,400 km2 (Black Sea)	Middle East Technical University	Turkey	Turkish Petroleum Company	Detection and Object-Based Classification of Offshore Oil Slicks Using ENVISAT-ASAR Images	Akar, Sertac (Middle East Technical University)	N/A	Süzen, Mehmet Lutfi (Middle East Technical University) Kaymakci, Nuretdin (Middle East Technical University)	2011	Journal - news, comment, reviews and research reports	Journal - news, comment, reviews and research reports	The aim of this study is to propose and test a multi-level methodology for detection of oil slicks in ENVISAT Advanced Synthetic Aperture Radar (ASAR) imagery, which can be used to support the identification of hydrocarbon seeps. We selected Andrusov Ridge in the Central Black Sea as the test study area where extensive hydrocarbon seepages were known to occur continuously. Hydrocarbon seepage from tectonic or stratigraphic origin at the sea floor causes oily gas plumes to rise up to the sea surface and form thin oil films called oil slicks. Microwave sensors like synthetic aperture radar (SAR) are very suitable for ocean remote sensing as they measure the backscattered radiation from the surface and show the roughness of the terrain. Oil slicks dampen the sea waves creating dark patches in the SAR image. The proposed and applied methodology includes three levels: visual interpretation, image filtering and object-based oil spill detection. Level I, after data preparation with visual interpretation, includes dark spots identification and subsets/scenes creation. After this process, the procedure continues with categorization of subsets/scenes into three cases based on contrast difference of dark spots to the surroundings. In level II, by image and morphological filtering, it includes preparation of subsets/scenes for segmentation. Level III includes segmentation and feature extraction which is followed by object-based classification. The object-based classification is applied with the fuzzy membership functions defined by extracted features of ASAR subsets/scenes, where the parameters of the detection algorithms are tuned specifically for each case group. As a result, oil slicks are discriminated from look-alikes with an overall classification accuracy of 83% for oil slicks and 77% for look-alikes obtained by averaging three different cases.	Synthetic aperture radar, Oil slick, Object-based classification, Black Sea	http://rd.springer.com/article/10.1007/s10661-011-1929-6	0	None - PDF provided on disk
Satellite	SeaWiFS	Tropical eastern Pacific	N/A	Charles Darwin Research Station, Galapagos	Ecuador	NASA research grant NAG5-8865 (through NorthCarolina State University)	SeaWiFS Satellite Monitoring of Oil Spill Impact on Primary Production in the Galapagos Marine Reserve	Banks, S. (Charles Darwin Research Station)	sbanks@fcdarwin.org.ec	N/A	2003	Marine Pollution Bulletin	Journal - news, comment, reviews and research reports	Near daily satellite monitoring of ocean colour using sea viewing wide angle of field viewing sensor (SeaWiFS) allowed the oceanic and near coastal chlorophyll-a distributions to be followed across the Galápagos Marine Reserve (GMR) from space. In the aftermath of the Jessica spill early indications suggested that, compared to the three preceding years 1998-2000, local chlorophyll concentrations over January 2001 were elevated across the Galápagos Marine Reserve [Biological Impacts of the Jessica Oil Spill on the Galápagos Environment: Preliminary Report. Charles Darwin Foundation, Puerto Ayora, Galápagos, Ecuador, 2001]. At the time of the spill the central and eastern extent of the archipelago was experiencing a spatially extensive moderate bloom event (0.5-2.5 mgm(-3) chl-a) extending over the central islands, including the source of the spill and areas of known impact such as the islands of Santa Fé, eastern Santa Cruz and Floreana directly in the advection path.Further investigation shows that chlorophyll across the affected regions of western San Cristóbal, Santa Fé, southeast Santa Cruz, eastern Floreana and eastern Isabela declined in the week directly following the spill event, yet rose in the successive month to levels analogous to preceding years. Although there may have been a localised effect of the spill upon near coast phytoplankton primary production in the short term, the observed variance in the weeks following the spill was not significant in comparison to the normal high variation between years and within the El Niño/Southern Oscillation signal.	Galapagos; Jessica; phytoplankton; marine reserve; primary production; SeaWiFS	http://www.sciencedirect.com/science/article/pii/S0025326X03001620	20	None - PDF provided on disk
Satellite	Synthetic Aperture Radar	N/A	N/A	Norwegian Defence Research Establishment University of Oslo, Department of Informatics	Norway	Norwegian Research Council Norwegian Defence Research Establishment	Oil Spill Detection by Satellite Remote Sensing	Brekke, Camilla (Norwegian Defence Research Establishment/Department of Informatics, University of Oslo)	Camilla.Brekke@ffi.no	Solberg, A.H.S. (Department of Informatics, University of Oslo)	2005	Remote Sensing of Environment	Scientific journal	This paper presents the state of the art for oil spill detection in the world oceans. We discuss different satellite sensors and oil spill detectability under varying conditions. In particular, we concentrate on the use of manual and automatic approaches to discriminate between oil slicks and look-alikes based on pattern recognition. We conclude with a discussion of suggestions for further research with respect to oil spill detection systems.	Synthetic aperture radar; Oil spill; Detectability; Manual detection; Automatic algorithms; Dark spot detection; Feature extraction; Classification	http://www.sciencedirect.com/science/article/pii/S0034425704003724	219	None - PDF provided on disk
Satellite	Synthetic Aperture Radar	N/A	N/A	Dalian Maritime University, Environment Information Institution	China	Unknown	Oil Spills Identification in SAR Image Using Mahalanobis Distance	Chen, Peng (Dalian Maritime University)	yeyuguang@sina.com	Zhou, Hui (Dalian Neusoft Institute of Information) Wang, Xiao Tian (Dalian Neusoft Institute of Information)	2011	Advanced Materials Research	Open Access Journal	This paper presents a method of oil spills identification in Synthetic Aperture Radar (SAR) image based on feature vector, it makes use of the advantages of SAR which can work on day and night and all weather conditions with high resolution monitoring for oil spills. Use the algorithm of Mahalanobis distance to identify the target object and gain the feature vector through evaluating SAR image of the dark area boundary. It is proved by experiment that the number of selected feature value is reasonable and more effective for estimating whether has oil spills than the traditional one. The accuracy rate can reach 96% or even more for using the algorithm of Mahalanobis distance and compare to the other methods of oil spills identification it is easy for programming implementation with less conditions.	oil spill identification, Mahalanobis distance	http://www.scientific.net/AMR.466-467.246	0	Yes - Article available for purchase

Peer Reviewed Remote Sensing Papers

Platform	Sensor	Geographical Area of Study	Areal Extent of Study	Institution	Country	Funding Source	Article Title	Principal Investigator/ Author	Contact Information	Co-Authors (if any)	Year	Source	Publication Type	Abstract	Keywords	Link to Website	No. of Citations	Copyright Issues?
Satellite	Moderate Resolution Imaging Spectroradiometer Synthetic Aperture Radar (Advanced)	Temperate Northern Atlantic	N/A	Instituto Nazionale di Geofisica e Vulcanologia Universitu di Bologna Oceanography Centre, University of Cyprus Instituto per le Scienze dell'Atmosfera e del Clima University of Athens	Cyprus Greece Italy	Italian Space Agency (PRIMI project - ASI Contract No. I/094/06/0)	Hindcast of oil-spill pollution during the Lebanon crisis in the Eastern Mediterranean, July–August 2006	Coppini, Giovanni (Instituto Nazionale di Geofisica e Vulcanologia/Centro Interdipartimentale di Ricerca per le Scienze Ambientali, Università di Bologna)	Giovanni Coppini Instituto Nazionale di Geofisica e Vulcanologia, Sezione di Bologna, Italy coppini@bo.ingv.it	Dominicis, Michela De (Instituto Nazionale di Geofisica e Vulcanologia) Zodiatis, George (Oceanography Centre, University of Cyprus) Pinardi, Nadia (Centro Interdipartimentale di Ricerca per le Scienze Ambientali, Universitu di Bologna) et al. (see report)	2011	Marine Pollution Bulletin	Journal - news, comment, reviews and research reports	MOON (Mediterranean Operational Oceanography Network http://www.moon-oceanforecasting.eu) provides near-real-time information on oil-spill detection (ocean color and SAR) and predictions [ocean forecasts (MFS and CYCOFOS) and oil-spill predictions (MEDSLIK)]. We employ this system to study the Lebanese oil-pollution crisis in summer 2006 and thus to assist regional and local decision makers in Europe, regionally and locally. The MEDSLIK oil-spill predictions obtained using CYCOFOS high-resolution ocean fields are compared with those obtained using lower-resolution MFS hydrodynamics, and both are validated against satellite observations. The predicted beached oil distributions along the Lebanese and Syrian coasts are compared with in situ observations. The oil-spill predictions are able to simulate the northward movement of the oil spill, with the CYCOFOS predictions being in better agreement with satellite observations. Among the free MEDSLIK parameters tested in the sensitivity experiments, the drift factor appears to be the most relevant to improve the quality of the results.	Lebanese oil-pollution event; Oil-spill modeling; Operational oceanography; Remote sensing; Levantine Basin	http://194.42.1.1/~georgios/pdfiles/MPB2011.pdf	6	None - PDF provided on disk
Satellite	Synthetic Aperture Radar	N/A	N/A	Shandong Marine Safety Administration Yantai Oil Spill Response Technology Center	China	Unknown	Application of the Marine Oil Spill Surveillance by Satellite Remote Sensing	Dan, Wu (Shandong Marine Safety Adm./Yantai Oil Spill Response Tech. Center)	N/A	Jifeng, Shen Yongzhi, Zhang Pu, Zhao	2009	Geoscience and Remote Sensing Symposium, 2008. IGARSS 2008. IEEE International	Conference Paper	Oil spill accidents are seen relatively frequent and becomes a severe threat to coastal and marine ecosystems and water quality. Thus, active surveillance and rapid response to marine oil spills is important and essential to environment protection. So, this paper lays emphasis on the research of monitoring the marine oil spills for application by satellite remote sensing especially SAR. Imaging characteristics of satellites and image-forming principle of oil spill information in remote sensing images are analyzed at first. Then how to monitor the marine oil spills by satellite remote sensing and how to identify and detect marine oil spills information in SAR images are discussed mainly. Through the practical applications examples of the marine oil spill surveillance by satellite remote sensing in oil spill accidents of oil tanker ldquoHebei Spiritrdquo, the method this paper proposed is proved to be very effectively and feasibly for the fast response and detection to oil spills especially in the waters near Bohai sea of China. Finally future development of marine oil spill surveillance is suggested with conclusion.	oil spill; satellite remote sensing; SAR; IdquoHebei Spiritrdquo; China; Bohai Sea; surveillance	http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=5200170&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D5200170	2	Yes - Article available for purchase
Satellite	Synthetic Aperture Radar	N/A	N/A	Università tor Vergata	Italy	Uknown	Neural Networks for Oil Spill Detection Using ERS-SAR Data	Del Frate, F. (Università tor Vergata)	delfrate@disp.uniroma2.it	Petrocchi, A. (Vitrociset c/o ESA/ESRIN) Lichtenegger, J. (ESA/ESRIN) Calabresi, G. (ESA/ESRIN)	2000	IEEE Transactions on Geoscience and Remote Sensing	Open Access Journal	A neural network approach for semi-automatic detection of oil spills in European remote sensing satellite-synthetic aperture radar (ERS-SAR) imagery is presented. The network input is a vector containing the values of a set of features characterizing an oil spill candidate. The classification performance of the algorithm has been evaluated on a data set containing verified examples of oil spill and look-alike. A direct analysis of the information content of the calculated features has been also carried out through an extended pruning procedure of the net.	ERS-synthetic aperture radar (SAR), neural networks, oil spill detection	http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=868885	110	Yes - can share with CCC license
Satellite	Synthetic Aperture Radar	Temperate Northern Pacific	N/A	California Institute of Technology	USA	David and Lucile Packard Foundation Keck Foundation Minerals Management Service NASA Earth Science Enterprise program USC Sea Grant Program	Coastal Pollution hazards in Southern California Observed by SAR Imagery: Stormwater Plumes, Wastewater Plumes, and Natural Hydrocarbon Seeps	Digiacome, P.M. (California Institute of Technology)	pmd@pacific.jpl.nasa.gov	Washburn, L. (UCSB) Holt, B. (California Institute of Technology) Jones, B.H. (USC)	2004	Marine Pollution Bulletin	Journal - news, comment, reviews and research reports	Stormwater runoff plumes, municipal wastewater plumes, and natural hydrocarbon seeps are important pollution hazards for the heavily populated Southern California Bight (SCB). Due to their small size, dynamic and episodic nature, these hazards are difficult to sample adequately using traditional in situ oceanographic methods. Complex coastal circulation and persistent cloud cover can further complicate detection and monitoring of these hazards. We use imagery from space-borne synthetic aperture radar (SAR), complemented by field measurements, to examine these hazards in the SCB. The hazards are detectable in SAR imagery because they deposit surfactants on the sea surface, smoothing capillary and small gravity waves to produce areas of reduced backscatter compared with the surrounding ocean. We suggest that high-resolution SAR, which obtains useful data regardless of darkness or cloud cover, could be an important observational tool for assessment and monitoring of coastal marine pollution hazards in the SCB and other urbanized coastal regions.	hydrocarbon seeps; runoff; slicks; Southern California; wastewater	http://www.sciencedirect.com/science/article/pii/S0025326X04002693	31	None - PDF provided on disk

