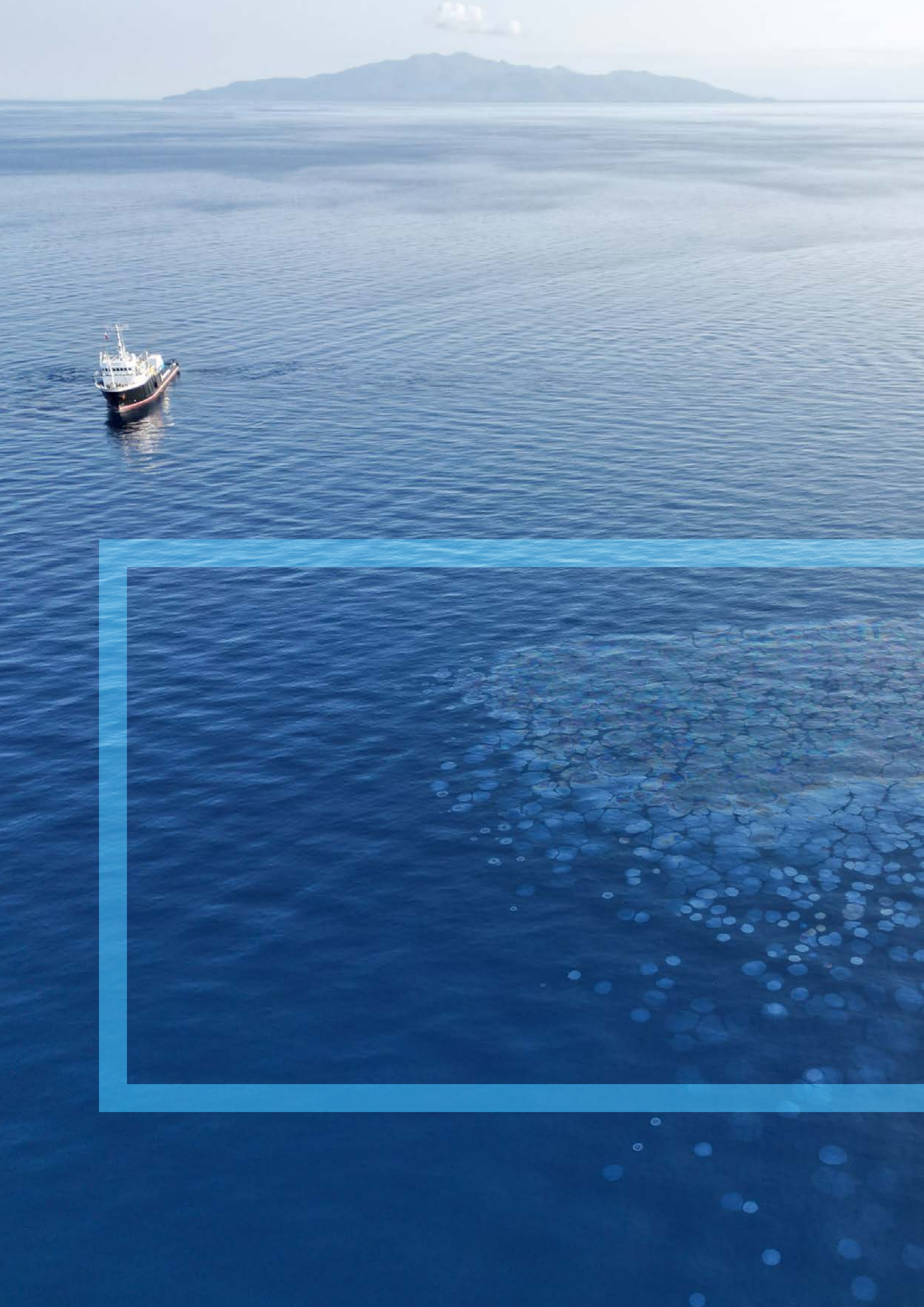
ITOPF
PROMOTING EFFECTIVE SPILL RESPONSE

TECHNICAL INFORMATION PAPER NO.1

Aerial surveillance of marine oil spills

Contents



Introduction

Aerial surveillance is an essential element of an effective response to most oil spills, for assessing the location and extent of oil contamination and verifying predictions of the movement and fate of oil slicks at sea. Observation from the air can also provide information facilitating deployment and control of spill response operations at sea, the strategic and timely protection of sites along threatened coastlines and the management of resources for shoreline clean-up.

This Technical Information Paper presents advice on planning and conducting an effective aerial surveillance strategy. Guidance is provided on preparing and performing aerial observation missions for each of the three main types of platforms available: manned aircraft, satellites and unmanned aircraft.

Aerial Surveillance Strategy

A variety of platforms are available for conducting aerial observation of spills at sea, the suitability of which is determined by the specifics of the incident and the objectives of the surveillance task. The most established method is the use of trained observers in manned aircraft to gain visual observations. Where available, the use of remote sensors mounted on either aircraft or satellites is now also considered standard practice. More recently, advancements in Unmanned Aerial Vehicles (UAVs) have increased their recognition as an alternative means of aerial observation and guiding operations during spill response.

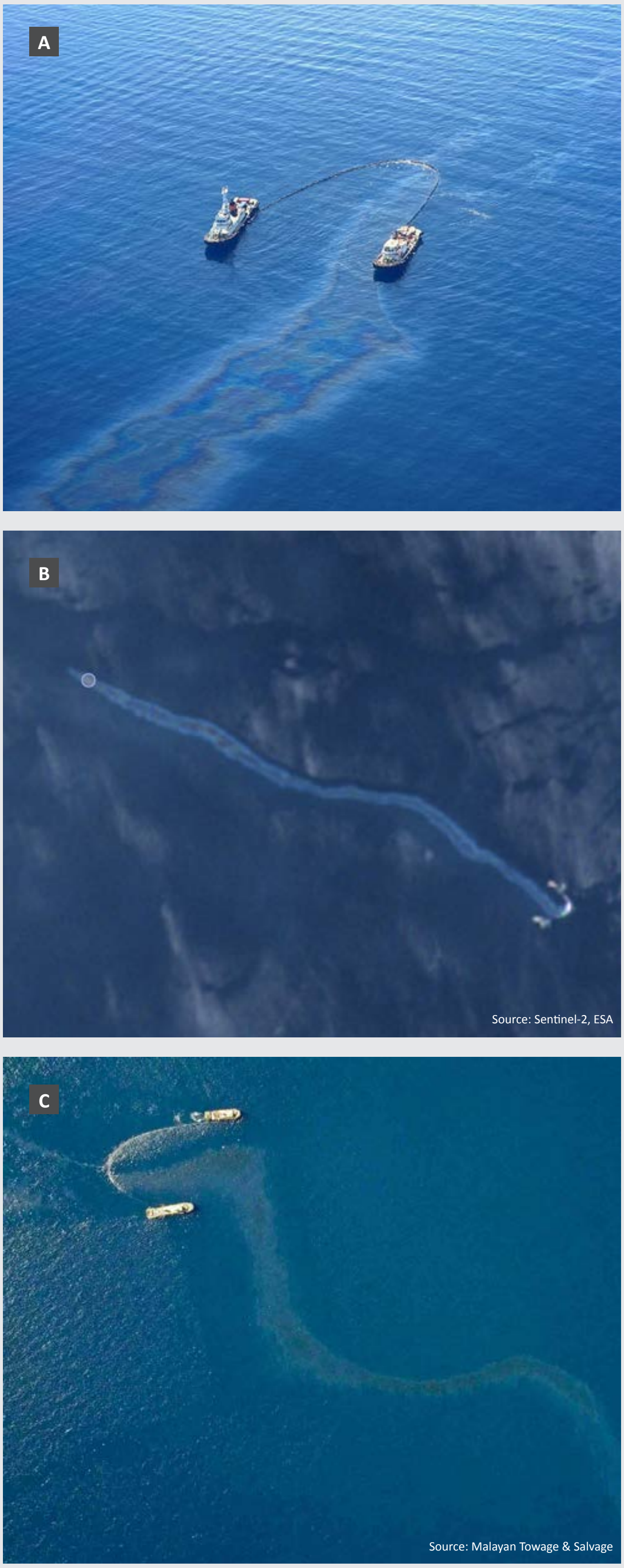
Rationale for aerial surveillance

Aerial surveillance can be performed for several purposes. In response to a marine incident, obtaining a bird's eye view can provide invaluable information to advise decision makers on response strategies. In addition to identifying the scale and extent of a spill and informing decisions on priorities, aerial observations can be used to guide resources involved in at-sea response operations to maximise their effectiveness.

For small-scale spills where it is possible to establish the extent of the contamination via surveys performed by boat or on foot, for instance a spill of limited volume in a confined area such as a port or a specific section of shoreline, aerial surveillance may not be required. However, for spills where the extent of contamination is unclear, or for larger-scale incidents affecting an extensive area, surveillance needs are often best met by aerial observations. At the outset of such incidents, reports from reconnaissance flights are often vital to establish the nature and scale of the pollution. Hence, aerial surveillance should be assigned a high priority in the initial stages of a response.

Source: TMEA

FIGURE 1 **Imagery of the same oil spill acquired at different times by different platforms: (A) helicopter, (B) satellite and (C) UAV.**



The geographic location of a spill also factors in determining the need for aerial surveillance. For spills occurring offshore, aerial surveillance frequently forms an essential component of the initial response and can form an important element of ongoing operations. Whilst aerial surveillance can be useful in the early stages of a response to spills occurring near shore, it typically becomes less of a focus as response operations progress and the need to observe the extent and evolution of contamination from the air declines.

The effectiveness of response vessels tasked with recovering floating oil at sea is limited inherently by the field of view of the oil. Ships' bridges and observation points may be only tens of metres above the sea surface meaning a full understanding of the extent and concentration of the oil cannot be readily understood. Consequently, skimmers and other recovery equipment cannot be effectively directed to main concentrations of oil without assistance.

Historically, manned aircraft have assisted by overflying a slick to direct response vessels accordingly. However, this assistance is limited by aircraft flight duration and the need to establish direct channels of communication between the aircraft and response vessel, the latter which can require specialised communications equipment. The ease in availability of UAVs has alleviated this problem markedly, with many specialised response vessels now equipped with dedicated UAVs for the purpose of surveying areas of oil to determine higher concentrations for optimum recovery efficiency. Although it is possible to observe certain at-sea response activities in some satellite imagery, the delivery time of the images make them impractical for operational use.

Similarly, the effectiveness of dispersant application on oil slicks can be enhanced by use of a spotter plane to direct the spraying aircraft to the areas of thicker oil. Aerial spraying of dispersant is best undertaken at relatively low altitudes for optimum droplet sizing and to counter crosswinds. Low altitude flying means a full appreciation of oil concentrations in a wider slick may be difficult to observe and a second aircraft at a higher altitude can be advantageous. The use of UAVs for such spotting tasks may be restricted by the presence of nearby spraying aircraft.

Platform selection

Fundamentally, there are two categories of data that can be collected during aerial reconnaissance. There is visible data (i.e. observations made in the visible part of the electromagnetic spectrum) collected via an observer, camera or sensor and data captured using sensors that detect radiation outside the visible part of the spectrum (such as infrared (IR)/ultraviolet (UV) or Synthetic Aperture Radar (SAR)/Side Looking Aperture Radar (SLAR)).

When selecting the most appropriate type of reconnaissance and associated platform, the key factors to consider include:

- the surveillance objectives
- the geographical extent and location of the spill
- environmental conditions, such as strong winds
- planning and logistical issues
- regulatory concerns, such as certification and permission to fly aircraft and UAVs.

Platform specific considerations, as well as advantages, can be found in the following table.

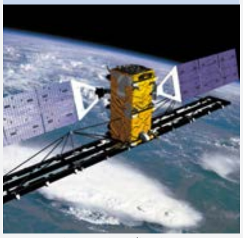
TABLE 1 Different platforms for aerial surveillance, their advantages, and considerations.

Platform	Advantages	Considerations
FIXED-WING MANNED AIRCRAFT 	• The speed and range of fixed-wing aircraft affords good geographical coverage. • Dedicated aircraft can have a range of sensors mounted on board.	• Aircraft selection should consider the operating speed, for if this is too fast the ability to observe and record oil will be reduced. • Aircraft selection should also consider the wing position, as a high wing aircraft provide much better visibility for observers. • For surveys over the open sea, the extra margin of safety afforded by a twin or multi-engine aircraft is strongly recommended. • Requires an airstrip.
ROTARY-WING MANNED AIRCRAFT (HELICOPTER) 	• Greater manoeuvrability and ability to hover provides flexibility when surveying nearshore waters and complex shorelines from helicopters. • Ideal for surveying intricate coastline with cliffs, coves, and islands. • Ability to land on suitable open terrain to inspect sites in more detail whilst conducting surveys (less easily done with fixed-wing aircraft).	• Helicopters typically have a shorter-range relative to fixed-wing aircraft and therefore more limited geographic coverage. • Safety must be assessed for helicopters hovering in the vicinity of a significant spill of highly flammable products. • For surveys over the open sea, the extra margin of safety afforded by a twin or multi-engine helicopter is strongly recommended.

Any manned aircraft used by trained observers must feature good all-round visibility and carry suitable navigational aids. The type and size of an aircraft will limit the number of people able to take part in a flight. For small fixed-wing aircraft, and helicopters in particular, the number of passengers can substantially affect fuel consumption and thus the range of the aircraft.

If there are two or more observers on a surveillance flight, they should work closely together to compare and confirm sightings. The lead observer directing the pilot should be experienced in aerial surveillance and be able to reliably detect, recognise and record oil pollution at sea. There should be a consistency of at least one observer throughout a series of flights, so that variations in reports reflect changes in the state of oil pollution and not differences between the perceptions of the observers.

TABLE 1 continued

SATELLITE  Source: Canadian Space Agency	• Satellites can cover a wide geographic area. • Good option for planned repeatable, longer-term observations. • The timing and frequency of overpasses, data download and processing time might lead to considerable delays in obtaining information.	• Sensors on satellites are still subject to potential environmental limitations (particularly cloud cover), therefore planned acquisitions may not be reliable.

For satellites, the key to successfully integrating their use into an aerial surveillance strategy will be to identify providers of the required images during the contingency planning phase. Utilising a provider that has access to multiple satellite options will increase the chances of obtaining the necessary imagery. Some satellite providers now provide imagery free of charge for research purposes, so although the imagery may not be suitable for real-time response, it could still be useful for establishing pre-spill conditions and for monitoring purposes.

FIXED-WING UAV  Source: EMSA	• Large/heavyweight UAVs have long range and endurance and are less constrained by weather conditions than smaller UAVs. • Can be used for situations when it is not suitable for a manned flight (such as the suspected presence of potentially hazardous gas clouds). • Can carry heavier payloads than smaller UAVs, including a wide range of sensors.	• Regulations are generally similar to that of manned aviation. • Usually operated by government agencies.
ROTARY-WING UAV 	• Small/lightweight UAVs can deliver prompt initial and regular surveys. • They have flexibility in terms of where and when they are launched. • Can also be used in difficult to access areas or situations not suitable for a manned flight.	• Need to ensure that any national restrictions/ certification and legislation is adhered to. • Can have limited range and battery life. • May not be able to fly in high winds or heavy rain. • May require vessel support if operating offshore.

Typically, the smaller and more common type of UAV seen during incidents must be operated within the Visual Line of Sight (VLOS) of the pilot who is required to always maintain unaided visual contact with the UAV and surrounding airspace whilst airborne. National regulations for UAV use vary, but some countries permit Extended Visual Line Of Sight operations (EVLOS) where one or more specially trained observers maintain the VLOS and communicate back to the pilot to ensure that the UAV remains a safe distance from other air users, structures, terrain or other hazards.

Flights operating Beyond the Visual Line Of Sight (BVLOS), where visual contact with the UAV is not maintained, require special permission from the relevant aviation authority – currently, UAVs operating under such conditions are not typically seen in oil spill response. Given the restrictions and regulations on operating UAVs, combined with other considerations such as range and environmental parameters, the potential role of UAVs should be assessed during the contingency planning phase so that they can be effectively incorporated into an aerial reconnaissance strategy.

