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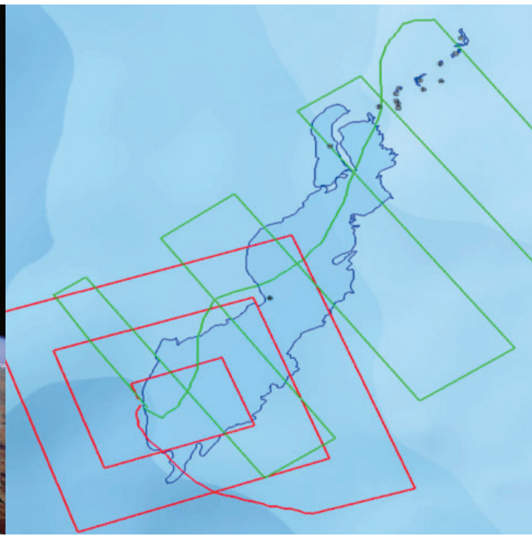
Satellite remote sensing of oil spills at sea

Good practice guidelines for the application of satellite remote sensing during oil spill response operations



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Satellite remote sensing of oil spills at sea

Good practice guidelines for the application of satellite remote sensing during oil spill response operations

Preface

This publication is part of the IPIECA-IOGP Good Practice Guide Series which summarizes current views on good practice for a range of oil spill preparedness and response topics. The series aims to help align industry practices and activities, inform stakeholders, and serve as a communication tool to promote awareness and education.

The series updates and replaces the well-established IPIECA 'Oil Spill Report Series' published between 1990 and 2008. It covers topics that are broadly applicable both to exploration and production, as well as shipping and transportation activities.

The revisions are being undertaken by the IOGP-IPIECA Oil Spill Response Joint Industry Project (JIP). The JIP was established in 2011 to implement learning opportunities in respect of oil spill preparedness and response following the April 2010 well control incident in the Gulf of Mexico.

The original IPIECA Report Series will be progressively withdrawn upon publication of the various titles in this new Good Practice Guide Series during 2014–2015.

Note on good practice

'Good practice' in the context of the JIP is a statement of internationally-recognized guidelines, practices and procedures that will enable the oil and gas industry to deliver acceptable health, safety and environmental performance.

Good practice for a particular subject will change over time in the light of advances in technology, practical experience and scientific understanding, as well as changes in the political and social environment.

Contents

About this guide

This Good Practice Guide (GPG) builds on two reports, one produced on behalf of the IPIECA-IOGP OSR-JIP entitled *An Assessment of Surface Surveillance Capabilities for Oil Spill Response using Satellite Remote Sensing* (IPIECA-IOGP, 2014a), and the second published by the American Petroleum Institute entitled *Remote Sensing in Support of Oil Spill Response* (API, 2013).

The API report focuses on how remote sensing is integrated into overall OSR activity (including the key individual roles remote sensing may be required to play), while the OSR-JIP report concentrates on the surveillance capabilities of satellites (such as the practical issues associated with data availability).

The objective of this Good Practice Guide is to synthesize and summarize the content presented within these reports, and to provide responders, regulators, statutory consultees, industry, non-governmental organizations, oil spill response organizations and academia with an overview of the strategic and operational application of satellite remote sensing for oil spill response.

Introduction

To respond to an oil spill effectively, those involved in the response operations require accurate and timely information on the location, the quantity and characteristics of the oil spilled and the characteristics of the areas likely to be impacted by the spilled oil. This information enables the incident command to effectively determine the scale and nature of the oil spill scenario, make decisions on where and how to respond, control various response operations and, over time, confirm whether or not the response is effective.

Surveillance is key to providing this 'situational awareness' during an oil spill response operation. It is supported by a range of different technologies and techniques, from traditional and well-tested observation from vessels and aerial platforms to the use of innovative, small-scale unmanned aerial vehicles (UAVs).

Satellite remote sensing for oil spill response

Satellite remote sensing (SRS) is an additional surveillance tool that can be readily used to provide synoptic and strategic information to the response. Remote sensing is the acquisition of data about an object or phenomenon without making physical contact with it, often using electromagnetic radiation. Satellites, and the sensors onboard, can be used as remote sensing platforms to measure properties of the Earth from above the atmosphere and to gather data that can be used for a variety of applications.

For oil spill response, satellite imagery provides information that can be used to support various missions, including assessing the initial (and potential future) extent and impact of a spill, planning response operations and monitoring the effectiveness of the response as a whole.

To fulfill these roles, satellite remote sensing must meet various requirements of the response, including delivering information within certain timelines or at regular intervals. It must also be able to operate in a variety of environmental conditions, including during adverse weather.

Operational guidance: using satellite remote sensing within an oil spill response

This GPG provides operational guidance on how to:

- prepare a satellite image plan;
- establish the roles and responsibilities required during the response;
- follow and manage the acquisition of satellite imagery; and
- understand the technology (and its limitations) involved.

A basic checklist that should be followed when using satellite remote sensing as part of an oil spill response can be found on page 57, and lists the steps that should be followed prior to, during and after an incident.

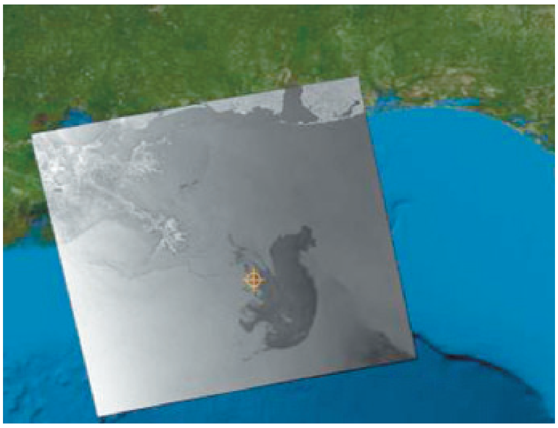
Oil spill surveillance

What is surveillance for oil spills?

Surveillance is the observation of a spill to gather information that is used to detect, identify, assess and monitor an ongoing spill scenario. Surveillance not only requires observation but also the recording, documentation and dissemination of the information gathered so that it can be shared with the necessary stakeholders within the response.

During an oil spill response, surveillance can be used for various roles and purposes. In particular, those organizing the response operations can use surveillance to enhance their situational awareness of the spill. In addition, the outputs from surveillance—including imagery and video, maps, spreadsheets and calculations—can be used for planning operations, monitoring and assessing the impact of recovery methods, validating and calibrating numerical models of the spill, and as a communication tool for briefing external parties, such as the media and the public. Furthermore, real-time surveillance can provide tactical support during a response, e.g. by using aircraft to 'spot' oil slicks and direct the dispersant application vessels to the appropriate area.

Surveillance information that has been recorded and documented can be used post-spill for a variety of other purposes, e.g. providing support for training courses and exercises, and for educational and academic reference. The information can also be used to help address any legal issues and regulatory requirements that have arisen from the spill.



Example of synthetic aperture radar (SAR) C-band microwave image of the Gulf of Mexico oil spill in 2010, captured by RADARSAT-2.

In addition to being used during oil spill response operations, surveillance can also be used as a preparedness measure to monitor areas at potential risk from oil spills (e.g. areas near installations, shipping routes, pipelines) on a routine or even a continuous basis.

The role of surveillance during an oil spill response

Surveillance is an essential part of the response toolkit, and provides valuable information on the evolving scenario during a response operation. Oil spill surveillance should provide the response team with:

- an initial detection (or confirmation) and assessment (characterization and quantification) of an oil spill *within a specified time frame*.
- ongoing assessment and synoptic monitoring of an oil spill **and** the response operations *at regular intervals*; and
- tactical support (constant monitoring) for operations and missions *at the required time and location*.

The delivery of information within the required time frame is critical for ensuring an adequate level of situational awareness, as well as helping with operational planning and communication.

Box 1 *What is situational awareness?*

Situational awareness is 'knowing what is going on around you'. For an oil spill response, situational awareness requires a holistic yet comprehensive understanding of the spill scenario; this is achieved by identifying, processing and comprehending critical elements of the information provided. Obtaining the right types of information and ensuring that it is correct and up to date is thus intrinsic to gaining an accurate situational awareness of an oil spill.

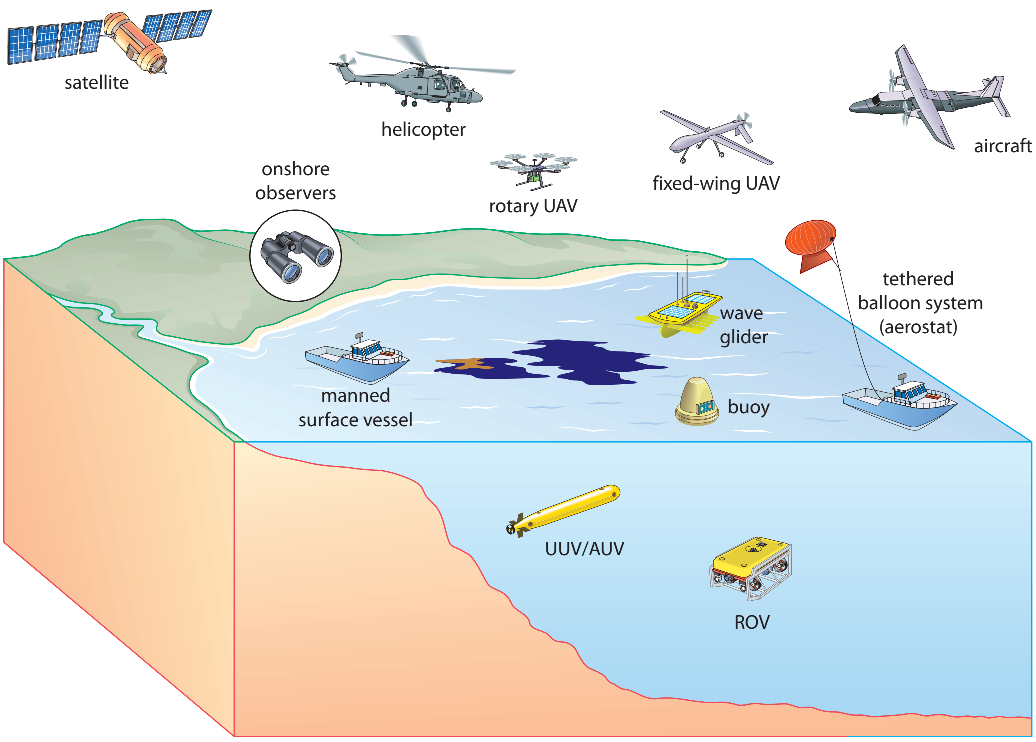
How does surveillance contribute to situational awareness?

Surveillance is used primarily to detect, characterize and preferably quantify spilled oil that may be present in on-water, in-water and onshore settings. Furthermore, surveillance can be used to gather information on the environment surrounding the oil spill. Surveillance can therefore provide much of the key information needed to inform the response about the evolving spill scenario, such as the locations of spilled oil (absolute and relative), estimates of the quantity of spilled oil, characterization of the oil, and even information on the operating conditions (weather forecasts, local terrain or hydrography, environmental sensitivities)—all of which are of critical importance for situational awareness.

The tools and approaches used for surveillance during a response

To ensure that the most appropriate information is provided efficiently during a response, an oil spill surveillance and monitoring programme should be put in place that uses a variety of surveillance approaches and tools to gather the information needed and support the ongoing response (Figure 1).

Figure 1 *Examples of surveillance tools that may be used in a response operation*



Surveillance tools can include:
- satellites (using optical, infrared and radar techniques);
- unmanned underwater vehicles (UUVs), including autonomous underwater vehicles (AUVs) (e.g. gliders) and remotely operated vehicles (ROVs);
- unmanned surface vessels (USVs), including autonomous surface vehicles (ASVs) (e.g. AutoNaut, wave gliders);
- surface vessels (using techniques including optical and radar, photography and video, and human eye);
- buoys, trackers and mounted systems (e.g. instruments mounted on rigs or moored independently);
- onshore observers (using human eye, photography and video)
- aerial platforms such as fixed-wing aircraft and helicopters (using techniques including human eye, optical and radar surveillance, photography and video);
- unmanned aerial vehicles (UAVs) (using optical and radar techniques); and
- tethered balloon systems (i.e. aerostats, using optical and infrared techniques).

Each tool has its advantages and limitations when used to gather information for oil spill response; these characteristics are outlined in the API report on remote sensing (API, 2013). For information on surveillance tools other than satellite remote sensing technologies see IPIECA-IMO-IOGP, 2015 and IPIECA-IOGP, 2016.

The advantages and limitations of satellite remote sensing technologies need to be considered in conjunction with the oil spill scenario, as a variety of different factors may affect the overall suitability of a particular tool. Factors that may need to be taken into account include:
- the size of the spill (and predicted duration);
- the location of the spill (both geographical position and type, e.g. offshore, inland);
- the environmental conditions;
- the operating conditions;
- the type of oil spilt and its behaviour during weathering (e.g. tendency to spread);
- logistical issues (e.g. access to deploy the technology);
- regulatory and political constraints (including control and regulation of airspace and the ocean, and local governance of technology);
- the type of response operations;
- when the information will be needed; and
- the ease of integrating and organizing different sources and types of information.

Observing a localized small spill

OSRL

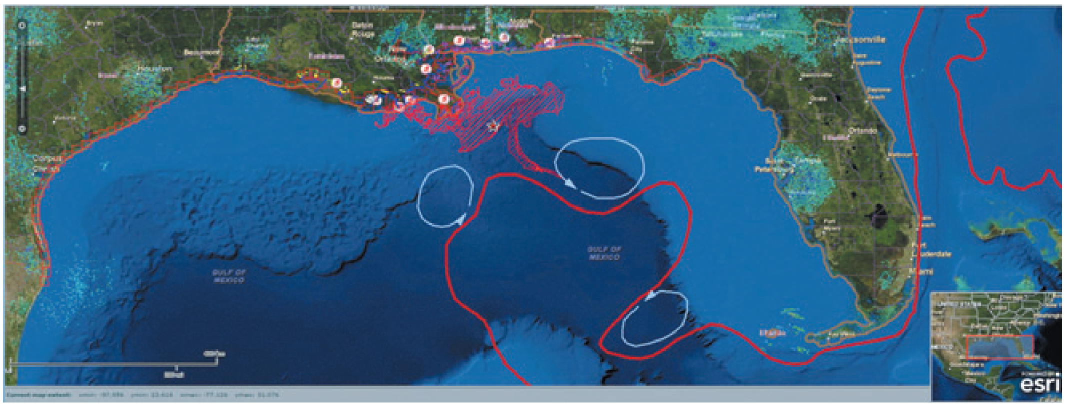
For example, a localized small spill may only require human observers; and the deployment of surveillance aircraft to monitor larger spills could be prevented by poor weather conditions. In general, to gather all the information required, a surveillance programme should utilize a combination of the surveillance tools that are appropriate for the response.

As an incident progresses, the demands on a surveillance programme will generally increase, and the programme often divides into strategic (situational awareness, operations planning and impact monitoring) and tactical (supporting operations) roles. Any tool used should be capable of meeting at least one of these roles and their requirements.

Measuring the effectiveness of a surveillance programme

The overall effectiveness of the surveillance programme will be most visible within the response's common operating picture (COP). The COP is a shared view of the incident and its operating conditions, and has been defined as '*a computing platform based on geographic information system (GIS) technology, which provides a single source of data and information for situational awareness, coordination, communication and data archival to support emergency management and response personnel and other stakeholders involved in, or affected by, an incident*' (IPIECA-IOGP, 2015a). The COP is used to support strategic and tactical decision making within the Incident Management System used to manage the response.

The COP allows response personnel and other stakeholders to view any data and information generated within the response, including surveillance data. Much of the information in the COP is static and can therefore be developed and pre-populated during the response planning phase for the location in question. If any surveillance-relevant information required by users is 'missing' from the COP, the surveillance programme will need to be improved and updated to ensure that all users' needs are meet. Detailed guidance on the elements that should be included in the COP can be found in IPIECA-IOGP, 2015a.



Waypoint Mapping/Esri

Surveillance data gathered during a response operation is fed into the GIS-based common operating picture to ensure that all stakeholders are operating from a common situational awareness standpoint.

Satellite remote sensing as an oil spill surveillance technique

Satellites are used as a surveillance tool for oil spill response because they can:

- capture imagery over a large area in a relatively short time period;
- capture imagery at varying levels of detail;
- capture different types of imagery, dependent on the sensor used;
- be tasked to collect imagery over a certain area on a repeatable basis;
- capture imagery in adverse weather conditions (dependent on the sensor onboard); and
- normally operate independently of logistical and political constraints.

Furthermore, the processing and analysis of the imagery can be fully or partially automated along with the output of the final product. Additional datasets can also be derived from imagery (such as information on other environmental conditions or the presence of hazards), while all final products can be easily incorporated into GIS software and displayed with other types of data.