Peer Reviewed Remote Sensing Papers

Platform	Sensor	Geographical Area of Study	Areal Extent of Study	Institution	Country	Funding Source	Article Title	Principal Investigator/ Author	Contact Information	Co-Authors (if any)	Year	Source	Publication Type	Abstract	Keywords	Link to Website	No. of Citations	Copyright Issues?
Satellite	Various	Western Indo-Pacific	N/A	Japan Oil Development Co., Ltd. JGI, Inc. Global Scan Technologies United Arab Emirates University	United Arab Emirates	Uknown	Operational Remote Sensing for the Detection and Monitoring of Oil Pollution in the Arabian Gulf: Case Studies from the United Arab Emirates	Essa, Salem (UAE University)	salem.essa@uaeu.ac.ae	Harahsheh, Hussein (Global Scan Technologies) Shiobara, Manabu (Japan Oil Development Co., Ltd.) Nishidai, Takashi (JGI, Inc.)	2005	Developments in Earth and Environmental Sciences	Scientific research collection - printed and digital	Oil spill pollution is a serious threat to marine environments along the UAE coast line. Considerable oil spills have been caused by accidental and deliberate oil sludge dumping from passing ships during the past. Damage to fishery, seawater desalination, and damage to plants and natural habitats are of real concern. The purpose of this study is to investigate and demonstrate the feasibility of using different types of satellite imagery for detecting oil spills in the Arabian Gulf, offshore the UAE. A number of satellite data were processed and analyzed by using images from early US intelligence satellites of the mid-seventies to the most recent earth observation satellites, European ENVISAT, 2003. The analysis focused not only on oil spill but also on various appearances of oceanographic phenomena. A practical method for discriminating oil spills is an invaluable tool for marine oil spill surveillance. It is confirmed that the offshore of the United Arab Emirates faces frequent occurrences of oil spills in the Arabian Gulf and in the Gulf of Oman. Discharged oil and widely spread oil slicks in offshore Fujairah were confirmed by a sea truth campaign carried out in early 2003. An Oil Spill Atlas is being edited and is due to be published by the UAE University this year. The work done is the first step towards oil spill monitoring of the offshore UAE and its adjacent waters. Near-real time monitoring using commercial satellites is thought to be feasible. Future earth observation satellites including the forthcoming Japanese ALOS and internationally operating earth observation satellites in conjunction with marine numerical modeling techniques are expected to be very efficient tools for marine pollution surveillance in the coming future. Finally, an operational monitoring system integrating near-real time satellite observation with GIS mainframe is an ultimate goal that would constitute the nucleus for an Early Warning System to protect the marine environment of the Gulf States against oil pollution.	oil spill pollution; UAE; oil sludge dumping; ENVISAT; Fujairah; Oil Spill Atlas; ALOS	http://www.sciencedirect.com/science/article/pii/S1571919705800278	1	Yes - Article available for purchase
Satellite	Synthetic Aperture Radar	Temperate Northern Atlantic	N/A	Joint Research Centre	Italy	European Commission	Towards an Operational use of Space Imagery for Oil Pollution Monitoring in the Mediterranean Basin; A Demonstration in the Adriatic Sea	Ferraro, G. (Joint Research Centre)	guido.ferraro@jrc.it	Bernardini, A (Joint Research Centre) David, M. (University of Ljubljana) Meyer-Roux, S. (Joint Research Centre) Muellenhoff, O. (Joint Research Centre) Perkovic, Marko (University of Ljubljana) Tarchi D. (Joint Research Centre) Topouzelis, Konstantinos (Joint Research Centre)	2007	Marine Pollution Bulletin	Journal - news, comment, reviews and research reports	Studies of operational pollution carried out by European commission - Joint Research Centre in the Mediterranean Sea for the years 1999-2004 are briefly introduced. The specific analysis of the Adriatic Sea for the same period demonstrates that this area has been characterized by a relevant number of illegal discharges from ships. After setting the historical background of the project AESOP (aerial and satellite surveillance of operational pollution in the Adriatic Sea), the content, partners and aim of the project are presented. Finally, the results of the first phase of the AESOP project are presented. The results seem very encouraging. For the first time in the Adriatic, real time detection of oil spills in satellite images and an immediate verification by the Coast Guard has been undertaken. An exploratory activity has also been carried out in collaboration with the University of Ljubljana to use automatic information system (AIS) to identify the ships detected in the satellite images.	oil spill; Illicit discharges; SAR, Monitoring; Mediterranean Sea; Adriatic Sea; Maritime surveillance	http://www.sciencedirect.com/science/article/pii/S0025326X06005005	25	None - PDF provided on disk
Satellite	Synthetic Aperture Radar	N/A	N/A	Joint Research Centre	Italy	European Commission	On the SAR Derived Alert in the Detection of Oil Spills According to the Analysis of the EGEMP	Ferraro, G. (Joint Research Centre)	guido.ferraro@jrc.ec.europa.eu	Baschek, Björn (Federal Institute of Hydrology, Germany) de Montpellier, Geraldine (Management Unit of the North Sea Mathematical Models) Njoten, Ove (Norwegian Coastal Administration) Perkovic, Marko (University of Ljubljana) Vespe, Michele (Joint Research Centre)	2010	Marine Pollution Bulletin	Journal - news, comment, reviews and research reports	Satellite services that deliver information about possible oil spills at sea currently use different labels of ''confidence'' to describe the detections based on radar image processing. A common approach is to use a classification differentiating between low, medium and high levels of confidence. There is an ongoing discussion on the suitability of the existing classification systems of possible oil spills detected by radar satellite images with regard to the relevant significance and correspondence to user requirements. This paper contains a basic analysis of user requirements, current technical possibilities of satellite services as well as proposals for a redesign of the classification system as an evolution towards a more structured alert system. This research work offers a first review of implemented methodologies for the categorization of detected oil spills, together with the proposal of explorative ideas evaluated by the European Group of Experts on satellite Monitoring of sea-based oil Pollution (EGEMP).	Sea satellite monitoring; SAR; Oil spills; Alert system designs; Maritime surveillance	www.vliz.be/imisdocs/publications/212363.pdf	8	None - PDF provided on disk

Peer Reviewed Remote Sensing Papers

Platform	Sensor	Geographical Area of Study	Areal Extent of Study	Institution	Country	Funding Source	Article Title	Principal Investigator/ Author	Contact Information	Co-Authors (if any)	Year	Source	Publication Type	Abstract	Keywords	Link to Website	No. of Citations	Copyright Issues?
Satellite	Synthetic Aperture Radar	N/A	N/A	Geodesy Space Centre Italian Space Agency	Italy	European Space Agency	Oil Spill Detection Using Marine SAR Images	Fiscella, B. (Dipartimento di Fisica Generale, Universitá di Torino)	fiscella@ph.unito.it	Giancaspro, A. (Telespazio, Geodesy Space Centre) Nirchio, F. (ASI, Geodesy Space Centre) Pavese, P. (Istituto di Cosmogeofisica, CNR) Trivero, P. (Universita del Piemonte Orientale)	2000	International Journal of Remote Sensing	Open Access Journal	A probabilistic approach to distinguish oil spills from other similar oceanic features in marine Synthetic Aperture Radar (SAR) images has been developed and tested. The method uses statistical information obtained from previous measurements of physical and geometrical characteristics for both oil spill and natural features. A sample image is evaluated using two different procedures to determine the probability that it is an oil spill, the results of the two procedures are then compared. The classification-algorithm performance was evaluated using a test dataset containing 80 examples that were oil spills and 43 that were natural features exhibiting characteristics similar to oil spills: more than 80% of the samples were classified correctly. The reliability of the method was then determined using a new dataset and similar results were obtained.	marine oil spill, SAR	http://www.tandfonline.com/doi/abs/10.1080/014311600750037589#preview	106	Yes - can share with CCC license
Satellite	Synthetic Aperture Radar	Temperate Northern Atlantic	N/A	Directorate General Joint Research Centre	Spain	European Commission	The Use of Satellite Radar Imagery in the Prestige Accident	Fortuny, Joaquim (JRC) Tarchi, Dario (JRC) Ferraro, Guido (JRC) Sieber, Alois (JRC)	European Commission - Directorate General Joint Research Centre Via E. Fermi, 1, I-21020 ISPRA (VA) Italy	N/A	2004	Proceedings of the Interspill 2004	Conference Paper	The support activities within the European Commission (EC) DG Joint Research Centre (JRC) during the Prestige accident are described. The basics of the methodology used to process and interpret the satellite images are introduced. Results showing the most relevant image interpretations illustrate the use of space-borne imagery in an emergency phase. Some example image interpretations are validated with results from visual inspections concurrently on the spot.	satellite radar imagery; oil spill; Prestige; Spain; SAR;	http://www.interspill.org/previous-events/2004/pdf/session2/473_FORTUNY.pdf	N/A	None - PDF provided on disk
Satellite	Moderate Resolution Imaging Spectroradiometer Robust Satellite Technique	Tropical Atlantic	N/A	Unknown (paper availabile in book, not yet received)	USA	Unknown	A New RST-Based Approach for Continuous Oil Spill Detection in TIR Range: The Case of the Deepwater Horizon Platform in the Gulf of Mexico	Grimaldi, C.S.L.	N/A	Coviello, I. Lacava, T. Pergola, N. Tramutoli, V.	2011	Monitoring and Modeling the Deepwater Horizon Oil Spill: A Record-Breaking Enterprise [Geophysical Monograph Series, Vol. 195]	Scientific journal	Oil pollution is a threat that increasingly concerns marine/coastal ecosystem. Timely detection and continuous update of information are fundamental to reduce oil spill environmental impact. EOSs, especially meteorological satellites, can be profitably used for a near real time sea monitoring thanks to their high temporal resolution and easy data delivery. In this paper, we present a new algorithm, based on the general Robust Satellite Technique (RST) approach, for automatic near-real-time oil spill detection and continuous monitoring (i.e., in both daytime and nighttime) by using optical data. The new RST scheme has been applied to the analysis of the recent oil spill disaster of the Deepwater Horizon Platform in the Gulf of Mexico. In particular, a dense temporal series of RST-based oil spill maps, obtained by using Moderate Resolution Imaging Spectroradiometer-thermal infrared records acquired in both daytime and nighttime during the 25–29 April 2010 period, are shown and commented. The results seem to confirm the good performance of the proposed approach in automatic detection of oil spill presence with a high level of reliability and sensitivity even in nighttime acquisitions. These achievements confirm the potential of optical data for oil spill detection and monitoring, thus suggesting their use in combination with radar acquisitions toward developing a multiplatform system that is able to furnish detailed and frequent information about oil spill presence and dynamics.	oil spill, robust satellite techniques, MODIS, near real time, thermal infared	http://www.agu.org/books/gm/v195/2011GM001105/2011GM001105.shtml	1	None - PDF provided on disk - need book
Satellite	Moderate Resolution Imaging Spectroradiometer	Tropical Northwestern Atlantic	13,210 km²	University of South Florida Comision Ejecutiva para el Manejo Integral del Lago de Maracaibo y su Cuenca Hidrografica, Governacion del Estado Zulia, Venezuela	USA Venezuela	Cooperative Institute for Coastal and Estuarine Environmental Technology (contract #03-751) NASA (grants NAG5-10738 and NAG5-11254)	MODIS Detects Oil Spills in Lake Maracaibo, Venezuela	Hu, Chuanmin (University of South Florida) Müller-Karger, Frank E. (University of South Florida)	Chuanmin Hu hu@seas.marine.usf.edu	Taylor, Charles (Judd) (University of South Florida) Myhre, Douglas (University of South Florida) Murch, Brock (University of South Florida) Odriozola, Ana L. (University of South Florida) Godoy, Gonzalo (Comisión Ejecutiva para el Manejo Integral del Lago de Maracaibo y su Cuenca Hidrográfica)	2003	EOS, TRANSACTIONS AMERICAN GEOPHYSICAL UNION, VOL. 84, NO. 33	Scientific journal	Starting December 2002, the oil industry operating in and around Lake Maracaibo in Venezuela suffered a series of accidents (Figure 1). Fires, the sinking of two barges, rupture of oil pipelines, spills from floating oil storage and transfer stations, and malfunctioning of oil extraction platforms led to extensive oil spills. Local and federal Venezuelan government oil industry experts directly observed the series of spills from aircraft, helicopter, and various surface vessels. The spills were recorded in December by official photography and video of leaking infrastructure, and unofficial recordings continued in January and February 2003 (http://wwwcomlago.com.ve/fotosvideos. html). These surveys did not provide sufficient spatial or temporal coverage to assess the magnitude, area covered, or duration of the spills. Clear images of the spill were captured with NASAs Moderate Resolution Imaging Spectroradiometer (MODIS), however. MODIS is effectively a sophisticated digital camera launched aboard the Terra satellite in December 1999, and aboard the Aqua satellite in April 2002 [Esaias et al., 1998; http://modis.gsfc.nasa.gov]. Its medium-resolution bands (250 and 500 m resolution) are available to the public, and have great potential in coastal monitoring. This article demonstrates how MODIS can provide basic and critical assessments of oil spills.	Lake Maracaibo; Venezuela; oil spill; MODIS;	http://optics.marine.usf.edu/events/GOM_rigfire/images/oil_spill_hu.pdf http://www.agu.org/pubs/crossref/2003/2003EO330002.shtml	0	None - PDF provided on disk
Satellite	Synthetic Aperture Radar	N/A	N/A	Chinese Academy of Sciences University of Calgary	Canada China	Uknown	A Level Set Method for Oil Slick Segmentation in SAR Images	Huang, B. (University of Calgary)	huang@geomatics.ucalgary.ca	Li, H. (Chinese Academy of Sciences) Huang, X. (Chinese Academy of Sciences)	2005	International Journal of Remote Sensing	Open Access Journal	Despite much effort and significant progress in recent years, image segmentation remains a challenging problem in image processing, especially for the low contrast, noisy synthetic aperture radar (SAR) images. This paper explores the segmentation of oil slicks using a partial differential equation (PDE)-based level set method, which represents the slick surface as an implicit propagation interface. Starting from an initial estimation with priori information, the level set method creates a set of speed functions to detect the position of the propagation interface. Specifically, the image intensity gradient and the curvature flow are utilized together to determine the speed and direction of the propagation. This allows the front interface to propagate naturally with topological changes, significant protrusions and narrow regions, giving rise to stable and smooth boundaries that discriminate oil slicks from the surrounding water. As the speckles are removed concurrently while the front interface propagates, the pre-filtering of noise is saved. The proposed method has been illustrated by experiments on oil slick segmentation using the ERS-2 SAR images. Its advantages over the traditional image segmentation approaches have also been demonstrated.	image segmentation; level set; oil slick; SAR; remote sensing; imaging science & photographic technology	http://www.tandfonline.com/doi/abs/10.1080/01431160512331326747#preview	21	Yes - can share with CCC license

Peer Reviewed Remote Sensing Papers

Platform	Sensor	Geographical Area of Study	Areal Extent of Study	Institution	Country	Funding Source	Article Title	Principal Investigator/ Author	Contact Information	Co-Authors (if any)	Year	Source	Publication Type	Abstract	Keywords	Link to Website	No. of Citations	Copyright Issues?
Satellite	Synthetic Aperture Radar	Temperate Northern Atlantic	41 km by 4-15 km	Russian Academy of Sciences	Russia	Russian Foundation for Basic Research	The Oil Spill from a Shipwreck in Kerch Strait: Radar Monitoring and Numerical Modelling	Ivanov, A. Yu (Russian Academy of Sciences)	ivanoff@ocean.ru	N/A	2010	International Journal of Remote Sensing	Open Access Journal	An oil-spill emergency occurred in Kerch Strait (between the Black Sea and the Sea of Azov) on 11 November 2007 after the sinking of the tanker Volgoneft-139 in a severe storm. The results of monitoring with Radarsat-1, TerraSAR-X and Envisat synthetic aperture radar (SAR)-equipped satellites with results from the numerical SPILLMOD model are compared. Analysis of the spatial distribution of oil pollution visible on the SAR images shows that the majority of oil was the result of this accident. SAR images were used to locate and calculate areas of regions with the greatest contamination by fuel oil. Comparison of these oil areas with results from the oil-spill prediction model generally shows good agreement.	Kerch straight, SAR, radar monitoring, numerical modeling	http://www.tandfonline.com/doi/abs/10.1080/01431161.2010.485215#preview	3	Yes - can share with CCC license
Satellite	Synthetic Aperture Radar	Cold Temperate Northwest Pacific	N/A	P.P. Shirshov Institute of Oceanology, Russian Academy of Sciences Ocean Remote Sensing Institute, Ocean University of Qingdao	China	Ministry of Education of China	Oil Spill Detection with the RADARSAT SAR in the waters of the Yellow and East China Sea: A Case Study	Ivanov, Andrei (P.P. Shirshov Institute of Oceanology, Russian Academy of Sciences)	Andrei Ivanov P.P. Shirshov Institute of Oceanology, Russian Academy of Sciences Nakhimovsky prospect 36, Moscow, 117851, Russia Tel: 7 (095) 124-7392, ivanoff@sio.rssi.ru	He, Ming-Xia (Ocean Remote Sensing Institute, Ocean University of Qingdao) Fang, Ming-Qiang (Ocean Remote Sensing Institute, Ocean University of Qingdao)	2002	CiteSeer	Open Access Journal	This application study highlights the potential of wide-swath synthetic aperture radar (SAR) imagery for the regional oil pollution monitoring. As a pre-phase of the pilot-project this paper presents the preliminary results of the oil spill observations with SAR in the Yellow and East China Sea. A set of full resolution Radarsat (ScanSAR Narrow) SAR images collected between November 15 and 22, 2000 over the Yellow and East China Sea was analyzed for presence of oil spills. By using visual and image processing methods oil spill candidates on the Radarsat images have been selected, their locations defined, statistic estimated and possible risk areas outlined. Results show that generally small oil patches (about several km) are uniformly distributed along the main ship routes and have been probably released from ships. Large oil slicks were observed near the coastline close to big seashore cities/ports, oil exploitation areas and river mouths. Additionally collected data on sea/weather conditions indicated that all oil spill candidates have been detected in a comparatively narrow range of wind conditions (3-7 m/s) and in a wide range of sea surface manifestations. It is concluded that the Radarsat SAR, in its ScanSAR mode, is valuable tool for oil spill detection/localization, but the detectability essentially depended on wind conditions. The results also indicate that despite of the international/domestic conventions and legislati on, oil spills in the sea are still remaining a main unsolved and uncontrolled environmental problem.	oil pollution; oil spill detection; Radarsat; synthetic aperture radar; SAR images	http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.131.5478&rep=rep1&type=pdf	3	None - PDF provided on disk
Satellite	Synthetic Aperture Radar	Temperate Northern Atlantic Southern coast of Norway	N/A	Nansen Environmental and Remote Sensing Center (NERSC)	Norway	Unknown	Coastwatch: Integrating Satellite SAR Imagery in an Operational System for Monitoring Coastal Currents, Wind, Surfactants and Oil Spills	Johannessen, O.M. (Nansen Environmental and Remote Sensing Center, Norway/Geophysical Institute, University of Bergen)	Ola.Johannessen@nrsc.no	Espedal, H.A. (Nansen Environmental and Remote Sensing Center, Norway) Furevik, B. (Nansen Environmental and Remote Sensing Center, Norway) Akimov, D. (Nansen Environmental and Remote Sensing Center, Russia) Jenkins, A. (Norwegian Meteorological Institute)	2002	Elsevier Oceanography Series	Scientific journal	This paper describes the ongoing efforts at the Nansen Environmental and Remote Sensing Center (NERSC) to integrate Synthetic Aperture Radar (SAR) imagery into an operational coastal monitoring system. The capabilities of the SAR to image ocean waves, internal waves, bathymetry, eddies, fronts, natural film, oil slicks and wind in the marine boundary layer, have previously been demonstrated. In order to quantify products of ocean fronts, natural films, wind speed and wind fronts, SAR imagery obtained along the southern coast of Norway has been analysed in conjunction with in situ information, numerical models and other available remote sensing data. The results are used in the process of validation and improvement of SAR ocean models and SAR operational applications.	SAR, oil spill. Remote sensing	http://www.sciencedirect.com/science/article/pii/S0422989402800526	2	Yes - Article available for purchase
Satellite	Synthetic Aperture Radar	Temperate Northern Atlantic	N/A	University of Wales Bangor	UK	Coastguard Agency of the Department of the Environment, Transport and the Regions, UK	A Comparison of visual Observations of Surface Oil with Synthetic Aperture Radar Imagery of the Sea Empress Oil Spill	Jones, B. (University of Wales Bangor)	bj@uces.bangor.ac.uk	N/A	2001	International Journal of Remote Sensing	Open Access Journal	A comparison has been made between the visual observations of surface oil and four satellite-borne Synthetic Aperture Radar (SAR) images taken during the Sea Empress oil spill in February 1996. Whilst the basic oil slick imaging capabilities of SAR are well documented, to be of use at the time of a major oil spill, the imagery must be able to provide information on the thickness of oil. This analysis suggests that, under certain environmental conditions, this is possible. The optimum wind speed for the identification of heavy surface oil is around 5-6 m s-1 . At this wind speed, light and medium sheen is not evident in the imagery and there is a distinction between the backscatter reductions due to heavy sheen and thick brown/black oil. At higher wind speeds, even thick oil slicks readily mix into the water column and their SAR signature weakens. In light winds, pattern recognition is very important to the identification of oil slicks. The images are more sensitive to the presence of sheen within the sheltered waters of Milford Haven than in the open coastal waters, indicating a possible relationship between sheen visibility in satellite-borne SAR and sea state.	wind speed; sheen visibility; Milford Haven	http://www.tandfonline.com/doi/abs/10.1080/713861238#preview	27	Yes - can share with CCC license

