

**Use of Remote Sensing Technology for Oil Spill Response:
An Overview Report to the Administrator of the California
Department of Fish and Wildlife (CDFW), Office of Spill**

DRAFT

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Executive Summary

Remote sensing technology is an important tool for open-water, near shore and shoreline spill response. The technology is capable of providing real-time information on the following: accurate spatial mapping of spilled oil necessary for locating and positioning recovery equipment and applying alternative response technologies such as in-situ burning or chemical dispersants; providing data on surface current direction necessary for predicting oil slick movement; providing qualitative information on oil slick thickness; providing 24-hour, all weather, slick position information which could significantly increase the mechanical recovery of spilled oil by extending cleanup operations into darkness. Platforms for remote sensing apparatus include helicopters, fixed-wing aircraft, drone aircraft, satellite, lighter than air balloons and ground base stations.

This report is an overview of traditional remote sensing tools that could be deployed in response to an oil spill in California. Also included is a section on data management during an oil spill response utilizing Geographic Information Systems (GIS) technology, and data dissemination via a Common Operational Picture (COP). The report concludes with practical recommendations to the OSPR Administrator based on real world experience at several smaller oil spills in California and at the Deepwater Horizon (MC-252) oil spill response in the Gulf of Mexico during the summer of 2010. Appendix I is a table listing remote sensing systems used at the Deepwater Horizon (MC-252) response, including their practical usefulness and limitations.

Introduction

Satellite and aerial imaging is being utilized throughout the world to aid oil spill detection, response, monitoring and for maritime surveillance. Until recently the European Union (EU) has led the development of remote sensing applications for oil spill detection and response. The Bonn Agreement¹ of 1969 is the mechanism by which the North Sea States and the European community work together to carry out surveillance as an aid to detecting and combating pollution at sea. The experience gained through the Bonn Agreement over the past thirty-six years has been codified in the Bonn Agreement Counter-Pollution Manual². In the last several years Canada has instituted a national program of satellite monitoring of the shipping lanes with their Integrated Satellite Tracking of Polluters (I-STOP)³ project and the National Aerial Surveillance Program (NASP)⁴. Both the European North Sea and Canadian operational programs analyze incoming Synthetic Aperture Radar (SAR) satellite imagery for signs of potential pollution (oil slicks). If seen, dedicated aircraft are dispatched for oil slick detection and mapping. The aircraft use Side Looking Airborne Radar (SLAR) or a combination of Ultra Violet (UV) and Thermal Infrared (TIR) imaging systems to help positively

¹ <http://www.bonnagreement.org>

² <http://www.bonnagreement.org/manuals>

³ <http://www.ec.gc.ca/glaces-ice/default.asp?lang=En&n=40897129-1>

⁴ <http://www.tc.gc.ca/eng/marinesafety/oep-ers-nasp-2195.htm>

identify oil signatures on the sea surface. No such operational programs currently exist in the US.

Electromagnetic Energy and Energy Distribution

The electromagnetic spectrum is a continuum of energy divided into discrete energy bands. Remote sensing technologies presently employed by the oil spill response community utilize the UV, Visible, TIR and Microwave energy bands (fig. 1).

There are two types of remote sensing systems, passive and active. Passive remote sensing systems record energy naturally radiated or reflected from an object. Generally speaking a passive sensor needs a relatively clear sky and daylight conditions, the exception being a thermal camera which can measure temperature regardless of daylight conditions but is hampered by clouds or fog. An active remote sensing system supplies its own source of energy which is directed at the subject in order to measure energy returned. An active system can operate independently of daylight or weather conditions.