The role of satellite remote sensing as part of an oil spill surveillance programme

SRS can be used to fulfill the strategic roles within a surveillance programme during an oil spill response, including:

- supporting the initial detection and assessment;
- conducting ongoing assessment and synoptic monitoring; and
- providing pre-spill and baseline data.

Each of these roles has its own data requirements. For oil spill response, the delivery of data within a required time frame is often the most critical requirement, as the value of satellite imagery data is greatly diminished by delays incurred between its receipt and the production of actionable intelligence. Table 1 on page 11 presents a checklist of the requirements that, as a surveillance tool, SRS would be expected to meet. In the case of ongoing assessment and synoptic monitoring, these requirements may change as the response progresses, i.e. towards the latter stages of clean-up, an image every 2–3 days may be sufficient.

The likelihood of SRS meeting these requirements is determined by various factors that will vary on a spill-by-spill basis, and will therefore need to be considered when choosing SRS as a surveillance tool.

Meeting the data requirements of a response

The factors that affect whether SRS can meet the requirements of an oil spill response include the:

- set-up and operation of a satellite remote sensing capability;
- data acquisition workflow process; and
- operating/environmental conditions.

For the initial assessment, the time it takes for data captured by SRS to be translated into information that can be used by the response will vary from one response to another.

Table 1 *Data requirements for satellite remote sensing*

	Roles of satellite remote sensing		
	Initial detection and assessment	**Ongoing assessment and synoptic monitoring**	**Pre-spill/baseline data**
	• Detection of an oil spill • Determination of the extent of the release and other characteristics • Providing situational awareness at the source • Supporting the selection of appropriate recovery methods	• Providing updates on the extent, location and tracking of the spill • Supporting and refining oil spill modelling/forecasting • Providing support to operations planning • Assessing the impact of response efforts	• Determining spill timelines • Identifying false alarms • Establishing pre-existing geographic setting and the environmental/ infrastructure condition • Identifying resources at risk • Providing support for modelling/forecasting
Requirements that SRS is expected to meet			
Data availability	**Minimum:** data delivery within 24 hours of data request **Goal:** data acquisition within three hours of data request	**Minimum:** data delivery within 24 hours of data request **Goal:** meeting all scheduled requests.	**Minimum:** data delivery within 48 hours of data request
Data collection frequency	**Minimum:** daily	**Minimum:** daily	**Minimum:** image from the last month before the spill **Goal:** image from the last 72 hours before spill
Coverage	**Minimum:** 100% of spill at required spatial resolution* **Goal:** additional imagery of critical or impact areas	**Minimum:** 100% of spill and surrounding area at required spatial resolution*	
Oil parameters to be assessed	**Minimum:** oil location and extent **Goal:** concentration, thickness**, condition		N/A
Other parameters to be assessed	**Goal:** identification of any factors that may impede the commencement of operations	**Goal:** post-spill near real-time conditions (environment, asset locations, conditions, access, hazard identification)	**Minimum:** pre-spill 'baseline' conditions **Goal:** ancillary datasets identifying resources at risk
Critical requirements for an oil spill response	**Minimum:** data format should be readable by GIS software/common operating picture **Goal:** to provide supporting information, including text explanations to help interpretations		

* May be provided by multiple images during the same acquisition.

** See Box 2, *Can (satellite) remote sensing determine oil thickness and type?* on page 14.

To deliver imagery within the first 24 hours of a spill will require that there are no time delays or lags in the imagery acquisition process, or that the image acquisition has been pre-planned (discussed later in this GPG). In the absence of pre-planned imagery, it is more likely that the first imagery will be available within the first 48–72 hours. Satellites may not, therefore, be suitable for 'short-lived' spills (e.g. less than 24 hours) or for time-critical missions; for the initial assessment of the spill—which should be conducted within the first 3–6 hours—aerial surveillance is likely to be the more suitable tool.

For ongoing assessment and monitoring, satellites can be programmed to acquire imagery at regular intervals, and the end products customized to fit the response requirements. As a result, satellites can generally be highly reliable in providing repeatable, routine and/or scheduled surveillance, and if there is any potential disruption to surveillance, this can be reported early on. This is important when regular information is required, such as to feed into daily briefings during operations planning. Satellites cannot, however, provide continuous monitoring; alternative tools, such as tethered balloons, should therefore be used if continuous monitoring is required for operations such as directing response vessels towards the oil.

The capability to provide 'historical surveillance' is also a key advantage of using SRS as a surveillance tool. Satellite archive imagery can also be used to provide pre-spill imagery of the area, which can help to identify when the spill occurred and show the characteristics and conditions of the surrounding environment. This is, however, dependent on a suitable image being present within the archive catalogue for the affected area, and cannot necessarily be guaranteed.

In general, satellites can operate independently of adverse weather conditions and operational constraints that may hinder other tools. For example, if the right sensor-satellite combination is used, satellites can acquire imagery in adverse weather conditions (e.g. cloud cover, rain). Other tools may be restricted by operational controls, such as the regulation of working hours for aircrews used in aerial surveillance. Furthermore, satellites are subject to fewer political constraints (e.g. ground or airspace controls) compared to other tools; however, if an area is subject to military restrictions, the use of satellite surveillance may not be possible. It is also possible that legal or regulatory provisions may impose restrictions on the use and sharing of certain surveillance data and information in some geographic locations.

Overall, satellites can provide a reliable and repeatable source of surveillance information to the response, but should be used in combination with other surveillance tools to ensure that all of the response's data requirements can be met.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Satellites should be used in conjunction with other surveillance tools to ensure that all of the response's data requirements are met.

Using satellite imagery to provide information to the response

The purpose of any surveillance tool is to provide information that can be used by end users to improve decision making within the response. The end users of satellite imagery may include:

- response staff (those in charge/command, those organizing general and specific operations and those in the field);
- the party responsible for the spill;
- regulatory or governmental organizations;
- the media; and
- the general public.

The information provided may be essential to informing situational awareness at the command level, or for providing operation-specific intelligence, e.g. the location of individual slicks when planning in-situ burning operations. Table 2 outlines the types of information that SRS can provide to the response through image processing and interpretation (by both human and computer analysis).

While this information can be provided by other surveillance tools, the imagery produced by satellites has various advantages over its counterparts that may make it a preferable option.

Table 2 *Information provided by satellite remote sensing*

Aspects of the spill/ response to be assessed	Information provided by SRS
Presence of oil on water	• Detection of oil on water • Rejection of false alarms • Validation of oil on water (using expert interpretation)
Oil spill measurements and characteristics	• Geographical location of the oil spill and individual slicks/monitoring slick movement • Extent of the oil spill • Number of slicks • Quantity of oil spilled (estimate)* • Type and condition of oil spilled (if possible, will require expert interpretation)*
Location of the oil spill/surrounding area	• Physical location (on-water, onshore, inland) • Associated environmental conditions (ocean currents, surface type, ice coverage) • Environmental sensitivities in the area (mangroves, nesting areas)
Operating conditions	• Associated physical characteristics that could impede operations • Access routes
Socio-economic factors	• Areas of habitation/urbanization nearby • Economic vulnerabilities (fishing zones, farmland)
Ongoing operations	• Location of resources and assets and number deployed

* See Box 2, *Can (satellite) remote sensing determine oil thickness and type?* on page 14.

Box 2 *Can (satellite) remote sensing determine oil thickness and type?*

The determination of oil spill thickness and type through the analysis of imagery is a prominent area of research in both the oil spill and remote sensing industries. Whether a remote sensor is deployed on a vessel, aircraft or satellite, it needs to be capable of distinguishing between different oil thicknesses across a spill to calculate spill volumes as well as improve the ability to plan ahead and determine the most appropriate recovery techniques.

Using image analysis to determine oil thickness and type requires the optimum combination of sensors, specific operating conditions and expert interpretation. Research is still being carried out on this technique, although some progress has been made in determining thickness using hyperspectral imagery. These advances are discussed further in the chapter on *Understanding satellite technology for oil spill response* on page 45.

The main advantages of using satellite imagery include:

- automation of the processing and analysis of data as soon as it is downloaded, e.g. to automatically detect oil spills and determine their extent (although this would normally be validated manually);
- the ability to fuse (integrate) several layers of data to help with data validation, e.g. using different types of data to help in the detection of false alarms;
- the ability to derive ancillary datasets that can inform other parts of the response (e.g., deriving oil movement, wind and current directions can help to validate and refine oil spill trajectory modelling);
- the ability to 'mosaic' (i.e. stitch together) imagery with relative ease, creating large-coverage imagery useful for base maps and operation planning;
- consistency of the format of the imagery and its outputs, enabling final products to be standardized across responses;
- additional datasets relating to other environmental conditions and hazards can be derived from the captured imagery; and
- final products can be easily incorporated into GIS software and displayed with other types of data.

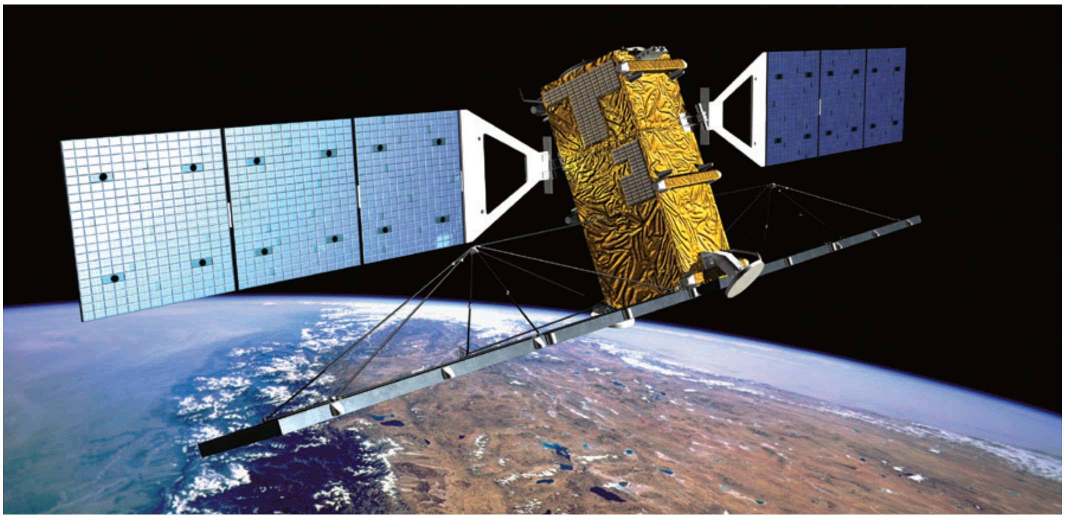
The data outputs from other surveillance tools are unlikely to provide all of these advantages. For example, while a highly intelligent camera system onboard an aircraft may be able to automate data processing and fusion, it is unlikely to match the coverage or level of detail that satellites are able to provide. In addition, data captured by the different technologies used during aerial surveillance—ranging from intelligent camera systems mounted onboard to hand-held cameras operated by human observers viewing the scene through an aircraft window—can be variable and may result in inconsistencies in the output format.

Establishing satellite remote sensing within the response

Recent advances in airborne remote sensing, and in UAV technology in particular, might lead some to believe that SRS no longer has a place in spill response. However, SRS remains a unique contributor to wide-area, synoptic views required by the COP. By combining the ability to schedule and programme satellites as well as automate the processing, analysis and delivery of the imagery, SRS can prove itself to be a robust and reliable way of acquiring and providing surveillance information throughout the response. Fundamentally, once the initial satellite imagery has been acquired, a plan can be implemented for future acquisitions. This will enable the response team to know the times and the frequency at which they will receive satellite imagery, as well as the area covered and the type of imagery received (although the quality or usefulness of the data captured will be subject to the appropriate weather conditions). This is of particular use for ongoing assessment and synoptic monitoring as well as operations planning, where the provision of consistent, regular and punctual information is critical to aiding the response.

The key challenge when establishing SRS within a response is the initial process of identifying and selecting the most appropriate satellite system and satellite imagery provider to use. It is essential that the personnel responsible for these decisions have appropriate authority and experience, otherwise the process can easily become drawn out or over-complicated.

The longer it takes to choose the required technology, the longer it will be before data acquisition can begin; this will therefore be an important constraining factor in determining whether SRS can meet the relevant data requirements for the initial time-critical mission of assessing the oil spill. This difficulty can be overcome by making the relevant preparations, preferably as part of the contingency planning process, in advance of a spill occurring. As the capability and coverage of a satellite is fixed, the most appropriate satellite system (and satellite imagery provider) can be pre-identified for a particular area, and even the expected timings, the revisit frequencies and spatial coverage can be determined to create a preliminary satellite imagery plan. The satellite imagery plan is an important preparedness measure that should be exploited within a response.



Selecting the most appropriate satellite can be one of the most crucial challenges for the response organization. The example on the left is RADARSAT-2, an advanced commercial radar satellite operated by MacDonald, Dettwiler and Associates Ltd.

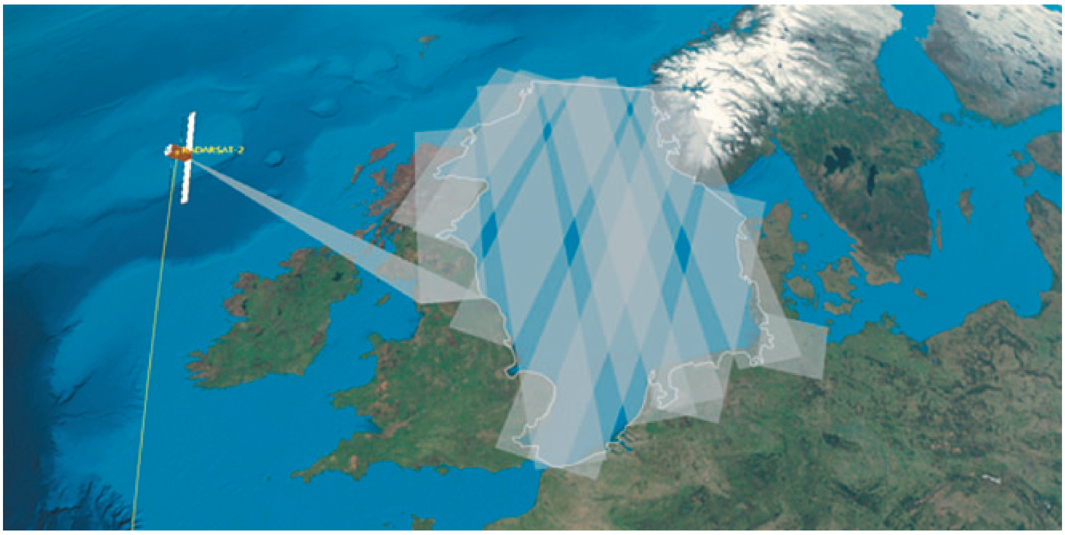
Developing a satellite imagery plan

To facilitate the efficient use of SRS as a surveillance tool during a response, it is recommended that the necessary groundwork is conducted as an oil spill preparedness measure, preferably as part of the oil spill contingency planning process (see Box 4 on page 17). This planning work should result in the formulation of a satellite imagery plan that contains the information necessary to commence SRS operations with the minimum delay in the event of an oil spill incident.

The development of a satellite imagery plan involves:

- identifying one or more satellite imagery provider(s);
- choosing the most appropriate technology for potential spill scenarios in the area of interest (AOI);
- developing a standard operating procedure for requesting the satellite imagery from the provider; and
- compiling the above information in a readily accessible format.

Once the satellite imagery plan has been finalized, it can be included as part of the oil spill contingency plan (OSCP) or incident response plan. The creation of an effective satellite imagery plan is described in more detail below.



Satellite coverage map of the North Sea by RADARSAT-2, illustrating a SAR low-incidence angle imaging mode over a nine-day period.

Preparedness for satellite remote sensing

The satellite imagery plan aims to increase the likelihood that the imagery is acquired successfully and used effectively in a response. The creation of a satellite imagery plan should follow a process similar to that of an OSCP; existing satellites and associated satellite imagery providers should first be compared to assess their relative capabilities and provision over the AOI for various scenarios, in particular accounting for seasonal weather conditions. The most appropriate choice of satellite technology and imagery provider is then made, and the details are documented within the plan. The plan should also describe the operating protocols and procedures that will be followed in the case of a spill, including how to order imagery from a satellite imagery provider, and the expected data requirements of the response.

The development of a rigorous satellite imagery plan requires those responsible for creating it to have:

- experience in understanding and using satellite remote sensing technology;
- an understanding of the expected data requirements of a potential response;
- knowledge of the various response scenarios that could occur over the AOI; and
- access to satellite image planning software that can aid in identifying the appropriate satellites (see Box 3).