Peer Reviewed Remote Sensing Papers

Platform	Sensor	Geographical Area of Study	Areal Extent of Study	Institution	Country	Funding Source	Article Title	Principal Investigator/ Author	Contact Information	Co-Authors (if any)	Year	Source	Publication Type	Abstract	Keywords	Link to Website	No. of Citations	Copyright Issues?
Satellite	Synthetic Aperture Radar	Temperate Northern Atlantic Central Indo-Pacific	N/A	National Technical University of Athens	Greece	National Technical University of Athens	Automatic Detection and Tracking of Oil Spills in SAR Imagery with Level Set Segmentation	Karantzalos, K. (National Technical University of Athens)	karank@central.ntua.gr	Argialas, D. (National Technical University of Athens)	2008	International Journal of Remote Sensing	Open Access Journal	Automatic detection and monitoring of oil spills and illegal oil discharges is of fundamental importance in ensuring compliance with marine legislation and protection of the coastal environments, which are under considerable threat from intentional or accidental oil spills, uncontrolled sewage and wastewater discharged. In this paper, the level set based image segmentation was evaluated for the real-time detection and tracking of oil spills from SAR imagery. The processing scheme developed consists of a pre-processing step, in which an advanced image simplification takes place, followed by a geometric level set segmentation for the detection of possible oil spills. Finally, a classification was performed for the separation of look-alikes, leading to oil spill extraction. Experimental results demonstrate that the level set segmentation is a robust tool for the detection of possible oil spills, copes well with abrupt shape deformations and splits and outperforms earlier efforts that were based on different types of thresholds or edge detection techniques. The developed algorithm's efficiency for real-time oil spill detection and monitoring was also tested.	oil spills, level set segmentation	http://www.tandfonline.com/doi/abs/10.1080/01431160802175488#preview	7	Yes - can share with CCC license
Satellite	Synthetic Aperture Radar	Temperate Northern Atlantic	N/A	National Technical University of Athens; Greek National Centre of Marine Research	Greece	National Technical University of Athens	An object-oriented methodology to detect oil spills	Karathanassi, V. (National Technical University of Athens)	karathan@survey.ntua.gr	Topouzelis, Konstantinos (Joint Research Centre) Pavlakis, P. (Hellenic Centre for Marine Research) Rokos, D. (National Technical University of Athens)	2006	International Journal of Remote Sensing	Open Access Journal	A new automated methodology for oil spill detection is presented, by which full synthetic aperture radar (SAR) high-resolution image scenes can be processed. The methodology relies on the object-oriented approach and profits from image segmentation techniques to detected dark formations. The detection of dark formations is based on a threshold definition that is fully adaptive to local contrast and brightness of large image segments. For the detection process, two empirical formulas are developed that also permit the classification of oil spills according to their brightness. A fuzzy classification method is used to classify dark formations as oil spills or look-alikes. Dark formations are not isolated and features of both dark areas and sea environment are considered. Various sea environments that affect oil spill shape and boundaries are grouped in two knowledge bases, used for the classification of dark formations. The accuracy of the method for the 12 SAR images used is 99.5% for the class of oil spills, and 98.8% for that of look-alikes. Fresh oil spills, fresh spills affected by natural phenomena, oil spills without clear stripping, small linear oil spills, oil spills with broken parts and amorphous oil spills can be successfully detected.	oil spill identification, object-oriented methodology	http://www.tandfonline.com/doi/abs/10.1080/01431160600693575#preview	27	Yes - can share with CCC license
Satellite	Synthetic Aperture Radar	Temperate Northern Atlantic	N/A	National Technical University University of Athens	Greece	Uknown	Automatic Identification of Oil Spills on Satellite Images	Keramitsoglou, Iphigenia (University of Athens)	ikeram@cc.uoa.gr	Cartalis, C. (University of Athens) Kiranoudis, C.T. (National Technical University)	2006	Environmental Monitoring and Assessment	Journal - news, comment, reviews and research reports	A fully automated system for the identification of possible oil spills present on Synthetic Aperture Radar (SAR) satellite images based on artificial intelligence fuzzy logic has been developed. Oil spills are recognized by experts as dark patterns of characteristic shape, in particular context. The system analyzes the satellite images and assigns the probability of a dark image shape to be an oil spill. The output consists of several images and tables providing the user with all relevant information for decision-making. The case study area was the Aegean Sea in Greece. The system responded very satisfactorily for all 35 images processed. The complete algorithmic procedure was coded in MS Visual C++ 6.0 in a stand-alone dynamic link library (dll) to be linked with any sort of application under any variant of MS Windows operating system.	Oil spills; SAR; Remote sensing; Sea surface; Marine pollution; Fuzzy logic	http://www.sciencedirect.com/science/article/pii/S1364815204003275	62	None - PDF provided on disk
Satellite	TerraSAR-X	Temperate Northern Pacific	N/A	Seoul National University	South Korea	Korea Meteorological Administration Research and Development Program under Grant CATER 2009-3113 Natural Science and Engineering Research Council of Canada Discovery Grant	Application of TerraSAR-X Data for Emergent Oil-Spill Monitoring	Kim, Duk-jin (Seoul National University)	djkim@snu.ac.kr	Moon, Wooil M. (University of Manitoba) Kim, Youn-Soo (Korea Aerospace Research Institute)	2010	IEEE Transactions on Geoscience and Remote Sensing	Open Access Journal	Synthetic aperture radar (SAR) signals can propagate through hazardous weather and atmospheric conditions with heavy cloud cover, volcanic dust, snow, or rain. The all-weather capabilities of SARs have attracted significant interest in remote sensing communities, since serious environmental disasters such as oil spills have been highly ??elusive?? to optical sensors, making visible spectrum data vulnerable to rapidly changing atmospheric conditions. In this paper, we discuss the technical functionalities of TerraSAR-X from the emergency response perspective, describing its technical abilities in terms of a damping ratio, radiometric accuracy, and noise level with reference to the actual Hebei Spirit oil-spill incident that occurred on the west coast of the Korean peninsula in December 2007. The damping ratios estimated from the TerraSAR-X data as a function of Bragg wavenumber for various wind speeds indicate that TerraSAR-X data can be effectively used to identify oil-spill areas with acceptable accuracy. We also received ERS-2, ENVISAT, RADARSAT-1, and ALOS PALSAR data for this oil-spill event, not simultaneously but with varying time delays. The processing results for the multitemporal data sets obtained from the X- and C-band SAR systems are useful since they can be used to determine the near-real-time migration of spilt oil. The results of the current study indicate that there are distinct advantages of using X-band TerraSAR-X data for oil-spill detection compared to the data obtained at other available frequencies.	damping ratio, emergency response, Hebei Spirit, oil spills, TerraSAR_X, X-band synthetic aperture radar	http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=5357426&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D5357426	11	Yes - can share with CCC license

Peer Reviewed Remote Sensing Papers

Platform	Sensor	Geographical Area of Study	Areal Extent of Study	Institution	Country	Funding Source	Article Title	Principal Investigator/ Author	Contact Information	Co-Authors (if any)	Year	Source	Publication Type	Abstract	Keywords	Link to Website	No. of Citations	Copyright Issues?
Satellite	Synthetic Aperture Radar	Temperate Northern Atlantic	N/A	Institute for Space Applications and Remote Sensing, National Observatory of Athens	Greece	Uknown	Evaluating the Performance of the Space-Borne SAR Sensor Systems for Oil Spill Detection and Sea Monitoring over the South-Eastern Mediterranean Sea	Kontoes, C.C. (National Observatory of Athens)	kontoes@space.noa.gr	Sykioti, O. (National Observatory of Athens) Paronis, D. (National Observatory of Athens) Harasi, A. (National Observatory of Athens)	2005	International Journal of Remote Sensing	Open Access Journal	Synthetic Aperture Radar (SAR) images have been extensively used for the detection of oil spills in the marine environment as they are independent of local weather conditions, cloudiness and sun illumination. The objective of the study was to provide the users with specific knowledge on SAR image availability over a target area and assess the monitoring capability (visibility of an area) with respect to the requirements for oil-spill detection and marine environment protection over the south-eastern part of the Mediterranean Sea. For this purpose, a web GIS tool has been implemented, enabling the users to submit their queries and receive answers in the form of reports and statistics, concerning the current image acquisition capability over the area of interest. It also provides the user with graphic representations of the sensors' swath coverages over the same geographic location. The system has been tested over the Hellenic Seas and the resulting figures denoting the temporal resolution in the observation are analysed and discussed. The analysis shows that the operation of the Envisat satellite, in conjunction with ERS-2 and Radarsat satellites, has significantly improved the monitoring capability. As shown, the increase in the number of observations over a target location can reach theoretically a level of 130%. In conclusion, the study provides the user with an assessment of the remaining technological gaps and unmet user needs in the domain of marine environment protection.	Remote Sensing, Imaging Science & Photographic Technology, web GIS,	http://www.tandfonline.com/doi/abs/10.1080/01431160500104129	1	Yes - can share with CCC license
Satellite	Synthetic Aperture Radar	Temperate Northern Atlantic Southeastern Baltic Sea	N/A	Atlantic Research Institute for Fishery and Oceanography LUKOIL-Kaliningradmorneft Marine Hydrophysical Institute, National Academy of Sciences of the Ukraine P.P. Shirshov Institute of Oceanology/Russian Space Research Institute/Geophysical Center, Russian Academy of Sciences Russian Research Institute for Space Instrument-Making State Oceanographic Institute	Russia	LUKOIL-Kaliningradmorneft	Operational satellite monitoring of oil spill pollution in the southeastern Baltic Sea: 18 months experience	Kostianoy, Andrey (Russian Academy of Sciences) Litovchenko, Konstantin (Russian Research Institute for Space Instrument-Making) Lavrova, Olga (Russian Academy of Sciences) Mityagina, Marina (Russian Academy of Sciences) Bocharova, Tatyana (Russian Academy of Sciences) et al.	kostianoy@mail.mipt.ru	N/A	2006	Environmental research, engineering and management	Open Access Journal	In June 2003 LUKOIL-Kaliningradmorneft initiated a pilot project, aimed to the complex monitoring of the southeastern Baltic Sea, in connection with a beginning of oil production at continental shelf of Russia in March 2004. Operational monitoring was performed in June 2004 - November 2005 on the base of daily satellite remote sensing (AVHRR NOAA, MODIS, TOPEX/Poseidon, Jason-1, ENVISAT ASAR and RADARSAT SAR imagery) of sea surface temperature (SST), sea level, chlorophyll concentration, mesoscale dynamics, wind and waves, and oil spills. As a result complex information on oil pollution of the sea, SST, distribution of suspended matter, chlorophyll concentration, sea currents and meteorological parameters has been received. In total, 274 oil spills were detected in 230 ASAR ENVISAT images (400x400 km, 75 m/pixel resolution) and 17 SAR RADARSAT images (300x300 km, 25 m/pixel resolution) received during 18 months. The interactive numerical model Seatrack Web SMHI (The Swedish Meteorological and Hydrological Institute) was used for a forecast of the drift of (1) all large oil spills detected by ASAR ENVISAT in the southeastern Baltic Sea and (2) virtual (simulated) oil spills from the D-6 platform. The latter was done daily for operational correction of the action plan for accident elimination at the D-6 and ecological risk assessment (oil pollution of the sea and the Curonian Spit). Probability of the oil spill drift directed to the Curonian Spit equals to 67%, but only in a half of these cases oil spills could reach the coast during 48 h after an accidental release of 10 m3 of oil.	monitoring, oil pollution, Baltic Sea	http://www.apini.lt/files/6f3eabb480a2218b165df95bf2c37b77	21	None - PDF provided on disk
Satellite	Advanced Very High Resolution Radiometer Synthetic Aperture Radar	Temperate South America Temperate Northern Pacific	N/A	Goddard Space Flight Center	USA	NASA	Wavelet Analysis of SAR Images for Coastal Monitoring	Liu, Antony K. (NASA)	liu@neptune.gsfc.nasa.gov	WU, Sunny Y. (NASA) TSENG, William Y. (NOAA/NESDIS) PICHEL, William G. (NOAA/NESDIS)	2000	Canadian Journal of Remote Sensing	Scientific journal	The mapping of mesoscale ocean features in the coastal zone is a major potential application for satellite data. The evolution of mesoscale features such as oil slicks, fronts, eddies, and ice edge can be tracked by the wavelet analysis using satellite data from repeating paths. The wavelet transform has been applied to satellite images, such as those from Synthetic Aperture Radar (SAR), Advanced Very High-Resolution Radiometer (AVHRR), and ocean color sensor for feature extraction. In this paper, algorithms and techniques for automated detection and tracking of mesoscale features from satellite SAR imagery employing wavelet analysis have been developed. Case studies on two major coastal oil spills have been investigated using wavelet analysis for tracking along the coast of Uruguay (February 1997), and near Point Barrow, Alaska (November 1997). Comparison of SAR images with SeaWiFS (Sea-viewing Wide Field-of-view Sensor) data for coccolithophore bloom in the East Bering Sea during the fall of 1997 shows a good match on bloom boundary. This paper demonstrates that this technique is a useful and promising tool for monitoring of coastal waters.	coastal zones; mesoscale features; wavelet analysis;	http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19990024877_1999026098.pdf	26	Can't provide - PDF for NASA version report from 1998
Satellite	Synthetic Aperture Radar	Temperate Northern Atlantic	N/A	Dalian Maritime University	China	Dalian Maritime University	Research on SAR Oil Spill Monitoring by SVM Based on Texture Features	Long, M. A. (Dalian Maritime University)	N/A	LI, Ying (Dalian Maritime University) Niu, Ying (Dalian Maritime University)	2010	Navigation of China	Open Access Journal	In view of the limitations of Synthetic Aperture Radar(SAR) in monitoring oil spill,this paper proposes that the gray-degree spatial distribution and structure characteristic of pixels should be considered in the classification. Meantime,texture-involving Support Vector Machine(SVM) classification method in remote sensing image processing is suggested in identification of oil slick to solve the problem of insufficient sample numbers.The oil spill accident of ship "Prestige" happened in Spain is taken as the example.The analysis of texture features that are extracted from target samples by GLCM indicates that mean,contrast,variance,entropy,and dissimilarity are effective for oil slick identification.Three methods: minimum distance,Maximum likelihood,and SVM are used to extract oil slick respectively.The results show that SVM has superior classification accuracy.	Support Vector Machine (SVM) classification; oil spills	http://en.cnki.com.cn/Article_en/CJFDTOTAL-ZGHH201001019.htm	0	Yes - Article available for purchase