Planning for aerial surveillance

Aerial surveillance is most effective if conducted as early as practicable from the outset of an incident to allow decision makers to obtain a prompt overview of the situation and plan an effective response. This is best achieved if aerial surveillance has been considered during the contingency planning process. Planning for aerial operations should include research into providers of the different types of surveillance platforms, their suitability for different scales of incident in different locations, determining mobilisation procedures and likely costs, and ideally establishing formal agreements/contracts with such providers to minimise potential delays when an incident occurs. For satellite surveillance, knowing where and how to obtain satellite imagery in advance is key. An understanding of the data acquisition process is also important, to know how the data will be processed and interpreted, timescales for the provision of final imagery and the format it will be provided in.

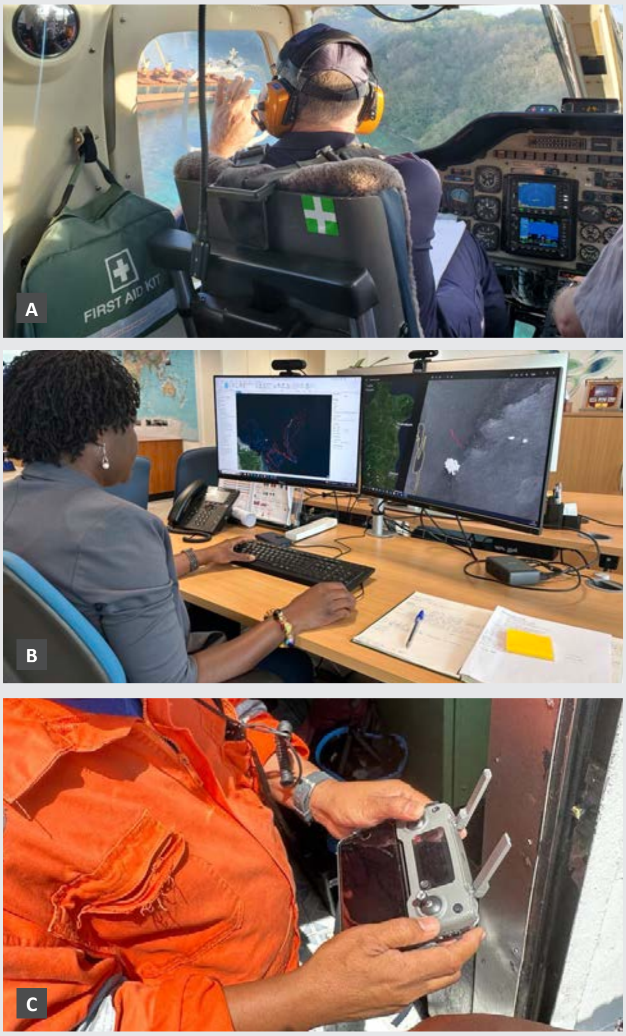
Where the surveillance objective is to document the movement of oil at sea, to be most effective, such surveillance should typically be conducted regularly and planned at appropriate intervals. Surveillance flights to establish and monitor the extent of pollution are ideally timed at the beginning of the day so that the results can be used during meetings to validate trajectory modelling and plan response operations. Furthermore, based on the scheduled acquisition of satellite data, aircraft availability might be planned to corroborate any findings from the satellite pass.

Reconnaissance flights of any type, including their timetabling and flight paths, should be coordinated to avoid unnecessary duplication between agencies and to reduce unnecessary risk arising from multiple airborne platforms. As the pollution situation is brought under control the need for aerial reconnaissance may reduce or come to an end. For all types of aerial surveillance, their integrated use into a response should be exercised regularly, and appropriate training given to relevant personnel. The strategy for aerial reconnaissance and contact details of relevant agencies, providers and operators should be key entries in contingency plans.

From the start of an incident, and as the response progresses, the various surveillance needs should be identified and matched to the most appropriate available reconnaissance platform. Furthermore, the aerial reconnaissance strategy should consider how the various surveillance platforms might be combined so that the data acquired is coordinated and complementary.

FIGURE 2

Observers conducting aerial surveillance via three different platforms (A) Manned aircraft - Observer in a helicopter (B) Satellites - Data analyst interrogating a satellite image several hours old (C) Unmanned aircraft - UAV pilot observing live footage alongside another observer.



Manned Aircraft

Planning and preparation

One of the most common and most effective methods of conducting aerial reconnaissance is through the use of trained observers onboard manned aircraft to record the appearance of oil at sea and assess the quantity of oil observed. Such surveillance missions may take place onboard aircraft specifically chartered for the task (often rotary-wing) or, alternatively, trained observers may join flights onboard dedicated fixed-wing aircraft that are routinely engaged in monitoring and surveillance work and therefore equipped with remote sensing systems-often under contract to national authorities.

Time in the air over a spill location is often limited during surveillance flights so it is imperative that thorough preparations are made to maximise the mission's effectiveness.

SAFETY

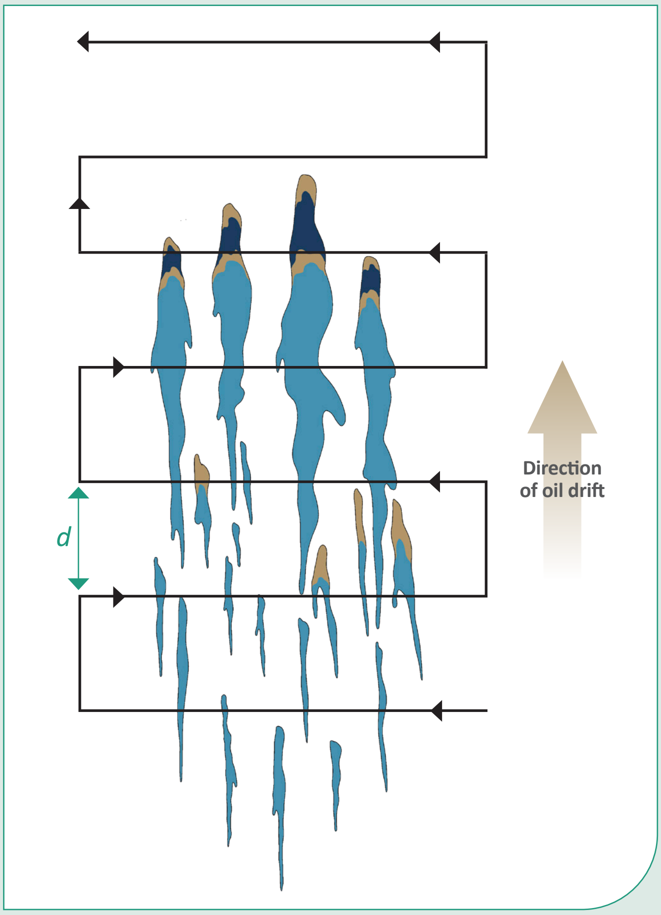
Safety considerations are paramount, and the aircraft pilot should be consulted on all aspects of the reconnaissance operation prior to departure. Those taking part in a flight should be thoroughly briefed beforehand on the safety features of the aircraft and procedures to be followed in the event of an emergency. Suitable personal protective equipment, such as manually inflated life jackets, should be available and worn.

SEARCH PLAN

In view of the errors inherent in oil movement forecasting, it is usually necessary to plan a systematic aerial search to ascertain the presence or absence of oil over a large sea area. A 'ladder search' is frequently the most effective method of surveying an area.

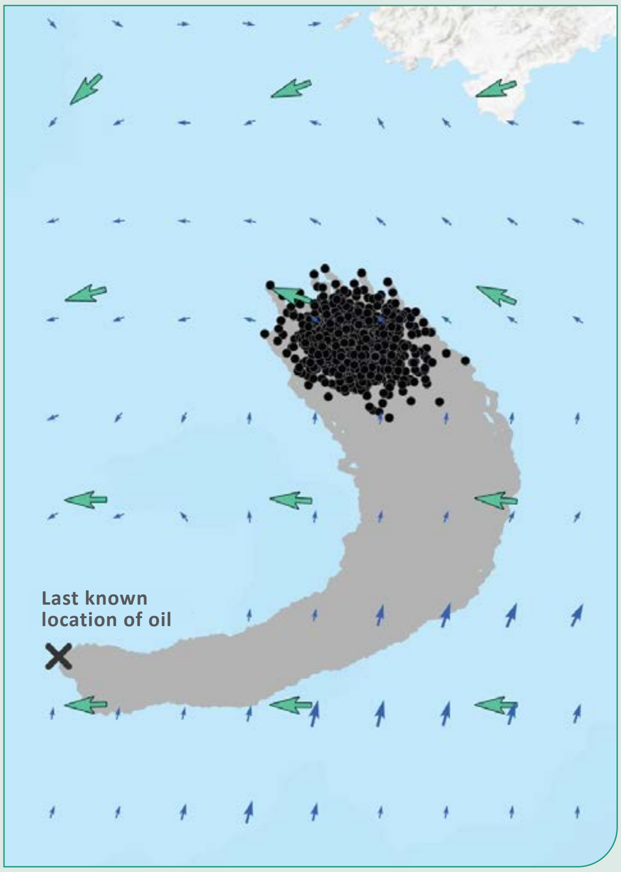
When planning a search, due attention must be paid to visibility and altitude, the likely flight duration and fuel availability, together with any other advice the pilot may give.

Depending on the wind speed, floating oil can become elongated and aligned parallel to the direction of the wind in long and narrow 'windrows'. It is advisable to arrange a ladder search across the predicted oil drift to increase the chances of oil detection. The distance (*d*) between the 'rungs' of the ladder search will be determined by the visibility, sensors onboard, and aircraft endurance.



TRAJECTORY MODELLING

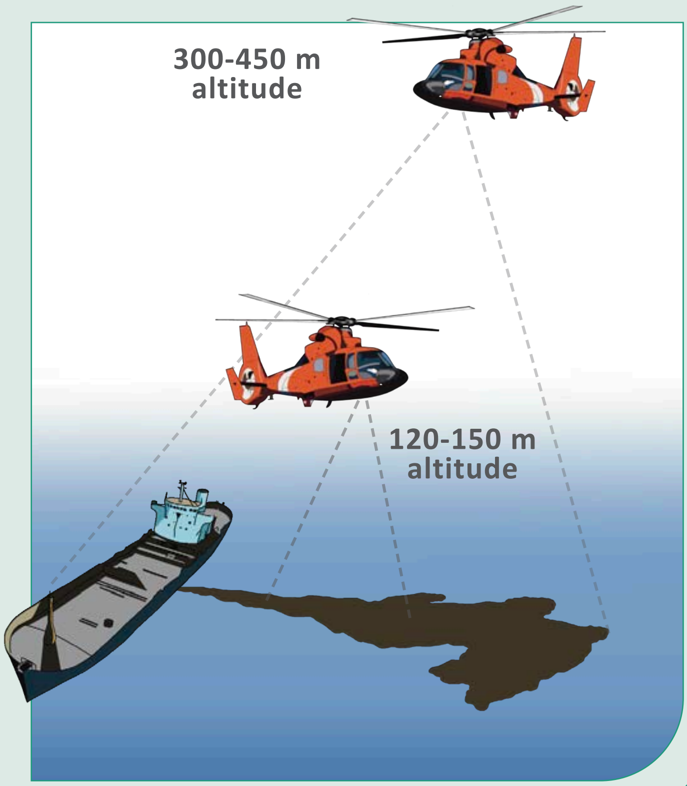
The task of predicting the position of the oil is simplified if data on winds and currents is available since both contribute to the movement of floating oil. It has been found empirically that floating oil will move downwind at about 3% of the wind velocity (**green arrows**).
In the presence of surface water currents, an additional movement of the oil at 100% of the current velocity (**blue arrows**) will be superimposed on any wind-driven motion. Close to land, the strength and direction of any tidal currents must be considered when predicting oil movement, whereas further out to sea the contribution of other ocean currents predominate over the cyclic nature of tidal movement. Thus, with knowledge of the prevailing winds and currents, it is possible to predict the speed and direction of movement of floating oil from a known position. Computer based oil spill trajectory models of varying sophistication will plot anticipated trajectories. However, the accuracy of both computer models and simple manual calculations depends on the accuracy of the hydrographic data used and the reliability of forecasts of wind speed and direction.



ALTITUDE

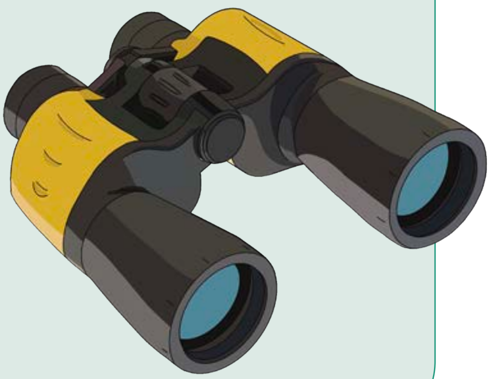
The search altitude is generally determined by the prevailing visibility. Over open sea areas, in clear weather 1,000-1,500 feet (300-450 metres) frequently proves to be an optimal height for manned aircraft for maximising the scanned area without losing visual clarity. However, it is necessary to drop to half this height or lower to confirm any sightings of floating oil or to analyse its appearance.

For helicopters, in the absence of any restrictions imposed by the pilot or by the nature of the coastline, a flight speed of 145-165 km/h and an altitude of 400-500 feet (120-150 metres) often proves a useful starting point. Depending on the surveillance objectives and observations made during the flight, if safety considerations allow, flying at even lower altitudes can allow the observer to conduct more detailed inspections.



OTHER CONSIDERATIONS

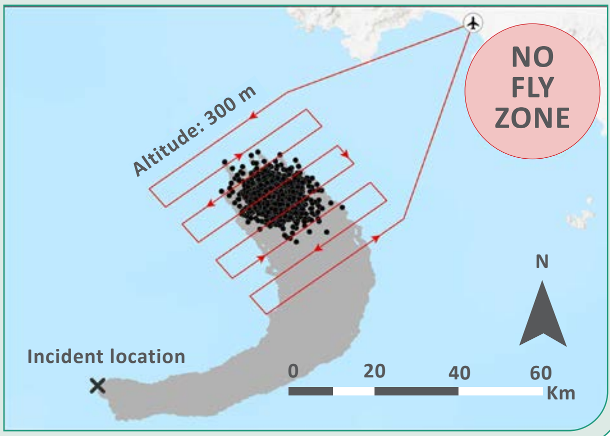
Flights should be planned to start and finish with sufficient sunlight to afford observation of the sea surface or shoreline. Weather conditions such as fog, mist, low cloud, snow and heavy rain can affect surveillance and may mean flying is impractical or unsafe. Other considerations are haze and light reflection off the sea, which can affect visibility of the oil. Spotting oil is often easiest with the sun behind the observer and it may prove more advantageous to fly a search pattern in a different direction to the one originally planned. Sunglasses with polarising lenses can assist the detection of oil at sea under certain light conditions.



FINALISE FLIGHT PLAN

A flight plan should be prepared in advance and agreed with the pilot and relevant authorities as appropriate, prior to boarding. This should take account of any available information that may reduce the search area as much as possible, such as the last known sightings and the expected trajectory of the oil. Any flight restrictions should be noted, some of which may be specifically imposed as a result of the spill. For example, it may be prohibited to fly over the shipping casualty, foreign or military airspace or certain environmentally sensitive areas where wildlife may be disturbed (e.g. breeding colonies of birds or seals).

Despite making careful predictions and planning a systematic ladder search, the actual pollution observed during the flight may still be different to the situation envisaged. It is important, therefore, for contingencies to be borne in mind and adjustments made during the flight, to maximise the chances of finding the oil and plotting its full extent, whilst still trying to maintain a logical and efficient flight plan.



COMMUNICATION

Instructions from the pilot on the use of headsets should be sought prior to take-off to avoid disruption of the communications with other aircraft and the traffic control authorities. Throughout the flight, communication with fellow observers and the pilot is important to monitor progress, confirm observations and to discuss and agree any desired and appropriate adjustments to the flight. If headsets are not available for all observers, having a pen and paper available for written communication can be helpful.

Depending on the objectives of the surveillance mission, it may be necessary to have direct communications with response vessels operating in the spill vicinity with the aim of guiding them towards the thickest concentrations of oil.

Appearance of oil

Oil spilled at sea undergoes marked changes in appearance over time as a result of weathering processes. It is important for observers to be familiar with these processes so that the presence of spilled oil can be reliably detected and its nature accurately reported.

Many oils spread rapidly over wide areas of the sea surface. Although the oil may initially form a continuous slick this usually breaks up into fragments and windrows due to circulation currents and turbulence (Figures 3, 5 and 7). As the oil spreads and the thickness reduces, its appearance changes from the black or dark brown colouration of thick oil patches to iridescent and silver sheen at the edges of the slick (Figures 3 and 4).