While these capabilities may be available 'in-house' for use by the party who is creating the plan (whether a company, response organization or government/regulatory agency), it is recommended that a satellite imagery plan be developed in conjunction with a satellite imagery provider. As the satellite imagery provider will be responsible for acquiring the imagery, they will need to be aware of the potential scenarios they may become involved in. They will play a major role in ensuring that the satellites chosen are available and suitable for use, and that the imagery requested is suitable for the response. Furthermore, as the satellite imagery provider will have access to their own satellite planning software, they will be able to provide further details regarding the sampling capabilities, including the projected satellite path, revisit capabilities and spatial coverage, as well as a potential imagery delivery schedule for the various satellites.

Box 3 *Satellite image planning software*

Commercial satellite image planning software is available, either as desktop packages or as web-enabled services. These can be used to optimize the assessment and monitoring of areas of interest, through trade-offs involving temporal and spatial sampling, cost and type of imaging sensors. One example is 'SaVoir', a multi-satellite swath planner provided by Taitus Software. SaVoir was originally developed for the European Space Agency to support operations of the International Charter for Space and Major Disasters. The aim was to provide an easy-to-use tool to quickly identify potential data acquisition opportunities over any area of interest and with any satellite and sensor combination, speeding the efforts in data ordering for disaster relief.

Box 4 *Oil spill preparedness and contingency planning*

Oil spill preparedness is part of a framework that seeks to improve industry's capability to respond to oil spills. The oil spill preparedness and response framework is founded on the belief that a successful response depends on well-trained personnel working to a well-developed response strategy that is adequately resourced and properly exercised and tested. The preparedness process consists of:

- identifying potential events;
- planning scenarios based on previous events that encompass the full range of potential impact and response challenges;
- developing response strategies based on these scenarios; and
- providing the response resources that are likely to be required.

The oil spill preparedness process is fundamental to contingency planning and the development of an OSCP. An OSCP is a document, or suite of documents, that provides guidance on how to respond to an oil spill, providing the instructions and information needed in a response and demonstrating that a rigorous planning process has been undertaken in building response capability for the region or facility at risk. The desired outcomes of both processes are to:

- ensure that pre-approved response strategies are in place to respond to a spill as rapidly and effectively as possible;
- help to overcome barriers during a response through rapid non-partisan decision making and the sharing of objective information; and
- leverage the right expertise before, during and after a spill through clear predefined roles and responsibilities, resulting in the designation of operational authority only to appropriate response parties.

All of the above increases the likelihood of a successful and effective response operation.

More information about the contingency planning process can be found in the IPIECA-IOGP Good Practice Guide on contingency planning for oil spills on water (IPIECA-IOGP, 2014b).

By involving the satellite imagery provider at an early stage, the party can benefit from any expertise and experience that the provider may have in using satellite remote sensing for oil spill response; this can help to further ensure that a robust plan is developed. In addition, involving the satellite imagery provider early on allows for a good working relationship to be established without the pressures of responding to an incident; this is likely to make it easier to work together in the future if an incident occurs. Establishing a good relationship with the imagery provider may also present additional tangible benefits—for example, the provider may have their own image planning template or other standardized protocols and procedures in place that can be adapted for the response, thereby reducing the amount of work that needs to be carried out in developing the plan.

Choosing a satellite imagery provider

When selecting a satellite imagery provider, it is recommended that a 'Request for information' is first prepared and sent to interested providers asking them to outline their capability for the provision of satellite imagery and coverage over the AOI. Different satellite imagery providers have access to different satellites, and the capability of each satellite is likely to vary depending on the types of sensors used and on the temporal and spatial coverage across geographical regions. It is therefore important to identify who can provide the optimal solution for the AOI. Once the most suitable satellite imagery provider(s) is identified, the satellite imagery plan can be developed with the provider's input as required. *Early engagement with satellite operators (and remote sensing specialists) is key to ensuring that SRS operations can be implemented efficiently at the time of an oil spill response.*

Access to multiple satellites

It is vital to ensure that the satellite imagery provider chosen has access to multiple satellites (and/or satellite operators); this will ensure that satellite imagery can be acquired as quickly as possible during a response. At any one point in a day, the availability of satellite imagery over a particular AOI can be limited. This is due to factors such as: weather conditions that may prevent the capture of usable imagery; satellites not being available for tasking due to maintenance issues; or that the AOI is poorly sampled by satellites at the particular time of day due to orbit configurations. These factors are discussed later in this guide. As a result, choosing a satellite imagery provider that has access to more than one satellite will increase the likelihood of a satellite being successfully tasked, and of usable imagery being captured within the required time frames.

Box 5 *Satellite imagery provider or satellite operator—or both?*

Satellite imagery providers act as a 'middleman', taking orders from customers and sending these requests on to satellite operators (who are responsible for tasking and maintaining the satellite). Often, the imagery provider and satellite operator will be the same company. In other scenarios, satellite imagery providers will have distributor agreements, allowing them to submit orders to the satellite operators for task requests and then provide the imagery to the client on behalf of the operator.

In the case of a significant incident, it is likely that the response will require access to *all* commercial satellites available to maximize the probability of success and protect against gaps in data due to tasking conflicts, transmission failures, etc.

Why will the satellite need tasking?

Satellites are generally used for collecting data prospectively and building up a library of imagery that can be referenced at any time. However, a pre-existing image library will not always be sufficient to satisfy a customer's specific requirements. For this reason, satellite operators offer various 'tasking' options to external parties. Tasking enables end users to order specific data from a particular pass of the satellite over the AOI, thereby providing end users with near real-time data. In practice, a combination of both approaches may be used. However, the majority of satellites suitable for oil spill response will operate as tasked satellites and will often have been tasked months in advance to complete acquisitions for particular purposes.

As a result, to acquire satellite imagery for an emergency response, an order will need to be submitted to the satellite operator that asks for the satellite to be tasked to acquire imagery over a certain AOI when it passes over on its next orbit. It is important to bear in mind that urgent tasking requests may need to take precedence over existing, potentially long-standing orders for data from the same satellite, and that the specific tasks requested by the response team will need to be carried out as soon as possible. For these reasons, a tasking order will need to be submitted as a 'high priority' request, and is therefore likely to incur additional associated costs.

Creating an oil spill satellite imagery plan

In general, a satellite imagery plan should provide:

1. **Contacts for ordering satellite imagery:** this should include the contact details of satellite imagery provider(s), as well as details of any existing agreements with those providers.
2. **A standard operating protocol (SOP) for ordering imagery:** clear instructions should be provided for ordering imagery, together with a description of the data specifications of the imagery and the expected final product. See below for addition information on the SOP.
3. **Potential acquisition plans for various timescales:** this should include example approaches to scheduling regular imagery acquisitions for various timescales.
4. **List of suitable satellites for varying scenarios:** an initial evaluation of satellites suitable for use for a range of scenarios, missions and operating/environmental conditions should be documented; the evaluation should include the satellite data capabilities (e.g. revisit frequency) and the expected temporal and spatial coverage over the AOI.
5. **Regulatory requirements for the use of satellite remote sensing within the AOI:** details of the regulatory requirements pertaining to the required imagery, frequency and delivery times or required coverage of the spill, should be clearly documented.
6. **Licensing and/or terms of use for the imagery:** the plan should include an outline of how the imagery can be used and shared within the response, together with any conditions governing its use, e.g. acknowledgement of the satellite imagery supplier/satellite provider.

Standard operating protocol

The specifications provided within the SOP include the data specifications (such as preference of imagery type and expectations for delivery times), final product specifications (such as the output format, expected details provided, map templates) and general organizational specifications (such as contact details, data sharing procedures) that would be required by the response. These specifications are used to pre-plan imagery and can be referred to during a response to help communicate exactly what is expected from the satellite imagery provider. Having these specifications to hand minimizes the time spent on ascertaining the response requirements, and also reduces the risk of ambiguity for both the response team and satellite imagery provider regarding what will be provided.

The specifications to be included within the SOP are outlined in Table 3 on page 21, which provides a minimum recommendation of the detail that should be pre-planned and ready to give to a satellite imagery provider, as well as preferred and optional details that can also be included within the satellite imagery plan.

Image pre-planning may also incorporate a potential acquisition plan. This would detail how to set up regular acquisition requests for varying periods of time, and should include information on when, and how often, imagery should be acquired, and whether this is likely to change as the response progresses or for certain missions. As this information is likely to be incident-specific, it can only serve as general guidance and should be updated, based on the spill scenario, before implementation during an oil spill response.

Regulatory requirements

The satellite imagery plan should acknowledge whether any regulatory requirements for using satellite imagery within a response exist for the AOI. For example, the plan should stipulate whether the use of satellite remote sensing is mandatory, and if so, what requirements it should be able to meet (e.g. capacity to operate during the night). The use of satellite remote sensing as part of an oil spill response operation is a relatively new technique, and its regulation is not yet standardized. It is therefore recommended that advice be sought directly from the regulators during the development of the satellite imagery plan. In addition, the licensing and/or terms of use should be agreed at the outset to ensure that the response operators are able to use the imagery according to their needs during a response.

Using and updating the satellite imagery plan

Once completed, the satellite imagery plan can be included within the OSCP as a supporting document. It can also be integrated with other field development and emergency response plans as necessary. As with the OSCP, the satellite imagery plan should be updated as and when the situation changes, for example when new satellites are launched or existing satellites retired from service, or when a new agreement is reached with a satellite imagery provider. As a minimum, the plan should be reviewed every 6–12 months.

Table 3 *Data specifications to be included in the standard operating protocol*

	Specification	Minimum	Preferred	Additional
Operational	**The required AOI with the respective coordinates**	• Coordinates available to hand (i.e. in note form) with longitude and latitudes. • The coordinates should be provided in an acceptable coordinate reference system (CRS).	• Coordinates should be provided in a format that can be interpreted by any GIS or image processing software, e.g. using a KML file or providing a CSV file with longitude and latitudes. • This should help prevent errors occurring when transmitting the coordinates of the AOI (e.g. transcribing coordinates over the telephone may result in latitudes and longitudes being inadvertently transposed or misinterpreted).	• For larger areas, areas of differing priorities or multiple AOIs, a geodatabase consisting of vector files for each AOI, plus information about each AOI within the attribute table (e.g. imagery requirements) should be available.
	Required delivery time	• Expectation of when the imagery is required/within a certain time frame.	• Daily plan of when imagery will be needed for the first few days of the response.	• Request for general timings of image acquisition and delivery times.
Data-specific	**Imagery requirements**	• Coverage of oil spill required. • Level of detail required.	• Coverage of oil spill required. • Type of imagery pre-identified. • Spatial resolution identified.	
	Oil parameters that should be assessed	• Extent of oil spill and individual slicks. • Estimated area covered by the spill.	• Extent of oil spill and individual slicks. • Estimated area covered by the spill. • Oil characterization.	
Output	**Final output requirements**	• Description of expected final product, e.g. PDF map, data files.	• Specification of final product level/level of processing required. • Analysis of the types of oil spills to be provided. • Types of products to be extracted from imagery.	• List of ancillary data sets to be provided.
	Map template (supporting information)	• List of expected features to be present on a map and/or with data sets.	• Standard template provided for PDF maps, containing all details required from imagery (e.g. surface area estimations). • Standard template established for providing data products, including original raster imagery and/or vector files of the digitized spills.	
Organization	**Contact details of those requesting imagery**	• Contact of preferred satellite imagery provider to be used.	• Direct contact details of a key individual within the preferred satellite imagery provider. • Details of the agreement with the preferred satellite imagery provider.	
	Data sharing procedures	• Details of an email address or file-sharing site for final products to be sent. • Basic data format provided.	• Open Geospatial Consortium (OGC)-compliant data formats provided.	• Access given to upload directly to the COP.

Establishing agreements with satellite imagery providers

During the creation of a satellite imagery plan, it may be beneficial to establish an agreement with the selected satellite imagery provider(s) that outlines the intent for both parties working together in the event of an oil spill response. The agreement may be informal or formalized through a Service Level Agreement (SLA). An SLA will provide a contractual obligation, stating the level of service expected by both parties; for example, the satellite imagery provider may agree to offer an emergency response 'on-call' service 24 hours a day for 7 days a week.

Whether formalized or not, the agreement should outline specific operational details regarding the authorization and implementation of the satellite imagery plan. For example, this may include a requirement for the response personnel to supply the imagery provider with an authorized request form before satellite tasking can begin, or a requirement for any potential costs to be

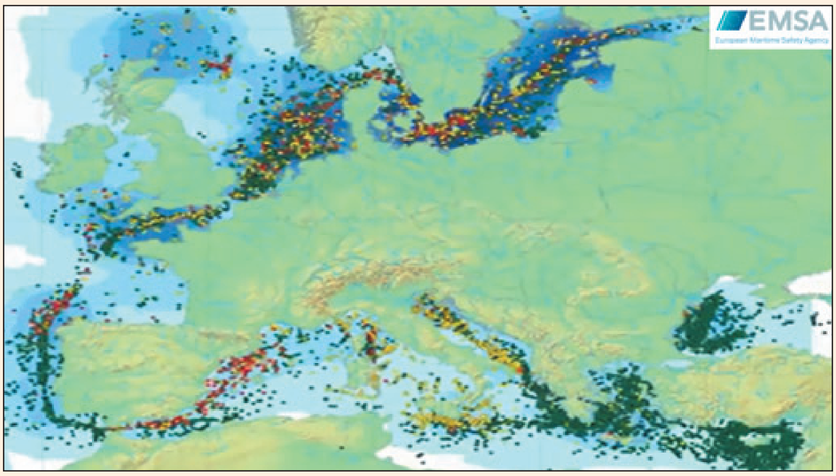
Box 6 *Oil spill detection and monitoring programmes*

As previously mentioned, surveillance can be used to monitor areas at risk from oil spills (e.g. near installations, shipping routes, pipelines) on a routine or even continuous basis as a preparedness measure. Many different techniques can be used to monitor these areas for oil spills, from flying UAVs along pipelines to identify leakages, to using helicopters to survey rigs.

Satellites can be used proactively on a routine basis to monitor areas at risk, providing an initial alert that a possible oil spill has been detected. Furthermore, satellites can cover large areas at risk, unlike mounted radar system on rigs and installations. As a result, satellites can be used for monitoring on a variety of scales, and are therefore appropriate for use in regional and global initiatives, as well as for meeting individual localized needs.

As a separate preparedness measure, satellite imagery providers are also able to provide oil spill detection programmes for individual customers, including customized programmes to monitor priority areas or during specific time periods.

Several oil spill detection/monitoring programmes are currently in place to monitor specific areas by using satellites. An example is the European Maritime Safety Agency's CleanSeaNet programme, which monitors waters close to European shores and provides an alert and the relevant imagery to member states when a possible oil spill is detected. The service supplies radar and optical satellite imagery to 28 participating states, including EU Member States and their overseas territories.



EMSA, 2011: *CleanSeaNet First Generation*, p8.

Example of a focus map generated from data captured by the European Maritime Safety Agency's (EMSA's) CleanSeaNet programme (16 April 2007–31 January 2011), which covers all European sea areas.

clearly communicated. An agreement can also be useful to help clarify and confirm the potential licensing and/or terms of use of the imagery between the party and satellite imagery provider (see also the section on *Using and communicating the imagery and data* on page 40).

The type of agreement with the imagery provider can range from a 'response-only' arrangement to a fully comprehensive 'preparedness' service. For example, an SLA may be put in place that offers many benefits other than reactive imagery acquisition, such as oil spill detection monitoring, the provision of satellite imagery updates to rule out false positives (see the list of potential false alarms in Table 14 on page 48), and the provision of archive imagery that can be used for baseline monitoring and as evidence for use in cases of illegal discharge (i.e. third parties 'dumping' oil near oil installations). In addition, the satellite imagery provider could provide access to a real-time assessment of potential image acquisition opportunities as part of the satellite imagery plan, so that the plan can be updated and executed without delay in an event of a spill.

From satellite remote sensing preparedness to response

The creation of a satellite imagery plan requires a person within the response party to take responsibility for its development and implementation; for large companies and organizations with sufficient capacity, this may be the task of a dedicated satellite remote sensing or technical specialist working on a particular preparedness project or assigned with general responsibility for the satellite remote sensing team.

It may also be the case that the development of the satellite imagery plan is outsourced to an oil spill response organization, a technical consultancy or the satellite imagery provider. Whenever the plan development is outsourced, an individual within the response party will still need to take ownership of the satellite imagery plan, even if this role only involves documentation and management (version updates) of the plan, and its distribution to stakeholders in the case of a spill.

For companies and organizations that do not have a satellite imagery plan in place for existing operations, it is recommended that an appropriate plan is developed; this task could be assigned to the same individual responsible for ongoing reviews and improvements in the preparedness and SRS capability of the company as a whole.

