DEVELOPMENT AND EVALUATION OF REMOTE SENSING AND PORTABLE GIS TECHNOLOGIES IN A REAL-TIME OIL SPILL DETECTION AND RESPONSE SYSTEM.

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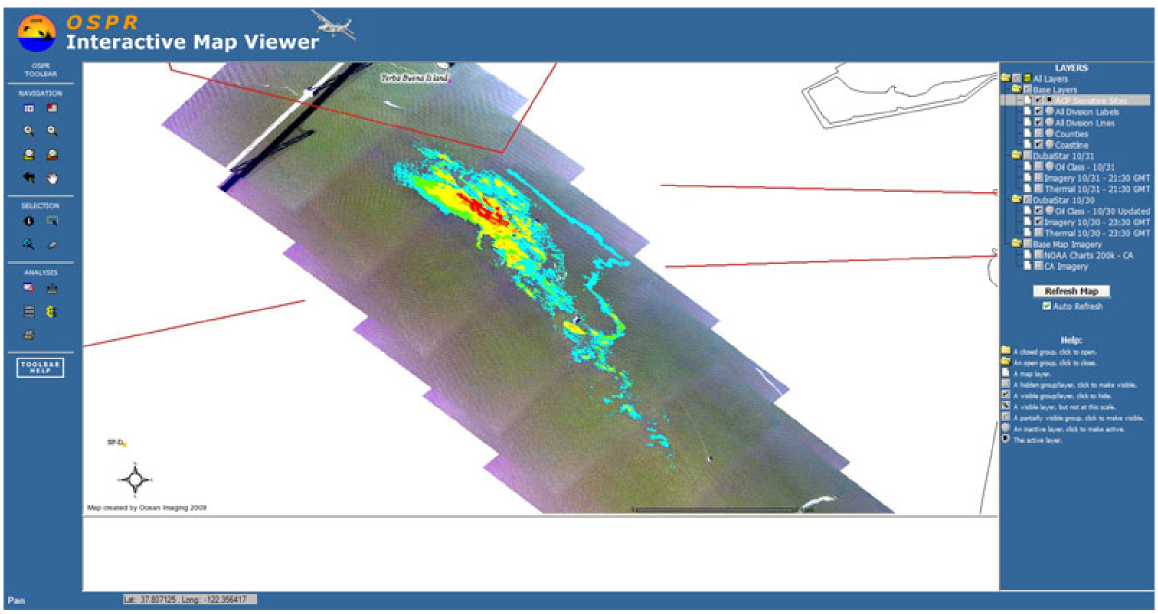

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On the Cover: Screen grab of aerial imaging data processed for oil film thickness as it appeared on the OSPR GIS web server developed through this project: the M/V Dubai Star oil spill, San Francisco Bay, 10/30/09.

EXECUTIVE SUMMARY

This project builds upon previous developments achieved during an initial OSPR SSEP project, and concurrent oil spill thickness imaging research funded by the Minerals Management Service, to allow near-real-time generation of digital GIS oil map products and their dissemination through a system that provides rapid access to oil spill locations, extents and thickness distributions derived through satellite and aerial remote sensing. The two-year work plan had three components: 1) hardware and software development and testing related to the acquisition, generation and dissemination of aerial imaging products, 2) development, testing and integration of the data access system with OSPR's present GIS systems, and 3) field demonstration/testing/evaluation of the developed system with multi-agency involvement. The development work was completed successfully and the new technologies were demonstrated during three oil spill exercises during the project. In addition, the newly developed system began to be utilized operationally, first in December, 2008 during response to an oil platform spill in the Santa Barbara Channel, and more recently in October, 2009 during response to the M/V *Dubai Star* spill in San Francisco Bay.

1. PROJECT BACKGROUND

Present-day first-order response to a reported or surveillance-detected oil spill by OSPR or Coast Guard (USCG) observers usually involves verbal communications, sometimes supplemented by sketches or oblique digital photos. Vital information such as the spill location, extents, estimated oil volume, etc. are then passed on to appropriate personnel to asses the best response. This strategy is subject to numerous limitations in location and spill characterization accuracy as well as the speed with which the information is distributed to the various personnel. In the past few years significant technological advances have been made in remote sensing-based detection and real-time mapping of oil spills, as well as wireless Geographical Information System (GIS) data transfer. These technologies could be readily implemented in an advanced oil spill detection/characterization system which would provide highly detailed, graphically-based spill information products with unprecedented accuracy and dissemination speed. The system would also allow rapid exchange of such information, when needed, through a standardized web-accessible system between different agencies and Oil Spill Response Organizations (OSRO) such as OSPR, the USCG, Clean Seas, etc.