Peer Reviewed Remote Sensing Papers

Platform	Sensor	Geographical Area of Study	Areal Extent of Study	Institution	Country	Funding Source	Article Title	Principal Investigator/ Author	Contact Information	Co-Authors (if any)	Year	Source	Publication Type	Abstract	Keywords	Link to Website	No. of Citations	Copyright Issues?
Satellite	Synthetic Aperture Radar	Central Indo-Pacific	N/A	Centre for Remote Imaging, Sensing and Processing, National University of Singapore	Singapore	Uknown	Marine Oil Spill Detection, Statistics and Mapping with ERS SAR Imagery in South-East Asia	Lu, J. (National University of Singapore)	jingxuan_lu@hotmail.com	N/A	2003	International Journal of Remote Sensing	Open Access Journal	With a large coverage, short repeativity, day and night, and all- weather capability, ERS SAR imagery has been proven to be a useful tool for ocean oil spill monitoring. The paper discusses ocean oil pollution detection, statistics and mapping in south-east Asian waters by using ERS-1/2 SAR data. The work is roughly divided into four main steps. Possible oil slicks are first identified from each image. Next, the scene in which most slicks have been detected within a frame is selected for re-examination and all oil slicks detected on this image are further classified into either high, medium or low probability categories. The overall statistical results are then complied and values of normalized oil slick occurrence intensity for various scenarios computed for each ERS frame. Finally, spatial oil spill distribution maps in the south-east Asian waters are derived. The results show very good agreement with shipping routes as well as in situ data in the region.	oil spill monitoring; oil slicks; oil spill distribution maps	http://www.tandfonline.com/doi/abs/10.1080/01431160110076216#preview	30	Yes - can share with CCC license
Satellite	Moderate Resolution Imaging Spectroradiometer	Temperate Northern Atlantic Temperate Northern Pacific	N/A	Dalian Maritime University	China	Uknown	Oil Spill Monitoring Based on Its Spectral Characteristics	Ma, Long (Dalian Maritime University)	home218@126.com	Li, Ying (Dalian Maritime University) Liu, Yu (Dalian Maritime University)	2009	Environmental Forensics	Scientific journal	Oil spills are frequent ocean pollution events and threaten the safety of the marine ecosystem. In order to implement a countermeasure in case of oil spills, it is necessary to monitor oil spills using remote sensing techniques. Spectral measurements were undertaken for five oil types in 2007. Based on oil spectral characteristics, this study demonstrates how moderate resolution imaging spectroradiometer (MODIS) can monitor oil spills in the Jeyeh storage tank-leaking event in Lebanon. With finer spectral resolutions and more spectral bands, MODIS provides the capability for the identification of oil spills.	oil spills, remote sensing, spectral characteristics, MODIS	http://www.tandfonline.com/doi/abs/10.1080/15275920903347024#preview	4	Yes - Article available for purchase
Satellite	Synthetic Aperture Radar	N/A	N/A	Brest ENST	France	RITMER program of the French Ministry of Research under the name DetecSuiv MARSAIS program of the EU	Partially Supervised Oil-Slick Detection by SAR Imagery Using Kernel Expansion	Mercier, G. (ENST Bretagne)	gregoire.mercier@enst-bretagne.fr	Girard-Ardhuin, Fanny (IFREMER)	2006	IEEE Transactions on Geoscience and Remote Sensing	Open Access Journal	Spaceborne synthetic aperture radar (SAR) is well adapted to detect ocean pollution independently from daily or weather conditions. In fact, oil slicks have a specific impact on ocean wave spectra. Initial wave spectra may be characterized by three kinds of waves, namely big, medium, and small, which correspond physically to gravity and gravity-capillary waves. The increase of viscosity, due to the presence of oil damps gravity-capillary waves. This induces not only a damping of the backscattering to the sensor but also a damping of the energy of the wave spectra. Thus, local segmentation of wave spectra may be achieved by the segmentation of a multiscale decomposition of the original SAR image. In this paper, a semisupervised oil-slick detection is proposed by using a kernel-based abnormal detection into the wavelet decomposition of a SAR image. It performs accurate detection with no consideration to signal stationarity nor to the presence of strong backscatters (such as a ship). The algorithm has been applied on ENVISAT Advanced SAR images. It yields accurate segmentation results even for small slicks, with a very limited number of false alarms.	Image analysis, oil spill, satellite applications, sea surface, synthetic aperture radar, water pollution	http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=1704970&url=http%3A%2F%2Fieeexplore.ieee.org%2Fiel5%2F36%2F35978%2F01704970.pdf%3Farnumber%3D1704970	37	Yes - can share with CCC license
Satellite	Synthetic Aperture Radar	Temperate Northern Atlantic	N/A	Università degli Studi di Napoli, Dipt. per le Tecnologie	Italy	Università degli Studi di Napoli	SAR Polarimetry to Observe Oil Spills	Migliaccio, M. (Università degli Studi di Napoli)	maurizio.migliaccio@uniparthenope.it	Gambardella, A. (Università degli Studi di Napoli) Tranfaglia, M. (Serco)	2007	IEEE Transactions on Geoscience and Remote Sensing	Open Access Journal	A study on sea oil spill observation by means of polarimetric synthetic aperture radar (SAR) data is accomplished. It is based on the use of a polarimetric constant false alarm rate filter to detect dark patches over SAR images. Then, the target decomposition theorem is exploited to distinguish oil spills and look-alikes. Experiments are conducted on polarimetric SAR data acquired during the SIR-C/X-SAR mission on October 1994. The data were processed and calibrated at the Jet Propulsion Laboratory, National Aeronautics and Space Administration. Results show that the new polarimetric approach is able to assist classification.	oil spills, radar polarimetry	http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=4069112&url=http%3A%2F%2Fieeexplore.ieee.org%2Fiel5%2F36%2F4069093%2F04069112.pdf%3Farnumber%3D4069112	53	Yes - can share with CCC license
Satellite	Synthetic Aperture Radar	Temperate Northern Atlantic Temperate Northern Pacific	N/A	Univ. degli Studi di Napoli, Dipt. per le Tecnologie	Italy	Univ. degli Studi di Napoli	On the co-polarized phase difference for oil spill observation	Migliaccio, M. (Universita` degli Studi di Napoli Parthenope)	migliaccio@uniparthenope.it	Nunziata, F. (Universita` degli Studi di Napoli Parthenope)  Gambardella, A. (Universita` degli Studi di Napoli Parthenope)	2009	International Journal of Remote Sensing	Open Access Journal	In this study dual-polarized synthetic aperture radar (SAR) measurements were used to enhance oil spill observation. The co-polarized phase difference (CPD) was modelled and used to characterize the scattering return from oil spills and biogenic slicks. The model predicts, under low to moderate wind conditions, a larger CPD standard deviation (σ) for oil with respect to the sea, while for biogenic slicks a σ value similar to that for the sea is obtained. Experiments accomplished with multilook complex (MLC) C- and L-band SAR data show that the model predictions are confirmed and that the C-band is, as expected, to be preferred to the L-band.	co-polarized phase difference, multilook complex	http://www.tandfonline.com/doi/abs/10.1080/01431160802520741#preview	29	Yes - can share with CCC license
Satellite	Synthetic Aperture Radar	Croatian Adriatic Sea Temperate Northern Atlantic	N/A	Croatia Institute of Oceanography and Fisheries P.P. Shirshov Institute of Oceanology, Russian Academy of Sciences	Croatia	Unknown	Oil spill monitoring in the Croatian Adriatic waters: needs and possibilities	Morovic, Mira (Institute of Oceanography and Fisheries)	morovic@izor.hr	Ivanov, Andrei (P.P. Shirshov Institute of Oceanology, Russian Academy of Sciences)	2011	Acta Adriatica	Open Access Journal	A set of spaceborne synthetic aperture radar (SAR) images and geographic information system (GIS) can significantly contribute to monitoring and identification of oil spills floating on the sea surface. Initially, the GIS has been proven as an excellent management tool for resources assessment, oil spill response and planning, and damage assessment, but the possibilities of GIS mapping also integrate geographical, remote sensing, oil & gas production/infrastructure data and slick signatures detected by SAR. Data from different sources such as nautical charts, geo-databases, ground truth and remote sensing data combined in GIS reveal offshore/onshore oil sources, and estimate the intensity and evolution of oil pollution. SAR and GIS together can significantly improve identification and classification of oil spills, leading to the product - oil spill distribution maps. This approach, applied successfully in different water basins, can also be applied to oil spill monitoring/ mapping in Croatian waters of the Adriatic Sea - it can contribute to understanding the spatiotemporal distribution of oil spills in the Adriatic Sea and be an ideal tool for an oil spill monitoring system. In the framework of the Croatian initiative towards regional cooperation in the Adriatic Sea, such an approach represents a good national opportunity. In this paper, the properties of SAR imagery, as the most reliable source of oil spill information, are described. The possibilities of a combined SAR-GIS approach to oil spill monitoring and GIS databases as a management tools for the protection of the Adriatic Sea are discussed.	Adriatic Sea, oil spills; monitoring and surveillance; SAR images; GIS; oil spill mapping	http://jadran.izor.hr/acta/pdf/52_1_pdf/52_1_5.pdf	1	None - PDF provided on disk

Peer Reviewed Remote Sensing Papers

Platform	Sensor	Geographical Area of Study	Areal Extent of Study	Institution	Country	Funding Source	Article Title	Principal Investigator/ Author	Contact Information	Co-Authors (if any)	Year	Source	Publication Type	Abstract	Keywords	Link to Website	No. of Citations	Copyright Issues?
Satellite	Synthetic Aperture Radar	Temperate Northern Atlantic Western Indo-Pacific	N/A	Geodesy Space Centre	Italy	European Space Agency; Italian Environment Ministry; Italian Space Agency	Automatic Detection of Oil Spills from SAR Images	Nirchio, F. (ASI, Geodesy Space Centre)	trivero@mfn.unipmn.it	Sorgente, M. (ASI, Geodesy Space Centre) Giancaspo, A. (Telespazio, Geodesy Space Centre) Biamino, W. (Universita` del Piemonte Orientale)  Parisato, E. (Universita` del Piemonte Orientale) Ravera, R. (Universita` del Piemonte Orientale)  Trivero, P. (Universita` del Piemonte Orientale)	2005	International Journal of Remote Sensing	Open Access Journal	A probabilistic method has been developed that distinguishes oil spills from other similar sea surface features in synthetic aperture radar (SAR) images. It considers both the radiometric and the geometric characteristics of the areas being tested. In order to minimize the operator intervention, it adopts automatic selection criteria to extract the potentially polluted areas from the images. The method has an a priori percentage of correct classification higher than 90% on the training dataset; the performance is confirmed on a different dataset of verified slicks. Some analyses have been conducted using images with different radiometric and geometric resolutions to test its suitability with SAR images different from European Remote Sensing (ERS) satellite ones. The system and its ability to detect and classify oil and non-oil surface features are described. Starting from a set of verified oil spills detected offshore and over the coastline, the ability of SAR to reveal oil spills is tested by analysing wind intensity, deduced from the image itself, and the distance from the coast.	oil spills, SAR, automatic detection	http://www.tandfonline.com/doi/abs/10.1080/01431160512331326558#preview	47	Yes - can share with CCC license
Satellite	Synthetic Aperture Radar	Temperate Northern Atlantic	190 km of coastline	Instituto Espanol de Oceanografia Universidad de Vigo	Spain	European Space Agency	Use of ASAR Images to Study the Evolution of the Prestige Oil Spill off the Galician Coast	Palenzuela, J.M. Torres (Universidad de Vigo)	marsacau@uvigo.es	Vilas, L. Gonzalez (Universidad de Vigo) Cuadrado, M. Sacau (Instituto Espan˜ol de Oceanografia)	2006	International Journal of Remote Sensing	Open Access Journal	Space-borne synthetic aperture radar has been proven to be a useful tool for ocean oil spill monitoring due to its large coverage, independence of the day–night cycle and all-weather capability. In this paper, a method for oil spill detection based on a visual interpretation was applied to two consecutive Advanced Synthetic Aperture Radar (ASAR) images acquired during the Prestige oil spill off the Spanish coast. The obtained oil spill information was integrated into a Geographical Information System (GIS) database in order to study the spatial distribution and the evolution of the slicks between both days, in addition to carrying out a comparison with field observations. The results show the great capability of monitoring and forecasting marine oil spills caused by large oil tanker accidents by means of the use of radar imagery jointly with other information, such as wind data or in situ observations.	oil spill detection, Prestige, GIS	http://www.tandfonline.com/doi/abs/10.1080/01431160512331314038#preview	18	Yes - can share with CCC license
Satellite	Synthetic Aperture Radar	Temperate Northern Atlantic	290,000 km2	Universidad Politecnica de Catalunya	Spain	Ministerio de Educaci´on y Ciencia of Spain/Grant 2001-SGR00221	Self-similar distribution of oil spills in European coastal waters	Redondo, Jose M. (Universidad Politecnica de Catalunya)	redondo@fa.upc.es	Platonov, Alexei K. (Universidad Politecnica de Catalunya)	2009	Environmental Research Letters	Open Access Journal	Marine pollution has been highlighted thanks to the advances in detection techniques as well as increasing coverage of catastrophes (e.g. the oil tankers Amoco Cadiz, Exxon Valdez, Erika, and Prestige) and of smaller oil spills from ships. The new satellite based sensors SAR and ASAR and new methods of oil spill detection and analysis coupled with self-similar statistical techniques allow surveys of environmental pollution monitoring large areas of the ocean. We present a statistical analysis of more than 700 SAR images obtained during 1996-2000, also comparing the detected small pollution events with the historical databases of great marine accidents during 1966-2004 in European coastal waters. We show that the statistical distribution of the number of oil spills as a function of their size corresponds to Zipf's law, and that the common small spills are comparable to the large accidents due to the high frequency of the smaller pollution events. Marine pollution from tankers and ships, which has been detected as oil spills between 0.01 and 100 km2, follows the marine transit routes. Multi-fractal methods are used to distinguish between natural slicks and spills, in order to estimate the oil spill index in European coastal waters, and in particular, the north-western Mediterranean Sea, which, due to the influence of local winds, shows optimal conditions for oil spill detection.	marine pollution detection, SAR images, oil spills, oil pollution index, remote sensing, turbulence, Zipf's law	http://iopscience.iop.org/1748-9326/4/1/014008/	3	None - PDF provided on disk
Satellite	Synthetic Aperture Radar	Temporate Northern Atlantic	N/A	Cedre	France	Uknown	The use of satellite radar to improve the surveillance of oil pollution over large areas; L'utilisation de satellites pour ameliorer la surveillance des pollutions par hydrocarbures sur des zones etendues	Samuel, V.K. (Cedre)	N/A	Parthiot, F. (Cedre)	2004	Revue de l'Electricite et de l'Electronique	Journal - news, comment, reviews and research reports	Quite recently, on November 13, the accident of the tanker Prestige loaded with 77 000 T of heavy fuel oil (Fuel no. 2) near the Galician coast has caused an unprecedented oil pollution mainly along the Spanish and French coast-lines. The purpose of this paper is to compare satellite derived observations with the other available information concerning the actual extension of the pollution especially during the first days, namely 17 and 18 of November. In addition, the problem of detecting and monitoring ship illegal discharges over large areas, such as the protected ecological zone (ZPE) in the Mediterranean sea, on a routine basis together with the ongoing aerial surveillance is commented and some suggestion are discussed.	tanker ships, ship illegal discharges	https://www.etde.org/etdeweb/details_open.jsp?osti_id=20457585	5	Yes - Article available for purchase
Satellite	Advanced Scatterometer QuickSCAT Synthetic Aperture Radar	N/A	N/A	Institute of Remote Sensing Applications, Chinese Academy of Sciences	South Korea China	Unknown	Oil spill monitoring using multi-temporal SAR and microwave scatterometer data	Shao, Yun (Institute of Remote Sensing Applications, Chinese Academy of Sciences)	N/A	Wei Tian, Shiang Wang, Fengli Zhang (Institute of Remote Sensing Applications, Chinese Academy of Sciences, Beijing)	2008	Geoscience and Remote Sensing Symposium, 2008. IGARSS 2008. IEEE International	Conference Paper	On the 7th of December 2007, the 146,000-ton oil tanker, Hebei Spirit, was wrecked and leaked more than 10,000 ton crude oil onto the sea off the west coast of the South Korea. In this paper, the monitoring of the oil spills in this pollution accident using multi-temporal Synthetic Aperture Radar (SAR) and microwave scatterometer (QSCAT and ASCAT) data was illustrated. The impact of this oil spill pollution on the China's marine environment was evaluated. The result shows the capability and the effectiveness of microwave remote sensing data in oil spill monitoring and forecasting.	Hebei Spirit, SAR, QSAT, ASCAT, China, microwave scatterometer, oil spill, South Korea	http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=4779617&url=http%3A%2F%2Fieeexplore.ieee.org%2Fiel5%2F4757194%2F4779256%2F04779617.pdf%3Farnumber%3D4779617	N/A	Yes - Article available for purchase