As soon as a spill is reported, the process of obtaining satellite imagery for the response can be put into action using the satellite imagery plan. Implementing the plan requires that one or more individuals within the response team have at least some basic knowledge and experience of working with satellite remote sensing. These individual(s) will be responsible for initializing and communicating the plan, and liaising with those in charge of organizing the response (the Incident Command) and with the satellite imagery provider. The responsible person(s) will also need to help update the existing data requirements to reflect the evolving scenario, including reviewing satellite options and their suitability for operation in changing weather conditions. If SRS preparedness measures have not been taken and a satellite imagery plan does not exist, the responsible person(s) will also need to take on the responsibility of developing a plan early on in the response effort. The different roles and responsibilities for the use of SRS should be clarified at the start of a response, and can be included in the satellite imagery plan, if appropriate.

Stakeholder roles and responsibilities

The use of satellite remote sensing within a response involves several stakeholders, who have varying roles and responsibilities to ensure that the satellite imagery plan can be implemented without delay and the resulting imagery can be used effectively within the response. The stakeholders and their roles are summarized below in Table 4.

An individual within the response team (whether this is the responsible party (RP), the oil spill response organization (OSRO) or other managing organization such as a local government agency) is required to take on the role of Coordinator at the start of a response. The Coordinator should be responsible for implementing the satellite imagery plan and liaising between the relevant stakeholders during the response. Preferably, an SRS Coordinator should be identified by companies, OSROs and local government agencies during the contingency planning process, and should be responsible for developing, updating and implementing the satellite imagery plan.

Table 4 *The roles and responsibilities of stakeholders when using satellite remote sensing for oil spill response*

Stakeholder	Role	Responsibilities
The responsible party (RP)	The party responsible for the spill, which in some cases will authorize the use of SRS. This party may also be responsible for managing the spill response and using the imagery directly.	• Provide the satellite imagery plan (if it exists). • Authorize the expenditure and use of satellite imagery. • Provide a Coordinator/Liaison responsible for managing SRS within the response.
The oil spill response organization (OSRO)	The organization coordinating and managing the response (*if not conducted internally by the RP*), and that will use the satellite imagery.	• Provide the satellite imagery plan (if it exists). • Provide a Coordinator/Liaison responsible for managing SRS within the response (if required).
The satellite imagery provider	The organization providing the imagery to the response. *The provider may be pre-identified within a satellite imagery plan or chosen during the response.*	• Develop a satellite imagery plan if one does not exist. • Provide satellite imagery according to the requirements outlined by the plan and ensure that it is appropriate for the response. • Ensure that the response personnel understand the acquisition timings and the resulting imagery provided.
Regulatory or governmental organizations (e.g. local government agency)	Organizations that may enforce any legal or regulatory requirements for the use of satellite imagery. *They may also use the imagery for their own purposes, or even be responsible for managing the response.*	• Inform stakeholders of any regulatory or legal requirements.

Satellite Remote Sensing (SRS) Coordinator

The initial task of the SRS Coordinator is to determine whether a satellite imagery plan exists for the spill area; the plan may be held by the RP or, if mobilized, the OSRO, or a local government agency. If a plan is not in place, the SRS Coordinator should take the necessary steps to develop a plan by:

- liaising with those organizing the response (i.e. the Incident Command—which usually consists of representatives from both the RP and the OSRO, as well as other key stakeholders such as maritime agencies and coast guards) to ascertain their needs and requirements;
- identifying a suitable imagery provider; and
- developing a satellite imagery plan with the help of the imagery provider.

Any existing plan will also need to be updated to reflect the operating environmental conditions.

Once a plan is in place, the image acquisition process can begin. Based on the response requirements and environmental conditions, the satellite imagery provider will determine the most appropriate technology to use for the scenario and, if required, will present potential options to the SRS Coordinator. The satellite imagery provider will then manage the acquisition process (from tasking to final product delivery) based on the specifications given by the SRS Coordinator; these will include the timescales, output format and any ancillary data requested. The SRS Coordinator should communicate these specifications and timescales to Incident Command and, once the final imagery products are received, manage and disseminate them within the response.

The responsibilities of the SRS Coordinator fall into the following five categories:

1. Awareness and understanding of any pre-existing satellite imagery plans for the area at risk.
2. Ordering imagery by liaising between satellite imagery providers and incident command (including chain-of-custody oversight).
3. Basic data management, and quality assurance and control of final products (including original data and imagery).
4. Basic interpretation of final products (e.g. understanding what the imagery depicts).
5. Sharing, stewardship, disclosure and dissemination of information and data.

To fulfill these tasks, the SRS Coordinator will need to have relevant knowledge, experience and organizational skills, including as a minimum:

- an understanding of the basic principles of remote sensing;
- a basic understanding of the different technologies available (including sensors and platforms);
- the ability to discuss and explain the relative advantages/limitations of the different technologies to stakeholders;
- the ability to explain the image acquisition workflow to stakeholders;
- experience in ordering imagery from satellite imagery providers;
- experience in using the final products offered by satellite imagery providers;
- the ability to project manage the acquisition process, including good communication and organizational skills; and
- the ability to manage (store and archive) the products delivered.

Meeting these requirements will help to ensure that the needs of the response are communicated accurately and efficiently between the incident command and the satellite imagery provider, and that the data is distributed among the appropriate personnel within the response as soon as it has been delivered.

Beyond coordination: establishing a Satellite Remote Sensing Team

In addition to liaising between stakeholders, and ordering and managing the satellite imagery, various other tasks will need to be completed so that the final products are ready to be used by the response. These tasks may include:

- imagery planning (forming initial orders and planning future tasking requests);
- data/image processing (including independent processing of imagery products received from the imagery providers);
- data generation;
- data validation and quality assurance;
- advanced data management, using databases and/or catalogues to help end users locate the required imagery; and
- integrating imagery into GIS software and/or the Common Operating Picture *(or providing data in a GIS-compatible format)*.

The satellite imagery provider conducts the majority of these tasks in the first instance, in particular image planning, processing and data validation. However, if the response team has the capacity, both in terms of time and resources (manpower, computing), and the capability to carry out these tasks independently, a technical SRS Team can be established.

The exact set-up of an SRS team will vary according to the nature of the response. For example, these responsibilities may rest with only one individual taking on the role of both SRS Coordinator and SRS Analyst; or a team may be established which includes several specialists, each with their own designated roles. In general, the various set-ups that may be established are:

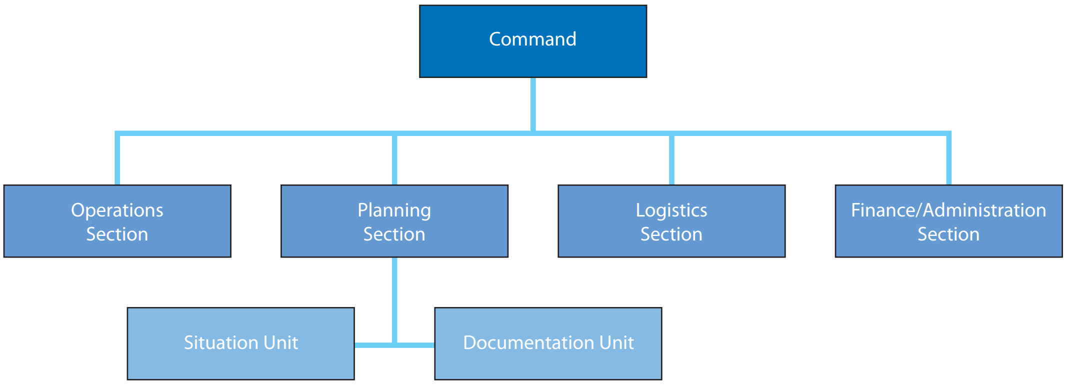
- a single individual within the response, acting as both SRS Coordinator and SRS Analyst;
- a team of specialists within the response, including an SRS Coordinator and separate a SRS Analyst; and
- an individual or small team of specialists within the response, including an SRS Coordinator, which also uses the satellite imagery provider to provide extra capacity when necessary.

However the team is structured, it is essential that they have appropriate experience and knowledge to complete all of the required tasks.

Integrating satellite remote sensing into an existing Incident Management System

An Incident Management System (IMS), such as the Incident Command System (ICS) used within the USA, is the fundamental command and control organizational structure of an emergency response team. For any response, a form of IMS will be in place that defines the roles and responsibilities of those involved in the response, as well as the units they belong to and the reporting structure within. Figure 2 illustrates the basic IMS structure. For more information on the IMS see the IPIECA-IOGP Good Practice Guide entitled *Incident management system for the oil and gas industry* (IPIECA-IOGP, 2014c).

Figure 2 *The organizational structure of an Incident Management System*

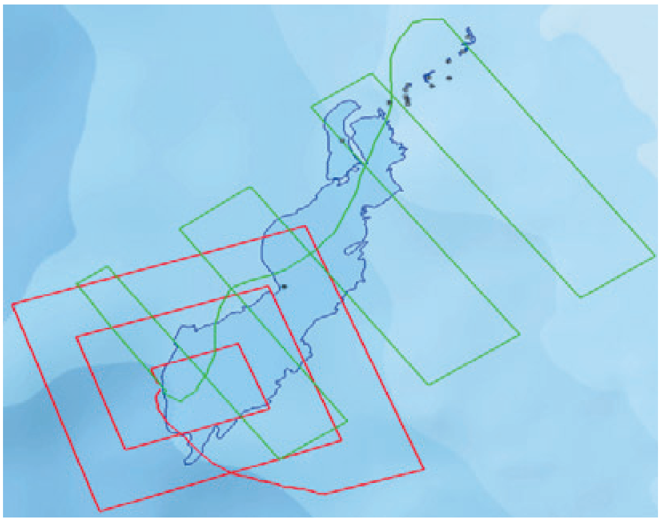


To integrate SRS into the response's IMS, it is recommended that the SRS Coordinator (and/or SRS Team) is assigned to the Planning Section and reports to the Situation Unit Leader. A central function of the Planning Section involves the collection and evaluation of operational information about the incident, including the current and forecasted situations (e.g. weather, oil spill trajectory, air quality, ecological and socio-economic features at risk) and the status of assigned resources. The Situation Unit will collect and evaluate situation information for the response (including information on actions currently being taken and forecasts of future incident management activities and information); the Documentation Unit will then manage the overall documentation for the response and develop an overall administrative record, including logs, files, plans, maps and other records for the response. In addition, the Planning Section will be responsible for establishing and maintaining the COP.

The SRS Coordinator should provide data and information to the Situation Unit so that they can be integrated into the overall information management process. The SRS Coordinator should also be aware of whether a GIS team is present within the response, and if so, should work with them to populate the COP with satellite imagery and data, ensuring that any protocols and procedures (such as naming conventions, data formats etc.) are consistent across the response. It is possible that the individual acting as SRS Coordinator may also be involved in other response teams.

Coordination with the Air Operations Team

The SRS Coordinator should also work closely with the Air Operations Team, which is responsible and accountable for the safe operation and tracking of aircraft, and typically operates out of the Operations Section. The Air Operations Team can use satellite imagery to identify areas affected by the spill, and to help guide surveillance/dispersant-spraying aircraft to their targets. The imagery can also be used to monitor the impact of aerial dispersant application.



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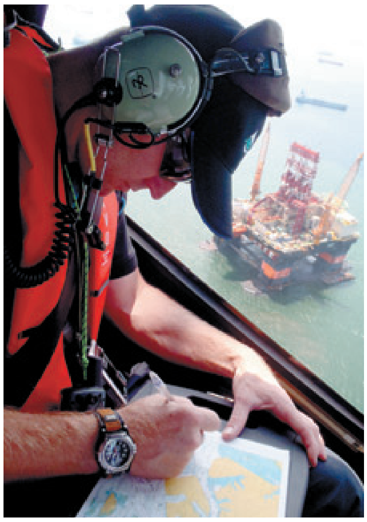


OSRL

Near right: map showing satellite surveillance data being used to guide aerial surveillance. The (blue) polygons show the outline of the oil detected by satellite (shape files in a map display), while two separate aerial surveillance overflights are illustrated in red and green, respectively.

RADARSAT-2 Data and Products ©MacDonald, Dettwiler and Associates Ltd., 2011. All Rights Reserved. RADARSAT is an official mark of the Canadian Space Agency.

Far right: conducting aerial surveillance.

To ensure that the Air Operations Team is using the most up-to-date information, the SRS Coordinator should inform the Team of the expected acquisition and delivery times of the satellite imagery. This will enable the Air Operations Team to schedule their operations to take place as soon as the imagery is available for planning. The SRS Coordinator should ensure that the Air Operations Team is able to access the imagery as soon as it is accessible. The IPIECA-IMO-IOGP Good Practice Guide entitled *Aerial observation of oil spills at sea* provides guidance on the strategic and operational use of aerial platforms for oil spill response (IPIECA-IMO-IOGP, 2015).

Working with the satellite imagery provider

As well as providing the imagery, the satellite imagery provider plays a major role in ensuring that the imagery ordered is appropriate for the response and that the final products are suitable for use by the end users. This is particularly important when:

- only an SRS Coordinator with limited SRS experience is present within the response team;
- a satellite imagery plan has not previously been developed; or
- the in-house SRS team does not have the capacity to fulfill all of the SRS tasks required.

Establishing a good working relationship with the satellite imagery provider is important and can be achieved by putting in place an agreement that outlines the requirements of the response.

The SRS Coordinator should be aware of any agreements that exist with a satellite imagery provider, whether as part of the satellite imagery plan or as an informal arrangement between parties. Parties to the agreement with the imagery provider may be the responsible party, an oil spill response organization, or both. For example:

- The responsible party may have a pre-existing agreement with a satellite imagery provider.
- If the responsible party is a member of an OSRO that has a pre-existing agreement with a satellite imagery provider, it is likely that the OSRO will manage the imagery acquisition on behalf of the responsible party as part of the SLA between the OSRO and the responsible party.
- If the responsible party is a member of an OSRO that has a pre-existing agreement with a satellite imagery provider **but** the responsible party also has its own agreement with a satellite imagery provider, the responsible party will need to decide which provider to use.

If an agreement is not already in place, the responsible party will need to decide how to establish one:

- If the responsible party is a member of an OSRO that **does not** have a pre-existing agreement with a satellite imagery provider, the responsible party will need to either establish an agreement directly with a satellite imagery provider **or** instruct the OSRO to establish an agreement on their behalf as an additional service.
- If the responsible party is **not** a member of an OSRO, they may:
  - establish an agreement directly with a satellite imagery provider; or
  - instruct an OSRO to establish an agreement on their behalf, while maintaining separation from the OSRO's other services.

Ultimately it is the decision of the responsible party to decide which satellite imagery provider should be used. The important provision is that an agreement is made by the SRS Coordinator, and that all stakeholders are made fully aware of its existence well in advance of, and during, a spill.

Working with regulatory and governmental organizations

During a spill, regulatory and governmental organizations will be present to monitor the progress of the response, ensure that all regulatory conditions are adhered to and report on the impact of the spill to the relevant authorities. In many places, the government may even take the lead on managing the response. In either situation, the SRS Coordinator should take a proactive role in engaging with the regulatory and governmental organizations, providing the relevant imagery and information when requested to do so. By providing large-scale synoptic coverage, satellite imagery is an important communication tool that can be used in a response. However, it needs to be used carefully. Distinguishing oil on an image often requires expert analysis; any imagery provided to external organizations (and released to the media and public) should therefore be accompanied by the instructions necessary to interpret what is shown on the image.

Regulatory and governmental organizations may also be a source of satellite imagery. Those which have their own oil spill monitoring programmes may have provided the initial notification of a spill, and will possess the original image(s) in which the oil was detected. This is a key advantage of having an oil spill monitoring detection programme in place, whether run by regulatory organizations or provided by a satellite imagery provider under contract to a specific company or customer. The original imagery can be used to begin updating the satellite imagery plan and to help select the most suitable technology for the response.

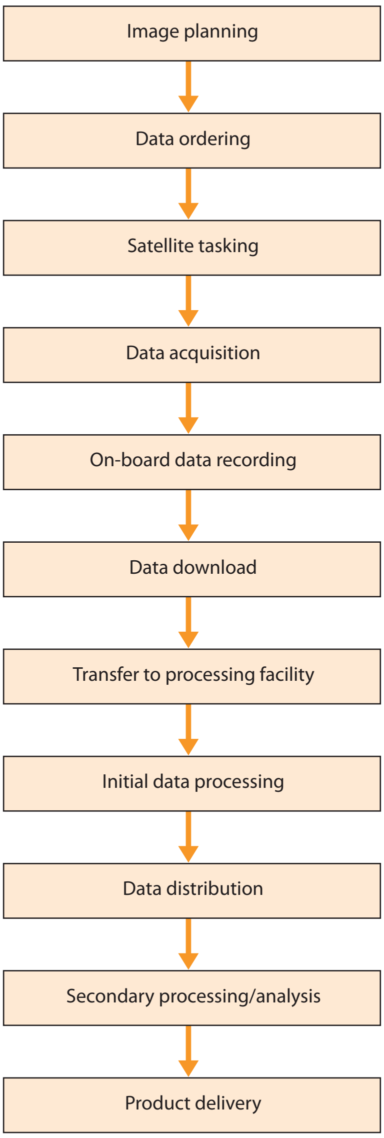
The satellite imagery acquisition workflow

As soon as a spill is reported, actions can begin to obtain satellite imagery for the response. Following the initial spill notification, the SRS Coordinator should begin image planning with the satellite imagery provider who will then be able to submit an order to the satellite operator as soon as it is authorized by the response.