Sheens consist of very thin films of oil and whilst these areas can be widespread, they represent a negligible quantity of oil. In contrast, some crude oils and heavy fuel oils are exceptionally viscous and tend not to spread appreciably but remain in coherent patches surrounded by little or no sheen. In rare circumstances, oils may sink below the water surface, impeding aerial observation and quantification. A common feature of spills of crude oil and some heavy fuel oils is the rapid formation of water-in-oil emulsions which are often characterised by a brown/orange colour and cohesive slicks (Figure 7).

FIGURES 3 AND 4

Large patches of sheen from a spill of intermediate fuel oil (IFO 180) observed from an aircraft (left) and later the same day at close range from a vessel (right). The patches contain areas of thin layers of oil spreading to areas of rainbow sheen and silver sheen.

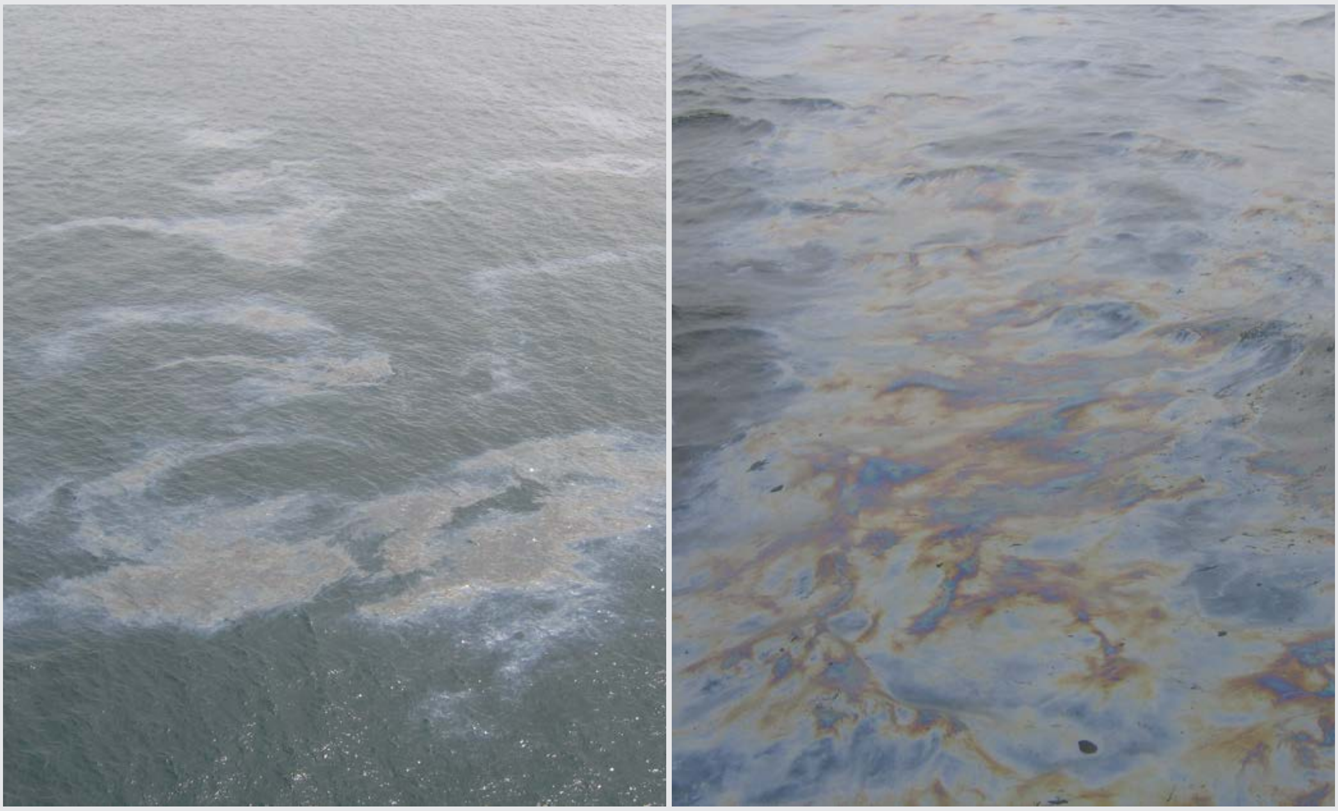


FIGURE 5 A band of black oil is observed from left to right of the picture. The wind, blowing across the oil, is pushing this band away from the observer resulting in perpendicular windrows of varied sheen.

FIGURE 6 A slick of heavy fuel oil (IFO 380) – note the absence of sheen.

FIGURE 7 Patch of brown/orange emulsified fuel oil observed alongside metallic and silver sheen.

Large amounts of debris in the water or spilled non-oil cargo (Figure 8) may mix with the oil to mask its appearance. Furthermore, from the air it is difficult to distinguish between oil and a variety of other phenomena commonly confused with oil (Figures 9-14). Phenomena that most often lead to mistaken reports of oil include cloud shadows, ripples, differences in the colour of two adjacent water masses, suspended sediments, floating, or suspended organic matter, floating seaweed, algal/plankton blooms, seagrass and coral patches in shallow water, and sewage and industrial discharges. Many shoreline features, for example vegetation or changes in rock strata, viewed from a distance bear a close resemblance to oil.

Initial sightings of suspected oil should be verified by over-flying at a sufficiently low altitude to allow positive identification. In instances where doubt exists, aerial observations should be confirmed by closer inspection from a boat or on foot.

FIGURE 8

Heavy fuel oil spilled as a result of the catastrophic failure of a bulk carrier. The soy bean cargo has mixed with the oil making realistic estimations of the volume of spilled oil difficult to determine.

FIGURE 9

Cloud cover resembling patches of black floating oil.

FIGURE 10

Benthic seagrass and seabed rock formations can confuse estimations of the amount of oil.

FIGURE 11

Patches of fringing coral reef may lead to false positives.

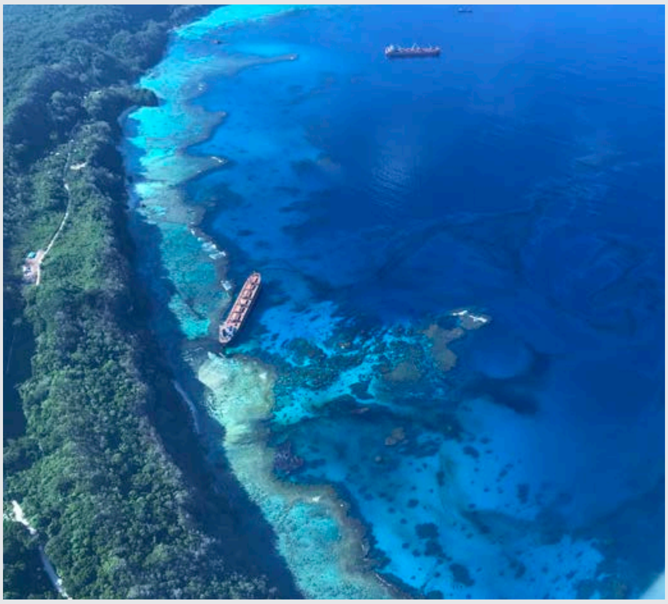


FIGURE 12

Sediment plumes observed alongside oil containment and recovery operations.

FIGURE 13

Freshwater run-off from a narrow creek meeting turbid brackish water giving the appearance of significant local pollution.

FIGURE 14

Clumps, patches or rafts of *Sargassum*, a genus of brown macroalgae (seaweed), drifting near the water's surface can appear similar to emulsified oil (see Figure 7) and cause false positives.

Quantifying oil volumes

An accurate assessment of the quantity of oil observed at sea during surveillance flights may not be possible due to the difficulties of gauging thickness and coverage. However, by considering certain factors it may be possible to estimate the volume of oil in a slick to an order of magnitude so that the required scale of the response can be planned. Because of the uncertainties involved, all such estimates should be viewed with considerable caution.

Oils with a low viscosity spread very rapidly and so oil layers quickly reach an average thickness of about 0.1 mm. However, the thickness of the oil layer can vary considerably within a slick or patch of oil, from less than 0.00004 mm to more than 1 mm. For more viscous oils the oil thickness may remain well in excess of 0.1 mm. The appearance of the oil can give some indication of its thickness.

Some oils form an emulsion by the inclusion of tiny droplets of water with wave action, which increases their volume. A reliable estimate of the water content is not possible without laboratory analysis, but figures of 50-75% are typical.

The thickness of emulsion can vary considerably depending on the oil type, the sea conditions and whether the emulsion is free-floating or held against a barrier such as a boom or the shoreline.

The Bonn Agreement Oil Appearance Code (BAOAC) is an example of a colour code used to quantify oil observed at sea based on five appearance categories. The Code was developed and adopted by the Contracting Parties to the Bonn Agreement (a regional agreement on responding to pollution incidents in the North Sea) and is used by many surveillance aircraft operators worldwide to quantify oil observed at sea.

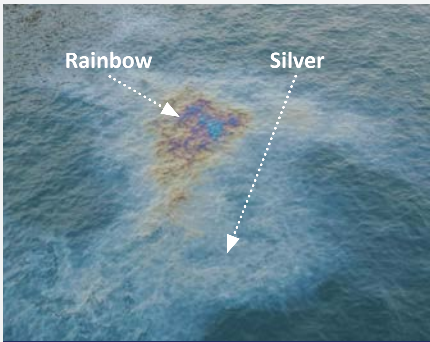
The BAOAC uses a thickness range for four of the five colour codes, thus giving these codes a minimum and maximum value for volume estimates. The Contracting Parties of the Bonn Agreement use the minimum value for any legal/enforcement purposes, whilst noting that the maximum volume is useful for operational purposes such as planning response capabilities. Due to the scientific research supporting the Bonn Code and its relative ease of use, it is popular with aerial surveillance operatives worldwide. Accounting for emulsion, ITOPF applies a slightly adapted version of the Bonn Code as explained in Table 2.

FIGURE 15 Spills in icy waters are difficult to quantify.

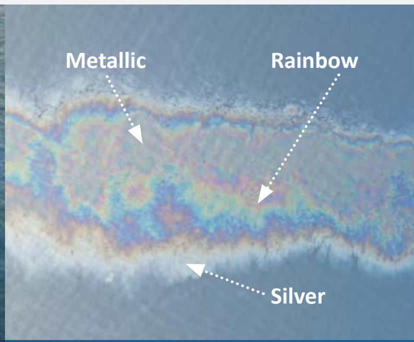
TABLE 2 Indicative thicknesses of oil at sea based on appearance. All figures, some of which are based on the Bonn Agreement's Oil Appearance Code (BAOAC), are intended to be used as an approximate guide.

Non-Actionable/Non-Recoverable Oil (Sheen)

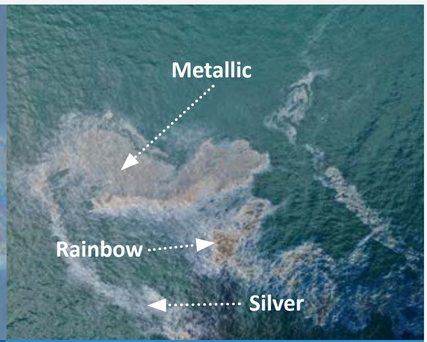
Appearance Descriptions	Thickness (mm)	Volume per km² (m³)	BAOAC ref.	Description
Silver/ Grey sheen	0.00004 - 0.0003	0.04 - 0.30	1	This thinnest sheen is not always easy to observe. Furthermore, volumes are not essential to note for operational purposes as the thickness of oil that appears like this equates to an insignificant amount per square kilometre, which is not conducive to recovery or any other type of response. It is expected to dissipate naturally.
Iridescent/ Rainbow sheen	0.0003 - 0.005	0.3 - 5.0	2	Easier to see than silver/grey sheen, however, volumes are still not essential to note for operational purposes as the thickness of oil that appears like this is also not conducive to recovery or any other type of response. In most cases, it is expected to dissipate naturally.
Metallic sheen	0.005 - 0.05	5 - 50	3	Oil that has a metallic appearance on the sea surface is the thickest of the three types of sheen, however, generally it is still not considered thick enough to focus response efforts on. It is usually a much darker grey than silver/grey sheen.



Silver



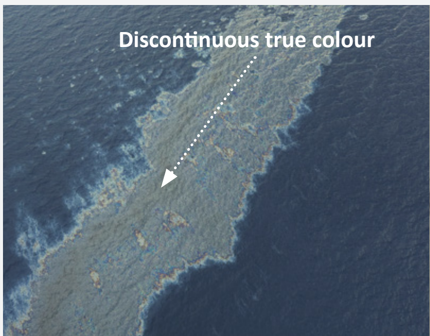
Rainbow



Metallic

Actionable/Recoverable Oil

Appearance Descriptions	Thickness (mm)	Volume per km² (m³)	BAOAC ref.	Description
Discontinuous true colour/ Transitional colour/ Patches of true colour	0.05 - 0.2	50 - 200	4	At this thickness range, oil can appear in patches of thicker true/natural colour amongst sheen, in calm conditions. This range can also account for when oil appears patchy due to small waves on the sea surface causing oil to collect in troughs and spread on crests. It can be difficult to detect as an observer in an aircraft, however, if it is observed, it can help to narrow down the range in possible thicknesses, and subsequently, volumes of oil that may be actionable/recoverable.
Continuous true colour/ Natural colour/ Dark/Black	> 0.2	> 200	5	At this thickness range, oils generally look like their true/natural colour. For fuel and crude oils, this is mostly black or dark brown. Determining an approximate upper limit for oil with this type of appearance is difficult as it can depend on the oil type and environmental conditions.
Light and dark browns/ Orange/ Black	> 1.0 (as a guide)	> 1,000 water and oil mixture (to be used as a guide)	No code	Emulsified oil can have many different appearances depending on the oil type and water content. Common colours can be orange or light brown, however, gauging the thickness of emulsion is particularly difficult because of their opaque appearance and limited spreading. A figure of 1mm may be used as a guide, but thicknesses of 1cm and significantly greater can sometimes be encountered.



Discontinuous true oil colour

Continuous true oil colour

Light brown (emulsified)

Quantifying oil volumes

When the sea surface is rough, it can be difficult or impossible to see less buoyant oil types, particularly if weathered, as they can be over-washed by waves, and remain just sub-surface for much of the time. In cold water some oils with high pour points will solidify into unpredictable shapes and the appearance of the floating portions may disguise the total volume of oil present. The presence of ice floes and snow may obscure large amounts or all the oil and will confuse the picture yet further (Figure 15). Residue from oils that have burnt may also be difficult to quantify.