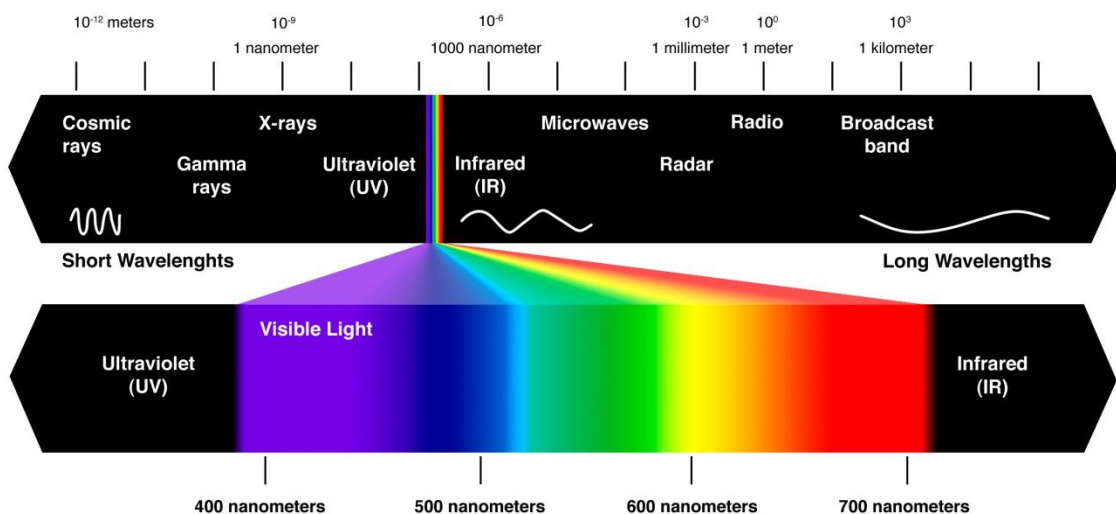


Figure 1. The electromagnetic spectrum and energy bands contained within.

Remote Sensing Technology and Sensor Types

Over the past two decades many technology review articles have been published concerning the use of remote sensing for oil spill detection and response in the marine environment (e.g. Fingus and Brown 1997, Lehr 2010, Leifer et al 2012). ASTM International (2008) has published an airborne remote sensing guide for detecting oil on water and most recently the American Petroleum Institute (API) published a planning guide for remote sensing support for oil spill response (API, 2013).

Visual Observation - The Bonn Agreement Oil Appearance Code

Visual observation from the air of floating oil is the simplest method of determining the location of an oil spill. However, obtaining satisfactory results requires a trained observer to characterize the oil and describe what is seen in standard terms. The color of an oil film depends on the way the light waves of different lengths are reflected off the oil surface, transmitted through the oil (and reflected off the water surface below the oil) and absorbed by the oil. The observed color is the result of a combination of these factors; it is also dependent on the type of oil spilled. Since the color of the oil is dependent on so many variables, an appearance cannot be characterized purely in terms of apparent color and therefore an 'appearance' code, using terms independent of specific color names, has been developed. The European response community has produced its own set of standards, the most widely disseminated being those connected with the Bonn Agreement. The Bonn Agreement Oil Appearance Code (BAOAC) is based upon previously published scientific papers, small-scale laboratory experiments, outdoor experiments and field trials (Bonn Agreement, 2009, Figure 2). Visual estimation of oil film thickness distribution is highly subjective and, if not done by specially trained and experienced personnel, tends to be inaccurate (Svejkovsky et al, 2012).

BAOAC Code	NOAA Code	Description	Layer Thickness Interval (inches)	Concentration (bbl./acre)
1	S	Sheen (silvery/grey)	$1.6 \times 10^{-6} - 1.2 \times 10^{-5}$	$1 \times 10^{-3} - 7.8 \times 10^3$
2	R	Rainbow	$1.2 \times 10^{-5} - 2 \times 10^{-4}$	$7.8 \times 10^3 - 1.28 \times 10^{-1}$
3	M	Metallic	$2 \times 10^{-4} - 2 \times 10^{-3}$	$1.28 \times 10^{-1} - 1.28$
4	T	Transitional Dark (or True) Color	$2 \times 10^{-3} - 8 \times 10^{-3}$	1.28-5.1
5	D	Dark (or True) Color	$> 8 \times 10^{-3}$	> 5.1
	E	Emulsified	Thickness range is very similar to dark oil	

Figure 2. The BAOAC as modified by NOAA. Rough values for slick thickness and oil concentrations can be derived. Be aware that thickness and volume estimates from aircraft observations have a high uncertainty due to many variables.

Optical Sensors

Optical sensors are passive imaging devices sensitive in the UV, visible and near-infrared (NIR). NIR is the portion of the TIR spectral region closest to the visible range. These sensors exploit differences in reflectance as the primary mechanism for detecting oil on water.

Photography and Videography

Traditional optical techniques rely on still photography and video cameras. This

technique does provide an economical means to chronicle oil spills. Standard photography and videography techniques do not work at night or when cloud cover or fog is present.

Ultra Violet (UV) Sensors

Passive UV sensors operate by capturing ultraviolet energy reflected from an oil film considerably different than water and, thus oil is easily detected on water. The thinner the oil slick the higher the ultraviolet signature, thus the sensor is best used to map the outer edge of an oil slick where sheen normally occurs. The UV sensor is best used in conjunction with a thermal IR sensor to fully document the extent and state of an oil slick. Shortfalls: UV sensors are subject to much interference including wind, sun glint, and kelp and other biogenic material. Further, UV sensors do not function at night or in cloudy or foggy weather.