The prime objective of this project was to utilize oil spill detection and mapping capabilities developed in former projects sponsored by OSPR and the Minerals Management Service (MMS), and collaborated-on with Ocean Imaging Corporation (OI), for the creation of a coast wide system that would provide very rapid, digital access to information on oil spill location, extents, thickness/volume characteristics and other related variables. The system was to utilize state-of-the-art mobile GIS technologies for data dissemination and management. The development and subsequent evaluation of such a system should not only result in increasing spill response efficiency but should also increase oil spill detection vigilance by facilitating the use of multiple scale surveillance resources (e.g. detection of a possible spill in large-scale Synthetic Aperture Radar (SAR) images leading to rapid mobilization of a regional aerial mapping scanner, leading to rapid field response). Additionally, it can increase the efficiency of collaboration between OSPR and other agencies such as the USCG, which is commonly involved in an oil spill response.

The two-year project contract was approved in November 2007 and terminated in December, 2009.

2. PROJECT OBJECTIVES AND MILESTONES

A previous SSEP-funded project resulted in the development of an oil mapping algorithm using a multispectral aerial sensor. The algorithm was successfully tested over oil seeps in the Santa Barbara Channel. A related project funded by MMS extended the algorithm's utility to include oil slick thickness measurement capabilities. This project build upon the previous developments to allow near-real-time (i.e. in the aircraft) generation of digital GIS oil map products and their dissemination through a system that provides rapid access to the information even by personnel in the field. The work plan had three components: 1) software development and testing related to the generation and dissemination of the products, 2) development, testing and integration of the data access system with OSPR's present GIS systems, and 3) field demonstration/testing/evaluation of the developed system with multi-agency involvement.

Work targeting the generation and dissemination of the real-time products focused on automating the in-flight data processing. In the previous work, the oil mapping algorithm required a number of manual steps as well as manual correction of frame geolocations which significantly slowed down the product generation process. The addition of an Inertial Motion-sensing Unit (IMU) unit to the multispectral imager owned by OI should allow accurate, automatic geolocation of the image frames. OI purchased the IMU unit with matching funds and conducted accuracy tests over target areas near San Diego. Additional software work involved increasing processing throughput of large image mosaics.

The development and integration of the data access system was to be done by OI in close collaboration with OSPR's GIS staff. A secure web server, integrated with OSPR's present system was to be established for data dissemination. Several GIS software alternatives for in-the-field use was to be evaluated, including no-cost (shareware) options. The goal was to allow remote access to the GIS data through a web browser interface (suitable for in-office use as well as portable display devices such as laptops and palmtops), while providing multi-level GIS interactivity (e.g. determining cursor location, turning different layers on/off, etc.).

Testing and evaluation work was to involve several flight tests over targets near OI's San Diego offices as well as tests over oil seeps in the Santa Barbara Channel. Acquisition of SAR satellite imagery in near-real time from Radarsat was also planned for the project's system testing and demonstration. A full scale test with multi-agency participation was planned to be conducted at Santa Barbara. This exercise was to involve the acquisition in near-real-time of a large scale satellite SAR image from Radarsat, leading to the identification of a target oil slick in the image. The aerial multispectral sensor will then be immediately mobilized and high resolution GIS map products of the target slick will be produced in-flight and disseminated over the developed system. Based on this information, the Coast Guard will mobilize one of its aircraft or helicopters stationed in the test region, which will utilize the GIS information on-board to find the slick and deploy into it a POPEIE sampler. The sampler will be subsequently recovered by a participating vessel. In addition to the Coast Guard, MMS and Clean Seas were expected to also participate in the test.

The specific project milestones, as stated in the work contract were:

Year 1:

- Automation of in-flight image processing
- Integration of IMU unit
- Testing of in-flight processing and product dissemination
- Development of GIS server system

Year 2:

- Integration of developed software system with OSPR's internal GIS network

- Testing of integrated system
- Field demonstration/testing/evaluation of the developed system with multiagency involvement
- Professional publication

As is detailed in the next sections, the milestones were successfully completed. In addition, during the project's duration the developed system was successfully utilized operationally during two actual oil spills: one in the Santa Barbara Channel in December, 2008 and one in San Francisco Bay in November, 2009.