Peer Reviewed Remote Sensing Papers

Platform	Sensor	Geographical Area of Study	Areal Extent of Study	Institution	Country	Funding Source	Article Title	Principal Investigator/ Author	Contact Information	Co-Authors (if any)	Year	Source	Publication Type	Abstract	Keywords	Link to Website	No. of Citations	Copyright Issues?
Satellite	Moderate Resolution Imaging Spectroradiometer Synthetic Aperture Radar	Temperate Northern Atlantic	N/A	Space Research Institute of the Russian Academy of Sciences	Russia	INTAS Black Sea Scientific Network RFBR	Multisensor Satellite Monitoring of Seawater State and Oil Pollution in the Northeastern Coastal Zone of the Black Sea	Shcherbak, S.S. (Russian Academy of Sciences)	olavrova@mx.iki.rssi.ru	Lavrova, O. Y. (Russian Academy of Sciences) Mityagina, M. I. (Russian Academy of Sciences) Bocharova, T. Y. (Russian Academy of Sciences) Krovotyntsev, V. A. (Scientific Research Centre of Space Hydrometeorology 'Planeta') Ostrovskiic, A. G. (Russian Academy of Sciences)	2008	International Journal of Remote Sensing	Open Access Journal	A new approach aimed at a better understanding of the state of pollution of the Black Sea coastal zone is suggested. It consists of the combined use of all available quasi-concurrent satellite information (NOAA AVHRR, TOPEX/Poseidon, Jason-1, Terra/Aqua MODIS, Envisat ASAR, ERS-2 SAR and QuikSCAT) and was first applied during an operational seawater monitoring campaign in the coastal zone of the northeastern Black Sea conducted in 2006. The monitoring is based on daily receiving, processing and analysis of data different in nature (microwave radar images, optical and infrared data), resolution and surface coverage. These data allow us to retrieve information on seawater pollution, sea surface and air-sea boundary layer conditions, seawater temperature and suspended matter distributions, chlorophyll-a concentration, mesoscale water dynamics, near-surface wind, and surface wave fields. Such an approach helps in oil spill detection with synthetic aperture radar (SAR), especially in distinguishing oil slicks from look-alikes. The focus is on coastal seawater circulation mechanisms and their impact on the evolution of pollutants.	oil spill detection, coastal seawater circulation	http://www.tandfonline.com/doi/abs/10.1080/01431160802175470#preview	14	Yes - can share with CCC license
Satellite	Synthetic Aperture Radar	Temperate Northern pacific	N/A	Ocean Remote Sensing Institute, Ocean University of China, National Laboratory for Ocean Remote Sensing, Ministry of Education of China	China	Ocean University of China Russian Foundation for Basic Research	Oil Spill Mapping in the Western Part of the East China Sea Using Synthetic Aperture Radar Imagery	Shi, L. (Ocean University of China)	shilj@orsi.ouc.edu.cn	Ivanova, A. Yu (Ocean University of China/Russian Academy of Sciences) He, M. (Ocean University of China) Zhao, C. (Ocean University of China)	2008	International Journal of Remote Sensing	Open Access Journal	Oil spills are one of the major environmental concerns, especially in the coastal zones of the ocean. Synthetic aperture radar (SAR) imagery from the European Remote Sensing (ERS)-2 and Envisat satellites has proved to be a useful tool for monitoring oil spills in the marine environment due to its all-weather and all-time capability. More than 600 scenes with SAR images acquired over the western part of the East China Sea in 2002-2005 were collected, and of these, 120 scenes containing pronounced oil spills were processed and analysed. To analyse SAR image signatures of the oil spills, a geographic information system (GIS) framework was used. The oil spills were distinguished from look-alike phenomena by using other remote sensing data, and contextual information was incorporated into the GIS to obtain an oil spill distribution map for the western part of the East China Seas. Analysis of the temporal and spatial distribution of the oil spills revealed the risk areas and confirmed previous findings that oil spills are mainly distributed along regional shipping routes. This verifies that illegal discharges from ships are the main source of oil pollution in this region. The detailed analysis also revealed different types of oil pollution and showed diurnal and seasonal variations in the amount of oil spills detected by SAR images acquired in the morning/evening time and in the summer/winter.	oil spills, GIS, illegal ship discharges	http://www.tandfonline.com/doi/abs/10.1080/01431160802175447	10	Yes - can share with CCC license
Satellite	Synthetic Aperture Radar	Temperate Northern Pacific Tropical Atlantic	N/A	University of Toulouse	France	Unknown	Ship and Oil-Spill Detection Using the Degree of Polarization in Linear and Hybrid/Compact Dual-Pol SAR	Shirvany, Reza (University of Toulouse)	N/A	Chabert, Marie (University of Toulouse) Tourneret, Jean-Yves	2012	IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing	Open Access Journal	Monitoring and detection of ships and oil spills using synthetic aperture radar (SAR) have received a considerable attention over the past few years, notably due to the wide area coverage and day and night all-weather capabilities of SAR systems. Among different polarimetric SAR modes, dual-pol SAR data are widely used for monitoring large ocean and coastal areas. The degree of polarization (DoP) is a fundamental quantity characterizing a partially polarized electromagnetic field, with significantly less computational complexity, readily adaptable for on-board implementation, compared with other well-known polarimetric discriminators. The performance of the DoP is studied for joint ship and oil-spill detection under different polarizations in hybrid/compact and linear dual-pol SAR imagery. Experiments are performed on RADARSAT-2 C-band polarimetric data sets, over San Francisco Bay, and L -band NASA/JPL UAVSAR data, covering the Deepwater Horizon oil spill in the Gulf of Mexico.	compact polarimetry, degree of polarization (DoP), depolarization, dual-pol, oil spill, ship detection	http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=6152171&url=http%3A%2F%2Fieeexplore.ieee.org%2Fiel5%2F4609443%2F4609444%2F06152171.pdf%3Farnumber%3D6152171	2	Yes - can share with CCC license
Satellite	Moderate Resolution Imaging Spectroradiometer Synthetic Aperture Radar	Tropical Atlantic	N/A	NOAA, Satellite Analysis Branch	USA	Unknown	NOAA's Satellite Monitoring of Marine Oil	Streett, D.	N/A	N/A	2011	Monitoring and Modeling the Deepwater Horizon Oil Spill: A Record-Breaking Enterprise [Geophysical Monograph Series, Vol. 195]	Scientific journal	During the Deepwater Horizon (DWH) spill, NOAA imagery analysts in the Satellite Analysis Branch (SAB) issued more than 300 near-real-time satellite-based oil spill analyses. These analyses were used by the oil spill response community for planning, issuing surface oil trajectories, and tasking assets (e.g., oil containment booms, skimmers, overflights). SAB analysts used both synthetic aperture radar and high-resolution visible/near IR multispectral satellite imagery as well as a variety of ancillary data sets to map the surface oil location. Satellite imagery included Envisat advanced synthetic aperture radar (European Space Agency (ESA)), TerraSAR-X (Deutsches Zentrum für Luft- und Raumfahrt), Cosmo-Skymed (Agenzia Spaziale Italiana), Advanced Land Observing Satellite (Japan Aerospace Exploration Agency (JAXA)), RADARSAT (MacDonald Dettwiler and Associates, Canadian Space Agency), Envisat MERIS (Medium-Resolution Imaging Spectrometer, ESA), SPOT (SPOT Image Corp., Centre National d'Etudes Spatiales), Landsat (NASA, United States Geological Survey (USGS)), Aster (JAXA, NASA), MODIS (Moderate Resolution Imaging Spectroradiometer, NASA), and advanced very high resolution radiometer (NOAA). Ancillary data sets included ocean currents, winds, natural oil seeps, and in situ oil observations. SAB personnel also served as the DWH International Disaster Charter Project Manager (at the official request of the USGS). The Project Manager's primary responsibility was to oversee the acquisition and processing of satellite data generously donated by numerous private companies and nations in support of the oil spill response. All SAB DWH analyses, starting with one issued 5 h after the rig sank through the final one in August, are still publicly available at the archive on the NOAA/NESDIS website http://www.ssd.noaa.gov/PS/MPS/deepwater.html. SAB has now acquired a 24 × 7 oil spill response capability and is addressing goals that will enhance its routine oil spill response as well as help assure readiness for the next spill of national significance.	oil spill, remote sensing	http://www.agu.org/books/gm/v195/2011GM001104/2011GM001104.shtml	0	None - PDF provided on disk - need book

Peer Reviewed Remote Sensing Papers

Platform	Sensor	Geographical Area of Study	Areal Extent of Study	Institution	Country	Funding Source	Article Title	Principal Investigator/ Author	Contact Information	Co-Authors (if any)	Year	Source	Publication Type	Abstract	Keywords	Link to Website	No. of Citations	Copyright Issues?
Satellite	Synthetic Aperture Radar	Temperate Northern Atlantic Mediterranean Sea	N/A	Joint Research Centre	Italy	European Commission	Satellite Mapping of Oil Spills in the Mediterranean Sea	Topouzelis, Konstantinos (Joint Research Centre)	Kostas.Topouzelis@jrc.it	BERNARDINI, ANNALIA (Joint Research Centre) FERRARO, DI SILVI E CASTIGLIONE GUIDO (Joint Research Centre) MEYER-ROUX, SERGE (Joint Research Centre) TARCHI, DARIO (Joint Research Centre)	2006	Fresenius Environmental Bulletin	Scientific journal	Besides accidental pollution caused by ships in distress, different types of deliberate and routine operational discharges of oil from ships affect the sea. Illicit discharges are the greatest source of marine pollution from ships, and the one which poses a long-term threat to the marine and coastal environment. Reliable monitoring methodologies and continuously updated comprehensive information are key elements to create effective contingency planning. The present activities of the Joint Research Centre (JRC), in the field of monitoring sea-based oil pollution using space-borne radar imagery, are described. A specific methodology for processing and interpreting a massive set of satellite images has been implemented. Such an approach allows to perform a systematic mapping of the possible illicit vessel discharges over all the European Seas. These maps and the associated statistics are repeated on an annual basis in order to assess its evolution. In particular, the results obtained during the period 1999-2002 for the Mediterranean Sea are presented. This analysis is of special interest due to the lack of a regular aerial surveillance as that in the North and Baltic Sea. This action helped to reveal for the first time what is the dimension of the oil pollution problem, thus stressing the need for more concerted international actions.	oil spill, sea pollution, illegal discharges, SAR	http://www.srcosmos.gr/srcosmos/showpub.aspx?aa=9844	9	Yes - Article available for purchase
Satellite	Synthetic Aperture Radar	Temperate Northern Atlantic	N/A	Joint Research Centre	Greece Italy	European Commission	Potentiality of feed-forward neural networks for classifying dark formations to oil spills and look-alikes	Topouzelis, Konstantinos (Joint Research Centre)	Kostas.Topouzelis@jrc.it	Karathanassi, V. (National Technical University of Athens) Pavlakis, P. (Hellenic Centre for Marine Research) Rokos, D. (National Technical University of Athens)	2009	Geocarto International	Open Access Journal	Radar backscatter values from oil spills are very similar to backscatter values from very calm sea areas and other ocean phenomena. Several studies aiming at oil spill detection have been conducted. Most of these studies rely on the detection of dark areas, which have high Bayesian probability of being oil spills. The drawback of these methods is a complex process, mainly because non-linearly separable datasets are introduced in statistically based decisions. The use of neural networks (NNs) in remote sensing has increased significantly, as NNs can simultaneously handle non-linear data of a multidimensional input space. In this article, we investigate the ability of two commonly used feed-forward NN models: multilayer perceptron (MLP) and radial basis function (RBF) networks, to classify dark formations in oil spills and look-alike phenomena. The appropriate training algorithm, type and architecture of the optimum network are subjects of research. Inputs to the networks are the original synthetic aperture radar image and other images derived from it. MLP networks are recognized as more suitable for oil spill detection.	oil spills, neural networks, multilayer feed-forward networks, multilayer perceptron networks	http://www.tandfonline.com/doi/pdf/10.1080/10106040802488526	6	Yes - can share with CCC license
Satellite	Synthetic Aperture Radar	Temperate Northern Atlantic	N/A	Joint Research Centre	Italy	European Commission	Investigation of genetic algorithms contribution to feature selection for oil spill detection	Topouzelis, Konstantinos (Joint Research Centre)	Kostas.Topouzelis@jrc.it	Stathakis, D. (Joint Research Centre) Karathanassi, V. (National Technical University of Athens)	2009	International Journal of Remote Sensing	Open Access Journal	Oil spill detection methodologies traditionally use arbitrary selected quantitative and qualitative statistical features (e.g. area, perimeter, complexity) for classifying dark objects on SAR images to oil spills or look-alike phenomena. In our previous work genetic algorithms in synergy with neural networks were used to suggest the best feature combination maximizing the discrimination of oil spills and look-alike phenomena. In the present work, a detailed examination of robustness of the proposed combination of features is given. The method is unique, as it searches though a large number of combinations derived from the initial 25 features. The results show that a combination of 10 features yields the most accurate results. Based on a dataset consisting of 69 oil spills and 90 look-alikes, classification accuracies of 85.3% for oil spills and in 84.4% for look-alikes are achieved.	oil spill detection	http://dstath.users.uth.gr/papers/IJRS2009_Topouzelis_etal.pdf	9	Yes - can share with CCC license
Satellite	Synthetic Aperture Radar	Temperate Northern Atlantic	N/A	Joint Research Centre	Greece Italy	European Commission	Dark formation detection using neural networks	Topouzelis, Konstantinos (Joint Research Centre)	Kostas.Topouzelis@jrc.it	Karathanassi, V. (National Technical University of Athens) Pavlakis, P. (Hellenic Centre for Marine Research) Rokos, D. (National Technical University of Athens)	2008	International Journal of Remote Sensing	Open Access Journal	Synthetic Aperture Radar (SAR) images are extensively used for dark formation detection in marine environment, as they are not affected by local weather conditions and cloudiness. Dark formations can be caused by man-made actions (e.g. oil spills) or natural ocean phenomena (e.g. natural slicks and wind front areas). Radar backscatter values for oil spills are very similar to backscatter values for very calm sea areas and other ocean phenomena because they dampen the capillary and short gravity sea waves. Thus, traditionally, dark formation detection is the first stage of the oil-spill detection procedure and in most studies is performed manually or using a fixed size window in which a threshold value is adopted. In high-resolution imagery, dark formation detection may fail due to the nonlinear behaviour of the pixel values contained in the dark formation and in the area around it. In this paper, we examine the ability of two feed-forward neural network families, i.e. Multilayer Perceptron (MLP) and the Radial Basis Function (RBF) networks, to detect dark formations in high-resolution SAR images. The general objective of this paper is to test the potential of artificial neural networks for dark formation detection using SAR high-resolution satellite images. Both the type and the architecture of the network are subjects of research. The inputs into the networks are the original SAR images. Each network is called to classify an area of the image as dark area or sea. The group of MLP networks can be recognized as the most suitable group for dark formation detection, as it presents reliable stable results for all the examined accuracies. Nevertheless, in terms of single topology, there is no an MLP topology that performs significantly better than the others.	dark formation detection, artificial neural networks, Multilayer Perceptron, Radial Basis Function	http://www.tandfonline.com/doi/abs/10.1080/01431160801891770#preview	12	Yes - can share with CCC license