Infra-Red (IR) Sensors

Thermal IR sensors (TIR) function by discriminating temperature differentials between objects, such as oil, and their background. TIR sensors not only provide information on the location of oil on water, but can also provide qualitative information on the thickness of the spilled oil. This is accomplished through the differential in TIR color signature between varying thicknesses of spilled oil (Svejkovsky and Muskat 2009). The advantage of the IR sensor is that it can be operated during both the day and night. However, the sensor cannot be used through a cloud cover as the water vapor in the clouds absorbs the signal.

Multispectral Sensors

Multispectral (MS) refers to passive sensors that measure reflected and/or emitted radiation in the UV, visible, and TIR wavelengths in a relatively small number of discrete spectral bands (4–50 spectral bands). While human vision is limited to visible light, multispectral sensors, or imagers, can collect data over a wider range of the EM spectrum and record the energy of a discrete number of spectral bands. MS sensors usually cover the visible portion of the electromagnetic spectrum, in addition to the NIR. Frequently, an MS based remote sensing platform will have a variety of different sensors onboard and therefore can collect data across the EM spectrum from the Visible to the TIR range (API 2013). NASA satellites equipped with Moderate Resolution Imaging Spectroradiometers provided responders with a multispectral, high-altitude view of the spreading oil. However, the satellites cannot glean important information related to the thickness of the slick, which is crucial for knowing where skimmers can do the most good

Ocean Imaging Corp.'s “Tactical Rapid Airborne Classification System” (TRACS)

Svejkovsky et al. (2012) describe a mobile system that combines MS and TIR sensors. The system consists of a JAI AT-200CL progressive-scan CCD camera with three selectable spectral bands, together with a TIR imager (Jenoptic IR-

TCM1024 un-cooled micro-bolometer) measuring emitted radiation from 7.5 to 14 μm . The spatial integration of the two sensors is based on a combined differential GPS and inertial measurement unit (IMU) with a circular positional error of 2 m, resulting in a spatial statistical error of less than 6 m. At an altitude of 3800 m, the ground resolutions are 2 m (MS) and 4 m (TIR), with a swath width of 2048 m.

This system, initially funded and conceptualized by the OSPR Scientific Study and Evaluation Program (SSEP), was designed from inception as a portable and affordable system for oil film detection and thickness determination for oil spill response which can be mounted in an aircraft of opportunity. While in-flight the TRACS system mosaics the acquired images, runs custom image processing algorithms to interpret the imagery and creates a output file in Geographic Information system (GIS) file format. Upon landing the GIS formatted data can be sent electronically directly to responder vessels and to the Situation Unit in the ICP for import into the Common Operational Picture (COP), for dissemination to the broad responder community.

Building on established principles of visual interpretation, the system uses a two-tiered process to generate oil spill information products with up to six oil thickness classes. In a first stage, a neural network is used to differentiate oil and water, while a second step involves extracting oil thickness classes using a fuzzy ratio-based classification. Field and experimental validation results confirm that the combination of MS and TIR imagery enables characterization of oil thickness of up to 2 mm (Svejkovsky and Muskat, 2009).

During the Deepwater Horizon response, repeat coverage with the TRACS system was also used to provide situational awareness with respect to vessels in the spill area, verify the effectiveness of sub-surface dispersant application and assess the impact of aerial dispersant application and the mapping of beached oil.

In-Situ Sensor - Fluorescence Detection – Slick Sleuth

Fluorescence detection, or fluorometry, is by no means new technology in and of itself. Typically, fluorometers use spectroscopy methods for fluorescence detection in the form of flow-through or in-water systems. The “Slick Sleuth™⁵” oil spill detector is a UV/fluorometry-type optical sensor. It can be mounted on bridge piers, buoys or an offshore production facility downward looking, to survey a specific target area. Any oil present in the target area will fluoresce and subsequently emit light of its characteristic wavelengths. When oil is detected an alarm is sent either audible or electronic.