The imagery acquisition workflow

The acquisition of satellite imagery forms a defined workflow (Figure 3). This can be used by the SRS Coordinator to outline to other stakeholders the timescale required for acquisition of the satellite imagery. Each step of the acquisition workflow is explained below.

Figure 3 *Image acquisition workflow*



Spill notification

The initial spill notification informs the responsible party or OSRO that a spill has been detected. The spill notification is important for SRS as it provides details of the location, including country or region, and coordinates of the spill, the type of area affected (e.g. inland, rivers, offshore, subsea, etc.), the date and time, and the source, cause and status of the spill. Environmental (e.g. weather) and sea conditions may also be given. These details should be provided to the SRS Coordinator to help with imagery planning.

Image planning

Using the information provided at the spill notification stage, the SRS Coordinator can update the satellite imagery plan and then consult with the satellite imagery provider to determine the most suitable options and put together an order for the satellite imagery. Using image planning software, the satellite imagery provider will determine the most appropriate technology to meet the requirements and priorities of the response, and will agree this with the SRS Coordinator. This agreement between the SRS Coordinator and the provider, often known as the 'tasking handshake', is a critical step in the acquisition workflow. The Coordinator is responsible for reviewing the tasking proposal, providing a map of the acquisition area, and reconfirming the AOI; this avoids any risk of the wrong area being targeted—something that could potentially occur, for example if latitude and longitude coordinates are inadvertently misquoted.

The image planning software should take into account whether or not a satellite is available for tasking. Table 5 lists the main reasons why a satellite may not be available.

Table 5 *Factors affecting the availability of a satellite*

Factor	Explanation
Satellite/sensor availability	There may be insufficient satellite resources available for acquisition due to maintenance and/or ongoing issues.
Higher priority acquisitions	A higher priority acquisition from another client (e.g. military) may conflict with the order.
Area	The target area may be restricted (i.e. acquisitions not allowed) due to security or for commercial reasons.

As a result, the image planning process may involve consideration of several different potential combinations of satellites to ensure that the optimal imagery can be acquired; using a satellite imagery provider that has access to a wide selection of satellite options will be beneficial for this process.

Data ordering

Once the most appropriate satellite(s) and operator have been identified, the imagery provider will place the order with the satellite operator. Orders which are required as a matter of urgency should be clearly marked with the appropriate priority level for the attention of the operator. The initial order for an oil spill response should be given 'emergency' or 'rush' priority to ensure that the required imagery is acquired, processed and delivered as quickly as possible. Priority orders are likely to incur additional costs but will ensure that the imagery is acquired at the next suitable opportunity. Table 6 explains the terms that are commonly used to describe different priority levels for tasking the satellites; note that the terms used and the expected timings may differ between satellite imagery providers and also between satellite operators.

Table 6 *Common priority levels assigned to the tasking of a satellite*

Priority level	Explanation
Standard/non-time critical	The order is agreed in advance (at least the previous day); acquisition occurs on a 'best effort' basis, i.e. when the satellite next passes over the AOI and there are no other tasking conflicts. Such orders can be superseded by higher-priority acquisitions.
Time-critical	The order is agreed in advance **and** acquisition occurs during a pre-agreed date/time period. Such an order takes priority over non-time critical orders and can be **guaranteed**, but may still be superseded by emergency orders.
Emergency/rush	The order can be placed at 4–12 hours notice; acquisition occurs on the next available pass over the AOI. Such an order takes priority over all other orders.

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Satellite tasking and data acquisition

If an order is accepted, the satellite will be tasked to acquire data when it passes over the AOI on its next orbit. Satellite tasking only occurs a limited number of times per day in set periods; these are known as the 'tasking windows'. If an order is not accepted within a particular tasking window, the response team will need to wait for the next tasking window, which will delay the acquisition of the imagery.

Once the satellite is tasked, the next opportunity for imagery acquisition—known as the 'acquisition window'—will depend on where the satellite is in its orbit in relation to the spill. If the spill is just behind the satellite when it is tasked, the acquisition will be delayed by at least the time it takes for a satellite to complete one full orbit (~100 minutes).

The acquisition of imagery may therefore take up to several hours from the point of order, dependent on the spill location and the set-up of the satellite and its operation. The potential delays should be considered when developing the satellite imagery plan (see also pages 37–38).

Onboard data recording and data download

Satellites transmit the recorded data to the satellite operator by downloading it to an available ground station which is set up and ready to receive the transmitted data. If a satellite has an immediate line of communication with a suitable ground station as it passes over the AOI, it will download the data almost immediately. If there is no ground station in the immediate line of communication, the onboard data recorder will store the collected data and download it to the next available ground station. This can result in a further delay in the imagery acquisition process.

Initial data processing

Once the data has been downloaded from the satellite, it will then undergo initial processing at the preferred processing facility (located either within the ground station or at a separate processing facility).

Due to the way in which the data are collected by the sensor, there will always be a need for a minimum level of initial processing. The initial 'raw' data acquired by the satellite—known as a 'Level 0' data product—are not directly suitable for oil spill response as they need to be converted from engineering units into geographically positioned and calibrated geophysical units. Imagery providers therefore license their products as 'Level X' products—where 'X' represents the level of processing applied—to provide an understanding of the processing that the data has undergone. Table 7 on page 33 describes common product levels and the respective processing that will have been applied.

For oil spill response, **Level 1B** or **Level 2A/B** products are the most suitable. Level 1B products can be used for standalone remote sensing applications, such as image classification or the generation of ancillary datasets. To use the imagery within GIS software and applications (such as the COP), it will need to be geo-referenced, and therefore a Level 2A/B product will be required (the coordinate reference system used should be specified in the metadata or within the map). To ensure efficiency during processing, the product level required should be predetermined during image planning.

Table 7 *Common satellite imagery product levels and processing applied*

Product level	Product type	Processing applied
Level 0	Raw instrument data	None
Level 1A	Reconstructed raw instrument data	Radiometric calibration; atmospheric correction
Level 1B	Geometric corrected and calibrated	Geometric correction; cloud cover cropped
Level 2A	Geo-referenced	Geo-referenced using standard cartographic map
Level 2B	Refined geo-referencing	Geo-referencing using ground control points
Level 3A	Gridded and quality controlled	Ortho-rectification (accounting for relief displacement within imagery)
Level 3B/ Level 4	Model output; derived variables	Band calculations for indices; overlaying of imagery from multiple sensors; modelling of data in imagery

At this stage in the workflow, the acquired imagery is ready for secondary processing and oil spill analysis by the imagery provider, or the SRS Team if present.

Oil spill analysis

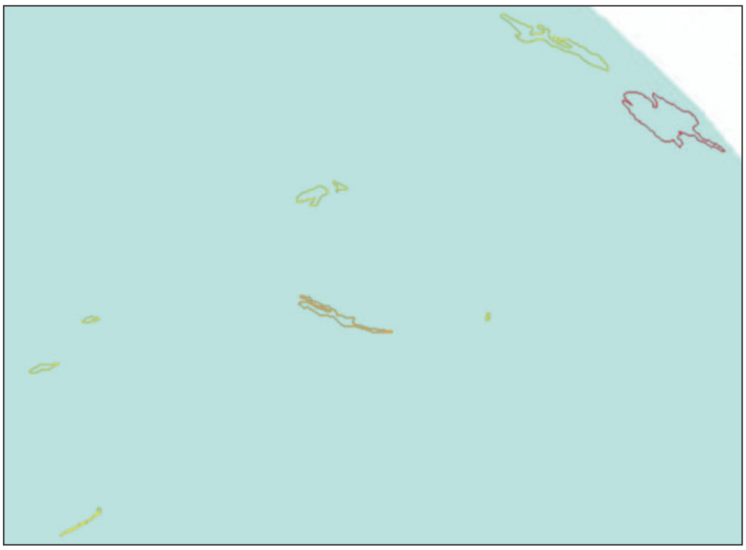
Only after initial processing should an SRS Analyst (with experience in using the data provided) interpret the imagery. This analysis is likely to be conducted by the satellite imagery provider unless the SRS Team has the capability, capacity and preference to process the imagery internally. Using image processing software, the SRS Analyst will analyse the imagery and determine whether it provides a valid indication of the presence of oil.

The information that the SRS Analyst will be expected to extract from the imagery includes:

- the location of the spill(s);
- the extent of the spill(s);
- estimations of the surface area covered by the spill(s);
- other characteristics of the spill (if applicable);
- identification of response resources and assets; and
- identification of false alarms.

While the analysis of single images can provide useful information, it may be preferable to use multiple images and/or data types to confirm the results of the analysis. The use of multiple types of data, known as data fusion, can also help identify false alarms within the imagery.

Below: satellite polygons (shape files) on a map display: the yellow, orange and red polygons illustrate the outline of the oil detected by the satellite; yellow and orange indicate a low confidence of oil; red illustrates the SAR signature, indicating that this is a probable instance of oil.



In addition to looking for oil spills within the imagery, the SRS Analyst may also create ancillary datasets from the imagery to help confirm the presence of oil. For example, the Normalized Difference Vegetation Index (calculated using red and near-infrared wavelengths) may be used in persistent inland spills to show whether areas have been inundated with oil. The index provides an indication of whether green vegetation is present or not, and by comparing baseline data with current imagery, the SRS Analyst can determine the likelihood of oil by measuring the deterioration of the vegetation. The same imagery may also be used to provide other types of information to the response, e.g. by identifying access routes, characterizing neighbouring infrastructure, and performing various planning activities.

Once the imagery has been interpreted and the observations validated by alternative data sources (and by another SRS Analyst, if available), the data and various final products should be created and provided to the response team.

Final product delivery

The most common data that can be extracted from an image are:

- the imagery itself;
- outlined/digitized oil slick features;
- estimations of oil slick areas;
- identification of assets and/or response operations; and
- ancillary information on environmental conditions, hazards and other man-made infrastructure (if applicable).

Depending on the response requirements, these data can be provided as a variety of final products in different output formats, from hard copy imagery and maps to data files and data streams. In general the COP will determine the output format of the final products provided as well as the specification and details of these output formats (e.g. templates and standards that should be used for both the data and its metadata).

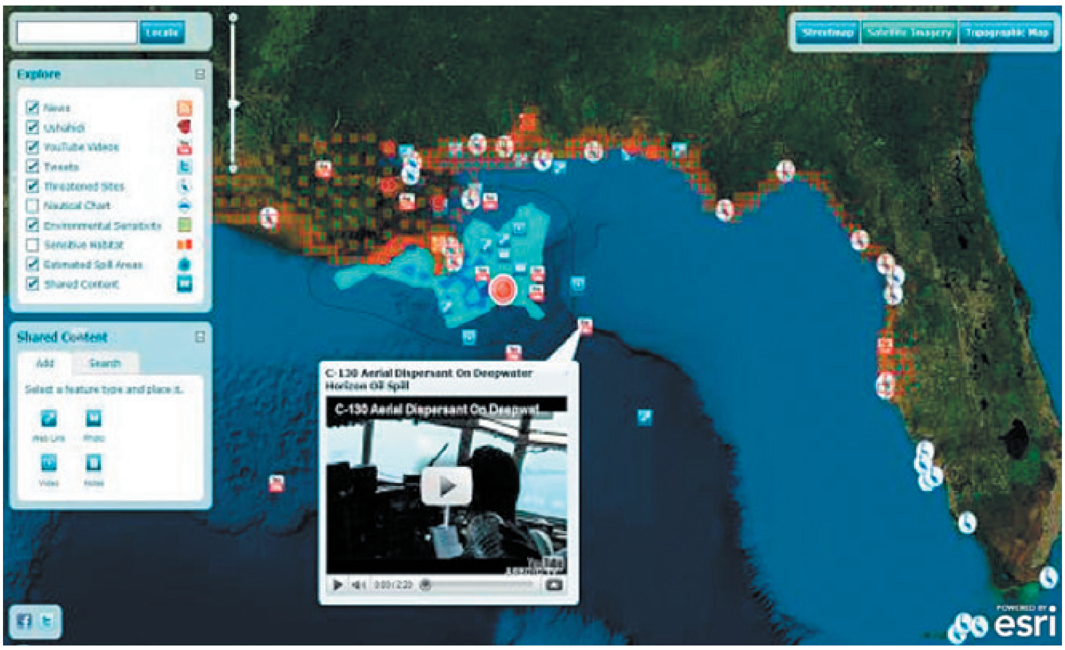
The Open Geospatial Consortium (OGC) provides industry-wide recommendations on the standards and formats that should be used when using spatial data; further explanation can be found in IPIECA-IOGP, 2015a.

To ensure that the data are accessible and usable by the appropriate stakeholders during an oil spill response, data suppliers should be encouraged to provide final products in common and, if suitable, editable formats. Table 8 on page 35 lists the recommended formats for each product type.

To ensure that the data are received in an appropriate format, the satellite imagery provider should follow an agreed set of data management protocols and procedures. Providers should ensure that the formats are compatible with the various different types of GIS and image processing software packages (including the different open source and proprietary systems), and that the data are accompanied by the information necessary to understand what is shown, the appropriate metadata, and instructions for use and/or licensing requirements. This will also help to ensure that the final products supplied can be integrated into the COP.

Table 8 *Recommended formats for final data products*

Product type	Usage	Product requirements	Formats
Hard copy maps, imagery and photographs	• Printing • Sharing within non-GIS users (by email, FTP etc.)	• Map features (title, legend) • Legible template	• PDF • PNG/JPEG
(Satellite) imagery and photography (e.g. aerial, observer) Other raster-based files	• Within GIS or image-processing software	• Geo-referenced • Metadata	• GeoTIFF • Images with geo-referencing data • Other raster formats
Oil slick features (digitized from imagery) Other vector-based files	• Within GIS or image-processing software	• Geo-referenced • Metadata • Data attribute explanations	Suitable for end user: • KML—GoogleEarth • Shapefile/GeoJSON/GML, GIS • Geodatabases
Web-based maps	• Share imagery/maps with non-GIS users • Create dashboards	• Explanation of what the maps show	• OGC compliant WMS, WFS, WCS, WMTS
Calculations, observations	• Share numerical and text data/information	• Data is accessible within products • Appropriate units provided	• Delimited text files (CSV, DBF, TXT)



Esri

Screenshot of Esri's web-based map integrating various data feeds during the Gulf of Mexico oil spill in 2010.

In the absence of a deployed COP, a GIS Specialist should be responsible for determining the preferred final products and output formats. In this scenario, as GIS and other spatial-based software will still be used, the COP data management procedures and protocols should still be followed for the products and formats agreed upon, for example using map templates for hard copy maps.

Box 7 *Creating a satellite imagery map template*

A common final product that should be provided by the satellite imagery provider is a map derived from the satellite image which outlines any oil spills present; if possible, an estimation of the slick area should also be provided. To ensure that a useful map is provided, it is recommended that a map template be developed in consultation with the satellite imagery provider before imagery is provided—preferably as part of the satellite imagery plan or while waiting for the imagery to be acquired.

The key features of a map template are outlined in Table 9 (below) and an example is presented on the right. Standardizing the template will ensure that the end users will understand the imagery throughout the response. The imagery should be provided in either PDF or PNG/JPEG output format (which are easy to open on mobile devices and share) and in an easy-to-interpret presentation, with explanations to help users understand what is shown.