3. RESULTS

3.1 IMU unit integration, in-flight software refinement and in-flight testing.

An operational oil spill mapping system should have the capability to not only accurately map the oil thicknesses but also generate a geographically accurate map of the spill's location. Logged DGPS information for each captured image frame theoretically provides an accurate position for the center of each frame. However, it does not provide information on the roll, pitch and yaw of the aircraft at the time of each frame capture. The lacking of these parameters introduces positional errors in the autogeoreferencing/mosaicking software. At aircraft altitudes of 10,000' we found these errors to cause individual frames to be offset up to 100 meters, thus creating an uneven image mosaic.

When flying over land, visible features present in the overlap area of succeeding image frames can be used to correct much of the positional error by fitting the individual frames to a base layer image or map of known accuracy (this can be done either manually or automatically with commercially available pattern recognition-based mosaicking software). When imaging over open ocean, however, such tie-point features are usually lacking and the roll/pitch/yaw error is thus not easily determined and corrected.

Roll, pitch and yaw information is provided by Inertial Motion detection Units (IMUs). IMUs are used in a variety of navigation equipment (e.g. aircraft autopilots) as well as for testing purposes and aerial photography. Their price range is from approximately $4000 to $150,000+. The upper price range units are commonly integrated with state-of-the-art aerial imagers costing $500,000 to $1,000,000. One of the prime objectives of this project was to develop an oil mapping hardware/software system that would be accurate and efficient, yet reasonably economical and hence affordable to various agencies and other oil spill responders. We thus evaluated the suitability of various IMUs for the purposes of mapping oil spills with sufficient accuracy.

Evaluation of accuracy specifications of several sub-$10K IMUs revealed that they will not provide either sufficient measurement accuracy or sufficiently high logging rate to significantly reduce the inherent positioning errors. Units made by Applanix Corp. – the most commonly used for high-end aerial measurement and imaging equipment – provide excellent overall performance but cost from $80,000 to $200,000. This was deemed excessive in view of the targeted overall system cost (@ $100,000).

Figure 1. Auto-georeferenced imagery of San Diego coastline using only DGPS coordinate information (top) and using DGPS/IMU information (bottom).

During spring 2008 our research team located a British IMU manufacturer – Oxford Technical Solutions - whose line of mid-priced IMUs includes units with theoretically acceptable performance specifications. The company's US representative kindly provided Ocean Imaging with a demo unit for actual real-world testing. An RT2500 unit (costing approximately $25,000) was tested in overflights over San Diego in the CDFG Partenavia aircraft in May, 2008. Figure 1 shows a typical result achieved when this unit was integrated with the thermal IR system (similar results were achieved with the multispectral DMSC). At 10,000' altitude, RMS positioning errors were reduced from 100+ meters to 5-8 meters. In light of the fact that oil on water constantly moves due to wave, wind and current action, and the image data processing and transmission can be expected to take 10-20 minutes, we deem a positional error of less than 10 meters at 10,000' flight altitude quite acceptable. Therefore, we recommend the Oxford Technical Solutions RT2500 IMU unit for the targeted oil mapping aerial system.

OI purchased the unit from external funds, as per original proposal and permanently integrated it with the DMSC and Jenoptik thermal IR camera systems.

3.2 GIS server development

With the need during an oil spill response to deliver GIS and remote sensing data to multiple levels of end-users, OI created the "OSPR Interactive Map Viewer" site using ESRI's ArcIMS software. The OSPR Interactive Map Viewer contains a layer list with common base layers that can be used during a spill response effort and in a post spill natural resources damage assessment. The available layers were chosen by OSPR's GIS staff who helped guide and customize the interface during its development. The internet-based Viewer was designed to allow multiple users from multiple agencies to access and work with the data without the need for specialized software. Presently, the hosting server is located in OI's offices and maintained by OI staff.

Along with the base layers, after an aerial image data acquisition and processing, OI uploads the remotely sensed data and thickness classification maps on the server, making them available to the response community usually within 30-40 minutes of data acquisition. OI also uploads surface current maps derived from high frequency radar systems available along many parts of the California coast. The various data layers can be turned on and off to customize the displayed map. Figure 2 shows a Map Viewer screen example with data from the Dubai Star spill in San Francisco Bay (see below).