Peer Reviewed Remote Sensing Papers

Platform	Sensor	Geographical Area of Study	Areal Extent of Study	Institution	Country	Funding Source	Article Title	Principal Investigator/ Author	Contact Information	Co-Authors (if any)	Year	Source	Publication Type	Abstract	Keywords	Link to Website	No. of Citations	Copyright Issues?
Satellite	Synthetic Aperture Radar	Temperate Northern Atlantic	N/A	Joint Research Centre; University of Athens; Hellenic Centre for Marine Research	Greece Italy	Institute for the Protection and Security of the Citizen, Sensors, Radar Technologies and Cybersecurity Unit, Italy	Detection and Discrimination between oil spills and look-alike phenomena through neural networks	Topouzelis, Konstantinos (Joint Research Centre)	Kostas.Topouzelis@jrc.it	Karathanassi, V. (National Technical University of Athens) Pavlakis, P. (Hellenic Centre for Marine Research) Rokos, D. (National Technical University of Athens)	2007	ISPRS Journal of Photogrammetry and remote Sensing	Scientific journal	Synthetic Aperture Radar (SAR) images are extensively used for dark formation detection in the marine environment, as their recording is independent of clouds and weather. Dark formations can be caused by man made actions (e.g. oil spill discharging) or natural ocean phenomena (e.g. natural slicks, wind front areas). Radar backscatter values for oil spills are very similar to backscatter values for very calm sea areas and other ocean phenomena because they damp the capillary and short gravity sea waves. The ability of neural networks to detect dark formations in high resolution SAR images and to discriminate oil spills from look-alike phenomena simultaneously was examined. Two different neural networks are used; one to detect dark formations and the second one to perform a classification to oil spills or look-alikes. The proposed method is very promising in detecting dark formations and discriminating oil spills from look-alikes as it detects with an overall accuracy of 94% the dark formations and discriminate correctly 89% of examined cases.	Oil spill; Neural networks; Training; SAR; Pollution	http://www.sciencedirect.com/science/article/pii/S0924271607000421	25	None - PDF provided on disk
Satellite	Synthetic Aperture Radar	N/A	N/A	Joint Research Centre	Italy	European Commission	Oil Spill Detection by SAR Images: Dark Formation Detection, Feature Extraction and Classification Algorithms	Topouzelis, Konstantinos (Joint Research Centre)	Kostas.Topouzelis@jrc.it	N/A	2008	Sensors	Open Access Journal	This paper provides a comprehensive review of the use of Synthetic Aperture Radar images (SAR) for detection of illegal discharges from ships. It summarizes the current state of the art, covering operational and research aspects of the application. Oil spills are seriously affecting the marine ecosystem and cause political and scientific concern since they seriously effect fragile marine and coastal ecosystem. The amount of pollutant discharges and associated effects on the marine environment are important parameters in evaluating sea water quality. Satellite images can improve the possibilities for the detection of oil spills as they cover large areas and offer an economical and easier way of continuous coast areas patrolling. SAR images have been widely used for oil spill detection. The present paper gives an overview of the methodologies used to detect oil spills on the radar images. In particular we concentrate on the use of the manual and automatic approaches to distinguish oil spills from other natural phenomena. We discuss the most common techniques to detect dark formations on the SAR images, the features which are extracted from the detected dark formations and the most used classifiers. Finally we conclude with discussion of suggestions for further research. The references throughout the review can serve as starting point for more intensive studies on the subject.	Oil spill; sea pollution; SAR	http://www.mdpi.com/1424-8220/8/10/6642	27	None - PDF provided on disk
Satellite	Synthetic Aperture Radar	Temperate Northern Atlantic	N/A	Joint Research Centre University of the Aegean	Italy	European Commission	Oil Spill Feature Selection and Classification Using Decision Tree Forest on SAR Image Data	Topouzelis, Konstantinos (University of the Aegean, Department of Marine Sciences)	topouzelis@marine.aegean.gr	Psyllos, Apostolos (Joint Research Centre)	2012	ISPRS Journal of Photogrammetry and Remote Sensing	Scientific journal	A novel oilspill feature selection and classification technique is presented, based on a forest of decision trees. The parameters of the two-class classification problem of oilspills and look-alikes are explored. The contribution to the final classification of the 25 most commonly used features in the scientific community was examined. The work is sought in the framework of a multi-objective problem, i.e. the minimization of the used input features and, at the same time, the maximization of the overall testing classification accuracy. Results showed that the optimum forest contains 70 trees and the three most important combinations contain 4, 6 and 9 features. The latter feature combination can be seen as the most appropriate solution of the decision forest study. Examination of the robustness of the above result showed that the proposed combination achieved higher classification accuracy than other well-known statistical separation indexes. Moreover, comparisons with previous findings converge on the classification accuracy (up to 84.5%) and to the number of selected features, but diverge on the actual features. This observation leads to the conclusion that there is not a single optimum feature combination; several sets of combinations exist which contain at least some critical features.	oil spills, decision tree forests, statistical separation indexes	http://www.sciencedirect.com/science/article/pii/S0924271612000329	0	None - PDF provided on disk
Satellite	Synthetic Aperture Radar	Temperate Northern Pacific	N/A	NASA NOAA	USA	NASA NOAA	Ocean Feature Monitoring with Wide Swath Synthetic Aperture Radar	Wu, Sunny (NASA Goddard Space Flight Center)	sunny@neptune.gsfc.nasa.gov	Liu, Antony (NASA Goddard Space Flight Center) Leonard, Gregory (NASA Goddard Space Flight Center) Pichel, William G. (NOAA/NESDIS Office of Research and Applications)	2000	Johns Hopkins APL Technical Digest	Open Access Journal	By providing better spatial coverage, wide swath synthetic aperture radar (SAR) can offer a more complete picture of various mesoscale ocean features. With better temporal coverage, SAR also supplies crucial information for the tracking and monitoring of these features using, for instance, the technique of two-dimensional wavelet analysis. Examples presented in this article of fronts in the Gulf of Mexico and off the mid-Atlantic coast, an oil spill off Point Barrow, Alaska, and internal waves in the South China Sea illustrate some of the myriad ocean applications that are better observed and monitored with wide swath SAR.	Internal wave, Oil spill, Remote sensing, Wavelet transform, Wide swath SAR	http://techdigest.jhuapl.edu/TD/td2101/wu.pdf	1	None - PDF provided on disk
Satellite	Synthetic Aperture Radar	Temperate Northern Pacific	400 km2	Research Institute of Petroleum Exploration & Development Institute of remote Sensing Applications, Chinese Academy of Sciences	China	Uknown	Remote Sensing Techniques for Oil Spill Monitoring in Offshore Oil and Gas Exploration and Exploitation Activities: Case Study in Bohai Bay	Yu, Wu-yi (Research Institute of Petroleum Exploration & Development)	N/A	LI, Jin (Chinese Academy of Sciences) SHAO, Yun (Chinese Academy of Sciences) QI, Xiao-ping (Research Institute of Petroleum Exploration & Development) LIU, Yang (Research Institute of Petroleum Exploration & Development)	2007	Petroleum Exploration and Development	Scientific journal	Marine oil spill pollution directly damages the marine environment and arouses international dispute. The space borne remote sensing monitoring techniques have advantages of wide area surveillance, multi-temporal resolution, prompt acquisition, and high precision. It has become one of the key marine oil pollution monitoring techniques. This paper takes the oil pollution accident occurred in March 2006 in Bohai Bay as an example. The Envisat ASAR data is used to determine the pollution origin and delineate the polluted marine area. The polluted area is precisely calculated based on the image interpretation and the analysis of the Envisat ASAR images collected on March 23rd, 2006.The total polluted marine area is more than 400 km2.This study shows that SAR remote sensing and GIS are important techniques to secure the environment issue during the marine oil exploration and exploitation. It is crucial to set up an emergency response system for the marine oil pollution and environment monitoring.	remote sensing, radar, oil spill monitoring, marine oil spill, marine environment	http://en.cnki.com.cn/Article_en/CJFDTOTAL-SKYK200703022.htm	10	Yes - Article available for purchase

Peer Reviewed Remote Sensing Papers

Platform	Sensor	Geographical Area of Study	Areal Extent of Study	Institution	Country	Funding Source	Article Title	Principal Investigator/ Author	Contact Information	Co-Authors (if any)	Year	Source	Publication Type	Abstract	Keywords	Link to Website	No. of Citations	Copyright Issues?
Satellite	Moderate Resolution Imaging Spectroradiometer Synthetic Aperture Radar	N/A	N/A	University of Bari The Institute of Intelligent Systems for Automation	Italy	National Research Council	Oil Spill Surveillance and Tracking with Combined Use of SAR and Modis Imagery: A Case Study	Adamo (University of Bari/Institute of Intelligent Systems for Automation, National Research Council) Carolis Pasquale Pasquariello (Institute of Intelligent Systems for Automation, National Research Council)	Maria Adamo Via Amendola, 122/D 70126 Bari, Italy Ph.: +39 080 5929437 Fax: +39 080 5929460 Email:adamo@ba.issia.cnr.it	N/A	2006	Geoscience and Remote Sensing Symposium, 2008. IGARSS 2008. IEEE International	Conference Paper	The use of satellite remote sensing for oil spills detection has been attempted, traditionally, with synthetic aperture radar (SAR) sensors. These sensors are the most suitable instruments to the detection of slicks, since they damp strongly short waves measured by SAR and oil spills appear as a dark patch on the SAR image. However, SAR systems do not offer the required temporal acquisition rate of the same area, to guarantee the possibility to monitoring large oil spill movement on the sea. We propose the use the Modis (Moderate Resolution Imaging Spectroradiometer) images acquired in sun glint conditions to reveal smoothed regions such as those affected by oil pollution. In this work we present a case study, in the Mediterranean Sea near the French coast, in which we have applied this methodology to a large oil spill detected on a SAR image of the 8th July 2002. Using two Modis acquisition in the same day, one by Modis/TERRA 20 minutes later the ERS2-SAR acquisition and the other by Modis/AQUA 80 minutes later the first Modis acquisition, we show that it is possible to surveil the oil spill in its movement towards north-west. Wind speeds and directions at 10 m above the sea surface were retrieved using the semi- empirical backscatter model CMOD4 on the SAR image, and utilized to track the movement of oil spill. Surface wind vectors predicted by the meteorological ECMWF model were exploited as guess input to SAR wind inversion procedure. The comparison between Modis images and the predicted position of the oil spill show an adequate agreement.	satellite remote sensing; oil spill; SAR; MODIS; Mediterranean Sea; CMOD4; ECMWF	http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=4241490&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D4241490	1	Yes - Article available for purchase
Satellite Water	Synthetic Aperture Radar	Temperate Northern Atlantic	N/A	University of South Florida	USA	Unknown	Evolution of the Loop Current System During the Deepwater Horizon Oil Spill Event as Observed with Drifters and Satellites	Liu, Y.	N/A	Weisberg, R. H. Hu, C. Kovach, C. Riethmüller, R.	2011	Monitoring and Modeling the Deepwater Horizon Oil Spill: A Record-Breaking Enterprise [Geophysical Monograph Series, Vol. 195]	Scientific journal	The ocean circulation patterns of the Gulf of Mexico (GOM) Loop Current (LC) system and their effects on the advection of the oil discharged during the Deepwater Horizon incident are described using in situ surface drifter trajectories and satellite observations from May to August 2010. These observations include altimetry-derived surface geostrophic velocities, sea surface temperature, ocean color, and surface oil locations. The elongated, northwestward penetrating LC retreated back from its northernmost position in late April 2010 and stayed farther away from the surface oil in the north during May 2010. Although the main body of the surface oil slick remained around the well site and on the Northern Gulf shelf, a small amount of the surface oil was entrained into the northern part of the LC system in mid-May 2010. An anticyclonic eddy in its formative stage then detached from the northern part of the LC in the latter part of May 2010, tending to break the direct connection between the northern Gulf with points farther south. Through interactions with smaller cyclonic eddies on either side, multiple short-lived detachment/re-attachment episodes continued for some time during the spill event, but without ever fully reestablishing a direct LC pathway from the region of the oil spill to the Florida Straits. The mean geostrophic current pattern during this time period showed a separated LC eddy in the eastern GOM. Such ocean circulation patterns helped retain the surface oil in the northeastern Gulf and kept an oil-free environment for most of Florida's coastal waters.	Gulf of Mexico, Loop Current, drifters, ocean color index, altimetry, oil spill	http://www.agu.org/books/gm/v195/2011GM001127/2011GM001127.shtml	2	None - PDF provided on disk - need book