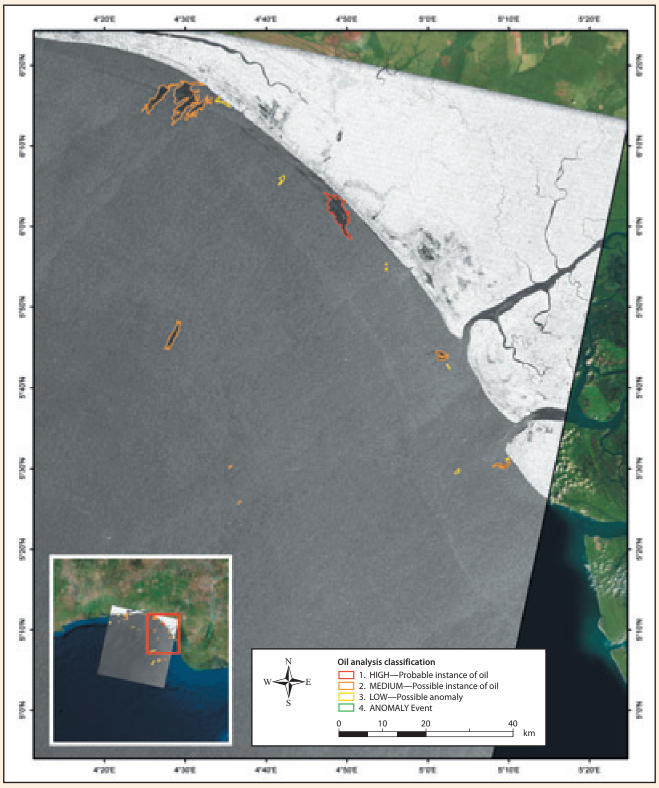


Table 9 *The key features of a map template*

Essential features	Desirable features	Optional features
• The image • Base map behind image, showing outline of potential oil slicks (plus estimation of probability) • The date and time the image was acquired • The sensor/satellite used • Cartographic information, including: projection; coordinate reference system; scale; north arrow • Legend (if applicable) • Interpretation instructions	• An overview map (showing image scene location(s)) • Estimations of slick area (if applicable) • Licensing instructions (if applicable) • Map graticules/grids	• Identification of assets (if applicable) • Labels on major landmarks and geographic references • Ancillary environmental, hazard or infrastructure information

Imagery acquisition workflow considerations

While the imagery acquisition workflow is theoretically a simple step-by-step process, it is subject to a variety of factors that can hinder the speed at which an image can be acquired, as well as the usability of the data. These factors include:

- turnaround time (lead and latency time delays);
- acquisition timings and revisit capabilities; and
- environmental considerations.

While these factors can, to an extent, be considered in advance, e.g. during the development of a satellite imagery plan, each incident will represent a unique scenario, with potential unanticipated challenges. As a result, these factors will need to be reconsidered when using SRS to understand the realistic availability and usability of the acquired imagery, particularly when using it for time-critical missions.

Data lead times and latency

Throughout the acquisition workflow, there is potential for delays to occur that will increase the time it takes to acquire an image after the order has been placed. These delays can be categorized as:

1. **lead-time delays:** the time between placing an order and the image being acquired by the satellite sensor; and
2. **latency:** the time between the image being acquired by the satellite sensor and the final product being delivered.

Lead time delays largely result from having to wait for both the tasking and acquisition windows, i.e. waiting for the satellite to be at the right point of its orbit, first to be tasked, and then to be over the AOI. They can also be caused by indecision on behalf of the response organization during the image planning stage, delayed contractual arrangements, or orders being rejected by the satellite operator.

The latency is mainly due to the satellite waiting to download the data to the next available ground station; this is dependent on the distribution and availability of suitable ground stations. In general, northern locations are better served as there is greater coverage by ground stations. Equatorial locations are not as well served, and it can take up to 100 minutes for a satellite to communicate with a ground station. Access to ground stations can also vary depending on the satellite operator. To minimize the potential delay in downloading the data, the satellite imagery provider should try to use satellites and operators with good access to ground stations.

The latency can also be affected by the efficiency of data processing carried out by the satellite operator and/or satellite image provider, and whether the final delivered product meets the needs of the response team. For example, data delivered without area calculations or without enough information to enable the response team to interpret the imagery will be unlikely to meet the immediate needs of the response; in such cases it may be necessary to repeat the imagery acquisition process.

These delays can have a serious impact on the utility of the imagery provided. For example, imagery is usually needed before operations are planned and conducted each day, and any imagery acquired during the previous evening or overnight will need to be delivered in time for the morning meeting; if the imagery is not delivered in time, it will be redundant and serve little purpose for the operational response team.

Time delays caused by the response can be managed and reduced by following the previous guidance on developing a satellite imagery plan (page 16) and pre-planning imagery (page 20). However, time delays caused by the satellite's operation cannot be reduced and will therefore need to be taken into account when planning the use of the imagery for time-critical missions, such as initial assessment and early operation planning.

Expected data acquisition timings and revisit capability

In addition to delays within the workflow, the temporal coverage of satellite sensors (i.e. when and how often data is collected) may affect the availability of imagery for acquisition.

Due to their orbital paths, satellites collect data at limited times during the day, often 'following' the same local time across the globe. While a response may prefer to have the latest information early in the morning for initial briefings, it is possible that the imagery may not be collected until midday, hence the latest information may not be available until the end of day. In addition, the revisit capability (i.e. how often a satellite will pass over the AOI in a day) will determine whether or not the required imagery can be acquired on the day the order is submitted. For example, if the response misses the only acquisition window for that day, it will need to wait until the satellite passes over the AOI on the following day. The revisit capability increases with higher latitudes, thus the temporal coverage is higher for spills near the poles than it is for those near the equator. Both of these timing factors should be taken into account when planning imagery acquisitions and the deployment of other assets, such as aerial surveillance.

Environmental considerations

The usability of the acquired imagery can be affected by the environmental conditions prevailing at the time of the acquisition. Many sensors onboard satellites require particular environmental conditions to be present to effectively detect oil on water; for example, a certain wave height is needed for some satellites to be able to distinguish between oil and water. To overcome potential issues with capturing poor imagery, particular types of sensors should be used in different environmental and weather conditions, such as rain, cloud or lack of daylight. While it is the role of the satellite imagery provider to determine the type of satellite used, it is important that the SRS Coordinator is able to explain these issues to other stakeholders. For further information on the effects of environmental conditions on the operation of different types of sensors see pages 47–50.

Managing the acquisition workflow

The time period between the initial spill notification and the delivery of the final imagery product is typically quoted as 3 and 72 hours, however this can vary substantially in practice. The precise timings of each stage will differ for each response and each acquisition. Delays can be minimized by developing a satellite imagery plan which ensures that factors within the control of the response team are pre-planned and well tested (e.g. by implementing procedures to submit an appropriate order as quickly as possible and to guarantee that the data are received in the correct format).

To manage these potential delays and the expectations of other stakeholders, the SRS Coordinator and satellite imagery provider should discuss and communicate the expected timings of acquisitions and downloads, and should update this information as necessary during the response.

Box 8 *Understanding the satellite imagery acquisition workflow in real time*

To understand the satellite imagery acquisition workflow in greater detail, an analysis was conducted by the OSR-JIP, in conjunction with leading satellite imagery providers, to compare and assess estimated lead times and latency for satellite imagery acquisition. This theoretical analysis was supported by a 'real-world' exercise, which tested the theoretical data lead times and latency periods. The OSR-JIP report (IPIECA-IOGP, 2015b) provides a numerical breakdown, which can help to provide quantifiable estimates for the time it may take to acquire satellite imagery.

The analysis also looked at comparing how the revisit capability and acquisition timings differed for various types of satellites, as well as how the environmental conditions could prevent certain types of satellites from being used.

Using and communicating the imagery and data

The final product(s) should be delivered to the SRS Coordinator to manage, catalogue and share, as required by the response. These products will be shared with the relevant stakeholders, who will use them for a variety of tasks. As a result, it is important that the final products are easily accessible and usable. The primary vehicle for sharing the products is the COP; this is a repository of all the data generated within, or used by, the response, and usually takes the form of a GIS-based platform that can be used to visualize multiple geospatial datasets and maps in a user-friendly application.

The SRS Coordinator should therefore provide the final products to those responsible for maintaining and updating the COP within the Planning Section. This helps to prevent data from becoming inaccessible or 'siloed', being misused, or simply forgotten about. In addition, the SRS Coordinator should provide the Documentation Unit with original copies of the final products to ensure that they are recorded and archived as the response progresses.

One key responsibility of the SRS Coordinator is to ensure that the final products are accompanied by complete metadata. The metadata should include details of who created the product and when, and the contact details in case end users have any questions. Also required is a complete description of the geodetic and, if applicable, projected coordinate reference system (CRS) to which the data are referenced, the details of the geo-referencing technique, and the estimated positional accuracy of the data. More information on the use of metadata can be found in IPIECA-IOGP, 2015a. In addition to the metadata, the **licensing details and terms and conditions of use** should be provided. Of particular importance is the need to ensure that any **sharing** and subsequent use of the satellite imagery has been agreed to by the satellite imagery provider.

Geo-referencing of satellite imagery

Remote sensing data are typically geo-referenced to a global geodetic CRS or datum (e.g. WGS 84) and to a projected CRS of the end user's choice—typically the Universal Transverse Mercator (UTM) grid. During an oil spill response the remote sensing data will need to be combined with asset location and other data in the GIS-based COP; these data will normally be referenced to a local geodetic CRS and may also be referenced to a projected CRS that is not UTM-based.

To map all data together so that they are correctly displayed in a spatial sense, all coordinates/positional data need to be transformed and/or converted into a common CRS. Failure to do this can typically result in errors of up to several hundred metres between different data sets. Bringing all data onto the same CRS is, however, straightforward in principle and may often be carried out 'on the fly' by the GIS. This would normally be the responsibility of the Geomatics Unit of the ICS (see IPIECA-IOGP, 2015a). However, the correct result requires that the CRSs of all the different data types and sources are fully defined and that the coordinate transformation parameters between the different geodetic CRSs/datums are known. This should also be considered during the initial implementation of the COP.

Licensing and sharing of imagery

Satellite imagery providers will provide all final products—imagery and data—for use under a specific end-user licence agreement (EULA), which includes the terms and conditions of use. The EULA will determine by whom, and how, the final products can be used and shared; the terms may differ between products and may also change over the course of the spill and during the months that follow. The licensing terms and conditions most commonly found in a EULA relate to:

- **Attribution:** does the product require attribution?
- **Sharing:** can the product be shared, internally or externally? If so, are there limitations?
- **Derivatives:** can other products be derived? If so, is an additional licence required?
- **Commercial use:** can the product be used for commercial purposes? If so, are there limitations?

Licensing

The licensing of the imagery and data, along with any terms and conditions of use, should be discussed with the satellite imagery provider **before** the agreement is put in place; each stakeholder should have an understanding of how the imagery can be used **before it is acquired**. For example, the imagery provider may require attribution on any final or derived products (from PDF maps to other datasets); this may be a logo or statement of copyright, which may need to be reproduced at a specified size or in a certain location. If further data is derived from the final products by the oil spill response team, the response organization will need to ascertain whether these datasets can be used under the same licensing terms as the original product.

As the sharing of imagery and/or data is crucial for an oil spill response, any licensing terms should suit the response needs. For example, it is likely that the imagery will be used as a base map for operational planning, whether as a map or data within a GIS application, and thus shared with responders on-scene. Any licensing agreement should permit this type of internal sharing, as well as the sharing of the product in the various output formats. This is particularly relevant as more data are now becoming integrated into a COP and are thus available to all those working within the response who have the relevant access rights.

Sharing of imagery

A licence to share data externally should be mutually agreed upon by the response and the imagery provider. The release of accurate imagery and data at the appropriate times is vital for preventing public uncertainties about the effectiveness of the response. All information should therefore be checked with the SRS Coordinator prior to release, and validated with other surveillance and operational observations to ensure that it is correct. In addition, the imagery provider should be required to consult with the SRS Coordinator and Incident Command before making any imagery and/or data public.

The SRS Coordinator should make sure that any licensing and terms and conditions of use relating to the sharing of imagery and data with external stakeholders are stipulated clearly in the agreement and/or in the satellite imagery plan.

Exploitation of the imagery and ancillary data in a response

The various stakeholders within the response will use the imagery and data to fulfill different purposes. As previously stated, the three key missions that satellite imagery can help with are:

- the initial detection and assessment of the oil spill incident;
- ongoing assessment and synoptic monitoring (including operations planning); and
- providing pre-spill and baseline data.

Satellite imagery will be used by different stakeholders for different purposes. This image was generated with imagery from NASA's MODIS instrument to show the extent of the oil spillage during the Macondo spill.

NASA/GSFC, MODIS Rapid Response (pubic domain image via Wikimedia Commons)

For each mission, the imagery and data can be used for a variety of applications by the various stakeholders within the response. Table 10 on page 43 outlines many of the tasks that stakeholders may wish to conduct.

Improving imagery provision during and after a spill

As with any part of the response, the provision of imagery during a spill is likely to encounter new challenges and limitations, whether during the image acquisition process or in the use of the end products by stakeholders. As a result, the SRS Coordinator should identify any issues with the current satellite imagery plan, determine how to improve the plan and, if required, communicate this to the satellite imagery provider. The SRS Coordinator should also ask for feedback from those using the imagery and data. As the provision of imagery is a repeatable process during the spill response, every reiteration can be improved immediately by the communication of issues and feedback.

The issues encountered, and feedback received, relating to the SRS capability should be recorded and then reviewed as part of the analysis of lessons learned, which is often conducted post-spill. The recommendations agreed upon should then be used to update and improve the existing satellite imagery plan, providing explanations or notes for future spills.

Table 10 *Potential uses of satellite imagery and ancillary data by different stakeholders in the response*

Potential user	Uses of imagery and data
Incident Command	• Uses imagery to determine and communicate the characteristics of the spill, including location, quantity estimations.* • Uses spill features derived from imagery to overlay on other datasets to provide situational awareness, e.g. spill location compared to resources at risks, infrastructure, etc. • Analyses and communicate the effectiveness of recovery methods by comparing the location/quantity of oil across time/several images. • Uses baseline imagery to determine the end of a response, comparing pre- and post-event conditions.
Operations Unit	• Uses the imagery as a base map for planning operations, including planning surveillance overflights, and overlaying current and future asset positions. • Uses imagery (and derived data) to identify areas requiring oil spill clean-up, e.g. impacted shorelines. • Uses imagery to monitor progress of operations, e.g. the progress or extinguishing of burns. • Uses quantity estimations to determine the optimal allocation of resources, e.g. the amount of dispersant or waste facilities required.* • Uses baseline imagery to determine the end of clean-up operations, e.g. how clean is clean?
Planning/Situational Unit	• Uses imagery to update current situational awareness for the response, including extracting positions of assets and resources from high-resolution imagery. • Updates existing forecasts and models for the oil spill trajectory modelling.
Press/Media Team	• Uses imagery to show the initial location and extent of the spill and how this changes over its lifespan. • Uses quantity estimations and imagery to show the effectiveness of the response operations.*
Legal Team	• Uses baseline and incident imagery to compare before and after, including clarifying the impact of the spill and quantity estimations.* • Uses spill features and imagery to show the trajectory of the spill over its lifespan and clarify areas impacted.

* See Box 2, *Can (satellite) remote sensing determine oil thickness and type?* on page 14.

Storing and archiving imagery

The SRS Coordinator should consult with the Documentation Unit to ensure that provisions have been made to store and archive the imagery and ancillary data appropriately during and after the spill. To help the Documentation Unit, the SRS Coordinator should set up (in accordance with COP recommendations) suitable data storage facilities that can be readily accessed (e.g. by date, data type, sensor type, etc.), and should provide guidance on naming conventions, data formats and the storage of associated metadata.

Due to the large sizes of satellite imagery files, it is important to have a central data storage solution in place before the imagery is delivered, in particular to avoid exceeding storage quotas on email systems or other personal storage devices. In addition, if a spill response is likely to continue for an extended length of time, it may be appropriate to archive imagery that is no longer current for day-to-day operations. In most incidents, it is recommended that data be archived on both physical and secure cloud-based storage platforms. Any solution put in place, including naming conventions, should be applied to any regularly-updated geospatial data made available to the response.

By deciding upon, and setting up, these structures and facilities in advance, either as part of the satellite imagery plan or during the initial image acquisition, users will be able to access data quickly and accurately. Furthermore, the availability of well-preserved and accessible information after the incident will aid in:

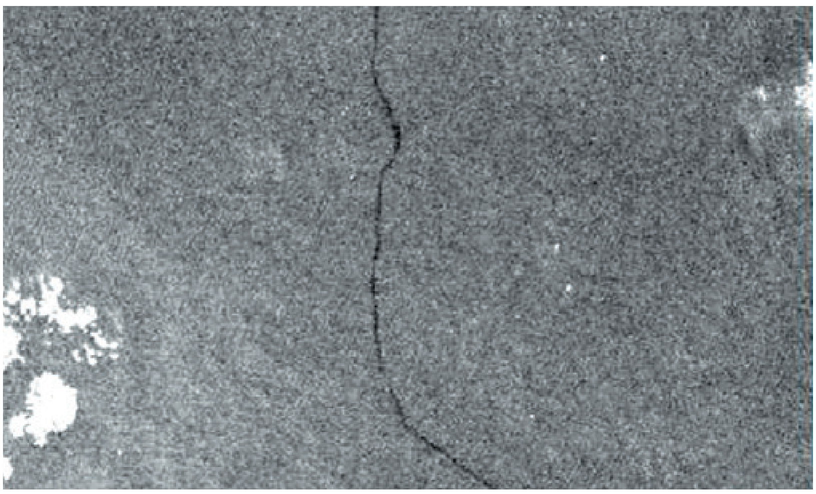
- training new responders and SRS team members in how to use imagery and data correctly;
- highlighting issues during the analysis of lessons learned; and
- providing evidence for later internal reviews and for potential litigation issues.