Microwave Sensors - Imaging Radar

Imaging Radar technology has been demonstrated to detect an oil film on the

⁵ <http://www.slicksleuth.com/>

ocean's surface. Imaging Radar is an active system that provides its own source of illumination. Imaging radars can "see" in darkness and through clouds and fog. Imaging radar measures the surface roughness. There are presently two basic types of radar systems used in oil spill response, SLAR and satellite based Synthetic Aperture Radar (SAR). In both systems a pulse of energy is directed to the surface at an oblique angle. At the Earth's surface, the energy in the radar pulse is scattered in all directions, with some reflected back toward the antenna (backscatter). A surfactant film on the ocean surface will have a dampening effect on wind generated water surface capillary (ripple) waves. The smooth ocean surface reflects the microwave energy away from the radar antenna thusly exhibiting a "dark" signature on the resulting radar image. The major shortcoming of imaging radar is that it does not discriminate between sheen and thick oil. The sensor is thus a useful tool for determining the overall footprint of the oil slick and modeling the trajectory of an oil spill but provides little information on the thickness and amount of oil present, an important data requirement for spill response and cleanup activities. Recent research has shown it is possible to characterize areas of thicker emulsified oil within an oil slick using SAR⁶ (Garcia et al, 2013).

Other drawbacks of imaging radar include: 1) at surface wind speeds below 5 knots capillary waves are not present (dead calm) and above 20 knots the ocean surface is too rough for the dampening effect to occur; 2) a number of natural conditions including wind shadows, kelp beds, plankton blooms, natural organic material, and fresh water fronts will lead to false positive signals.

The most readily available SAR is satellite based, thus acquiring imagery is dependent on the location of the satellite. MDA Geospatial Services has two operating commercial SAR satellites, RADARSAT 1 and RADARSAT -2. MDA Geospatial Services is the only SAR vendor geared for real-time delivery of SAR imagery for maritime domain awareness. NASA/JPL SAR uses a Gulf Airstream jet aircraft as its deployment platform. JPL is not geared for rapid deployment nor real-time processing. SLAR is based on an aircraft platform and is therefore a much more flexible system for imaging. Transport Canada has an oil spill response SLAR mounted on a dedicated De Havilland Dash-8 pollution surveillance aircraft based in Vancouver, BC.

HF Radar

High Frequency Radar (HFR) is a technology for measuring ocean surface current velocities over 100's of square miles simultaneously. These radar systems measure the speed and direction of the ocean surface currents in near real time. HFR is recognized nationally as a cost-effective solution to augment the existing system of in situ measurements and to provide increased spatial and temporal resolution. Use of HF Radar to provide ocean surface current estimates for oil spill modeling can be a powerful tool as it is synoptic and operational in

⁶ <http://www.jpl.nasa.gov/news/news.php?release=2012-337>

real time, and extends over large spatial areas. High frequency radar data is often used to help forecast where the oil or other material will flow.

HF Radar has proven to be an effective tool for spill response in California. California voters through a ballot initiative in 2002 passed Prop 40, a \$2.6 billion bond act that provided funds for a variety of programs related to water quality, coastal resources, and historical/cultural programs. In 2005, the California State Coastal Conservancy and the State Water Resources Control Board invested \$21 million from voter-approved Propositions 40 and 50 funds to build the infrastructure to map ocean surface currents. The California Coastal Ocean Currents Monitoring Program (COCMP) uses a suite of technologies, HF radar in particular, to track ocean surface currents in near real-time. The 54 land-based stations now span the California coastline, providing anyone with access to the Internet the ability to track past and near real-time movement of California's coastal waters, including any floating pollutants. Unfortunately long term funding for the HF radar network has not been identified.

Laser Fluorosensor

The fluorosensor is an active UV sensor that utilizes a narrow-band UV laser for stimulating fluorescent emission from spilled oil on water. The sensor works by using a laser to irradiate the sea surface. When the laser strikes oil, a characteristic visible spectrum is recorded by the sensor. The laser fluorosensor has the ability to detect and characterize different types of fresh and weathered oil. Due to the mechanics of the system it needs to be flown at low altitude resulting in a thin line of data along the laser track. A recently developed scanning laser fluorosensor extends the line of measurement into an image path of up to 200 meters (Brown and Fingus, 2003). Because of the size and weight the laser fluorosensor must be flown in a large aircraft such as a DC-3. Laser fluorometry has not yet been successfully utilized for operational support during an actual oil spill. In January of 2011 Environment Canada decommissioned the only such system based on the North American continent⁷.