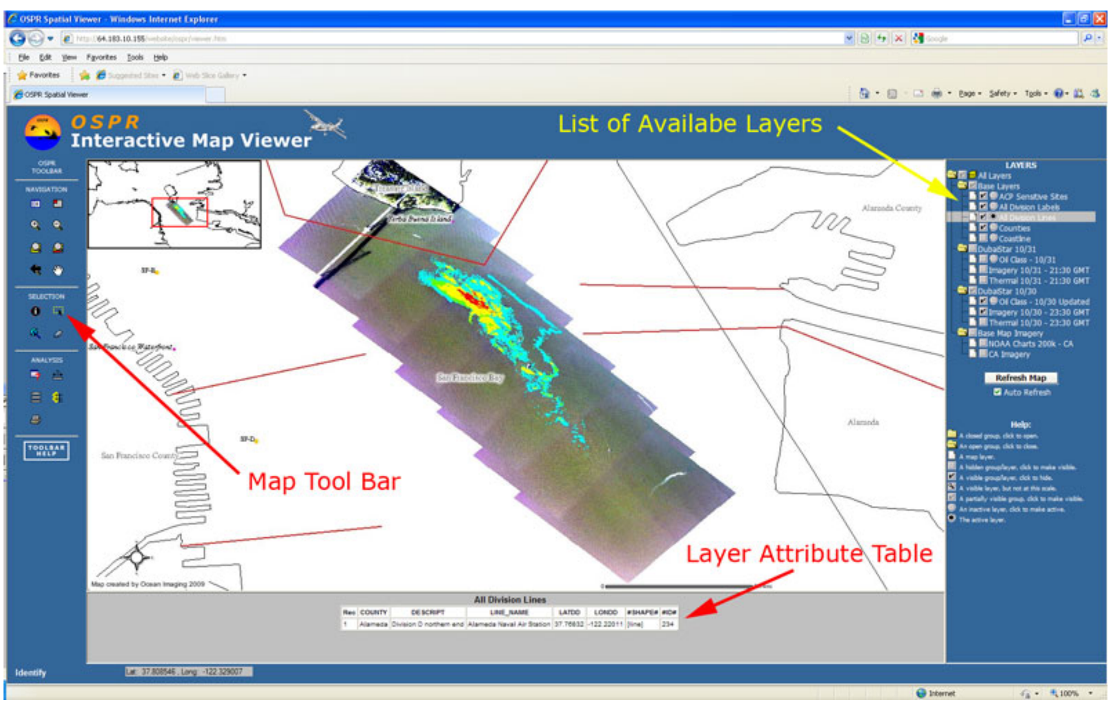


Figure 2. OSPR Interactive Map Viewer screen during the Dubai Star oil spill.

The following table summarizes the interactive tool choices available to the user:

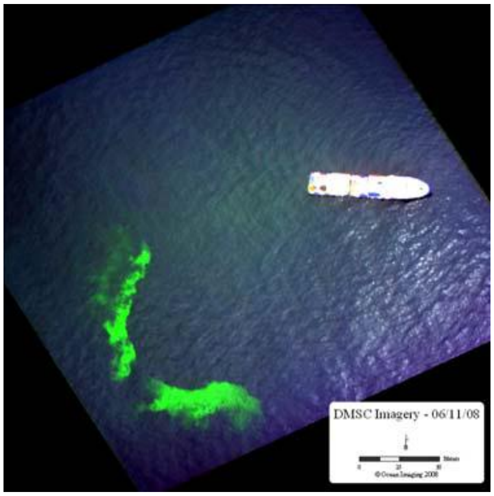
Navigation	
	Toggle Legend - clicking this tool toggles the "Legend View" & "Layer List"
	Overview map - toggles on and off the overview map located in the upper left hand corner of the map viewer
	Zoom In - zooms in to the specified area
	Zoom Out - zooms out to the specified area
	Zoom Full - clicking this tool will automatically zoom to the map's default extent
	Zoom Active - clicking this tool will automatically zoom the map to the extent of the active layer
	Zoom Back - clicking this tool will automatically zoom the map back to the previous extent
	Pan - click this tool and move the map in any direction
Selection	
	Identify - by selecting this tool and clicking it on an active layer, an html table will show attribute information, on the bottom of the map viewer, pertaining to the active layer
	Select Box - allows you to drag a box around shapes from an active layer and the corresponding attribute information will show up at the bottom of the map viewer
	Select by line or polygon - allows you to draw a line or polygon around features you want to select from the active layer
	Clear Selected Features - click this button to clear all selected features
Analysis	
	Query - allows you to query the attributes of the active layer
	Measure - allows you to draw a line to measure distance and segment distance. Use the set units tool to change units.
	Set Units - allows you to set your display units in feet, meters, kilometer and miles
	Buffer - allows you to buffer selected points,
	lines or polygons selected with the selection tool
	Print - allows you to print current map page view