APPENDIX B

LESSONS LEARNED FROM RECENT OIL SPILLS SPREADSHEET

Lessons Learned from Recent Oil Spills

Platform	Sensor	Institution	Produced for	Country	Oil Spill Event	Event Date	Article Title	Article Date	Principal Investigator/ Author	Contact Information	Co-authors	Keywords	Link to Website	Copyright Issues?
Aerial	Multispectral	CDF&G Joseph Mullin Consulting, LLC NOAA Ocean Imaging Corp.,	BP BSEE CDFG	USA	Deepwater Horizon	2010	Operational Utilization of Aerial Multispectral Remote Sensing during Oil Spill Response: Lessons Learned During the Deepwater Horizon (MC-252) Spill	2012	Svejkovsky, Jan (Ocean Imaging Corp.)	Ocean Imaging Corp. 201 Lomas Santa Fe Dr., Suite 370, Solana Beach CA 92075. jan@oceani.com, 858-792-8529	Lehr, William (NOAA) Muskat, Judd (CADFG) Graettinger, George (NOAA) Mullin, Joseph (Joseph Mullin Consulting, LLC)	multispectral visible; oil spill; near-IR; thermal IR; aerial imaging system; Deepwater Horizon	http://www.oceani.com/ http://www.oceani.com/PDF/OI_PERS_InPress_%2002_06_2012.pdf	None - PDF provided on disk
Aerial	Medium format vertical imaging multispectral Thermal imaging	Icaros Inc.	ASPRS 2011 Annual Conference	USA	Deepwater Horizon	2010	Lessons Learned in Emergency Remote Sensing and BP Response during Deepwater Horizon	2011	Nir, Arik (Icaros Inc.) Shechter, Eatay Ben (Icaros Inc.)	arik@icaros.us eatay@icaros.us	N/A	Emergency, Remote Sensing, Icaros, Deepwater Horizon, IDM200, IPS2.0, Thermal, Multi Sensor, Data Fusion, Mapping, Multi platform	http://www.asprs.org/a/publications/proceedings/Milwaukee2011/files/Nir.pdf	None - PDF provided on disk
Aerial	Forward-looking infrared	MIROS ASr NOFO Norconsult AS SINTEF	Norwegian Clean Seas Association for Operating Companies (NOFO)	Norway	small oil tanker spill in the North Sea	2006	Recent Experience from Multiple Remote Sensing and Monitoring to Improve Oil Spill Response Operations	2008	Jensen, Hans V. (NOFO)	N/A	Andersen, Jorn H.S. (Norconsult AS) Daling, Per S. (SINTEF) Nost, Elisabeth (MIROS AS)	remote sensing; oil spill response; aerial forward looking IR-video; FLIR; North Sea;	http://www.iosc.org/papers_posters/2008%20068.pdf	None - PDF provided on disk
Aerial Satellite	Airborne Visible / Infrared Imaging Spectrometer Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations Hyperspectral Moderate Resolution Imaging Spectroradiometer Near Infrared Synthetic Aperture Radar Thermal infrared	BOEMRE NASA NOAA NSF UC Davis USGS	US Department of Commerce (?)	USA	Deepwater Horizon	2010	State of the Art Satellite and Airborne Marine Oil Spill Remote Sensing: Application to the BP Deepwater Horizon Oil Spill	2012	Leifer, Ira (University of California)	ira.leifer@bubbleology.com	Lehr, William J. (NOAA) Simecek-Beatty, Debra (NOAA) Bradley, (University of California) Clark, Roger (USGS)	Oil spill; Deepwater Horizon; Remote sensing; Lidar; Near infrared; Thermal infrared; Satellite; Airborne remote sensing; Synthetic aperture radar; MODIS; Hyperspectral; Multispectral; Expert system; False positives; Technology readiness; Operational readiness; Visible spectrum; Oil water emulsions; Spill response; AVIRIS; Synthetic aperture radar; UAVSAR; Fire; CALIPSO; Oil slick thickness; Laser fluorescence	http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1344&context=usdeptcommercepub&sei-redir=1&referer=http%3A%2F%2Fscholar.google.com%2Fscholar%3Fhl%3Den%26q%3DState%2Bof%2Bthe%2Bart%2Bsatellite%2Band%2Bairborne%2Bmarine%2Boilspillremotesensing%253A%2BApplication%2Bto%2Bthe%2BBP%2BDeepwater%2BHorizonoilspill%26btnG%3D%26as_sdt%3D1%252C44%26as_sdtp%3D#search=%22State%20art%20satellite%20airborne%20marine%20oilspillremotesensing%3A%20Application%20BP%20Deepwater%20Horizonoilspill%22	None - PDF provided on disk
Aerial Satellite	Infrared Optical Side-Looking Airborne Radar	JITF (Joint Industry Oil Spill Preparedness & Response Task Force)	American Petroleum Institute	USA	Deepwater Horizon	2010	Joint Industry Oil Spill Preparedness and Response Task Force: Draft Industry Recommendations to Improve Oil Spill Preparedness and Response	2010	Ecosystem Management & Associates, Inc.	410) 394-2929 x113 Ship Point Business Park 13325 Rousby Hall Road Lusby, Maryland 20657 USA	N/A	Oil spill; Deepwater Horizon; spill response; oil sensing and tracking; dispersants; in situ burning;	http://www.masgc.org/gmrp/documents/oilresponse.pdf	None - PDF provided on disk
Satellite	Moderate Resolution Imaging Spectroradiometer	University of Mississippi Geoinformatics Center	National Institute for Undersea Science and Technology	USA	Deepwater Horizon	2010	The Effectiveness of Using MODIS Products to Map Sea Surface Oil	2010	Innman, Allison Greg, Easson	Mississippi Mineral Resources Institute 111 Old Chemistry University, MS 38677 USA	University of Southern Mississippi National Institute for Undersea Science and Technology	MODIS, Sea surface oil, Deepwater Horizon, Mapping, Gulf of Mexico	http://mmri.olemiss.edu/Home/projects/docs/2011-03-30-002.aspx	None - PDF provided on disk

APPENDIX C

OIL SPILL RESEARCH AND DEVELOPMENT PROGRAMS SPREADSHEET

Current Oil Spill Research and Development Programs

Platform	Sensor	Institution	Country	Funding Source	Program Title	Principal Investigator	Co-Investigators and Institutions	Program Dates	Abstract	Notes	Link to Website	Results Public Domain?
Aerial	Infrared Multispectral	Ocean Imaging Corporation	USA	Bureau of Safety and Environmental Enforcement	Oil Spill Response Research (OSRR) Program - "Open Water Multispectral Aerial Sensor Oil Spill Thickness Mapping in Arctic and High Sediment Load Conditions" - Project #658	Svejkovsky, Jan (Ocean Imaging Corporation) Muskat, Judd (CA Department of Fish and Game)	N/A	2010 - 2012	Ocean Imaging's current aerial thickness mapping system is routinely deployed during oil spills in California. For this to occur in other U.S. geographic areas the technology must be tested and validated under oceanographic and environmental conditions that were not experienced during initial development. The existing system was developed and operationally tested under temperate sea and atmospheric conditions with reasonable water clarity. Many geographic regions with oil and gas activities experience conditions outside of this realm. There is a need for system testing under extreme conditions such as the Arctic conditions experienced at high latitudes. With the rapid advancement of digital camera imaging technology a new, much more compact, less expensive and simpler to operate hardware could be utilized in the future systems. There is a need for the testing of simplified, self contained multispectral system configurations. This project is a direct continuation of TAR projects 544 and 594. Tasks: The project is comprised of six research/development and test/demonstration phases that also represent the project's major milestones. Some tests are dependent on specific seasons (i.e. wintertime experiments at Ohmsett and summer (ice free) testing on Alaska's North Slope). 1.Determination and initial testing of a digital data dissemination system suitable for the Arctic region. 2.Wintertime testing of oil thickness mapping sensor at Ohmsett and subsequent cold condition thermal Infrared (IR) oil mapping algorithm development. 3.Development of a simplified multispectral imaging system. 4.System testing on Alaska's North Slope. 5.System testing in highly turbid waters such as those in the Gulf of Mexico. 6.Development of new image processing/classification algorithms that will allow mapping and classifying the spatial distribution patterns of floating oil emulsions with different weathering, thickness and water content characteristics.	N/A	http://www.bsee.gov/Research-and-Training/Technology-Assessment-and-Research/Project-658.aspx	N/A - No results available
Aerial	Laser Flourosensor	OGP JIP Oil in Ice	UK	International Association of Oil & Gas Producers (OGP)	Airborne laser fluorosensor	Uknown (see notes)	N/A	2012 - Present	The objective is to assess performance of airborne LSF in Arctic field conditions with respect to oil detection and quantification on ice, snow and water surfaces as well as below a thin layer of new sea ice. LFS has been identified as a promising tool for detecting and possibly quantifying oil on the surface of solid ice and snow and/or on the surface of brash and slush in pack ice. LFS is independent of light conditions (darkness) and is believed to be a valuable tool for systematic, large scale, initial detection of oil in ice-covered waters. Oil detection and quantification by LFS systems are used operationally onboard maritime surveillance aircraft operated by the German Department of Transport and Environment Canada.	RFI for JIP projects posted 2/2012, full program info not yet available	http://www.sintef.no/Projectweb/JIP-Oil-In-Ice/Program-overview/Remote-sensing/Airborne-laser-fluorosensor/	N/A - No results available
Aerial Handheld	Ground Penetrating Radar	OGP JIP Oil in Ice	UK	International Association of Oil & Gas Producers (OGP)	Ground Penetrating Radar	John Bradford (Boise University)	N/A	2012 - Present	GPR is tested as a method to detect oil under sea ice (0.6 - 0.9 meter) and oil covered with snow spilled on top of ice. This work is performed in close cooperation with John Bradford at Boise University, USA. The GPR system is operated both handheld on the ice and airborn from a helicopter.	RFI for JIP projects posted 2/2012, full program info not yet available	http://www.sintef.no/Projectweb/JIP-Oil-In-Ice/Program-overview/Remote-sensing/Ground-penetrating-radar-GPR/	N/A - No results available
Aerial Satellite	Advanced Very High Resolution Radiometer Hyperspectral Imaging Medium Resolution Imaging Spectrometer Moderate Resolution Imaging Spectroradiometer Sea-viewing Wide Field-of-view Sensor Synthetic Aperture Radar	Florida Institute of Oceanography	USA	Gulf of Mexico Research Initiative Year One Block Grant	Early Warning 4-D Remote Sensing System to Assess Synoptic Threats to Coastal Ecosystems of Florida and of Adjacent States and Nations	Muller-Karger, Frank (University of South Florida)	Bostater, Charles (Florida Institute of Technology) Fries, David (Bioplex Technologies, Inc) Goldgof, Dmitry (University of South Florida) Hall, Lawrence (University of South Florida) Lohrenz, Steven (University of Massachusettes Dartmouth) Melo, Nelson (University of Miami) Roffer, Mitchell (Roffer's Ocean Fishing Forecasting Service, Inc.) Shay, Lynn (University of Miami)	2010 - Present	Oil that entered the environment from the Deepwater Horizon oil spill site represents a threat to coastal and pelagic ecosystems of the Gulf of Mexico region. Repeated and frequent mapping of surface and subsurface oil plumes over this large region was required for monitoring, forecasting and mitigation efforts. This two-year Collaborative Project organized experts from the region to conduct research under Category 1, i.e. to determine the distribution and extent of oil and dispersants. The approach built on the team's infrastructure, long history of time series research of the oceanography of the Gulf, and strong multidisciplinary academic education programs to also contribute to Categories 2 (baseline studies) and 3 (contribute to an integrated observing system). The project combines satellite and airborne observations collected by the remote sensing team with habitat and contaminant measurements from ships and other platforms to characterize oil and dispersant distribution and their environmental impacts. The team uses extensive connections in the fisheries, oil and other industries, and establish robust collaborative linkages with other biogeochemical, ecological, and modeling efforts to combine observations and minimize uncertainties in the identification and characterization of surface and subsurface oil. Synoptic assessments are developed by combining real-time satellite images (SeaWiFS, MODIS, MERIS, AVHRR visible and infrared, and synthetic aperture radar), detailed maps of coastal habitats impacted by the contaminants derived using airborne hyperspectral imagers, large-scale maps of the subsurface circulation obtained from sensors launched from NOAA hurricane hunter aircraft crossing the Gulf, and meticulous shipboard observations of oil presence and composition collected by other teams. The synoptic assessments have helped target coastal areas for high spatial resolution digital imaging and mapping conducted using the airborne cameras after oil contamination. Our ongoing historical satellite time series (1993-present) studies provide a context for assessing change. The information will be synthesized in written reports to support other studies, numerical forecasting efforts, and mitigation plans. The reports build on products we generated during the blowout incident and which were made available openly to decision makers and the general public. From a scientific and technical point of view, the project evaluates the various strategies used by different experts for manual image interpretation, and will lead to strategies for automated image thematic classification. The project will help understand the impact of the contaminants along the coasts of U.S. Gulf, over spatial scales ranging from centimeters to over a thousand kilometers. This work is conducted by experts from the University of South Florida, the University of Miami, the Florida Institute of Technology, VODA LLC, Inc., and the University of Southern Mississippi. We collaborate with other institutions engaged in collecting baseline and monitoring observations.	Listed as current project on Florida Institute of Oceanography website, no end date found	http://gulfresearchinitiative.org/research/awards/project-overview-3/?pid=48	N/A - No results available
Aerial Satellite	Various Unspecified (Optical and Radar based Imaging Systems)	N/A	USA	National Wetlands Research Center (NWRC) of the USGS	Cooperative Ecosystem Studies Unit, Gulf Coast CESU (Funding Opportunity #: G12AS20067)	N/A	N/A	2012 (July - closing date for applications for grant)	The National Wetlands Research Center (NWRC) of the U.S. Geological Survey (USGS) is offering a funding opportunity to a CESU partner for research that advances the development of interferometric and polarimetric radar remote sensing techniques and their integration with optical remote sensing data for mapping and monitoring coastal ecosystems, particularly in response to man-made and natural disasters. Although this research is to focus on the northern Gulf of Mexico, the expected technology advances will have direct implications to global remote sensing of coastal resources. The CESU recipient will conduct research that builds on and complements ongoing NWRC efforts to develop a near on-demand, regional remote sensing system that integrates the relevant aspects of optical and radar based imaging systems to address current limitations in strategic mapping and monitoring of coastal resources. (1) Advance the physical linkage between polarimetric radar backscatter and the occurrence of oil and subcanopy flooding in coastal wetlands. a. Develop empirical	Research grant notice	http://www07.grants.gov/search/search.do;jsessionid=s8F1QvQMdvNx3pm4qnTQLHF5TBHJn7w19V5Tv2b4j6SC1d6hYzxn!-1391769738?oppId=179597&mode=VIEW	N/A - No results available