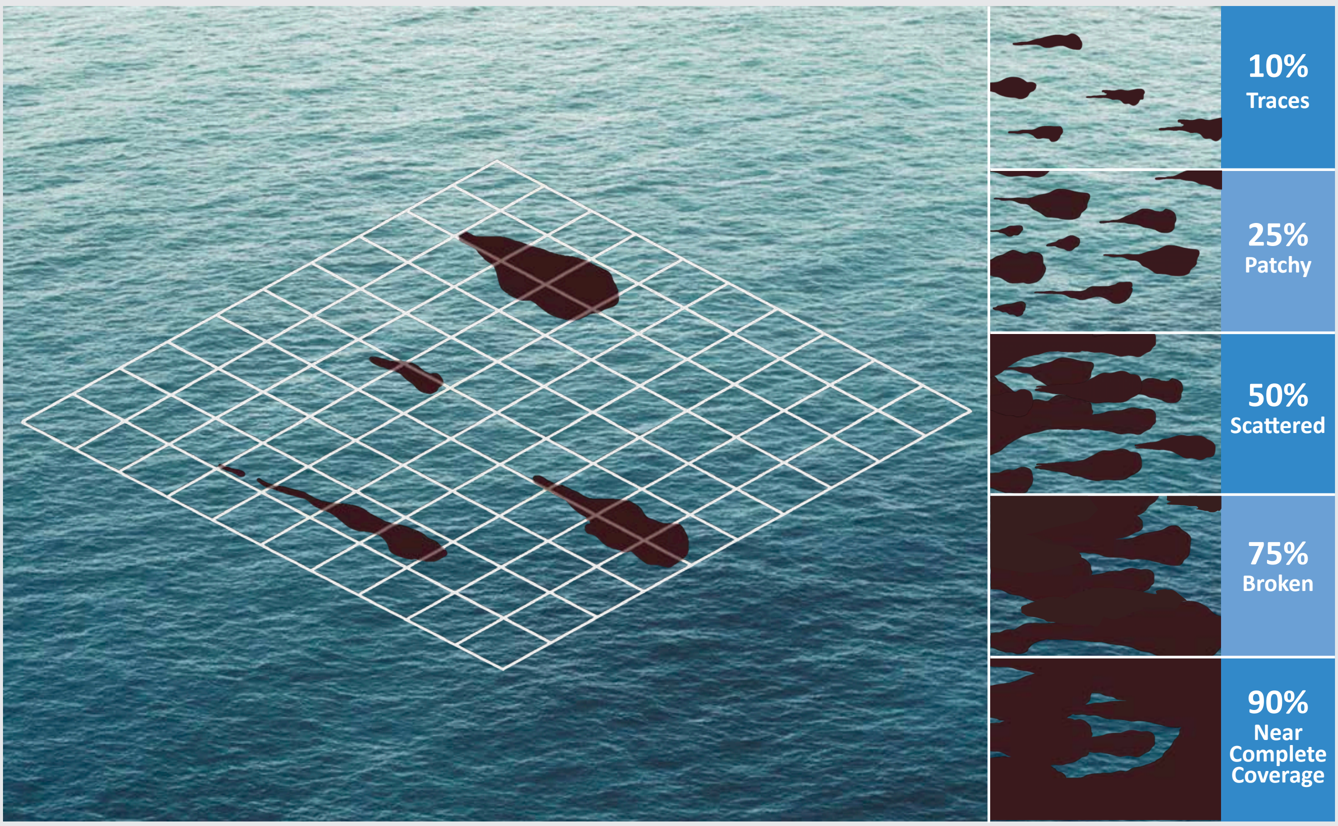
To estimate the amount of floating oil it is necessary not only to determine thickness but also the coverage of the various types of oil observed (Figure 16). Due account needs to be taken of the patchy incidence of floating oil so that an estimate may be made of the actual area of coverage relative to the total sea area affected.

To ensure response efforts are focused on the most significant areas of oil pollution, information on the relative and heaviest concentrations is important. To avoid distorted views, it is necessary to look vertically down on the oil when assessing the distribution.

Nonetheless, an accurate assessment of the % coverage is difficult to achieve and too precise an estimation is inadvisable due to margins of error. The diagrams in Figure 16 below may be used as a reference guide. More experienced observers may be able to interpolate intermediate coverage.

The extent of the affected sea area needs to be recorded during the flight. Marking waypoints using Portable Global Positioning Systems (GPS) receivers and GPS Apps on mobile devices or acquiring geo-referenced imagery are useful ways to accurately record the limits of the main areas of oiling.

FIGURE 16 **Illustration of percentage coverage. It is difficult to make an accurate assessment of the percentage coverage and it is advisable to try not to be too precise with the estimation. The drawings on the right-hand side may be used as a reference guide.**



The following provides an example of the process of estimating oil quantities.

STEP ONE

Based on the waypoints marked during the surveillance flight the overall affected area can be calculated. A simple way of doing this is drawing a rectangle around the observed oil and calculating its area. The slick (or slicks if broken) may only cover a percentage of the rectangle, therefore, you may need to estimate an initial percentage cover for total oil.

e.g. a broken slick spanning approximately 2 km by 7 km, where oil covers approximately 80% of the rectangle, making the total oiled area 11.2 km².

STEP TWO

The next step is to estimate the percentage cover of each type of oil appearance in the oiled area.

e.g. 10% emulsion patches and 90% silver sheen.

STEP THREE

The final step is to calculate the estimated volume of each appearance of oil observed. Using the estimated percentage cover in conjunction with the approximate volume of oil per km² values the final calculation can be made.

Estimated Percentage Cover	Approximate Minimum Volume per unit area (m^3/km^2)	Approximate Maximum Volume per unit area (m^3/km^2)	Estimated Minimum Volume	Estimated Maximum Volume
10% emulsion patches	1,000	> 1,000	*11.2 km² x 10% x 1,000* = 1,120 m^3	> 1,120 m^3
90% silver sheen	0.04	0.30	*11.2 km² x 90% x 0.04* = 0.40 m^3	*11.2 km² x 90% x 0.30* = 3.02 m^3

Since 50-75% of this emulsion could be seawater, the minimum volume of oil present could amount to approximately 280-560 m^3. This example also serves to demonstrate that although sheen may cover a relatively large area of sea surface, it makes a negligible contribution to the volume of oil present. Consequently, for accurate reporting, an observer must be able to distinguish between sheen and thicker patches of oil.

The adoption of common terms to describe the distribution of oil at-sea (such as streaks, windrows, patches) can also provide an indication of the amount of oil present in a given area. In combination, the estimate of percentage cover together with regular use of selected terms to describe the appearance and distribution of oil, provides a consistent and flexible method of describing the amount of oil in an area to a degree of accuracy sufficient for response decisions to be made.

The difficulties of estimating the quantity of observed oil should not be underestimated, since even with well-established guidance, there remains an element of subjective interpretation. Using observers who are trained and experienced is therefore a key factor in obtaining reliable and consistent results from such aerial surveillance flights.

When assigning resources in accordance with chosen response strategies, the potential margins of error in trying to gauge the quantity of oil spilled will have greater implications for incidents involving larger volumes of oil. Conversely, time spent trying to determine the actual volume of spilled oil for smaller incidents can be especially unproductive since the volume associated with any margin of error will be relatively small. Any quantity established via observations made during surveillance flights should be considered as a best estimate rather than an accurate assessment.

Although estimates on the quantity of oil at sea are routinely calculated based on aerial observations, quantification of shoreline oiling from the air presents additional problems and is not recommended. Helicopters, and UAVs, can be helpful in surveying shorelines for several purposes, however, the extent to which oil has penetrated shoreline substrates, pooled in rocky crevasses, entered mangrove stands etc cannot be ascertained from the air and is best established by surveys on the ground.

Recording and reporting

Photographs and short video clips provide an invaluable record of oil pollution and can be rapidly disseminated to a wide audience to assist command and control of the response. Whenever possible, features such as ships and the coastline should be included to give an idea of scale.

Observations made by trained observers onboard manned aircraft can be recorded and automatically geo-referenced on a mobile device using appropriate mapping and GPS apps, or on a portable GPS device itself. Waypoints should be marked to identify the location and extent of observed oil, its appearance, and other notable features so that observations can be mapped and visualised.

Maps and images can be included in an aerial surveillance flight report, along with the flight details, volume calculations, and any remarks. An example for a template of a flight report is given in Figure 17.

An app designed specifically for recording observations during surveillance flights is a useful tool. Such apps can have functionality that allow for automatic calculation of the area covered and quantity of oil observed based on the data entered and can aid the timely dissemination of information to the command centre. However, digital tools are not always available, therefore it is important to be aware of alternative methods for recording observations.

Examples of maps produced following an overflight, including key features that should be recorded, are provided in Figures 18 and 19.

HANDHELD CAMERA SPECIFICATIONS

- Fast shutter speeds of 1/500th second or greater are recommended to avoid blurring from the motion and vibration of the aircraft. Maintaining a larger aperture is recommended when using faster shutter speeds to reduce the level of image noise.
- Polarising filters can potentially assist in sharpening the visual definition of oil on water by reducing glare; however, sheen, which relies on the reflection of light, may be less visible. Furthermore, some polarising filters produce colour distortions through aircraft windows made of plastics. UV filters can help to reduce atmospheric haze.
- Cameras with in-built GPS are useful to obtain geo-referenced photographs, but enabling this feature will generally shorten the camera's battery life.

FIGURE 17 Example of an oil spill aerial surveillance report.

ITOPF

Aerial Survey Report

Summary

Date: *08/05/2024*

Observer name: *Susannah Domaille*

Organisation: *Sonado Incident Management Team*

Take-off / landing location: *Sonado-West Helipad / Sonado-West Helipad*

Take-off / landing time: *17:45 / 19:30*

Weather:

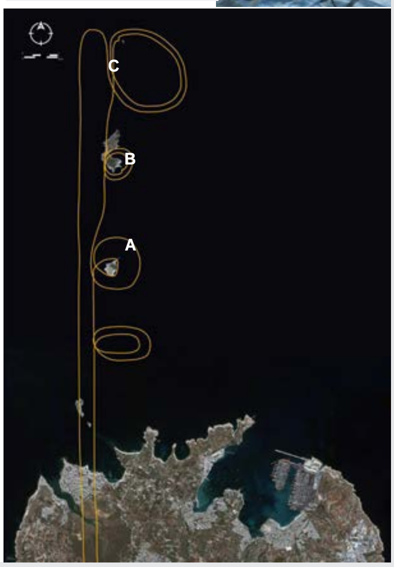
Temperature: 24°C

Wind direction: NNW

Wind speed 7 knots

Cloud cover: 5%

Aircraft type: Helicopter
Aircraft model: Bell 206
Aircraft callsign: S-1968
Sensors utilised: Visual only



Slick	Latitude	Longitude	Length (km)	Width (km)	Area Cover (%)	Oil Appearance (% coverage) 1	2	3	4	5	Other	Min. Volume (m^3)	Max. Volume (m^3)
A	106.417254°	-26.907563°	0.300	0.040	20	20	-	-	-	80	-	0.38	> 0.38
B	106.412309°	-26.881876°	0.600	0.100	40	80	-	-	-	20	-	0.96	> 0.96
C	106.426743°	-26.831234°	3.800	2.200	50	60	10	-	30	-	-	62.93	> 253.64
											TOTAL	**64.27**	**> 254.99***

Other observations:

- *Emulsion and true colour observed, therefore uncertainty around maximum thickness and volumes.
- Marine bloom observed at -26.958029°, 106.404241°.
- Submerged seagrass observed at -26.922376°, 106.401997°.
- High concentration of unidentified debris located at -26.887179°, 106.405785° in proximity of stranded containers.

FIGURE 18

Flight path of a fixed wing aircraft from an incident in Brazil where the source of oil pollution was unknown. A ladder search was used to search for oil. Although no oil was observed, a type of cyanobacteria, also known as sea sawdust, was observed which could have been mistaken for oil. Following the flight, a report was made that documented these observations as well as the flight path.

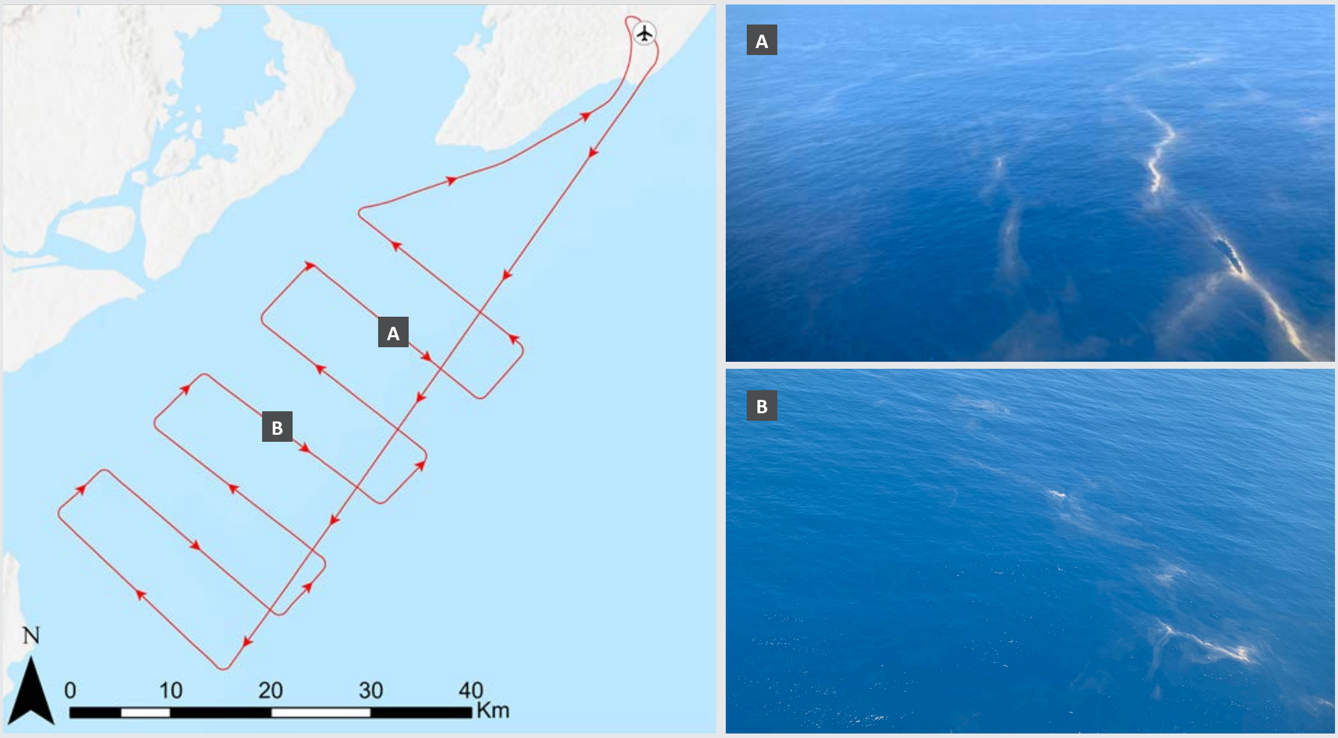


FIGURE 19

Flight path of helicopter, which after reaching the location of the known source of oil (wreck site), followed the perimeter of the observed slick. Waypoints were marked for response vessels and oil observations, denoting where oil became fragmented, and any changes in oil appearance.

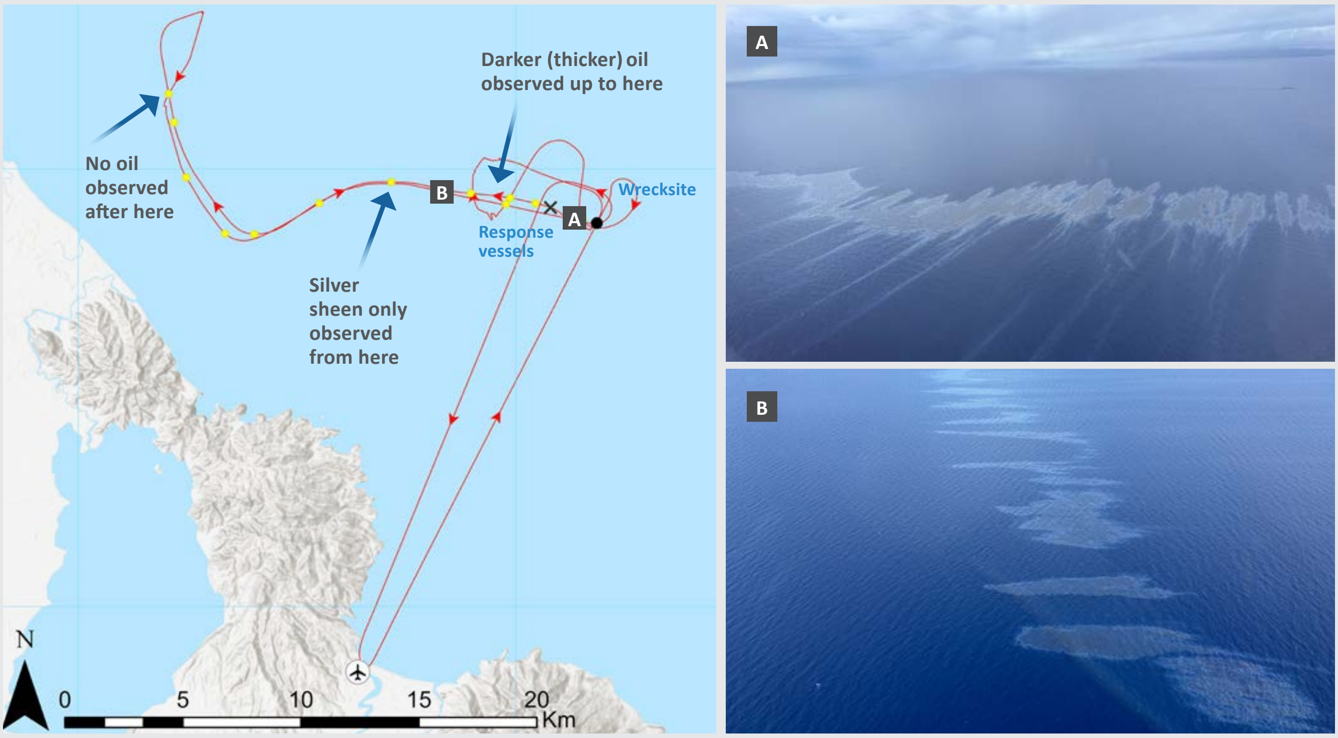
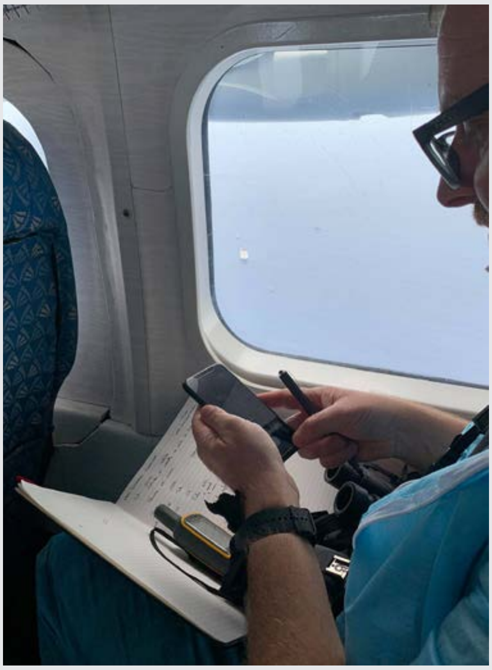


FIGURE 20

A back-up to any mobile device should be available during the flight.