Drones, Balloons and Other Remote Sensing Platforms

Drone aircraft (also known as an Unmanned Aerial Vehicles (UAV) or Unmanned Aircraft Systems (UAS)) are currently being evaluated for oil spill response. AeroVironment Corp. markets the "Puma" UAS platform that currently is being evaluated by both NOAA and Chevron Shipping Company as a reconnaissance tool for the Shoreline Cleanup and Assessment Technique (SCAT) and Natural Resource Damage Assessment (NRDA) processes. When outfitted with a conventional video camera and a TIR imager (7.5 μm to 14 μm), drone aircraft have the potential to deliver information quickly and economically for areas of difficult access. The more quiet nature of small drone aircraft may make this an

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http://www.thestar.com/news/canada/2011/01/12/environment_canada_mothballs_cuttingedge_technology.html

attractive tool for reconnaissance near biological sensitive areas such as shorebird roosting sites and colonies or Pinniped haul out sites. Be Aware that flying a UAS still requires special permission from the FAA. As of this writing Vandenberg AFB airspace is the only airspace open (to NOAA) for drone based remote sensing experimentation.

MSRC has an Aerostat (balloon) based sensor platform based in Richmond, CA. Aerostats, can be deployed from MSRC's Responder Class vessels or other strategically placed marine or land-based platforms. The Aerostat can be tethered up to 500 ft. in accordance with FAA rules and without special permits under most circumstances, and carries a payload consisting of an HD camera for visual images, a thermal infrared (TIR) camera for oil classification, and an AIS repeater. The HD and TIR images as well as AIS data are viewed on a tablet style computer. The prime value of the aerostat includes 1) unmanned operation, 2) ability to be used under cloud cover, which can impact aerial TIR, 3) the ability to be used at night, and 4) perhaps most importantly, to provide locational data to track the oil as it migrates and moves.

Ship mast based remote sensing systems are employed by both MSRC and Clean Seas as tactical tools to aid on-water recovery. MSRC employs the Rutter Sigma S-6 X-Band Oil Detection System. MSRC and Clean Seas both use the FLIR M-625L Infrared camera.

Data Management with GIS

Computing technology has advanced to the point where it is now standard practice to employ complex GIS within the Incident Command Post (ICP). Simultaneously, field data collection has been migrating to mobile computing applications which output GIS files that are quickly displayed for real-time situational awareness. From the initial emergency response, through clean-up and sign-off, much data with a spatial component is generated and many disparate data sets are collected. More efficient data integration, management and visual analysis affords Incident Commanders and Section Chiefs the ability to make informed and timely planning, operational and strategic decisions.

Traditionally, GIS maps were created in the ICP from field sketches, field notes and verbal reports. Processing of this data by the GIS Unit is very time consuming and prone to error. Preliminary efforts to streamline and automate field data collection by OSPR utilized GPS receivers to record waypoints and track lines. Since then more elegant electronic field data collection applications installed on "smart phones" and tablet devices have been developed including those for "Wildlife Recovery and Transport", "Resources at Risk" over flights, and the "Shoreline Cleanup and Assessment Technique" (SCAT). Other recent advancements allow for real-time aerial remote sensing of the ocean surface for slick detection, detailed mapping of the slick properties, and displaying the output from coastal High Frequency (HF) radar installations for real-time visualization of local ocean surface current fields.

Once these data are incorporated into the on-site GIS, a web-based Common Operational Picture (COP) is utilized for overall situational awareness and timely dissemination of relevant geospatial data. The National Oceanic and Atmospheric Agency (NOAA) introduced the Environmental Response Management Application® (ERMA) during the Deepwater Horizon response. ERMA is a web-based GIS tool that assists both emergency responders and environmental resource managers in dealing with incidents that may adversely impact the environment. ERMA integrates and synthesizes various real-time and static datasets into a single interactive map, thus provides fast visualization of the situation and improves communication and coordination among responders and environmental stakeholders. OSPR has worked closely with NOAA to develop, enhance and deploy Southwest ERMA. Southwest ERMA is California's COP of choice for web-based data dissemination and incident situational awareness.

At ICP Houma, Louisiana, during the Deepwater Horizon (MC-252) oil spill response many responders were from outside of the region and unfamiliar with the local geography. Area base maps with a standardized coast line and place names were not readily available for several days which added unnecessary confusion to the mix. As a lesson learned, in order to avoid this situation for an oil spill response in California, OSPR and NOAA have pre-loaded Southwest ERMA with pertinent base maps, charts and spill response planning data from the three California Area Contingency Plans (ACPs). These data are deliberately made freely available to the general public via the Southwest ERMA web-viewer without any user login credentials required.