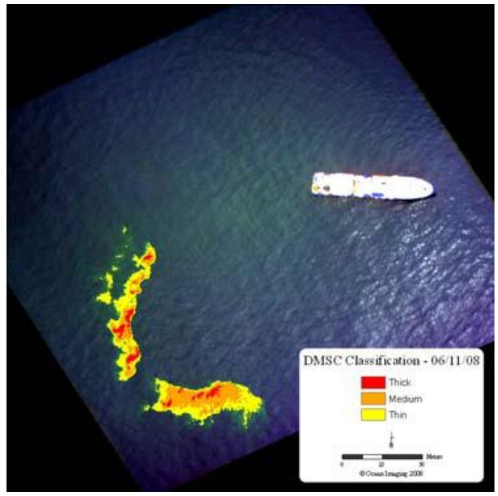
3.3 Field demonstrations

The developed oil mapping system has been fully integrated. It consists of: a) DMSC multispectral imager; b) Thermal IR imager; c) IMU/DGPS; d) Sprint wireless data network modem; e) directional antenna for the wireless network. The system was operationally tested on 6/11/08 as part of a Chevron initiated multi-agency oil spill drill off San Diego. The system was mounted in California Dept. of Fish & Game's aircraft and flown over the drill vessel which dispersed fluoroscene dye to simulate an oil slick. The vessel and "slick" were imaged simultaneously with DMSC and IR systems and the digital image data were then immediately sent to OI's server via the wireless data network from approximately 5 miles offshore. The data were then processed to "map" the oil slick and its "thickness" (simulated by dye intensity) distribution and posted on the (first generation) multi-agency distribution GIS server being developed by OI for OSPR. Total time between initial image acquisition and the final posting was 17 minutes. Figure 3 shows the original imagery as transmitted and the final classification posted on the GIS server.

MMS and OSPR collaborated on staging a technology demonstration exercise in the Santa Barbara Channel on 11/13/08. The objective was to provide a wide audience with hands-on opportunity to see the developed oil mapping system in action. Prior to the start of the exercise, a Radarsat SAR image of the Santa Barbara Channel was acquired by OSPR in near-real-time. This image showed as series of dark (ie. low radar return) areas west of Platform Holly, that could be indicative of oil slicks. A chartered vessel was used to bring the participants to the "suspected oil spill" area (which contains natural oil seeps). The spectator group was briefed on the nature and science of the seeps by UCSB researchers, and were shown a demonstration of oil boom and recovery equipment by Clean Seas who provided a vessel and equipment for the exercise. The participants then observed the CDFG aircraft conduct imaging flyovers over the oil features. Communication between the aircraft imaging crew and the observer vessel was conducted by radio. The Radarsat image and corresponding DMSC multispectral image are shown in Figure 4.

The imaged data were processed in-flight and posted on the web-based GIS server. Upon the observer vessel's return into Santa Barbara Harbor, an on-line demonstration and discussion of the imaging results was provided to the participants. The demonstration was well attended, with representatives from MMS, OSPR, Clean Seas, the U.S. Coast Guard, state and local government, and the news media. A report and interview on the project was broadcast on National Public Radio and several newspaper articles were published.