MANUAL CALCULATION OF CONTAMINATION EXTENT

If GPS equipment fails, or is not available, the extent of contamination can be estimated by conducting a timed overflight at a constant speed.

Example: If whilst flying at a constant speed of 250 km/h, it takes 65 seconds and 35 seconds respectively to fly the length and width of the affected area, it is possible to calculate the following:

$$\frac{65\ seconds\ \times 250\ (km/h)}{3600\ (seconds\ in\ one\ hour)} = 4.5\ km$$

$$\frac{35\ \times 250}{3600} = 2.4\ km$$

This gives a total area of approximately 11 square kilometres.

To ensure an observer's continued ability to record findings in the event of equipment failing, it is good practice to have multiple options for recording observations available during the flight (Figure 20). This could be a second device, a handheld GPS or paper maps/charts to manually map observations.

Although movement caused by manoeuvring and turbulence may affect the quality of any video recording made, short, high resolution video clips captured during surveillance flights on digital cameras or mobile devices can provide an additional useful tool for recording observations. Dedicated surveillance aircraft are usually able to record high resolution video footage and may therefore offer an alternative method of recording.

Observations, tracks of flight paths, waypoints and images will need to be visualised and presented in a format appropriate for the command centre (whereby the output can be integrated into a GIS or other software systems) and to a level of detail appropriate for the intended purpose of the surveillance flight. The original data files containing the flight paths and waypoints should be saved for subsequent reference.

The findings of any surveillance mission should be reported promptly after the flight and provide a clear depiction of the nature and extent of oil pollution. Information should be reported in a consistent manner so that, by comparing records from previous flights, an understanding may also be gained on how the situation has developed over time.

Remote sensors

Cameras relying on visible light are widely used to record the distribution of oil on the sea but can be supplemented by other airborne and spaceborne remote sensing instruments which detect radiation outside the visible spectrum and can provide additional information about the oil. Remote sensing instruments are routinely used to detect, monitor and identify the source of marine discharges but can also be used to assess accidental oil spills.

Whilst advances in technology have reduced the size of equipment, many remote sensing systems remain bulky and can only be used from dedicated aircraft into which they are installed. However, instruments such as the handheld Forward Looking Infrared (FLIR) camera provide a portable remote sensing system that is not limited to dedicated aircraft.

Where information from remote sensors is being used in a response, ideally, someone in the command centre familiar with remote sensing technology should oversee the acquisition of data and use of the resulting information in the decision-making process.

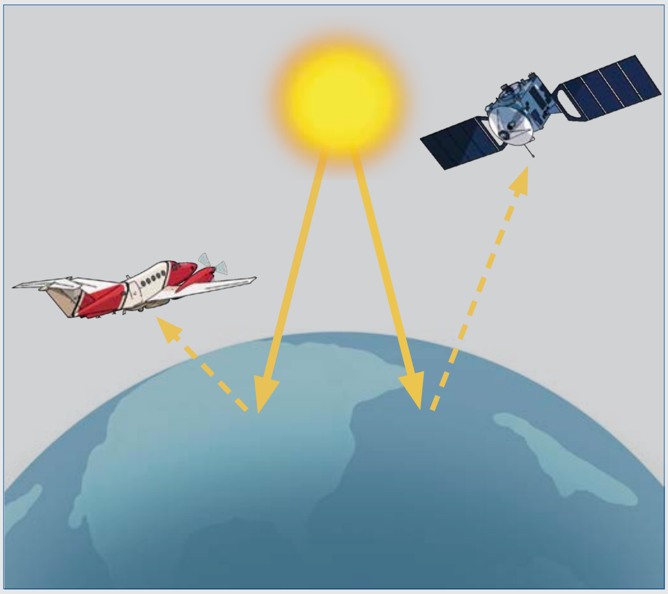
Remote sensing instruments are generally split into two categories active sensors and passive sensors. Active sensors emit a source of radiation and rely on sophisticated electronic analysis of the return signal to detect oil (Figure 21A), whilst passive sensors do not emit a source of radiation, instead they measure emitted/reflected radiation that occurs naturally, mostly from the sun (Figure 21B).

All sensors require highly trained personnel to operate them and interpret the results, particularly as discharges other than oil or natural phenomena may give similar results/false positives.

A list of active and passive sensors, not restricted to sensors for manned aircraft, that can be used to aid surveillance in oil spill response is given in Table 3.

Further information on the most commonly used sensors is provided in the satellite section of this TIP.

FIGURE 21 (A) Schematic diagram of passive sensors. (B) Schematic diagram of active sensors.



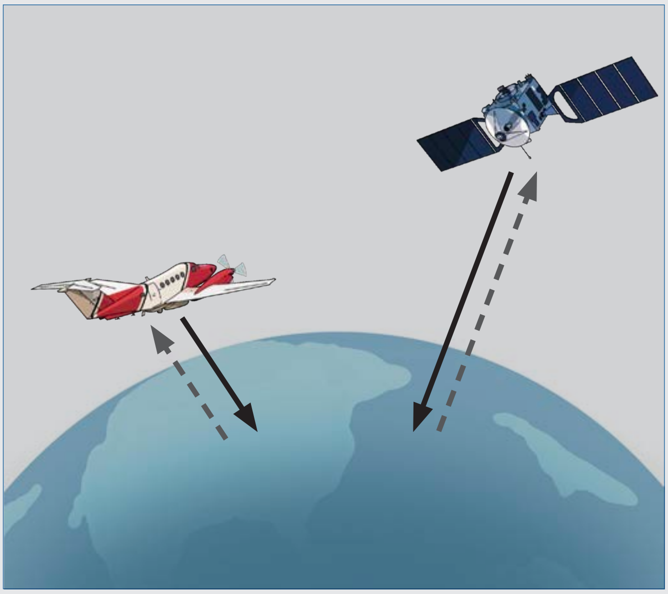


TABLE 3 **Different sensing instruments, their electromagnetic spectrum band, and associated considerations for oil spill detection (can be mounted on multiple platforms).**

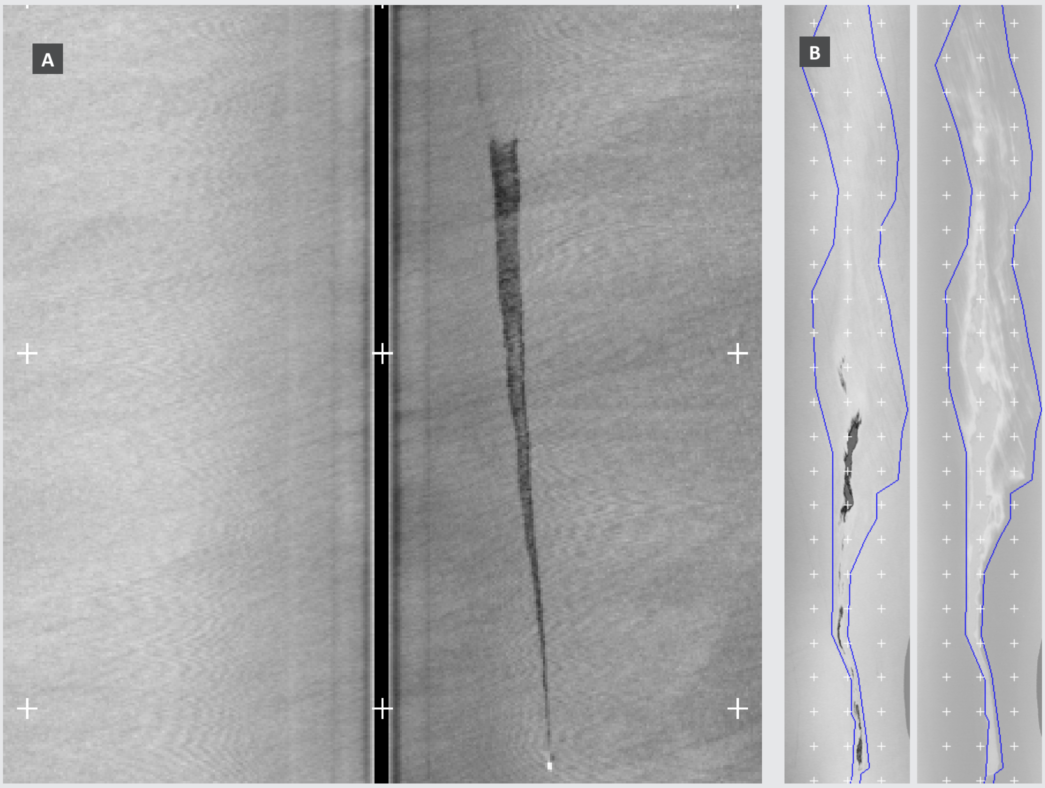
	Instrument	Band	Advantages & Considerations
Active	Side-Looking Airborne Radar (SLAR); Synthetic Aperture Radar (SAR)	Microwave	Radar systems detect the capillary waves created by the wind at the sea's surface. The presence of oil smooths or 'dampens' these capillary waves reducing the amount of 'backscatter' received by the radar, subsequently appearing as a darker area on imagery. Radar can penetrate through cloud and does not require sunlight; however, many natural phenomena can also supress capillary waves and give possible false positives. Generally, wind speeds between 4 and 20 knots are necessary for oil detection as it is heavily dependent on sea state.
Active	Laser Fluorosensors (LF)	UV	An LF is a device that emits a laser beam at a specific wavelength and detects the fluorescence emission from the target. When the laser beam hits oil, it excites the molecules and causes them to emit light at different wavelengths. By analysing the fluorescence spectrum, the device can identify the type and thickness (if less than 20 microns) of oil present on the surface. An LF is useful for oil spill detection and monitoring because it does not require sunlight and can distinguish oil from other substances. However, an LF cannot penetrate through cloud.
Passive	Microwave radiometer	Microwave	A microwave radiometer detects oil by measuring the microwave radiation emitted by the sea surface. Oil reduces the emissivity of the surface, causing a drop in the observed radiation. The change in emissivity caused by the oil layer is used to estimate the thickness of the oil. Radiometers can penetrate through cloud, and do not require sunlight to operate. However, they cannot detect emulsified oil or very thin layers of oil.
Passive	Thermal infrared cameras, such as forward-looking infrared (FLIR) camera; Near-infrared (NIR) camera	Infrared	FLIR cameras detect oil on water by capturing the thermal infrared radiation emitted by objects. Oil typically has a different thermal signature than water. The camera can distinguish temperature variations, allowing it to identify and visualise the presence of oil on the water surface based on differences in thermal characteristics. Similarly, NIR cameras capture the reflected or transmitted light in the near-infrared region, and the distinctive spectral signature of oil allows for differentiation from the surrounding water. Neither sensor requires sunlight, and both can detect relative thicknesses of a slick. However, false positives such as seaweed may interfere with detection, and very thin layers of oil or emulsions with high water content may not be visible.
Passive	Digital camera; Compact Airborne Spectrographic Imagers (CASI)	Visual	Digital cameras and multispectral imagers capture imagery in the visible region of the electromagnetic spectrum, however, they vary in the number of bands they can capture. This imagery can infer some oil thickness ranges and relative thicknesses, however, they require sunlight and clear skies. It is possible to detect false positives.
Passive	Ultraviolet camera	UV	Passive UV cameras detect oil on water by capturing ultraviolet light naturally emitted or reflected by substances on the water surface. Oil exhibits specific ultraviolet signatures, allowing the camera to distinguish it from water and other materials. UV cameras are useful as they can detect oil of all thicknesses and provide some information on relative thicknesses, however, they require sunlight and are susceptible to false positives.

A combination of different devices can be adopted to overcome the limitations of individual sensors and to provide better information about the extent and nature of the oil. Where dedicated surveillance aircraft are available, combined SLAR and IR/UV systems are typically used.

SLAR can be flown at sufficient altitude to provide a rapid sweep over a wide area, up to 20 nautical miles either side of the aircraft. However, SLAR is unable to distinguish between very thin layers of sheen and thicker oil patches, and the images thus need to be interpreted with caution. Aircraft equipped with a combination of SLAR and IR can define the total extent of the slick using SLAR and once the oil has been located, provide qualitative information on slick thickness and the areas of heavier pollution with images from the IR and visible sensors. In daylight an IR/UV sensor combination can fulfil a similar function although the range is limited compared to SLAR. The UV sensor detects all the oil covered area, irrespective of thickness, whilst the IR sensor is capable, under appropriate conditions, of delineating the relatively thick layers. Figure 22 provides an example of the imagery acquired by SLAR and an IR/UV system, commonly found onboard dedicated search and rescue aircraft used for aerial surveillance of oil spills.

Data acquired through remote sensors onboard aircraft can be analysed in real time by trained observers either onboard the aircraft or on the ground where direct downlink facilities are available to transmit the images.

FIGURE 22 (A) a SLAR image acquired by a manned aircraft of an oil slick emanating from a moving vessel. The vessel appears white as the return signal is strong. Oil appears black as the return signal is weak. SLAR data cannot be collected directly below the aircraft, as shown by the black vertical line in the centre. (B) Imagery from an IR/UV system onboard a manned aircraft. The left image is the IR image, where darker patches resemble the relatively thick patches of oil due to stronger IR emissivity. However, an exact thickness cannot be determined. The image on the right is the UV image of the same slick, acquired at the same time. The UV camera can detect more oil than an IR image, generally the thinner parts of a slick that the IR camera missed (Source: Transport Canada National Aerial Surveillance Program (NASP)).



Use of Remote Sensing

After being involved in a collision with another vessel, a general cargo vessel experienced severe structural damage to its hull and grounded on a sandbank in Belgium with its stern partially submerged. Heavy fuel oil leaked from the casualty over several days, necessitating an at-sea response.

A Coast Guard fixed-wing aircraft, equipped with SLAR, was used to conduct aerial surveillance. Four flights occurred each day to monitor the evolving slicks and direct response operations. The SLAR was used to sweep a wide area (approximately 20 km either side of the flight path, excluding directly below) to check for presence of floating oil (Figure 23). As SLAR can help with fast detection of oil on the sea surface ranging from thick patches of black oil down to areas of thin silvery sheen, it only took 15 minutes to survey both Belgian and Dutch waters.

However, the SLAR could not differentiate between the different thicknesses of oil, therefore, it could not be used solely to assess the relative quantities of oil at sea. When weather permitted, a visual inspection was needed to confirm findings and determine the appearance of oil to estimate thicknesses (Figure 24). Unfortunately, over time, whilst the lighter parts of the oil evaporated, heavier parts became submerged below the sea surface, making aerial surveillance ineffective, even with SLAR.

CASE STUDY LEARNING POINT

Using SLAR is a fast and effective way to look for oil in most weather conditions, however, it did not provide any information on thickness and observations still required validation by visual observation.

FIGURE 23 SLAR imagery acquired onboard Belgian Coast Guard aircraft (Source: MUMM-RBINS).