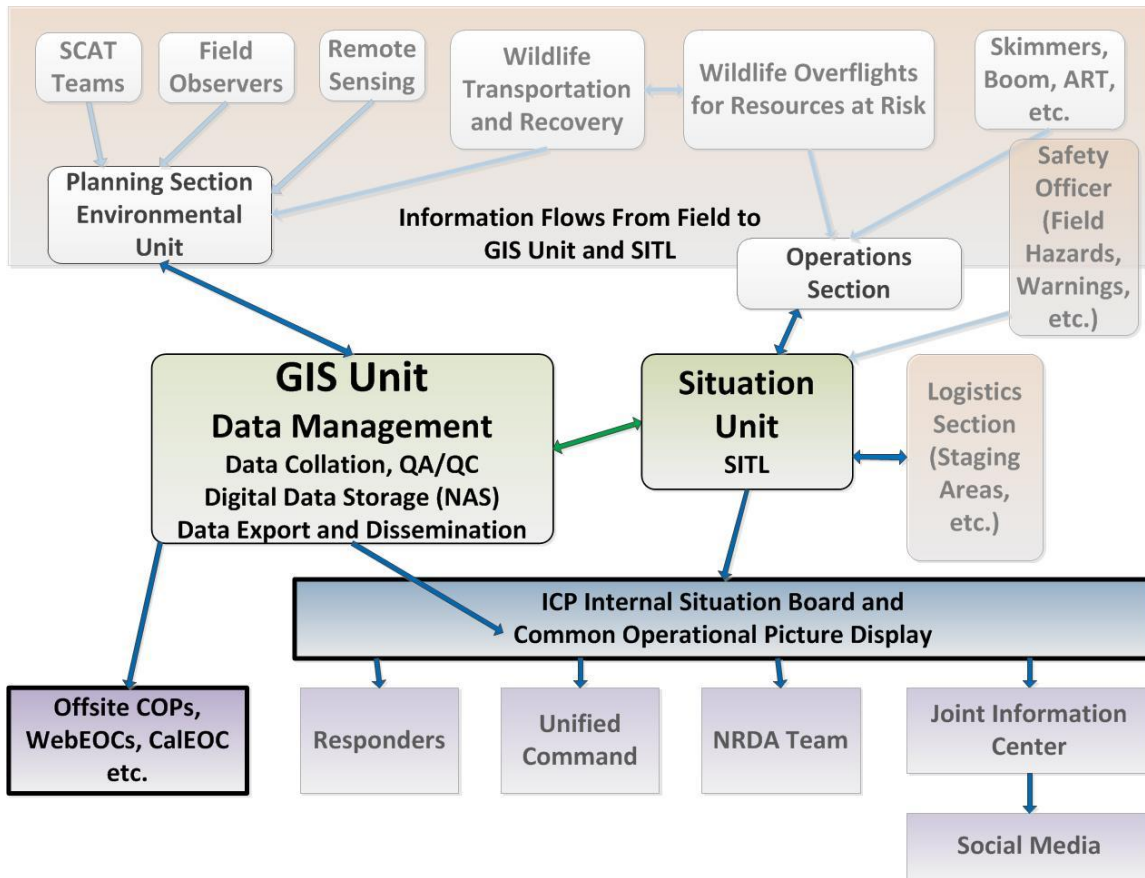


Figure 3. This figure diagrams the flow of information from the field through the Planning and Operations Sections to the Situation Unit or directly to GIS. There, field data is verified, processed and digitally stored by the GIS Unit. The data/information is then posted to the COP for dissemination to responders and displayed in the ICP for situational awareness.

National Integrated Ocean Observing System (IOOS)

The national Integrated Ocean Observing System (IOOS) is a comprehensive system for obtaining ocean information and making it available to those relying on this critical information for safe and efficient navigation and oil spill response. The Integrated Coastal Ocean and Observation Act was signed into law by President Obama in March 2009. The law established NOAA as the authorizing body of IOOS, a partnership between 17 federal agencies and 11 Regional Associations for Coastal Ocean Observing (RAs). In California, two RAs, the Central and Northern California Ocean Observing System (CeNCOOS), and the Southern California Coastal Ocean Observing System (SCCOOS), represent California's coast for the national IOOS. Combined, partners of these two RAs include over 100 state and federal agencies, non-profit programs, industries, and research institutions.

Ocean Observing Systems can provide and package IOOS information on sea state conditions (e.g. surface current speed and direction, wave dynamics, tides, subsurface current speed and direction, wind, temperature, and salinity), as well as ship tracking through the Automatic Identification System (AIS).