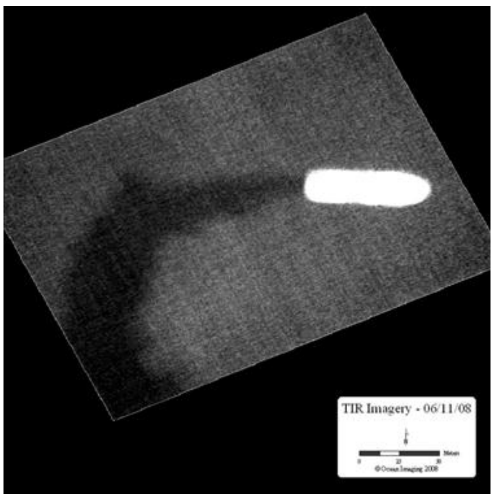
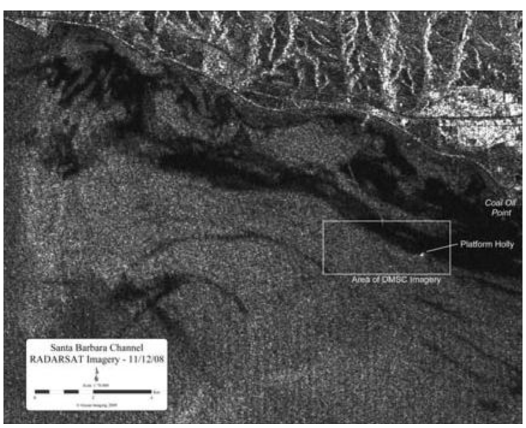


Figure 3. Multispectral (upper left) and thermal IR (lower left) imagery of the spill drill vessel dispersing dye simulating and oil spill. The images were sent to OI for processing directing from the aircraft. A GIS-compatible "oil" spill map (below) was posted on a web-accessible server 17 minutes later for multi-agency access.



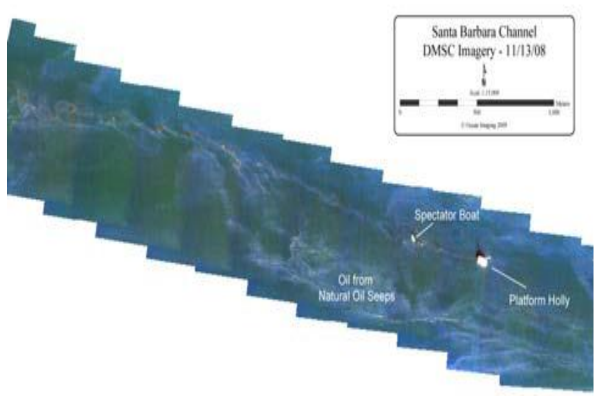


Figure 4. Radarsat SAR image (left) showing suspected oil slick features as dark streaks, and DMSC multispectral image (above) confirming the existence of oil on the surface acquired approximately 13 hours later. (SAR image Copyright by Radarsat International)

As part of this project, OI also participated in a regional oil drill in October, 2009 in the Santa Barbara Channel. The drill involved a hypothetical spill from an offshore platform. OI mobilized their system on both days of the drill in the CDFG Partenavia aircraft and imaged a suitable test target. With the multitude of natural oil seeps in the Channel, the objective was to image an actual crude oil slick, fully process the imagery and post it on the developed web server in near-real time. The image data were acquired and processed while still in-flight. The relatively large coverage area and hence file sizes made it difficult, however, to efficiently send the digital products from the aircraft via a wireless cell card. The plane therefore landed in Santa Barbara upon which the data products were uploaded onto the GIS server. (The wireless equipment worked much more efficiently while stationary on the ground.) On both days the fully processed GIS oil distribution maps were made available to OSPR and the rest of the Unified Command Post within 45 minutes of data acquisition.

4. OPERATIONAL USE DURING OIL SPILLS

During the second year of the project, the developed imaging and web server systems began to be utilized operationally during actual oil spills off California. The first instance was during response to a spill from an offshore oil platform in the Santa Barbara Channel in December, 2008 and the second in November, 2009 when oil was spilled into San Francisco Bay during a fuel transfer. The use of the developed technologies during these events is described below. It must be noted that since both incidents remain open cases from a legal standpoint, this report does not include information related to actual amounts spilled as computed from the imagery or other information deemed confidential to the case.

4.1 The Platform “A” spill in Santa Barbara Channel.

Early on 12/7/2008 staff working on Platform A in the Santa Barbara channel reported a spill from the platform due to a ruptured hose. The initial spilled volume estimate of 30 gallons was subsequently revised to 1100 – 1400 gallons. The response included aerial overflights by MMS, OSPR and privately chartered helicopter, Clean Seas and other ship deployment, and oil recovery. OSPR requested OI to conduct and overflight with the developed system in late afternoon on 12/8/2008. Image data were collected with the multispectral and IR sensors over the oil spill area. The data were immediately processed and posted on the web-accessible GIS system within 40 minutes of data acquisition, making them available to the Unified Command for guiding the recovery operations. OI conducted another flight on the morning of 12/10/08 and acquired, processed and