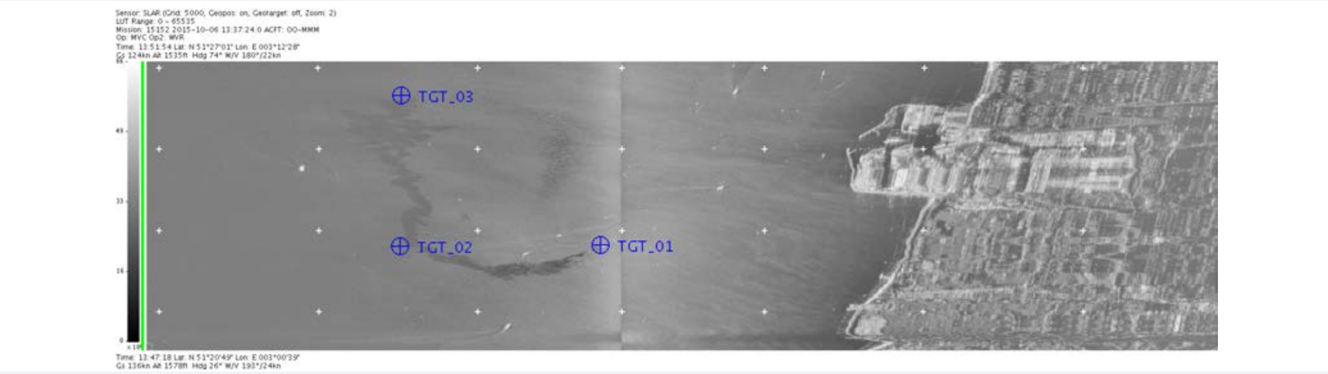


FIGURE 24 Visible image of oil spill response vessels recovering oil during a good weather window. Observations made from the aircraft were used to help direct vessels.

Satellites

Planning and preparation

Understanding the process of acquiring satellite imagery is fundamental to its effective and efficient integration into a response. The time taken between capturing imagery using sensors on satellites and its availability to an interpreter has inherent delays therefore imagery currently cannot be analysed in real time. Acquiring satellite imagery involves a sequence of steps, each of which has an associated 'window of time'.

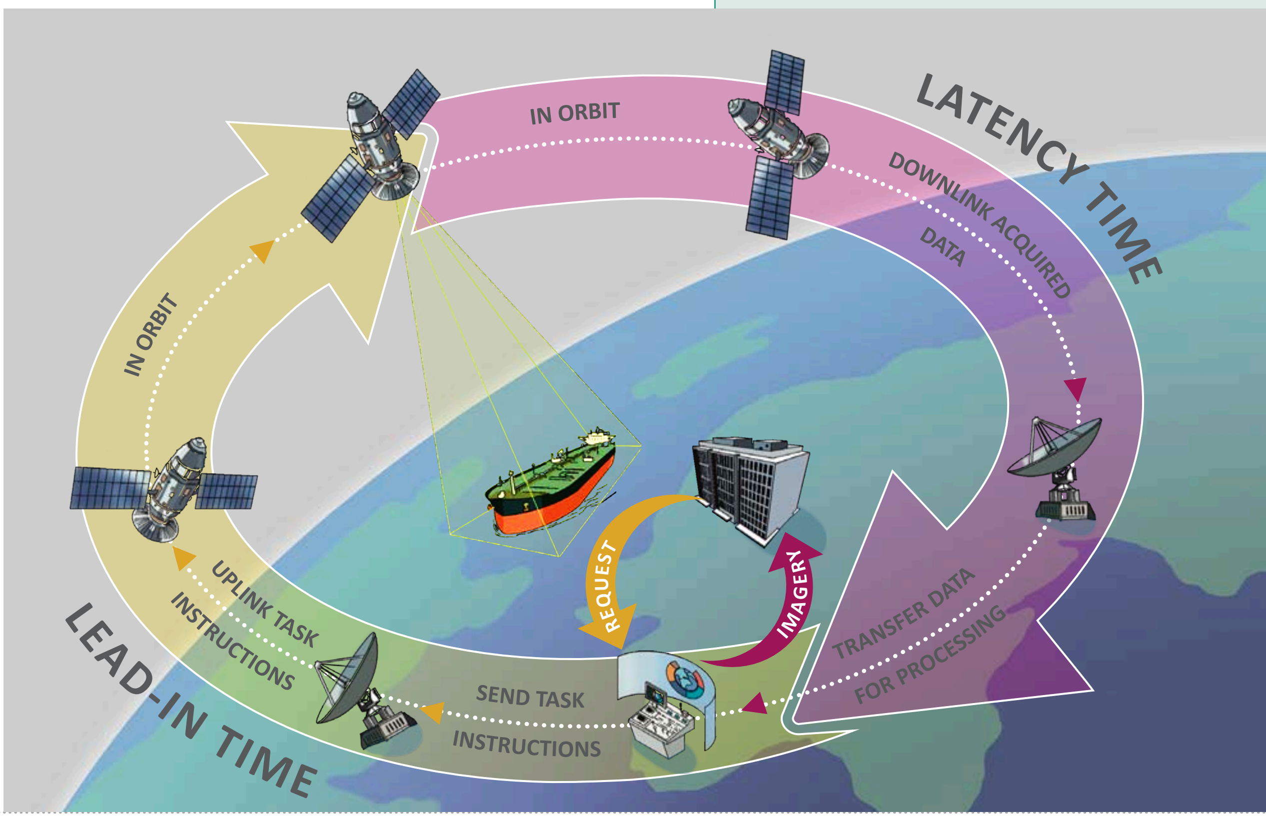
Satellite tasking may only be possible to do a few times a day, and if a tasking window has just been missed it may be a few hours until the next tasking window opens. The delay in satellite imagery being transmitted is dependent on the availability of the next ground station, which is influenced by geographic location and sometimes satellite provider. Occasionally, satellites can transmit to other satellites that are in range of a ground station, reducing latency time.

Once an image is acquired, the raw data is downloaded to a ground receiving station for initial processing (either at the ground receiving station or another processing site). It is then sent to the data provider, who conducts further processing of the data, such as calibration and georeferencing to a pre-agreed criterion. The imagery will then need to be analysed by an expert who interprets the imagery to identify features consistent with the characteristics of oil and eliminate any false positives.

A further limitation of all satellite imagery is that the frequency with which a satellite passes over the same area can range from hours to days depending on the orbit (with higher latitudes having greater coverage). This delay can be partially overcome by tasking more than one satellite platform.

SATELLITE LEAD-IN AND LATENCY TIME

The 'lead-in time' is the time required between placing the order, typically done by submitting a tasking request to the satellite operator or an authorised reseller, which includes specific details about the desired image, such as the area of interest, the imaging parameters, and the desired timeframe for image acquisition, tasking the satellite, and the image being acquired, whereas 'latency time' is the time between image capture and delivery of the final product to the requesting party.



Remote sensors

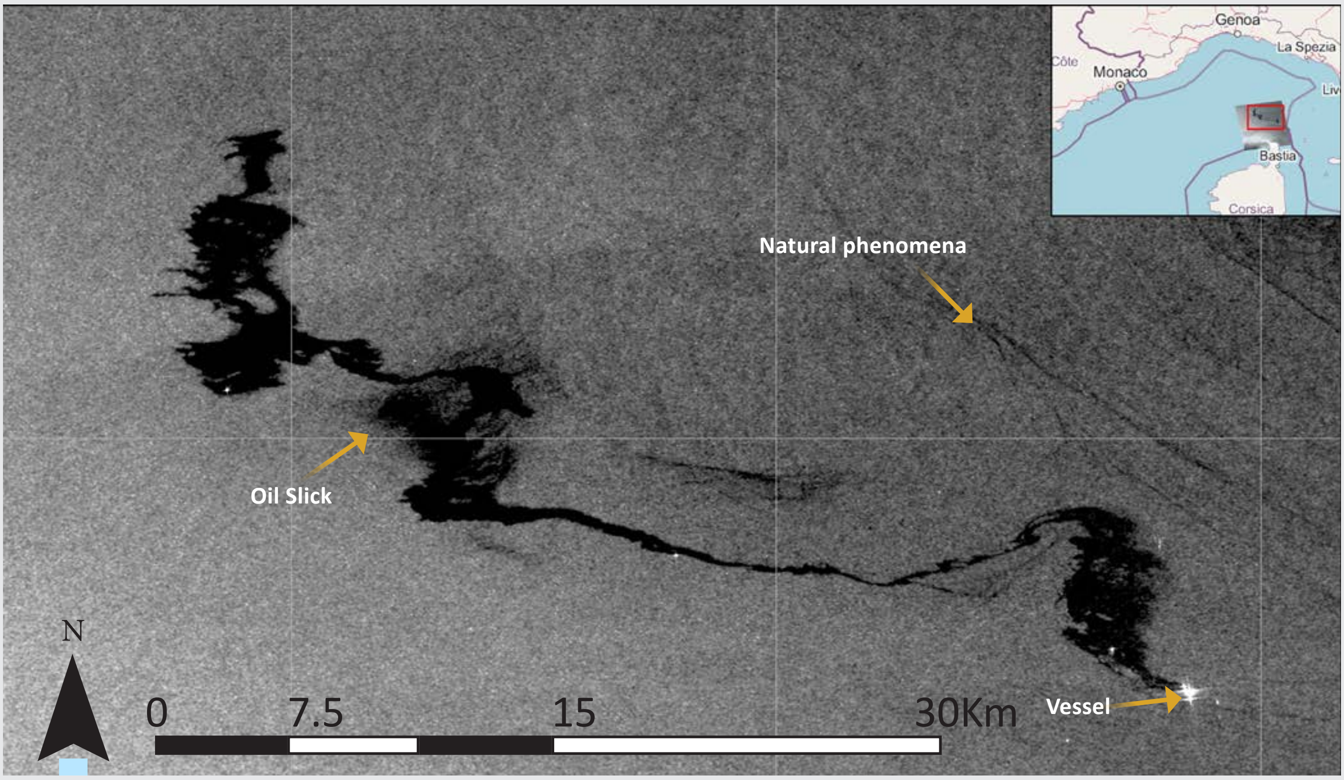
> **The use of satellite-based remote sensors to detect oil on water is considered an integral component of surveillance strategies, and because such images cover extensive sea areas, they can provide a comprehensive picture of the overall extent of pollution .**

The passive sensors used include those operating in the visible and infrared regions of the spectrum, whilst Synthetic Aperture Radar (SAR), an active sensor, operates in the microwave region (see Table 3, page 26). Some satellites can have multiple sensors onboard.

However, as with airborne platforms, sensors on satellites can be restricted by environmental conditions. For example, optical sensors rely on cloud-free skies to get a clear image of the sea surface. For SAR, there is a limited range of wind speeds within which oil slicks can be detected. These sensors measure the microwave backscattering properties of the sea surface and detect the dampening effect of the oil compared to the surrounding sea. If the sea state is too calm (wind speeds less than 2 on the Beaufort scale or 5 knots), then the waves created are not 'rough' enough to cause backscatter from the sea surface and hence the signature of an oil slick cannot be distinguished. Conversely, if the wave height is too great (caused by winds over 6 on the Beaufort scale or 20 knots), the effect of capillary wave dampening caused by floating oil is not visible. Whilst SAR is not limited by the presence of cloud and can be used at night, as with all radar imagery, SAR images often include several features that can look similar to an oil slick (false positives), and can be mistaken for oil, such as sea ice, algal blooms, wind shadows and rain squalls and so requires expert interpretation. There could also be occasions when satellite imagery may not be available, for example because of maintenance or other priority taskings.

Figure 25 below shows a Sentinel-1 SAR image that has been processed to enhance the contrast between the observed oil slick and the water. Along with oil, vessels and natural phenomena, which could be mistaken for false positives, are also observed in the image.

FIGURE 25 Sentinel-1 SAR image acquired north of Corsica in the Mediterranean showing a long slick emanating from a vessel. Natural phenomena and vessels are also observed within the image.



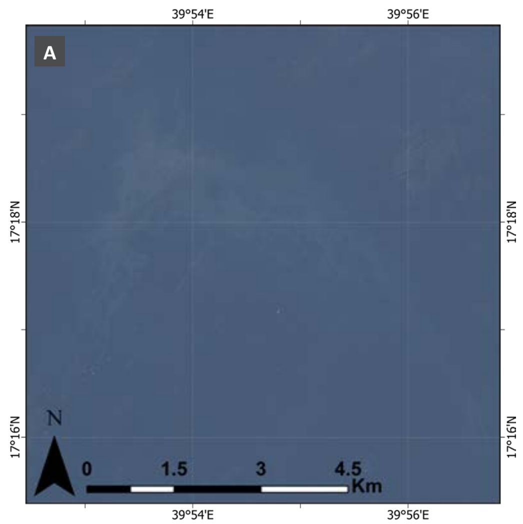
Appearance of oil

Given the extensive geographic area which can be covered by satellite imagery, the resultant data is used to detect and identify oil slicks and to track their movement. How the oil is visualised in the final imagery will largely depend on the sensor used to capture the information and the processing of the data.

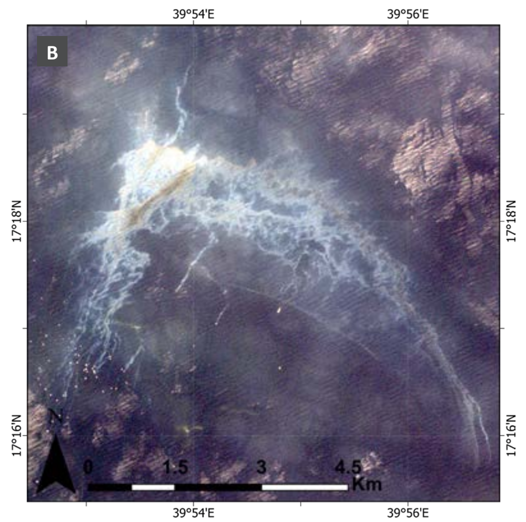
It is usually advisable to confirm any findings from satellites with visual observations to ensure they have been correctly interpreted. Knowing the timing of upcoming satellite passes and the likely timescale for results being made available, may allow for some pre-planning of aerial surveillance flights to corroborate the results of satellite data.

FIGURE 26

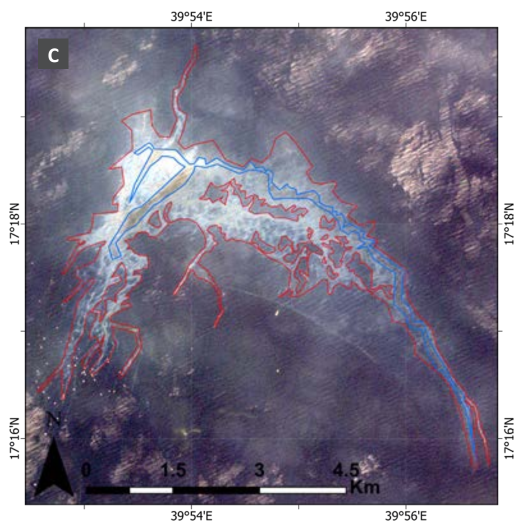
(A) Optical image acquired by Sentinel-2A satellite. The image had been processed to correct ground geometric distortions prior to being made available online. However, the oil slick captured in the image does not clearly stand out.



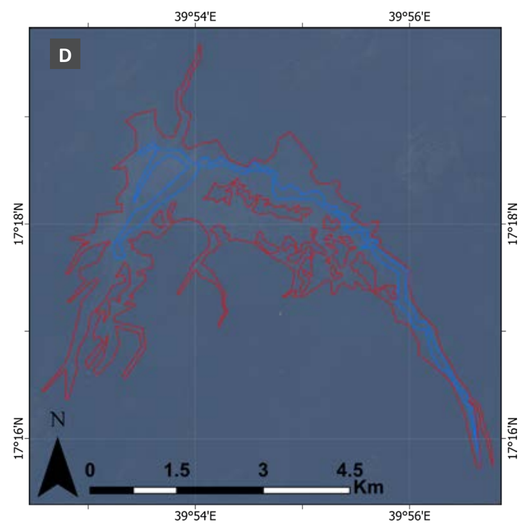
(B) The same image as A after adjusting its image properties, such as brightness and contrast. An obvious oil slick can be seen in the image, as well as other natural features.



(C) Contours drawn around the observed slick using GIS. The red contour resembles the perimeter of the whole observed slick, whilst the blue contour resembles the perimeter of the darker area of the slick, which could indicate thicker oil.