The SRS Coordinator should ensure that the licensing requirements allow the final products—and derived information—to be used post-spill, and should note whether the licensing terms stipulate any additional requirements for the storage and sharing of the imagery and associated data.

Using satellite imagery as evidence for illegal discharge

Satellite imagery can be used to help historically trace the source of a spill. For example, for areas covered by oil detection monitoring programmes imagery may exist which contains evidence of when a spill was first detected; it might even be possible to visually identify the source of the spill from the imagery. In addition, for offshore spills, other data (such as that from Automatic Identification Systems) covering the same date and time can be used to connect a vessel path with a spill. This can help to trace the origin of the spill and identify the responsible party, and in some countries the imagery can be used as evidence for the prosecution in cases of illegal discharge.

Illegal discharge from a vessel, detected by satellite radar



The image on the left shows an illegal discharge from a vessel, detected by satellite radar. The black line illustrates a trail of palm oil residue 30 km long; the crew had been washing its tanks which had contained the oil.

Understanding satellite technology for oil spill response

Determining which satellite (or satellites) to use in a response will primarily be the responsibility of the satellite imagery provider. However, to explain to other stakeholders why certain satellites are used, or in some cases not used, for the response the SRS Coordinator requires a basic understanding of satellite technology and how the set-up of a satellite affects its suitability for use within an oil spill response.

This section provides a brief introduction to satellite technology. For more information see the OSR-JIP report entitled *An Assessment of Surface Surveillance Capabilities for Oil Spill Response using Satellite Remote Sensing* (IPIECA-IOGP, 2014a) and the API planning guidance entitled *Remote Sensing in Support of Oil Spill Response* (API, 2013).

The basics of satellite technology

A remote sensing satellite consists of two main components: the 'bus' or 'platform' and the onboard remote sensors. The platform consists of the operational equipment to keep the satellite running, e.g. fuel, onboard computer, solar panels etc., and acts as the vehicle to carry the onboard remote sensor which acquires the data and/or imagery.

Each satellite is designed to fulfill a pre-planned mission. The design determines how the satellite is set up (the platform used, the onboard sensors, the scanning mode of the sensors, the angle at which the sensor scans) and the orbit that the satellite has been placed into (e.g. orbit altitude and inclination).

In addition, the satellite may be designed to provide spatial coverage only for certain areas. For example, the European Space Agency (ESA) Sentinel-1 radar imaging satellites (which are designed to acquire data for input to ESA's Copernicus programme) only offer spatial coverage to specific pre-selected geographical areas over the globe.

Satellite technology for oil spill response

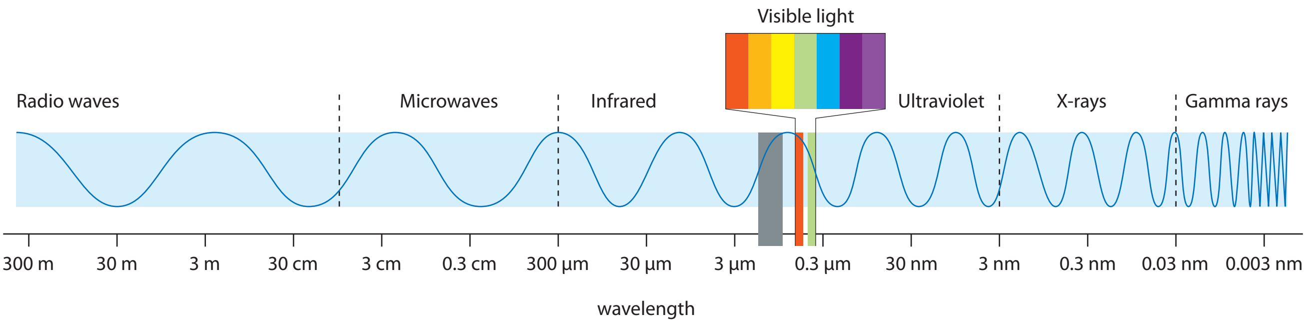
For oil spill response, the two primary factors that will determine whether a satellite can be used are:
1) whether the type of onboard sensor will be able to acquire usable imagery within the operating environment; and
2) whether the temporal and spatial coverage provided by the satellite will meet the data requirements of the response.

The latter is discussed briefly in the section on satellite imagery acquisition workflow on pages 30–39.

Types of remote sensors used for oil spill response

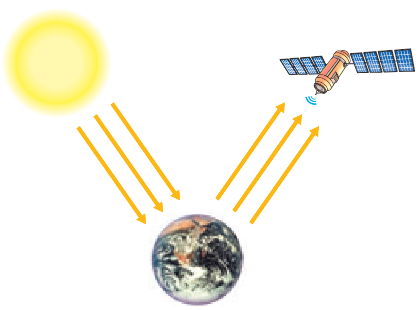
Remote sensors produce imagery by using different wavelengths within the electromagnetic spectrum (see Figure 4 on page 46) to detect and measure different properties about the earth; these measurements are then recorded as pixel data and combined together to produce the imagery.

Figure 4 *The electromagnetic spectrum*



Remote sensors measure these properties either actively or passively, depending on the wavelengths used. The differences between active and passive sensors are shown in Table 11 (below).

Table 11 *The differences between active and passive sensors*

	Passive sensors	Active sensors
Measuring method		
Process	Passive sensors detect natural radiation emitted or reflected by the targets or phenomena being observed.	Active sensors emit their own pulse of energy and then measure the signal that is reflected back to the sensor.
Advantages	• The visible imagery is usually simple to process and interpret.	• Rely on internal sources and, as a result, are able to operate during day or night, as well as during some adverse conditions. • Can be configured to optimize the sampling of the surface and focus the energy to achieve a high spatial resolution or to minimize atmospheric absorption.
Limitations	• Rely on external sources to provide the energy and wavelengths required for detection. • Are subject to limitations on when they can be used, e.g. during daylight and clear weather conditions. • Can be affected by weather conditions, e.g. radiation can be absorbed or distorted by clouds, haze, etc.	• Are more complex than passive sensors in terms of technology, and create complexities and challenges in the processing and interpretation of imagery.

The most common types of passive sensors used for satellite remote sensing for oil spill response are those that operate in the visible, infrared and thermal infrared bands. Sensors operating in these bands are known as optical sensors.

The most common type of active sensor used for satellite remote sensing for oil spill response is radar, specifically synthetic aperture radar (SAR) which uses the microwave band.

Each type of sensor uses a different region of the various wavelengths within the electromagnetic spectrum to measure properties about the phenomena it is observing (see Table 12).

To detect oil, an SRS Analyst will look for variations within the measurements taken; whether these variations will be visible within the imagery will be determined by the environmental conditions.

Table 12 *The different types of sensors and their bands*

Sensor type	Sensor band	EM range	What does it measure
Optical (passive)	Visible	0.4–0.7 μm	Reflected sunlight
	Infrared	Near = 0.74–1.4 μm Short wave = 1.4–3.0 μm	Naturally emitted radiation
	Thermal infrared	3.0–14.0 μm	Surface temperature
Radar (SAR) (active)	Microwave	X-band = 8–12 GHz / 2.5–3.75 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	Radar backscatter

Using optical and radar (SAR) sensors for oil spill response

The different types of sensors available for satellite remote sensing are subject to a range of operational sensitivities to environmental conditions. This will have an impact on whether each type of sensor will be suitable for use in a particular oil spill response operation. The type of sensor most appropriate for the response will first be determined by the location of the spill, and then by the weather and operating conditions.

Location of an oil spill

The location of an oil spill will determine the type of surface on which the oil has been spilt, e.g. water in offshore spills, sand for shoreline or inland spills, or even ice-covered water in higher latitudes. For satellite remote sensing, only specific types of sensors will be appropriate for use over each of these surface types. In addition, the variations that SRS Analyst will be looking for within the acquired data may be different depending on the surface being analysed.

Offshore spills / spills on water

Most experience in the application of SRS for oil spill response has been gained in the offshore environment. The contrast between oil and water is great enough to enable much of the electromagnetic spectrum to be used to detect oil spills. Each type of sensor has been proven to provide basic detection of oil on water, and in some cases they can also detect other characteristics such as the oil/water ratio.

Table 13 summarizes the data captured by the most common types of optical and radar sensors; these data are used by the SRS Analyst as the basis for identifying potential oil spills offshore.

Table 13 *Remote sensors for oil spill detection in offshore locations*

Sensor type	Sensor band	How the sensor detects oil
Optical (passive)	Visible	Colour / non-specific absorption Sun-glint on water
	Infrared	Absorption at specific wavelengths (0.8, 1.2, 1.73 and 2.3 µm)
	Thermal infrared	Temperature of spill area relative to surroundings (e.g. oil retains heat better than seawater and appears warmer in the early evening)
Radar (SAR) (active)	Microwave	Changes in surface roughness (i.e. gravity waves, capillary waves) caused by the damping effect of the spilled oil

The SRS Analyst will look for variations in the acquired imagery as evidence of spilled oil; it is therefore important to note that these variations may not be clearly visible in the imagery if the environmental conditions are not optimum for the chosen sensor. Furthermore, the SRS Analyst will need to be aware of potential false alarms that may be present within the data. The common causes of false alarms for the different sensors and bands are outlined in Table 14.

Table 14 *Potential false alarms, by sensor/band, in the offshore environment*

	Synthetic aperture radar (SAR)	Thermal infrared (TIR)	Short-wave infrared (SWIR)/ near infrared (NIR)	Visible light (VIS)
Biological	Biogenic slicks, mineral oils		Biogenic slicks, mineral oils, weed and kelp beds, reflected sunlight	
Oceanographic	Freshwater plumes, fronts, internal waves	Upwelling, water inflows, fronts		
Bathymetric	Shallow water modulation			Shallow water feature
Atmospheric	Variable surface wind stress, rain cells, wind shadows		Cloud shadow	
Man-made	Turbulent ship wakes	Man-made heat sources		

As the various sensors/bands are sensitive to different phenomena that may present themselves within the imagery, the use of different types of imagery (e.g. optical as well as SAR) can be effective in distinguishing oil spills from features such as wind shadows (which are often misinterpreted as oil spills in SAR imagery). It is important that an SRS Analyst interpreting the imagery is aware of the types of false alarms that may be present for the spill location. One strategy to help the SRS Analyst is to build up a picture of false alarm patterns that may occur in similar offshore locations and for particular sensor types.

Onshore (inland) spills

The use of satellite remote sensing for the detection of oil onshore, and in rivers and estuaries, is not as well established as it is for offshore spills. These environments are often highly variable with different types of surfaces present, including soils (at varying levels of saturation), varying densities of vegetation cover and the presence of water. These varying conditions can lead to large numbers of false positives, thereby increasing ambiguity in the interpretation of imagery, particularly when using SAR sensors. As a result, airborne surveillance is a more reliable technique for detecting surface oil in the onshore environment, and the use of satellite remote sensing for the emergency detection of inland oil spills is not recommended. SRS can, however, be used for the indirect detection of oil spills, using methods such as studying stressed vegetation, or using change detection algorithms. Furthermore, during a spill, optical SRS imagery can be used to provide up-to-date information on local conditions to support the response, such as information on access routes, or on environmental conditions such as land cover.

Spill on ice/ice-covered water

It is possible to use satellite remote sensing for detecting spills on ice or ice-covered water in certain environments:

- In cases where the oil spill is in an area of open water that has less than 30% ice coverage, the spill will be detectable by all sensors discussed above—albeit less easy than on water alone.
- In areas with more than 30% ice coverage, detection becomes more challenging. Usually only optical sensors are used; if the oil is between the ice floes, the ice signatures can overwhelm and complicate the oil signature within SAR imagery. However, some specialists—such as the Canadian Ice Service—are increasingly able to distinguish oil from ice.
- For oil on top of the ice, optical sensors can be used to detect oil.
- For oil encapsulated within or trapped under ice, there is no proven method of using SRS to detect the oil.

The effective use of SRS for detecting oil spilled on ice or ice-covered water will depend on the environmental conditions being suitable. In particular, for spills in higher latitudes, the loss of daylight in winter months—and the presence of adverse weather conditions—will limit the efficiency of optical sensors.

Example of oil in sea ice

USGS/Creative Commons

The use of SRS for detection of oil in ice environments is covered in more detail in the IOGP report on oil spill detection and mapping in low visibility and ice (IOGP, 2013). The report provides an evaluation of current technology available for low visibility and ice surveillance together with recommendations for implementing SRS in these environments.

Operating environmental conditions

Once the location has been taken into account, the main driver determining the most appropriate type of sensor will be the operating environmental conditions. These include the:

- presence of daylight;
- presence of cloud cover;
- presence of adverse weather conditions (e.g. rain, fog, haze, snow);
- sea conditions (offshore spills); and
- presence of ice.

Table 15 summarizes the effects of environmental conditions on the different types of sensors.

In general, passive (optical) sensors are unable to operate at night, in cloudy conditions, and/or in poor weather. SAR (an active sensor) does not rely on the presence of daylight for a source of radiation nor is its microwave signal impaired by atmospheric conditions. Only very calm or rough seas and the presence of ice restrict the use of SAR for SRS in the offshore environment. **As a result, SAR sensors are usually the 'go-to' sensors for use in SRS operations for oil spill response in an offshore environment.**

It is important to note that while optimal SAR acquisition modes are available in theory, in practice the response team will often need to take whatever acquisition modes are available based on the recommendations of the satellite imagery provider.

Table 15 *The effects of environmental conditions on the operation of different types of sensors*

	Synthetic aperture radar (SAR)	Thermal infrared (TIR)	Short-wave infrared (SWIR)/ near infrared (NIR)	Visible light (VIS)
Daylight	Works both day and night	Works both day and night with clear skies	Works in daylight hours only (VIS, NIR) Works in daylight and dusk hours only (SWIR)	
Cloud cover	Works in cloudy skies	Works only in clear skies with limited cloud cover		
Adverse weather (cloud, rain, fog)	Works in cloud, rain or fog	Will not work in adverse weather	SWIR works in hazy or foggy conditions	Will not work in adverse weather
Sea conditions	Will not work well in very calm seas (<3 m/s) or rough seas with wind speeds >12 m/s	Will not work in very rough seas		
Ice	Will not work well in open water with ice concentrations >30% or on ice	Will work in most ice environments, except when oil is encapsulated in or under ice		

Key imagery characteristics

The remote sensor equipment onboard a satellite will determine the type of imagery acquired as well as key imagery characteristics such as the spatial resolution, spectral resolution and radiometric resolution (see Table 16). These characteristics are specifically designed by the satellite operator, based on the operator's understanding of the data requirements that the mission needs to fulfill.

Table 16 *Definitions of key imagery characteristics of sensor technology*

Characteristic	Definition	Metric	How does it affect the imagery?
Spatial resolution	The minimum distance between two targets that allows them to be separately detected or resolved	Distance (m/pixel): • High: 0.41–4 m • Medium: 4–30 m • Low: 30– >1,000 m	If the resolution is not high enough, the sensor may be unable to discern small objects or phenomena, e.g. separate slicks.
Spectral resolution	The number of discrete spectral bands in which the sensor can collect reflected radiance.	Number of bands: • High: 100 bands • Medium: 3–15 bands • Low: 3 bands	Multiple bands can provide more information; however low spatial resolution is sometimes required to reduce noise in imagery.
Radiometric resolution	The number of levels of energy recorded, per pixel, in each spectral band.		If the resolution is not high enough, the sensor may be unable to distinguish between the different levels of reflected, emitted and scattered radiation.
Swath width *(also partially determined by the satellite's orbit geometry)*	The distance that can be covered by a sensor in a single scan as it orbits along its path.	Metre/kilometre	The sensor may not cover enough of the AOI—this can be overcome by constructing a mosaic of imagery from parallel, previous or subsequent paths over the AOI.