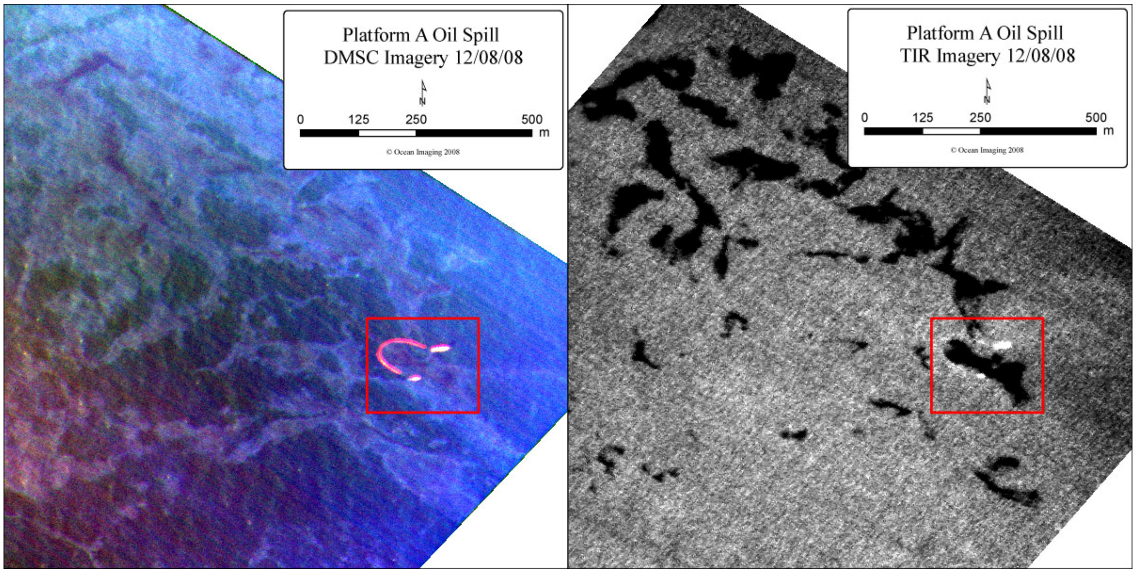


Figure 5. Unclassified multispectral visible (left) and thermal IR (right) imagery of part of the Platform A spill area. In the multispectral image different colors correspond to different oil thicknesses. In the IR data thinner films are not distinguishable but the thickest oil patches show strong contrast. Note the two response vessels surrounding a recoverable thickness oil patch with a containment boom.

disseminated the imagery within 30 minutes of initial data acquisition. The 12/10/08 imaging results showed only small areas of aged and emulsified oil in the general area, which were judged to be residues from natural seepage and not related to the spill. OI also found a small fresh sheen feature offshore which was linked by the responders to a diesel spill from a private vessel. The data supported independent aerial visual surveys that no more recoverable oil from the platform spill was present, and recovery operations were suspended. The 12/8/08 data were subsequently analyzed for total spill volume estimates. Because the imaging activities, thickness classifications and resulting total volume estimates are part of materials used for settlements in this incident, we are not authorized to reproduce detailed results in this public report. We are showing one example in Figure 5, which shows original multispectral imagery and thermal IR imagery of part of the spill area on 12/8/08. Since none of the spilled oil features exceeded the 0.2mm thickness limit of the multispectral data set, the multispectral data could be used to map oil thicknesses over the entire spill. The IR data were very useful, however, since they very strongly depicted the locations of the thickest, recoverable oil patches. The IR image in Figure 5 shows two recovery vessels successfully encircling one of these patches with a containment boom.

The use of the developed mapping system was well received by the responders and also received media coverage (e.g. http://www.oceanconserve.org/shared/reader/welcome.aspx?linkid=112837&keybold=oil%20AND%20%20spill%20AND%20%20cleanup).

4.2 The M/V Dubai Star spill in San Francisco Bay.

On the morning of 10/30/2009 the M/V Dubai Star tanker was refueling approximately 2.5 miles south of the Oakland Bay Bridge in San Francisco Bay. Around 7am the heavy IFO began escaping from the refueling system and into the Bay. A multi-agency response was quickly mounted and the Unified Command authorized OI to mobilize from San Diego and image the resulting spill. OI met up with CDFG's Partenavia aircraft, flew to San Francisco and imaged the spill around 3:30pm. The processed GIS image data were made available to Unified Command via the developed web server within 30-40 minutes of image acquisition. Figure 6 shows the collected imagery from the multispectral and thermal IR systems as well as the final thickness classification (the thickness color key is not included to maintain confidentiality of the total volume information).