Discussion and Recommendations to the OSPR Administrator

For a moderate (Tier 2) spill response in California the recommended remote sensing technology is an airborne integrated multispectral/thermal IR sensor package such as the TRACS system described above. This system has been used operationally and successfully for response and evaluating oil spill damages for marine and inland spills (e.g. Suisun Marsh (Kinder-Morgan Pipeline), Kern County (Chevron well blowout) and the San Francisco Bay Area (Cosco Busan), to name a few).

For a large scale oil spill event in California (Tier 3 spill response), an excellent resource to complement the TRACS system for very large area overflight reconnaissance would be the specially equipped Dash-8 pollution surveillance aircraft operated by Transport Canada based in Vancouver, BC⁸. This Canadian Government equipment may be accessed through the Pacific States British Columbia Oil Spill Task Force Mutual Aid Agreement. The Dash-8 was used extensively during the Deepwater Horizon response. Another resource for synoptic coverage is MDA's⁹ RADARSAT (SAR) satellites. MDA can deliver interpreted SAR images in real-time (within 1 ½ hrs. after acquisition). MDA also has contracts with other satellite companies and can therefore provide high resolution imagery from optical satellites (e.g. QuickBird, IKONOS, WorldView 1&2, etc.) in less than real time.

At the response to the blow out of BP's Macondo well and the subsequent sinking of the Deepwater Horizon drill rig much remote sensing technology was employed. The systems most useful to the immediate response were: 1) RADARSAT SAR for the synoptic view of the entire Gulf of Mexico, 2) the SLAR system on-board Transport Canada's de Havilland Dash-8¹⁰ for daily reconnaissance overflights of the entire slick area and 3) the OI system which was targeted for specific missions including daily offshore oil recovery planning, oil trajectory modeling, dispersant application effect documentation, beached oil mapping and documentation of the relative oil amount along the spill's offshore perimeter. Table 1 lists all of the remote sensing systems deployed for the Deepwater Horizon response on a daily bases from ICP Houma.

⁸ <http://www.tc.gc.ca/eng/marinesafety/oep-ers-nasp-2195.htm>

⁹ <http://gs.mdacorporation.com/SatelliteData/SatelliteData.aspx>





¹⁰ The Icelandic Coast Guard has an identically equipped de Havilland Dash-8 which was employed while the Transport Canada was temporarily down for R&R.

A final comment: OSPR should provide financial support in order to ensure the California Ocean Currents Monitoring Program (COCMP) HF Radar network stays active. This state-wide coastal current monitoring network has proven to be of much value for tracking local ocean surface current fields and for verifying the predictive model for the oil slick trajectory (e.g. NOAA's GNOME or ASA's OilMap).

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Appendix I

REMOTE SENSING SYSTEMS USED AT THE DEEPWATER HORIZON (MC-252) RESPONSE

<i>Vendor</i>	<i>Tool</i>	<i>Platform</i>	<i>Applications</i>	<i>Time Frame for Delivery</i>	<i>Limitations</i>
Transport Canada MART Pacific, Vancouver	Side Looking Airborne Radar - SLAR Still Photography	 de Havilland Dash-8	Maps detailed outline of Slick Oblique Photographs Measures ocean surface roughness.	Two hours after mission completion Fly in the morning, data ready for evening data integration meeting	Potential for false positive due to natural phenomena, dead calm, sea grass, sediment load, etc. Cannot determine oil slick thickness or weathering state
Iceland Coast Guard	Side Looking Airborne Radar - SLAR	 de Havilland Dash-8	Maps detailed outline of Slick Measures ocean surface roughness.	Two hours after mission completion Fly in the morning, data ready for evening data integration meeting	Potential for false positive due to natural phenomena, dead calm, sea grass, sediment load, etc. Cannot determine oil slick thickness or weathering state
Ocean Imaging Corp.	Digital Multispectral Camera Thermal Imager Oblique still photography	 NOAA Twin Otter	Maps oil slick thickness for recoverable vs. non-recoverable oil. Provides detailed thickness values, sheen through fresh oil and emulsion. Provides geo-referenced data in GIS format in near real time. High detail mapping of slick thickness values. Best for detailed mapping of multiple select targets.	Immediate quick look classification for recoverable oil delivered via email. Detailed image classification in 2-3 hours	Small footprint covers tens of square miles.
U.S. Customs and Border Patrol	Forward Looking Thermal-IR	 Cheyenne PA-42	Oblique video and still images. Measures ocean surface temperatures	Within several hours of touchdown	Images and video can be confusing and difficult to interpret unless you are within a know area of oiling.