(D) The contours of the slick placed on the original image. The total area of the lighter appearing oil is approximately 8 km^2 and the total area of the darker appearing oil is less than 1 km^2.



Quantifying oil volumes

The ability of sensors to distinguish between the different categories of oil thickness is under development and being refined. Relative thicknesses can sometimes be inferred in optical imagery based on slick appearance, however, determining thicknesses by applying the BAOAC (as mentioned in Table 2, page 19), for example, is yet to be proven.

An example of the analysis steps for optical imagery is given in Figure 26, where the image, acquired by Sentinel-2, shows an oil spill and floating containers from a sunken vessel in the Red Sea. The darker area within the observed oil likely indicates a thicker part of the slick, with the lighter areas likely being thinner.

In the same way that limitations of the sensors can be overcome, to a certain degree, by combining and overlaying information from different sensors on manned aircraft, some satellites have multiple sensors onboard and thus are also able to build up a more detailed picture of the oil.

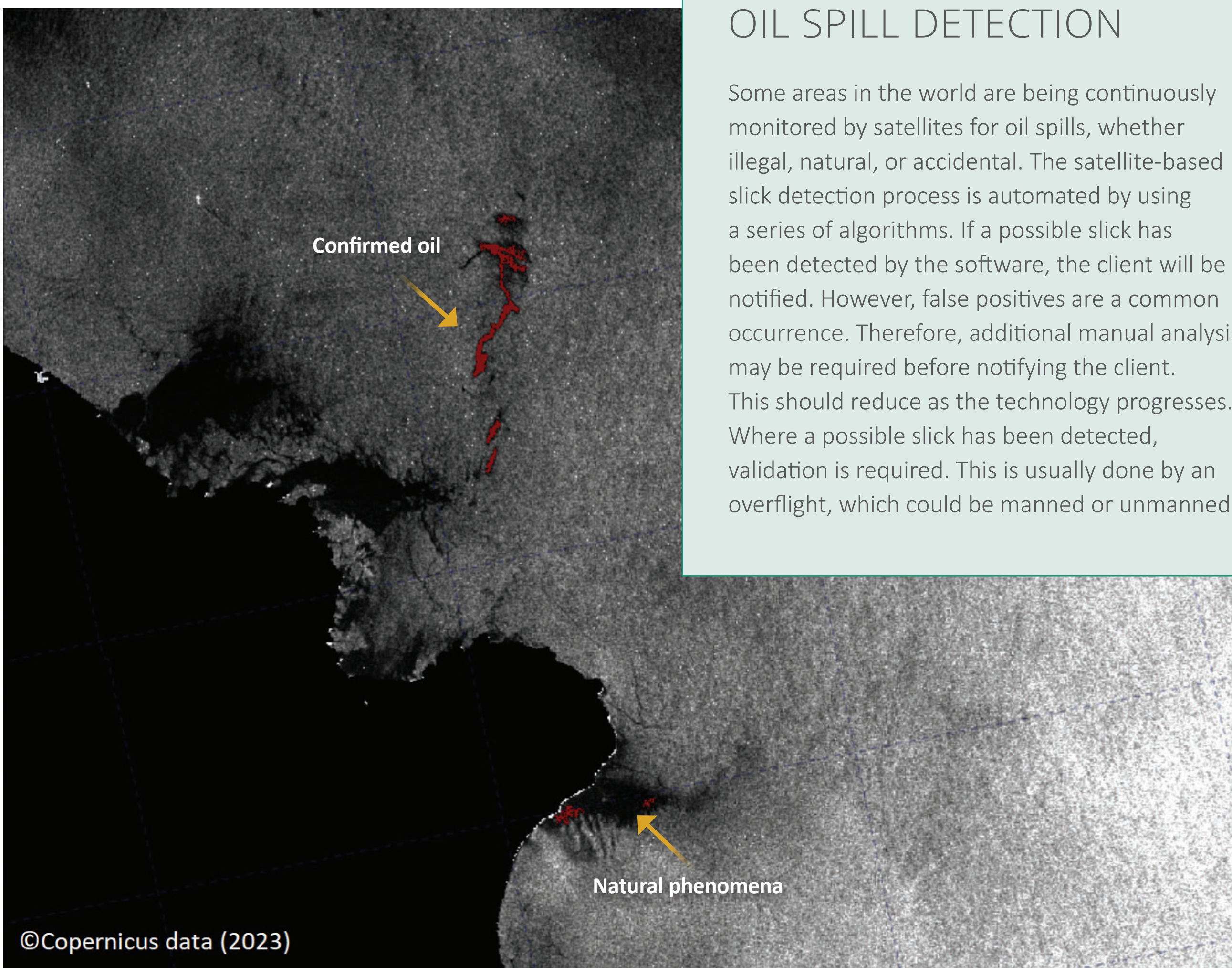
Recording and reporting

Recent studies show that for satellite SAR imagery the lead-in time is often longer than the latency time. Therefore, although in many instances satellites are unlikely to provide the initial images of a spill, the strength of satellite surveillance lies in allowing for planned, repeated, relatively reliable image acquisition. Overpass time has improved in recent years thanks to increased availability of satellites and ground stations and so-called ‘satellite constellations’ being formed by satellite providers, with re-visit times of hours rather than days for most areas.

The data generated by increasingly complex sensors is ever increasing, and consideration should be given to the format and management of such data, especially how it is received, accessed, and integrated into any GIS software being used in the command centre.

SATELLITE-BASED OIL SPILL DETECTION

Some areas in the world are being continuously monitored by satellites for oil spills, whether illegal, natural, or accidental. The satellite-based slick detection process is automated by using a series of algorithms. If a possible slick has been detected by the software, the client will be notified. However, false positives are a common occurrence. Therefore, additional manual analysis may be required before notifying the client. This should reduce as the technology progresses. Where a possible slick has been detected, validation is required. This is usually done by an overflight, which could be manned or unmanned.



CASE STUDY

Use of Satellite Imagery

A vessel, carrying both persistent and non-persistent bunkers, sank in deep waters with the closest land being several hundred kilometres away. Shortly after the incident, a slick, reportedly appearing solely as a sheen, was observed by the vessels on site. Owing to the physical characteristics of the oil, the quantity being observed, and the remote location, it was agreed that an active at-sea response was not required, however, the situation needed monitoring. Authorities and responders tasked satellites to acquire daily imagery of the wreck site, conducted trajectory modelling, and carried out overflights using a fixed-wing aircraft.

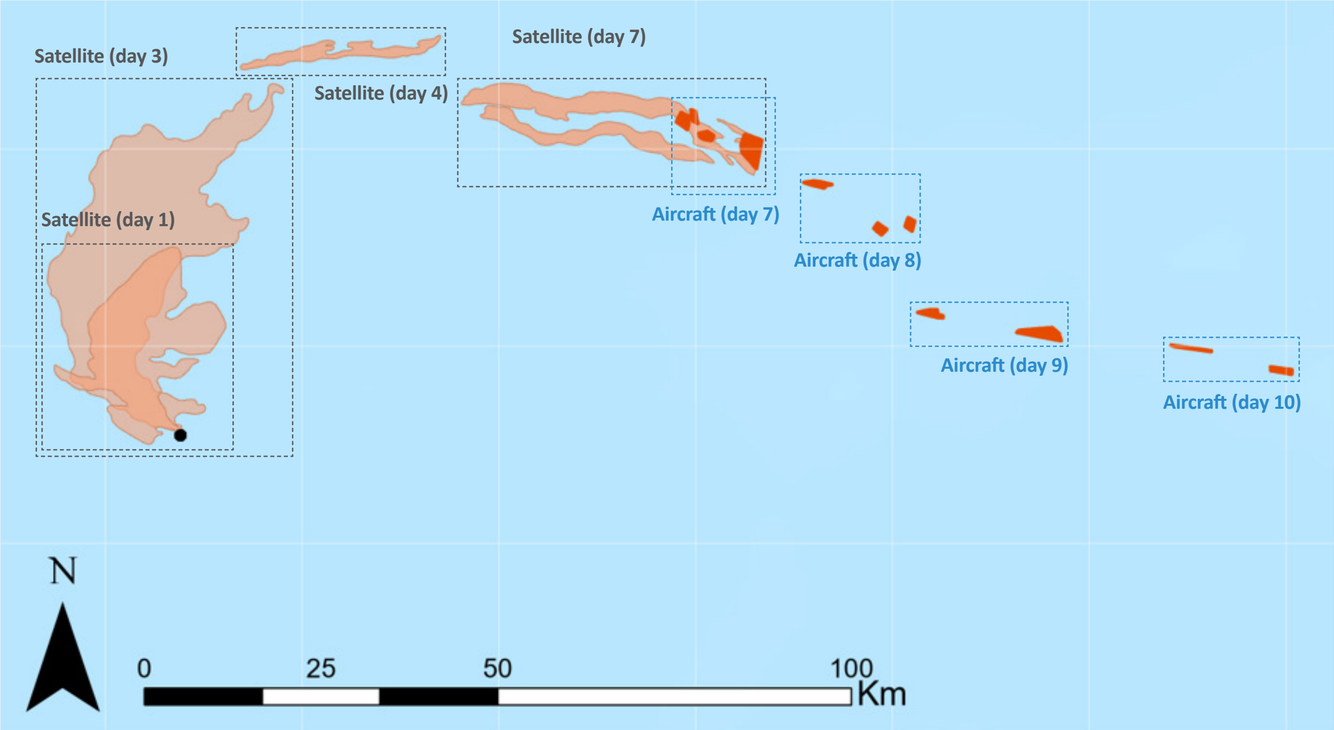
Upon analysing the satellite images (which provide a view over a large area), it was apparent that the behaviour of the slick deviated from the typical characteristics of sheen, with a portion persisting at sea for several days. As part of the daily overflights to monitor the sinking location, responders also monitored the drifting slicks that were evident in the satellite imagery. These were found to be small, erratic slicks of emulsified oil that were rapidly dissipating.

Given that both on site vessel observations and subsequent aerial surveillance consistently revealed only sheen at the sinking location for 12 consecutive days, that the emulsified erratic slicks were naturally dissipating, the considerable distance from the shoreline, and the fact that trajectory modelling suggested an extremely low probability of any oil coming ashore, authorities and responders made a pragmatic strategic decision to rely exclusively on satellite imagery for continued monitoring. For several weeks, daily acquisitions of satellite imagery were conducted over the sinking location. As the quantities of oil observed emerging from the wreck diminished and the risk of a significant spill lessened over time, the frequency of satellite image acquisitions was gradually reduced. Figure 27 shows a map of the slick outlines observed via aircraft and satellite imagery.

CASE STUDY LEARNING POINT

Satellite imagery can be used as a tool to observe and monitor large areas of open seas, to aid aerial surveillance by providing additional information regarding the trajectory and actual position of slicks, and to continue monitoring remotely, especially if the incident occurs far from shore.

FIGURE 27 Evolution of the size of an oil slick over 10 days, as observed in satellite imagery on days 1 to 7, and from an observer in a fixed-wing aircraft on days 7 to 10.



Unmanned Aircraft

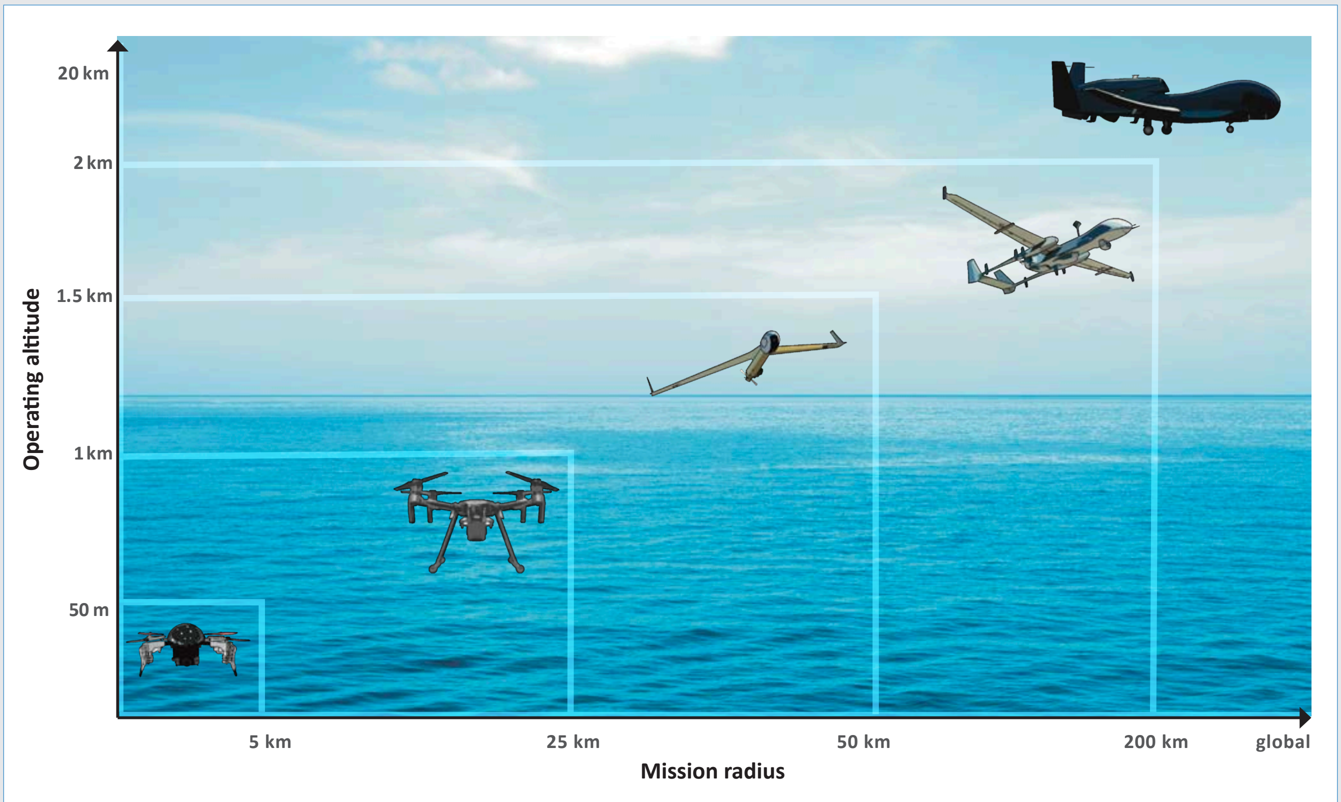
The use of UAVs in oil spill response has grown rapidly in recent years and now provides another proven platform for obtaining observations of oil at sea. UAVs are available in different classes, typically categorised by weight and/or range, and vary in their payload capacities (Figure 28 below).

One of the advantages of using UAVs for aerial observations is that their flexibility means they can overcome some of the limitations of more traditional surveillance methods.

For example, they can be less restricted in where they can be launched from and can fly in hazardous environments where a manned flight might be inappropriate. Whilst the longer range afforded by fixed-wing and rotary aircraft means these platforms are still best suited to establishing the extent of pollution over wide geographic areas, UAVs can be particularly useful for specific, localised surveillance tasks such as surveying pollution within sensitive or restricted sites, conducting surveys for shoreline clean-up operations, guiding response vessels conducting at-sea response, or validating oil spill trajectory modelling predictions.

Now that the use of UAVs in spill response is becoming more commonplace, seeing the aerial viewpoint on situations (such as the progress of clean-up operations on a specific section of shoreline for example) is becoming more frequent, whereas previously such progress would have typically been documented only from ground level.

FIGURE 28 Connection between UAVs operating altitude, its mission radius and size. There is no single, global classification system for UAVs. They can be classified according to their size, range and/or type.