Table 17 *Imagery characteristics for each sensor/band type*

<table>
<tr><th colspan="2"></th><th>Synthetic aperture radar (SAR)</th><th>Thermal infrared (TIR)</th><th>Short-wave infrared (SWIR)/ near infrared (NIR)</th><th>Visible light (VIS)</th></tr>
<tr><td colspan="2">What does it measure?</td><td>Radar backscatter</td><td>Surface temperature</td><td>Natural emitted radiation</td><td>Reflected sunlight</td></tr>
<tr><td rowspan="3">Spectral resolution</td><td>• Wavelengths</td><td>L to X band</td><td>8.0–15.0 µm</td><td>NIR: 0.75–1.4 µm
SWIR: 1.4–3.0 µm</td><td>0.4–0.7 µm</td></tr>
<tr><td rowspan="2">• No. of wavelengths</td><td rowspan="2">1 (multiple polarizations often available)</td><td>n/a</td><td colspan="2">High resolution: ~3 to 8</td></tr>
<tr><td colspan="3">Medium resolution: ~7 to ~230</td></tr>
<tr><td colspan="2" rowspan="2">Spatial resolution</td><td rowspan="2">~1 to ~500 m</td><td>n/a</td><td colspan="2">High resolution: <1 m to ~10 m</td></tr>
<tr><td colspan="3">Medium resolution: ~10 m to ~1 km</td></tr>
<tr><td colspan="2" rowspan="2">Swath width</td><td rowspan="2">~5 to 500 km</td><td>n/a</td><td colspan="2">High resolution: ~10 to 90 km</td></tr>
<tr><td colspan="3">Medium resolution: ~30 to ~60 km</td></tr>
</table>

When determining an appropriate satellite/sensor technology for use in the response mission, the satellite imagery provider will take into account the needs of the mission to determine the type of imagery characteristics required. For example, for a general response, medium-to-high resolution imagery will be required (to distinguish between different slicks and between other objects), with a swath width that preferably covers the entire spill. However, as Table 17 on page 51 shows, the disparity between the imagery characteristics provided by the different types of sensors is not particularly great, and the main concern for the satellite imagery provider will still be to ensure that the most appropriate type of sensor is used according to the response scenario, e.g. with regard to the location and prevailing environmental conditions.

Spatial and temporal coverage

In addition to choosing the most appropriate sensor for the location and environmental conditions, a further consideration that the satellite imagery provider will take into account is the temporal and spatial coverage provided by the satellite. The temporal resolution describes when, and how often, the AOI can be imaged by the satellite; these characteristics are known as the 'acquisition timing' and 'revisit frequency', respectively, and are described below:

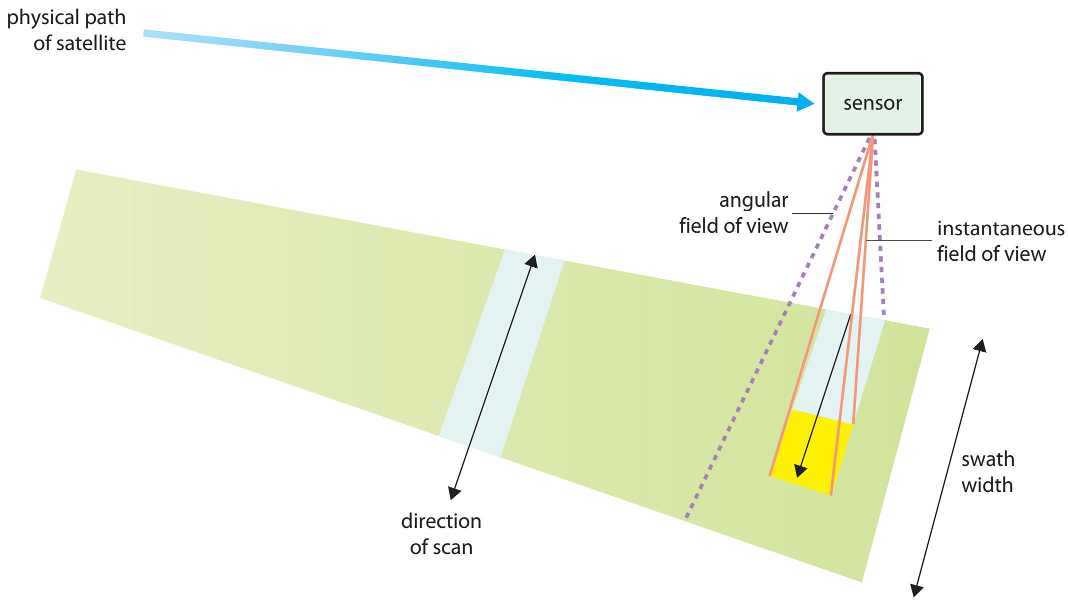
- **Acquisition timing:** SAR satellites can exploit both day and night passes, and are therefore able to sample the AOI twice a day—once on the ascending orbit and once on the descending orbit. For low latitudes, this diurnal sampling is constrained to two short time periods, usually early morning and late afternoon; higher latitudes have a more diffused range of sampling times although these still take place around the early morning and early evening periods. By comparison, optical satellites generally acquire imagery between 10.00 am and 1.00 pm local time on the descending orbit; the lack of daylight on the ascending path rarely allows the acquisition of usable imagery. All satellites in near-polar orbits have a greater range of timings in higher latitudes then in equatorial regions due to the increased revisit frequency (see below).
- **Revisit frequency:** Higher latitudes are likely to be imaged more frequently than equatorial locations due to the increasing overlap in adjacent swaths. The revisit frequency will also depend on the satellite parameters; for example, RADARSAT-2 can acquire data in the near and far ranges, which provides more opportunities for revisiting the AOI. Satellite constellations can achieve significantly higher revisit rates due to the use of multiple platforms working collectively; for example, the DigitalGlobe constellation (consisting of the WorldView-1, GeoEye-1, WorldView-2 and WorldView-3 satellites) is able to image an AOI at any time between 9.00 am and 3.00 pm local time. The satellite imagery provider/satellite operator will provide advice on the revisit frequency of the various platforms recommended for the response.

Further information, including maps that depict the revisit frequencies of major SAR and optical suppliers, can be found in IPIECA-IOGP (2014a).

The spatial coverage per orbit will be determined by a combination of sensor angle, scan mode and the orbit altitude, which results in a specific remote sensing geometry that will determine the swath width of the satellite (see Figure 5).

A larger swath width will allow the satellite to cover more area as it builds up its imagery; however this can often be to the detriment of the level of detail (spatial resolution) that the satellite can provide.

Figure 5 *Remote sensing geometry*



Other operational considerations

The operational advantages and disadvantages of each type of sensor should also be considered. In general, imagery produced by sensors that operate on the visible band (i.e. those that measure reflected sunlight) are the simplest to interpret, whereas the interpretation of SAR and thermal infrared imagery will require a higher level of expertise.

Overall, the satellite imagery provider will take into account all of these factors when planning the most appropriate satellite—or combination of satellites—to use to acquire imagery for the oil spill response operation.

Using multispectral and hyperspectral sensors for oil spill response

There is growing use of multispectral and hyperspectral sensors for oil spill response. These sensors integrate multiple bands of wavelengths between the ultraviolet, visible and infrared wavelengths to determine specific spectral signatures (i.e. unique 'fingerprints') for oil.

Broadband multispectral sensors are designed to use a relatively small number of discrete bands (between 4 and 50) within specific wavelengths. Hyperspectral sensors use more than 100 bands at different optical wavelengths (including thermal infrared) to determine the spectral signatures. Their spatial resolution is relatively coarse, however they provide a wide range of spectral frequencies that can be useful in detecting and, in some cases, characterizing oil.

MODIS (Moderate Resolution Imaging Spectroradiometer) image of the Gulf of Mexico oil spill in 2010. MODIS is an example of a broadband multispectral sensor, with 36 spectral channels.

B.A.E. Inc./Alamy Stock Photo

High-resolution multispectral sensors can achieve a higher spatial resolution but will have limited spectral sampling only in the visible and near-infrared wavebands; as a result they are only effective when used in daylight, cloud-free conditions.

The collection of data across multiple spectral ranges can reduce the likelihood of false positives; however, the volume of data generated is extensive and post-processing can be time-consuming, resulting in longer turnaround times for data as well as requiring greater technical skills.

In addition to multispectral sensors, multi-sensor satellites are available that combine several different sensors, such as ultraviolet and thermal infrared, to improve the detection of oil and reduce the likelihood of false positives. However, these combinations of sensors are still subject to the same limitations as the individual sensors. More information can be found in the API report on the use of remote sensing in oil spill response (API, 2013).

Innovation in satellite remote sensing technology for oil spill response

Beyond the innovations in the use of sensors, advances in the operation of satellites should further improve the utility of SRS for oil spill response, including:

- **Launching smaller satellites:** small satellites can be launched quickly and in significant numbers to significantly enhance sampling of the surface.
- **The creation of satellite constellations:** a growth in the use of satellite constellations will enhance the overall revisit capability, including potential daily revisits from high-resolution optical imagery (subject to weather conditions). Furthermore, if the satellites are networked, data can be sent between them, allowing the satellite nearest to a ground station to download the data, thereby reducing the waiting time for a downlink.
- **Building more ground stations:** more ground stations—both permanent and portable—will lead to improved data turnaround times.

Artist's impression of the Terra Bella SkySat Constellation

In addition, the OSR-JIP report entitled *Surface Surveillance Capabilities for Oil Spill Response using Remote Sensing* (IPIECA-IOGP, 2015b) recommends that the oil industry focus for the future should be on the use of SAR technology for oil spill response for the following reasons:

- Sensors using new bands (L and S) will be available in the coming years: it is anticipated that these will eventually become as widely available as existing C and X band sensors, hence the industry should become more familiar with this type of data for use in oil spill response. In particular, the potential advantages and limitations of these frequencies should be evaluated to assess their ability to detect oil spills.
- New capabilities of polarimetric SAR—an advanced imaging radar system—should be evaluated: this may be of value for oil spill characterization as well as detection, for example to help discriminate between sheens and thicker oil, or to offer greater sensitivity for detecting oil in ice.

Further information on these innovations is provided in IPIECA-IOGP, 2015b.

Recommendations for improving satellite remote sensing for oil spill response

Satellite remote sensing technology is advancing continually, providing benefits ranging from improvements in the spatial resolution of sensors to developments in the atmospheric correction of image data. For oil spill response, such developments create new opportunities to test and enhance the capabilities and applications of satellite remote sensing for detecting and characterizing oil spills. Improvements in satellite and sensor technology will lead to greater availability and potential use of satellite remote sensing for oil spill response. There is also potential for organizational improvements to enhance the use of satellite imagery, as recommended by the OSR-JIP. These include:

- **Improving data access plans:** new methods of purchasing and guaranteeing access to satellite data should be considered, for example pre-purchasing imagery at a favourable rate for guaranteed priority in acquisitions, or offering subscription-type purchase models.
- **Offering direct tasking of satellites:** it may be possible for users to carry out tasking requests themselves for certain planned missions, using a ground terminal with direct tasking uplinks: this is likely to be more practical for satellite constellations where tasking can be distributed among multiple satellites.
- **Providing real-time delivery:** there is potential to introduce real-time streams of data published directly to the web (and refreshed as new imagery is available), although this may initially reduce the level of processing that the imagery can undergo.
- **Cross-company satellite planning software:** the development of software that can identify suitable data for an oil spill response from among a vast range of cross-company data sources could provide considerable benefits; for example, data availability would not limited by the contacts or commercial interests of one satellite imagery provider.
- **Creating and testing of satellite imagery plans:** following the guidance in this document, plans should be established and tested as part of regular oil spill exercises to improve understanding of the availability and usability of satellite imagery, and to provide a basis for ongoing training in satellite imagery planning.
- **Development of cooperative surveillance programmes within and between industry and regulators:** coordination within and between companies and organizations to enable the pooling of knowledge, resources and costs will help to develop national and regional satellite imagery plans, as well as enabling the sharing of knowledge on new technology and techniques; collaboration on training and exercises would also contribute to improving overall expertise and skill levels.

The OSR-JIP report (IPIECA-IOGP, 2015b) also recommends that a regular 'horizon scan' should be undertaken by individual companies, organizations and the industry as a whole to ensure that all stakeholders are aware of upcoming satellite remote sensing technologies and data formats.

Critical steps in using satellite remote sensing for oil spill response

Below is a basic checklist of steps that should be followed prior to, during and after an incident.

Before an incident

Task
Identify an SRS Coordinator within the organization
Create a Satellite Imagery Plan for the AOI
Identify potential suppliers of SRS data
If possible, select a provider(s) and set up agreement(s)
Create/obtain environmental sensitivity index (ESI) maps and the underlying spatial data for the AOI
Set up the standard operating protocols (SOPs) for data ordering, delivery and storage
Set up a GIS framework for the AOI

During an incident

Task
Identify the SRS Coordinator within the response
Work with the Planning Section and Incident Command to identify and agree information needs
Update Satellite Imagery Plan with incident detail and information needs
Discuss needs with the satellite imagery provider and order initial imagery (follow acquisition workflow plan)
Set up necessary hardware and software for receiving and using final products
Set up storage for final products
Establish long-term imagery acquisition plan (if applicable)
Incorporate final products into the COP
Use final products

After an incident

Task
Ensure data are archived and protected (confidentiality/access control, integrity, accessibility)
Conduct a review of lessons learned to evaluate the use of imagery
Review and update the satellite imagery plan, incorporating improvements as necessary

List of acronyms

AOI	Area of interest
API	American Petroleum Institute
ASV	Autonomous surface vessel
AUV	Autonomous underwater vehicle
COP	Common operating picture
CSV	Common separated values
DBF	Database file
EULA	End user licence agreement
FTP	File transfer protocol
GIS	Geographic information system
GML	Geography markup language
GPG	Good Practice Guide
ICS	Incident Command System
IMS	Incident Management System
JPEG	Joint Photographic Experts Group
KML	Keyhole markup language
NIR	Near infrared
OGC	Open Geospatial Consortium
OSCP	Oil spill contingency plan
OSR	Oil spill response
OSRO	Oil spill response organization
PDF	Portable document format
PNG	Portable network graphics
ROV	Remotely operated vehicle
RP	Responsible party
SAR	Synthetic aperture radar
SLA	Service level agreement
SOP	Standard operating protocol
SRS	Satellite remote sensing
SWIR	Short-wave infrared
TIR	Thermal infrared
TXT	Text
UAV	Unmanned aerial vehicle
USV	Unmanned surface vessel
UUV	Unmanned underwater vehicle
VIS	Visible
WCS	Web coverage service
WFS	Web feature service
WMS	Web map service
WMTS	Web map tile service

Glossary of terms

Acquisition timing: the time(s) at which the satellite will image the AOI.

Acquisition window: the opportunity for imagery acquisition.

Active sensors: emit own pulse of energy and then measure the signal that is reflected back to the sensor.

Common operating picture (COP): a single, comprehensive, display of relevant operational and planning information that provides an overall status of priorities, activities and resources. A COP facilitates collaborative planning and helps to achieve situational awareness. A COP may be in the form of status boards and/or digital information displays that are kept current by the Situation Unit.

Latency: the time period between the image being acquired by the satellite sensor and delivery of the final product.

Lead-time: the time period between placing an order and the image being acquired by the satellite sensor.

'Level 0' data product: the initial 'raw' data downloaded by the satellite. These data are not directly suitable for oil spill response because they first need to be converted to a usable format.

'Level X' data product: licensed imagery product, i.e. imagery that has been processed, where 'X' represents the level of processing applied.

Passive sensors: detect natural radiation emitted or reflected by the targets or phenomena being observed.

Radiometric resolution: the number of levels of energy recorded, per pixel, in each spectral band.

Remote sensing: acquisition of data on an object or phenomenon without making physical contact with it, often using electromagnetic radiation.

Revisit frequency: the time it takes for a satellite to return to the AOI on its next orbital pass.

Satellite remote sensing: use of satellites (and the sensors onboard) to measure properties of the Earth from above the atmosphere, and to gather data.

Situational awareness: knowing what is going on around you; the ultimate aim is to enable the Incident Command and other stakeholders in the response to make effective decisions and minimize the impact of a spill.

Spatial resolution: the minimum distance between two targets that allows them to be separately detected or resolved.

Spectral resolution: the number of discrete spectral bands in which the sensor can collect reflected radiance.

Swath width: the distance that can be covered by a sensor in a single scan as it orbits along its path.

Tasking window: the opportunity for satellite tasking—usually occurs at a limited number of times per day in set periods.

Temporal resolution: describes how often, the AOI can be imaged by the satellite.

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IPIECA

IPIECA is the global oil and gas industry association for environmental and social issues. It develops, shares and promotes good practices and knowledge to help the industry improve its environmental and social performance; and is the industry's principal channel of communication with the United Nations. Through its member led working groups and executive leadership, IPIECA brings together the collective expertise of oil and gas companies and associations. Its unique position within the industry enables its members to respond effectively to key environmental and social issues.

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IOGP
International Association of Oil & Gas Producers

IOGP represents the upstream oil and gas industry before international organizations including the International Maritime Organization, the United Nations Environment Programme (UNEP) Regional Seas Conventions and other groups under the UN umbrella. At the regional level, IOGP is the industry representative to the European Commission and Parliament and the OSPAR Commission for the North East Atlantic. Equally important is IOGP's role in promulgating best practices, particularly in the areas of health, safety, the environment and social responsibility.

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