Current Oil Spill Research and Development Programs

Platform	Sensor	Institution	Country	Funding Source	Program Title	Principal Investigator	Co-Investigators and Institutions	Program Dates	Abstract	Notes	Link to Website	Results Public Domain?
N/A	Trained Dogs	OGP JIP Oil in Ice	UK	International Association of Oil & Gas Producers (OGP)	Special trained Dogs	Buvik, Turid (Trondheim Dog Training institute) Brandvik, Per Johan (SINTEF)	N/A	2012 - Present	The objective is to study if special trained dogs can be used to detect oil spills hidden in snow or ice. Trondheim Dog Training institute (www.trondheimhundeskole.no) is SINTEFs cooperative partner in this activity and the owner Turid Buvik is responsible for the dog training. Extensive training has been performed in 2007/08 both in laboratories and in the field (Trondheim and Svalbard). The preliminary results are very promising.	RFI for JIP projects posted 2/2012, full program info not yet available	http://www.sintef.no/Projectweb/JIP-Oil-In-Ice/Program-overview/Remote-sensing/Special-trained-Dogs/	Publically accessible articles for previous research are available
ROV	LightTouch (Tuneable Diode Laser Spectrometer)	OGP JIP Oil in Ice	UK	International Association of Oil & Gas Producers (OGP)	LightTouch system	Shell Global Solutions	N/A	2012 - Present	The objective is to incorporate further testing of the Shell Global Solutions LightTouch system in future spill experiments for detection of oil in and under ice. Shell Global Solutions LightTouch system (LTS) is an ethane gas sensor which can be used to detect methane gases from oil trapped in or under ice. The system was tested with oil under ice in the Cold Region Research and Engineering Laboratory (CRREL) in US in 2004. The system detected ethane originating from the oil under ice with an ice thickness of 35 cm.	RFI for JIP projects posted 2/2012, full program info not yet available	http://www.sintef.no/Projectweb/JIP-Oil-In-Ice/Program-overview/Remote-sensing/LightTouch-system/	Publically accessible articles for previous research from 2004 are available
Satellite	Synthetic Aperture Radar	Florida Institute of Oceanography	USA	Gulf of Mexico Research Initiative Year One Block Grant	Coast Watch: Remote Sensing and Verification Sampling of Oil Spill Impact on Florida Coast	MacDonald, Ian (Florida State University)	Garcia-Pineda, Oscar (Florida State University) Snyder, Richard A (University of West Florida)	2010 - Present	As oil continues to make landfall along the NE Gulf of Mexico coast, there is an immediate and ongoing need for accurate assessment of landfall and landfall prediction. This project is proposed as collaboration between FSU and UWF, but intends to coordinate closely with coastal sampling operations on the Gulf coast. Where oil reaches the coast, first order measurements and sampling is required to document scale and intensity of impact. The group will coordinate three basic deliverables: 1.Conduct sea-level sampling and analysis of the oil and water column to provide regular ground truth for the remote sensing and NRDA level demonstration of oil properties, distribution, and impact. 2.Compile continuing remote sensing detection of probable hydrocarbon signals in satellite images, with a focus on the Florida coastline using Texture Classifying Neural Network Algorithms and related image processing methods. 3.Coordinate basic lea-level observation by research vessels and responder vessels operating in the offshore spill area. Results of the ground-truthed remote sensing assessment will be shared with modeling efforts being conducted by relevant institutions (e.g. COAPS, Univ. S. Florida). Coastal hydrocarbon surveys will be conducted from three locations long the coast. The sampling results will document impact levels for future damage and impact assessment.	Listed as current project on Florida Institute of Oceanography website, no end date found	http://gulfresearchinitiative.org/research/awards/project-overview-3/?pid=47	N/A - No results available
Satellite	Cloud Aerosol Lidar with Orthogonal Polarization LANDSAT Moderate Resolution Imaging Spectroradiometer Synthetic Aperture Radar	Naval Research Laboratory at Stennis Space Center, NASA/Langley Research Center, and NOAA/STAR	USA	NASA - Gulf of Mexico Initiative ROSES A.28	Oi Slick Detection Using NASA Active and Passive Sensors	Gallegos, Sonia (Naval Research Lab - Stennis)	Pichel, William (NOAA/STAR) Hu, Yongxiang (NASA-Langley Research Center) Arnone, Robert (Naval Research Lab)	2010 - Present (? - see notes)	Currently, there are no efforts to monitor oil slicks operationally from space. Agencies around the Gulf respond to chance sightings, almost exclusively. The Naval Research Laboratory at Stennis Space Center, NASA/Langley Research Center, and NOAA/STAR propose to pool their collective expertise with passive and active space borne sensors, and with spaceborne oil detection to develop automated and interactive techniques to produce the basis of an operational oil monitoring system for the Gulf of Mexico. The sensors to be employed are the AQUA/Moderate Resolution Imaging Spectroradiometer (MODIS), the Cloud Aerosol Lidar with Orthogonal Polarization (CALIOP), the Synthetic Aperture Radar (SAR), and LANDSAT. To identify the slicks several techniques such as neural network classifiers, edge detectors, polygon algorithms, and sensor fusion algorithms will be tested. Once the best techniques have been demonstrated, the generation of the oil products will be transitioned to the NOAA Satellite Analyses Branch (SAB) in Camp Springs, Maryland. The SAB will mass produce maps for the NOAA/Emergency Response Division (ERD) to be used in oil spill emergency response. The maps will also be assimilated into the General NOAA Operational Modeling Environment (GNOME), to forecast oil trajectories. This transition path will be highly effective during and after hurricanes when the agencies ERD supports in the Gulf of Mexico may be relocated to areas with restricted access to information. By transferring our products to a location outside of the danger zone we ensure that any agency in the Gulf can access oil spill information in a timely and effective manner. The proposed application addresses NASA's Applied Science Program areas of: Disaster Management, Weather, Water Resources and Climate change. It aligns well with the goals of two partners of the Gulf of Mexico Alliance: The Habitat Conservation and Restoration Team, and the Coastal Community Resilience Team.	No end date found, no results found, assumed on-going	http://science.community.nasa.gov/home/asp-projects/roses-a-28/oil-slick	N/A - No results available
Satellite	Synthetic Aperture Radar - L-Band Formation Flying	Australian Centre for Space Engineering Research (ACSER)	Australia	Australian Space Research Program (ASRP)	Garada - SAR Formation Flying	Dempster, Andrew (University of New South Wales) Rizos, Chris (UNSW) Verhagen, Sandra (UNSW) Teunissen, Peter (UNSW) Hall, David (EADS Astrium) Tuohy, Ian (BAE Systems Australia)	Cohen, Martin (Surrey Satellite Technology Ltd) Tsitas, Steven (UNSW) Middleton, Robert (UNSW) Yu, Kegen (UNSW) Parkinson, Kevin (UNSW) Shivaramaiah, Nagaraj (UNSW) Wu, Jinghui (UNSW) Buist, Peter (UNSW) Qiao, Li (UNSW)	2011 - Present	Garada, funded by the Australian Space Research Program (ASRP), is a collaborative space engineering research project at the Australian Centre for Space Engineering Research (ACSER). Working to user requirements, the project is developing the business case, design and technologies for a constellation of low cost and light-weight Synthetic Aperture Radar (SAR) spacecraft that can image the earth at night and in any weather. These will meet requirements for flood monitoring in Australia and have application to forest monitoring for carbon accounting, border protection, oil spill detection, agricultural monitoring and ocean surface current mapping. The research consortium consists of UNSW, Astrium Limited, Curtin University of Technology, Delft University of Technology, General Dynamics and BAE Systems.	N/A	http://www.garada.unsw.edu.au/	Several publically accessible articles are available on the project thus far.

Current Oil Spill Research and Development Programs

Platform	Sensor	Institution	Country	Funding Source	Program Title	Principal Investigator	Co-Investigators and Institutions	Program Dates	Abstract	Notes	Link to Website	Results Public Domain?
Satellite	Various Unspecified (space born radar and optical data; AIS and LRIT)	GMES (Global Monitoring for Environment and Security)	Multiple European countries	European Commission	SeaU (Multisensor Satellite Technologies for Oil Pollution Monitoring and Source Identification)	Pedersen, Gunnar (listed as contact person)	Partners: Kongsberg Satellite Services (KSAT), Norway; e-GEOS, Italy; Collecte Localisation Satellites (CLS), France; Norwegian Computing Centre (NR), Norway; Nansen Environmental and Remote Sensing Centre (NERSC), Norway; EDISOFT S.A., Portugal; ACRI-ST, France	2011 - Present (Duration listed as 36 months)	The overall objective of the SeaU project is to improve the current state-of-the-art methodology for satellite based oil spill detection and monitoring, and demonstrate through deliveries to existing and new users how these improvements can contribute to the development of a next generation sustainable downstream service. The SeaU project will, in close cooperation with existing and new users, establish an interface for integration of multi-disciplinary information in accordance with relevant standards and directives, and improve the oil detection methodology in compliance with user requirements. It will include multidisciplinary data and information, e.g. space born radar and optical data, and other environmental data such as vulnerable areas, bird cliffs etc. Another part of the project is to improve source detection and identification of polluters, with user of land based and space born sensors (AIS, LRIT), and also implement oil drift models in the operational service. In close cooperation with existing and new users, the project will result in new and improved operational oil monitoring service for end users in Europe.	N/A	http://www.gmes.info/pages-principales/projects/project-database/database-of-projects/?idproj=218&what=1&page=14&cHash=05b7be1cf361ea76ca4c8ce527212ca9	N/A - No results available
Satellite	Synthetic Aperture Radar	University of Miami	US	Gulf of Mexico Research Initiative - RFP-II Investigator-Based Awards (GoMRI Years 2-4)	Monitoring of Oil Spill and Seepage Using Satellite Radars	Hans Graber (CSTARS-University of Miami)	Haus, Brian (RSMAS-University of Miami) Romeiser, (RSMAS-University of Miami) Hargrove, Sr., John (CSTARS-University of Miami)	2012 - Present	After the Deepwater Horizon oil drilling platform at BP's Macondo well exploded and sank on April 20, 2010, a wide range of human resources and technology assets were mobilized in a massive effort to contain and mitigate the effects of this environmental catastrophe. The previous two decades had seen progress in the development of Synthetic Aperture Radar on satellite platforms for the detection and characterization of oil on the sea surface, but the DWH incident would provide by far the most significant demonstration of its operational utility. The proposed work addresses the ultimate goal of the GoMRI to improve the ability of society to respond to the impacts of petroleum pollution within the theme of improved technology for hydrocarbon detection and characterization. The technology development that we believe will result from the proposed work will provide the government and industry agencies tasked with spill response with increased situational awareness in general, and will allow them to act more quickly and effectively by concentrating resources where they are most needed. Improved spill mitigation will ultimately improve human health and economic well-being by limiting damage to the ecosystem.	N/A	http://gulfresearchinitiative.org/project-overview-3/?pid=230	N/A - No results available
Various Unspecified	Multispectral Infrared	University of Houston	US	Gulf of Mexico Research Initiative - RFP-II Investigator-Based Awards (GoMRI Years 2-4)	Novel Sensor System for the Early Detection and Monitoring of Offshore Oil Spills	Shih, Wei-Chuan	Glennie, Craig Han, Zhu	2012 - Present	Despite the pressing needs, effective detection and quantification of oil spills has not become a technological reality. Current detection methods employ manual identification using routine helicopter surveys, which are severely limited in their efficiency, by weather conditions, cost, and safety considerations The Gulf of Mexico (GOM) requires an efficient, reliable, automated and cost effective method of monitoring for spills, especially given that 90% of the more than 6000 platforms in the GOM are unmanned and unpowered. To this end, this project aims to develop an innovative sensor system to quantify oil film thickness using multispectral infrared (IR) imaging and computational reconstruction. Such a system can aid human observers in making objective and accurate decisions, or alternatively be installed on the platform as an automated and permanent sensor for 24/7 operations, replacing or greatly reducing the frequency of current helicopter surveys. The team will exploit the novel ultrasensitive detection mechanisms in the spectral and thickness modulations of oil films recently modeled and experimentally confirmed by the PI. These novel contrast mechanisms will enable the measurement of oil film thickness with 24/7 detectability. The proposed system seamlessly integrates passive multispectral imaging with a computational core to exploit the benefits of data sparsity. The system is potentially an extremely cost-effective permanent sensor installed on platforms for offshore oil spill detection. Alternatively, the proposed system could be integrated with a small unmanned aerial vehicle (UAV) for task-specific missions. Ultimately, many sensor systems can be installed on multiple platforms, forming a sensor network for oil spill trajectory monitoring and environmental forensics.	N/A	http://gulfresearchinitiative.org/project-overview-3/?pid=225	N/A - No results available
Various Unspecified	Various Unspecified (system/database of various platform and sensor data)	Nansen Environmental and Remote Sensing Center	Norway	European Commission	NETMAR: Open Service Network for Marine Environmental Data	Sandven, Stein (NERSC - Department of Polar Environment Remote Sensing) Hamre, Torill (NERSC - Department of Polar Environment Remote Sensing)	N/A	2010 - Present	OBJECTIVES: NETMAR aims to develop a pilot European Marine Information System (EUMIS) for searching, downloading and integrating satellite, in situ and model data from ocean and coastal areas. It will be a user-configurable system offering service discovery, access and chaining facilities using OGC, OPeNDAP and W3C standards. It will use a semantic framework coupled with ontologies for identifying and accessing distributed data, such as near-real time, model forecast and historical data. EUMIS will also enable further processing of such data to generate composite products and statistics suitable for decision-making. Project Summary: NETMAR aims to develop a pilot European Marine Information System (EUMIS) for searching, downloading and integrating satellite, in situ and model data from ocean and coastal areas. NETMAR will develop interoperability and connectivity between heterogeneous data systems to meet the demand for information from different user groups. Standardising data and metadata formats, as well as exchange protocols, are the first steps to bridge existing marine data systems. The next step is to define the semantics of the services, including an uncertainty model, to allow transparent computer-based discovery. Developing a semantic framework for marine data services, backed by a multilingual and multidomain ontology enabling searches across (human) languages and application domains, is therefore a key task. EUMIS will enable search for and use single services, as well as to compose new and more powerful services by service chaining, defining the workflow of the composite service using existing services as "building blocks". EUMIS will then merge established standards and tools with these new "building blocks" for application in practical monitoring of the marine environment. This will be done through a set of use cases in different European seas, where identified users will test and evaluate the EUMIS. The use cases include monitoring and forecasting of oil spills, plankton blooms and Arctic sea ice. Furthermore, the use cases will validate an ecosystem model, study the relation between physical and biological variables and data exchange with coastal web atlases.	N/A	http://www.nersc.no/project/netmar	N/A - No results available

Current Oil Spill Research and Development Programs

Platform	Sensor	Institution	Country	Funding Source	Program Title	Principal Investigator	Co-Investigators and Institutions	Program Dates	Abstract	Notes	Link to Website	Results Public Domain?
Various Unspecified	Various Unspecified	N/A	USA	Bureau of Safety and Environmental Enforcement	Presolicitation Notice: Broad Agency Announcement (BAA) Number E12PS00012 for Proposed Research on Oil Spill Response Operations	N/A	N/A	2012 (January - presolicitation posted)	Synopsis: Broad Agency Announcement (BAA) Number E12PS00012 for Proposed Research on Oil Spill Response Operations in the US Outer Continental Shelf DESCRIPTION:The U.S. Department of the Interior, Bureau of Safety and Environmental Enforcement (BSEE), solicits White Papers for specific areas of interest to the BSEE Oil Spill Response Research (OSRR) Program which includes oil spill planning, preparedness, containment, monitoring, recovery, treatment, and response in the U.S. Outer Continental Shelf (OCS). When appropriate, the research shall be conducted consistent with prior research. BACKGROUND: The BSEE OSRR Program is requesting White Papers to be submitted in accordance with the terms of this announcement. Authors of selected White Papers will be requested to submit full proposals. Proposals selected for funding by BSEE may receive funding from Fiscal Year (FY) 2012. The BSEE anticipates that $5,000,000 may be available for the initiation of new research addressing topics identified through this announcement. The BSEE does not anticipate any one award exceeding $1,000,000. NOTICE: The BSEE may share the White Papers with other organizations for review. Potential contractors shall notify the BSEE if they do not want their White Papers/proposals shared outside of BSEE. The BSEE anticipates awards resultant to this announcement will be made on a Firm Fixed-Price (FFP) basis. OBJECTIVES: The topics for the FY 2012 oil spill response research funding should be limited to the following topics: ... 7. Remote Sensing Techniques- BSEE is seeking White Papers that address the use of various remote sensing techniques to improve and facilitate the efficiency of various response countermeasures (mechanical containment and recovery, in situ burning, and the use of dispersants) during an oil spill. These techniques could encompass a variety of methods and be hosted on a variety of platforms. White Papers should include information on equipment capabilities and limitations, data download and dissemination capabilities, real-time data communication capabilities with response assets, and integration of data into the overall response control systems. Technologies/techniques that have previously undergone some degree of development should clearly indicate how funding by BSEE will advance the state of the art.	White papers due March 2012, no announcement of awards found	https://www.fbo.gov/index?s=opportunity&mode=form&id=1bfbfd220914ddb6496a70750209cb7e&tab=core&tabmode=list&=	N/A - No results available

AMERICAN PETROLEUM INSTITUTE

1220 L Street, NW
Washington, DC 20005-4070
USA

202-682-8000

Additional copies are available online at www.api.org/pubs

Phone Orders:	1-800-854-7179	(Toll-free in the U.S. and Canada)
	303-397-7956	(Local and International)
Fax Orders:	303-397-2740	

Information about API publications, programs and services is available on the web at www.api.org.