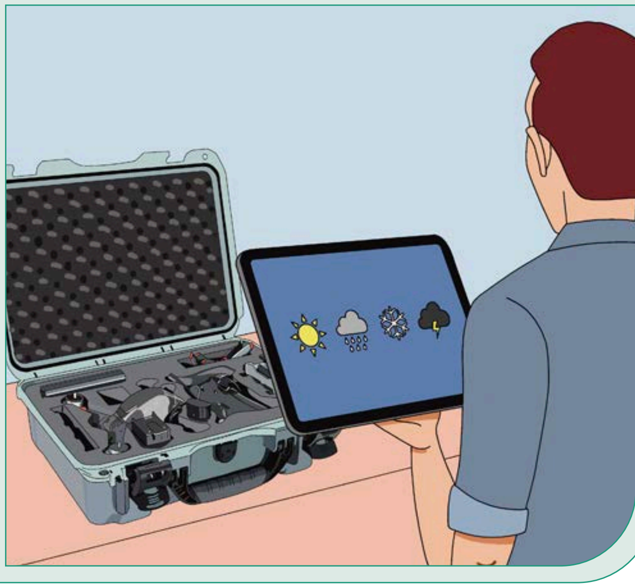
Planning and preparation

Rotary wing UAVs are generally less expensive than fixed-wing UAVs and are therefore the models typically used by commercial organisations and the public. The drawback of rotary wing UAVs is that, in general, they have a smaller range compared to fixed wing UAVs and have limited battery life, both of which need considering when assessing the suitability of rotary wing UAVs for the required surveillance task. Even for the smaller class of UAVs, constraints applicable to more traditional aerial surveillance still apply (such as limiting environmental conditions) as well as policy considerations like national regulations on the use of UAVs.

The window of opportunity to conduct surveillance using UAVs may be limited by weather conditions, so it is vital that preparations are made in advance so that the platform is ready and available when conditions allow. Prior to any UAV flight taking place, final preparations should be completed by means of a 'pre-flight checklist' to ensure that UAV flights are both safe and effective.

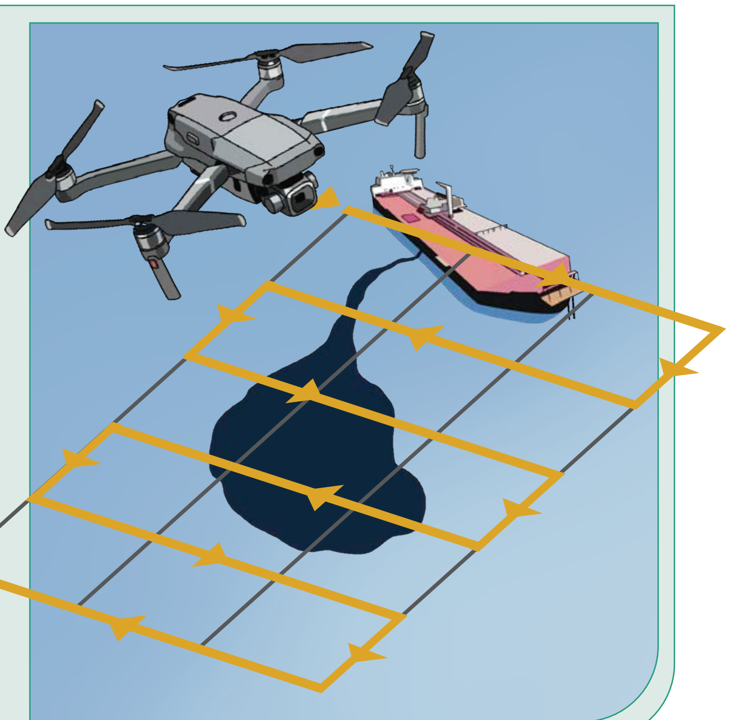
FLIGHT PLANNING

The UAV operator (or other responsible person) should be certain they have a national licence to fly where required, that the UAV itself meets any requirements of the national aviation authority, that the planned flight conforms to local legislation/regulations and any necessary permissions have been granted. Operators should consult in advance a local weather forecast to ensure that favourable conditions are predicted for the flight duration. Even slight head or cross wind speeds can dramatically affect battery duration. Usually, a trained observer will be required to work alongside the pilot to help direct the flight, maintain visual sight of the UAV or analyse the imagery being received.



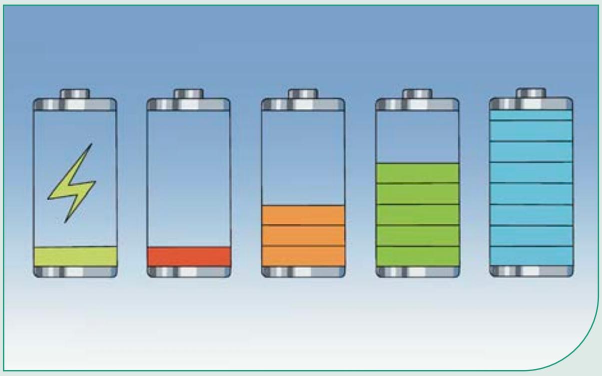
FLIGHT PATH

The objectives of the surveillance flight will largely dictate the type of path flown. The UAV may be operated manually during the flight to give the greatest degree of flexibility, this may be especially suited to instances where the surveillance task is exploratory in nature. Alternatively, waypoints can be uploaded in advance into a flight planning app to fly the UAV along a specific path, allowing for a semi-autonomous flight. This may be suitable for flights surveying the shoreline for example. Waypoints can also be programmed to direct the UAV to fly a formation to obtain a series of photos that can be 'stitched' together to create a mosaic image of the area of interest. Repeat flights along the same path can be planned to determine progress of the clean-up or natural cleaning over time. Usually, it is recommended that UAVs are launched and landed manually.



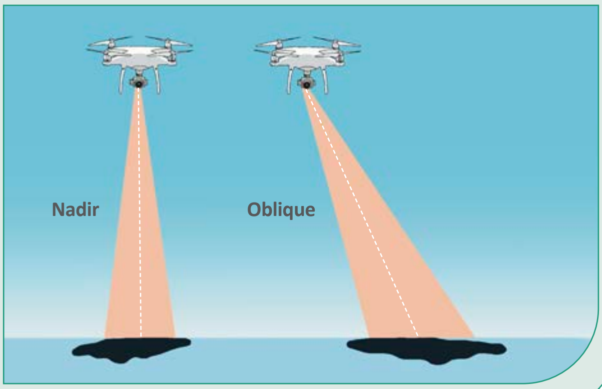
ENDURANCE

One of the main shortcomings of using small rotary wing UAVs for aerial surveillance is that flight duration limited by relatively short battery life. Micro or mini units typically engaged in spill response activities have a battery life of approximately 20-30 minutes. Ensuring batteries are fully charged at the start of a flight and having multiple, fully charged, batteries available will extend the time a UAV is able to spend in the air.



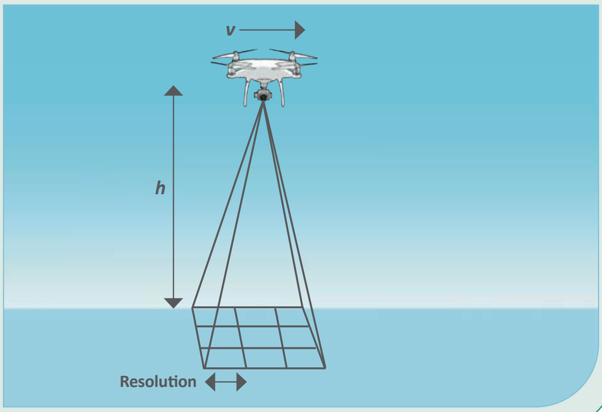
CAMERA ANGLE

Depending on the imagery required, the camera position on the UAV can be set to either nadir or oblique. Nadir has the camera pointing vertically downward and is most appropriate when the surveillance task is to create a 'mosaic' of images. Having the camera set to an oblique angle, where images are taken with the camera axis not perpendicular to the ground/object, is suited to providing a more operational view.



ALTITUDE AND SPEED

The altitude (*h*) and speed (*v*) at which a UAV is flown will depend upon the vehicle itself, the surveillance objectives, and regulatory restrictions. To survey a large area quickly, it will be necessary to fly a UAV at higher altitudes and greater speeds, however, this may compromise the resolution of the imagery. If high resolution is required to achieve the surveillance objective, it may be necessary to operate a UAV at lower altitudes and speeds.



OTHER CONSIDERATIONS

It is often helpful for the operator of the UAV to have a mechanism for screening sunlight from the viewing device to assist in viewing the imagery coming from the UAV camera. If waypoints are being programmed into a flight planning app, it is advisable to do this in a location where there is good internet connection. Prior to the flight it is advisable to inspect the UAV components, ensure the UAV is connected to the remote controller, test that the camera is able to record and make sure that an SD card with adequate storage space is in place.

Remote sensors

Currently, the most common sensor used onboard UAVs engaged in aerial surveillance is a digital camera, capable of capturing still and video footage. Digital cameras are readily available, and the footage does not require as much interpretation expertise as other sensors might. Miniaturised IR, UV, multispectral, and hyperspectral sensors for smaller UAVs exist and can also be utilised for oil detection, however, limitations such as availability, costs, and data processing need to be considered. The use of other sensors, such as radars, are primarily seen on larger, fixed-wing UAVs used by organisations such as the military, as they require larger payload capacities and are more costly. Currently, only manned aircraft and satellite platforms provide these sensor capabilities for oil spill aerial surveillance.

Appearance of oil

When conducting overflights using UAVs, the appearance of oil will depend on the sensor used. As with acquiring imagery via a manned aircraft, the same limitations exist, such as false positives, weather, and sea-state that may affect or impede observations. One of the advantages of using UAVs to record and document the appearance of oil is that relative to fixed-wing and rotary aircraft, they can fly much lower and capture detailed images of the oil.

Images obtained during UAV flights can be taken either manually, in which case it is recommended that the operator has the UAV hover whilst the image is taken or automatically either at pre-set waypoints or at pre-set distance or time intervals.

If the operator of the UAV is not suitably trained in making observations of oil during aerial surveillance flights, it is important that someone familiar with making such observations has input into the UAV flight planning and, ideally, be present with the operator during the flight to help direct and modify the flight path and capturing of imagery depending on what is being observed.

UAV CAMERA SPECIFICATIONS

- The Ground Sample Distance (GSD) is essentially the real-world size of a pixel in images and is key to dictating the accuracy of an aerial survey. The GSD is measured in cm/pixel – the lower the GSD the higher the accuracy of the data.
- The altitude at which an image is captured is a key variable in the GSD obtained, but the following camera specifications directly affect GSD:
  - Size of camera sensor
  - Camera resolution
  - Focal length of the camera lens
  - Aperture
- The optimal GSD will depend on the UAV mission objectives. Industries requiring a high level of precision when using UAVs for mapping (such as in construction) may require a GSD of 1-2 cm. Other applications, such as obtaining imagery for real estate planning, may achieve suitably detailed images with a GSD of 5 cm or above.
- Cameras come in various standard sizes. Larger cameras have better light-gathering ability at the same resolutions, whilst smaller cameras need longer exposure times to achieve the effective outcomes. The size of the camera will affect the aerodynamics and weight of the UAV and therefore its flight time.
- Camera resolution is the number of pixels it will map. Higher-resolution camera units will achieve a greater GSD for an equally sized camera sensor as compared to lower resolution.
- A camera with mechanical (global) shutter (as opposed to an electronic shutter) will reduce the rolling shutter effect from fast motion which causes heavy distortions to images.
- A built-in gyroscope is crucial for UAV stability and thus for recording clear and accurate observations. The gyroscope sends information to the flight control system on changes to the pitch, roll and yaw of the UAV. The flight control system readjusts the UAV's position ensuring it remains stable.

Quantifying oil volumes

The suitability of using imagery obtained during UAV flights to make initial estimates on the quantity of oil at sea will largely be dictated by how extensive the area of pollution is coupled with the specifications of the UAV intended for the mission (such as range, endurance, intended altitude, resolution of imagery etc).

For pollution incidents covering an extensive area, initial observations and estimates on quantification of oil at sea may be best carried out using trained observers and/or sensors on manned aircraft. However, if operators are confident in the UAV's ability to map and record the entire area of pollution in sufficient resolution to allow for an estimate of volume of oil to be made (using the same method, explained on page 21, as trained observers in manned aircraft would), then using UAVs to make such initial observations may be appropriate. UAVs can be useful for conducting regular monitoring of continued releases of oil in the latter stages of an incident. In such instances, the typical extent and quantity of oil may have already been assessed by other surveillance means, and therefore the mission objective is to qualitatively determine whether there has been any significant change in the trajectory and overall volume of pollutant released.

Recording and reporting

For surveillance conducted using a UAV, a detailed flight log should be completed by the operator. Information such as the date, time, and location of all flights, should be recorded and any significant observations noted.

The flight tracks, waypoints, images, and any video should be downloaded and copied from the storage card and any flight programming app being used.

Due the large file sizes that can be generated, multiple, shorter videos are preferable to a single long video. However, more commonly, still imagery can be acquired and 'stitched' together to create a 'mosaic' of images covering a larger area (Figure 29). When mapped on GIS, this can make calculating the area and subsequently volume of slicks more accurate than manually marking waypoints during overflights.

FIGURE 29 **Series of drone images, acquired over a oil slick from nadir camera angle. Vessel included in the far-right image for scale (Source: Waves Group).**

LONG RANGE UAVS

The EMSA RPAS service utilises dual engine fixed wing UAVs which have an endurance of up to 10 hours, can fly at a range of up to 800 km and an altitude of up to 5,000 m. The UAVs are equipped with SAR and IR sensors so can provide operational information on the size and shape of a slick, volume estimation and identification of 'hot-spot' areas.

Photo source: EMSA

In the future, it will become increasingly feasible to routinely see larger, fixed-wing UAVs (with their longer range, greater endurance, and increased capacity for heavier payloads) used for aerial reconnaissance of marine oil spills. Such UAVs are currently used by the European Maritime Safety Agency (EMSA) as part of their Remotely Piloted Aircraft Systems (RPAS) service. This expected rise in the use of fixed wing UAVs, combined with developments in miniaturising remote sensors, means that the nature and extent of UAV use in oil spill response is set to both expand and become more common place in future years.

The use of UAVs is an area undergoing rapid technological and regulatory developments at the same time as decreasing costs and wider availability. Going forward, one of the key challenges for use of UAVs and remote sensing will be to develop systems that allow for the processing of images on board to avoid data management issues.

Long Term Monitoring

A containership sank in shallow waters approximately 8 nm from the nearest shoreline. The wreck continuously leaked fuel oil for several months (Figure 30). At first, daily helicopter surveillance flights were carried out to map the oil slick and record its appearance. The slick initially stretched up to 10 km in length, and over 100 m in width in some places. Its appearance, observed from the helicopter, was always in the form of sheen. The wind and currents in the vicinity of the wreck remained constant due to monsoonal weather, therefore, the direction of the slick also remained constant.

An important surveillance focus was the wreck itself and monitoring any changes to the oil release rate. Therefore, a UAV was deployed twice daily (morning and evening) from a salvage vessel that was stationed nearby. It enabled a much better view than from the vessel itself. Although the UAV was limited by range, being able to only survey the first 2 km of the slick, it could provide far more detailed footage of the oil around the wreck than photographs taken by an observer in a helicopter. As the need for the daily helicopter flights decreased, knowing that the full extent of the slick was unlikely to change unless there was a change in release, they were appropriately reduced to weekly, before terminating altogether.

To complement the aerial surveillance, freely available satellite imagery was obtained from the European Space Agency. The optical and SAR imagery provided an additional means of recording the full extent of the slick, helping to determine any change to the situation.

CASE STUDY LEARNING POINT

Regular monitoring of the wreck using a UAV was a more efficient way of observing the status of the oil leak from the wreck in the long term than a helicopter.

FIGURE 30 A drone image of a continuous oil leak from sunken vessel (Source: Resolve Marine).

Key Points

- An initial assessment of a spill is essential to determine the extent of pollution to allow responders to define the clean-up strategy. For many spills, this is typically best done from the air.
- To be most effective, the use of aerial reconnaissance as part of a response should be considered during the contingency planning process to enable rapid mobilisation of relevant resources at the start of an incident.
- Aerial reconnaissance can allow the movement of oil, its appearance and estimated volume to be determined, threatened resources identified and operational responses monitored.
- Where available, different reconnaissance platforms can be used and potentially combined based on the specific surveillance needs of the incident.
- Thorough preparations are required for all types of aerial reconnaissance to ensure the most reliable results are obtained and that maximum benefit is gained from each surveillance mission.
- Information obtained using sensors should be interpretated by experts since such systems also detect other features which may be confused with oil.
- Compared to more traditional aerial surveillance platforms, UAVs offer a comparatively flexible surveillance tool, and the nature and extent of their use is set to expand in future years.
- All information recorded during any aerial reconnaissance mission needs to be communicated to the command centre in a consistent, concise, and timely manner.
- Aerial platforms can assist with effective deployment of at-sea response resources.

TECHNICAL INFORMATION PAPER NO.1

Aerial surveillance of marine oil spills

PROMOTING EFFECTIVE SPILL RESPONSE

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