The OI team imaged the affected region again in early afternoon of 10/31/09 (fog prevented any morning aerial recognizance). The remaining oil was aligned in a relatively narrow band along a current shear zone a few hundred meters to the northwest of its position the previous day. The system multispectral data revealed that some of the oil had become emulsified overnight. The processed data were uploaded onto the web server within 30 minutes of data acquisition. A pair of skimmers worked their way along the band, and thus recovered the vast majority of the remaining oil. As was the case in the Santa Barbara Platform A spill work, the second flight provided documentation of

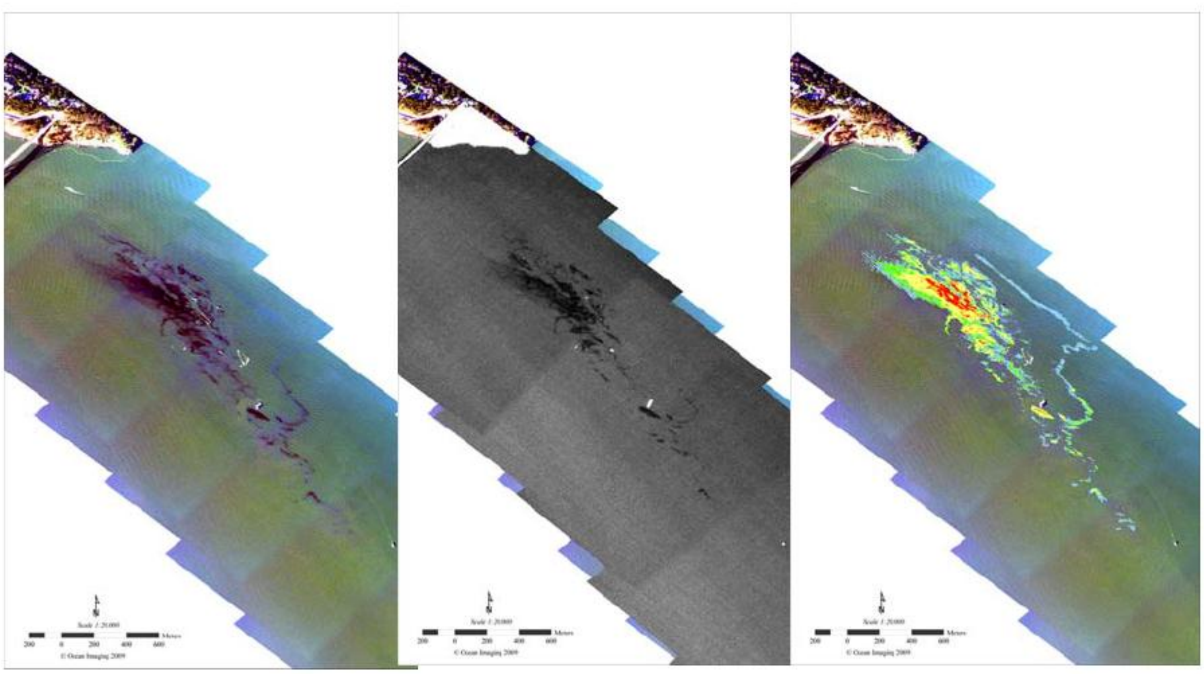


Figure 6. DMSC multispectral (left), thermal IR (center) and resulting oil resulting oil thickness distribution map (right) of the M/V Dubai Star oil spill on 10/30/2009.

the presence/absence of recoverable oil remaining in the area and thus served to verify when recovery operations could be suspended.

5. PROFESSIONAL PUBLICATION

Results from this and the preceding OSPR-funded projects have been presented at various conferences, including at the International Oil Spill Conference (IOSC) in Savanah, Georgia, May 4-8, 2008, and the Clean Pacific Conference in Portland, Oregon September 15-16, 2009. Results have also been presented at annual workshops co-organized by Chevron and OSPR in San Ramon, California. Papers discussing the work and results have been published in the IOSC 2009 Conference Proceedings and in Sea Technology (Volume 50(8), August 2009). A manuscript describing the completed work and operational applications is presently being prepared for publication in Marine Pollution Bulletin or similar peer-reviewed publication.