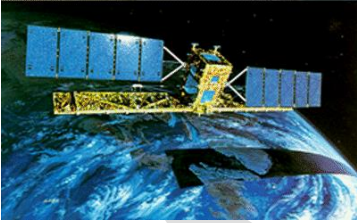
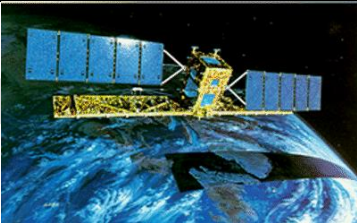
Icaros, Inc.	Digital Photography	 Light Aircraft	Digital still frame photography. Provides geo-referenced data in GIS format	Within several hours of mission completion	Individual frames have large contrast difference from edge to edge.
Airborne Data Systems	ADS Spectra-View	 Piper Navajo	High resolution multispectral imagery for detection of thick patches of oil. Provides geo-referenced data in GIS format.	Within several hours of mission completion	Individual frames have large contrast difference from edge to edge. Imagery requires interpretation. More subtle oil features may go undetected.
MDA Geospatial Services	Synthetic Aperture Radar Satellites. RADARSAT 1 and 2	 Satellite	Synoptic view of entire slick. Measures ocean surface roughness.	Daily image	Potential for false positive due to natural phenomena such as dead calm, sea grass, sediment load, etc. Cannot determine oil slick thickness or weathering state. Polar orbit, image acquisition dependant on location of satellite.
NASA	Terra and Aqua Satellites. MODIS Multispectral Sensor	 Satellite	Synoptic view of entire slick. Multispectral image	Daily image	Cannot determine oil slick thickness or weathering state. Polar orbit, image acquisition dependant on location of satellite.

Table 1. Remote sensing systems used daily during the early days of the Deepwater Horizon (MC-252) oil spill response.

Bibliography

American Petroleum Institute. 2013. Remote Sensing in Support of Oil Spill Response, Planning Guidance. API Technical Report 1144. American Petroleum Institute. Washington, DC.

ASTM. 2008. Standard Guide for Selection of Airborne Remote Sensing Systems for Detection and Monitoring of Oil on Water. ASTM F2327 – 08. ASTM International. West Conshohocken, PA.
DOI: 10.1520/F2327-08

Brown, C. E., & Fingas, M. F. (2003). Development of airborne oil thickness measurements. *Marine Pollution Bulletin*, 47(9-12), 485-492.
doi:[http://dx.doi.org/10.1016/S0025-326X\(03\)00203-0](http://dx.doi.org/10.1016/S0025-326X(03)00203-0)

Fingas, M. F., & Brown, C. E. (1997). Review of oil spill remote sensing. *Spill Science & Technology Bulletin*, 4(4), 199-208.
doi:[http://dx.doi.org/10.1016/S1353-2561\(98\)00023-1](http://dx.doi.org/10.1016/S1353-2561(98)00023-1)

Garcia-Pineda, O., I. MacDonald, C. Hu, J. Svejkovsky, M. Hess, D. Dukhovskoy, and S.L. Morey. 2013. Detection of floating oil anomalies from the Deepwater Horizon oil spill with synthetic aperture radar. *Oceanography* 26(2):124–137,
<http://dx.doi.org/10.5670/oceanog.2013.38>.

Lehr, W. 2010, Visual Oil Observations and the Bonn Agreement , Proceedings of the Thirty-third Arctic and Marine Oilspill Technical Program Technical Seminar, Environment Canada, Ottawa Ontario. Pp. 669-678.

Leifer, I., B. Lehr, D. Simecek-Beatty, E. Bradley, R. Clark, P. Dennison, Y. Hu, S. Matheson, C. Jones, B. Holt, M. Reif, D. Roberts, J. Svejkovsky, G. Swayze, and J. Wozencraft. State of the Art Satellite and Airborne Marine Oil Spill Remote Sensing: Application to the BP Deepwater Horizon Oil Spill. Remote Sensing of Environment, vol. 124, pp. 185-209, Sep. 2012. [\[paper\]](#)

Svejkovsky, J., W. Lehr, W. Muskat, G. Graettinger, and J. Mullin. 2012. Operational Utilization Of Aerial Multispectral Remote Sensing During Oil Spill Response: Lessons Learned During The Deepwater Horizon (MC-252) Spill. *Photogrammetric Engineering & Remote Sensing* 78(10):1,089–1,102.

Svejkovsky, J. and J. Muskat, 2009. Development Of A Portable Multispectral Aerial Sensor For Real-Time Oil Spill Thickness Mapping In Coastal And Offshore Waters. Final Report for U. S. Minerals Management Service Contract M07PC13205, 33p.