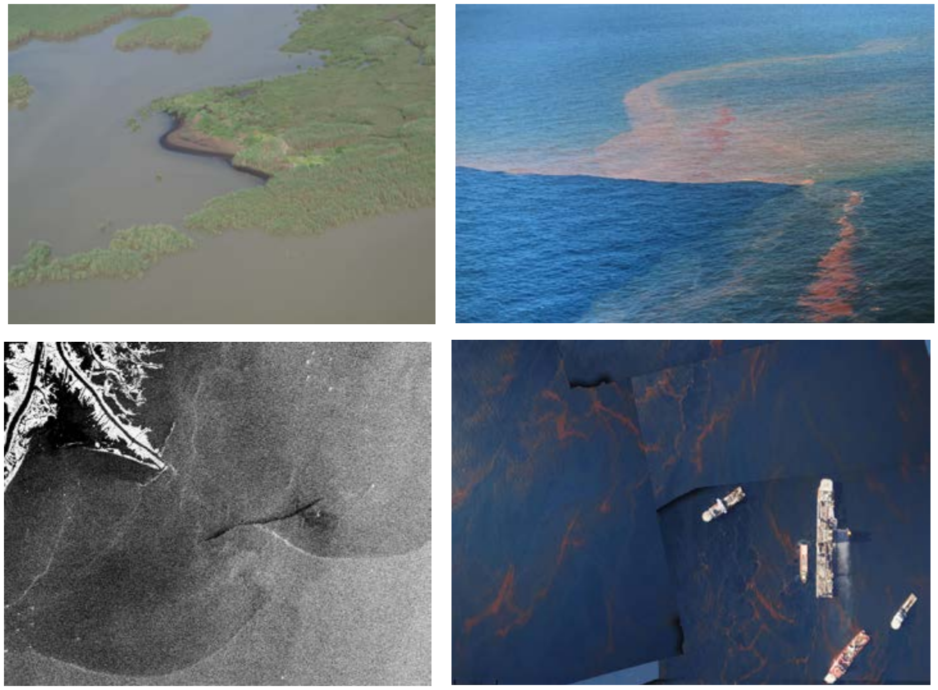

Photo Credit: Unified Command, U.S. Coast Guard

OIL OBSERVING TOOLS WORKSHOP REPORT

OCTOBER 20 -22, 2015

COASTAL RESPONSE RESEARCH CENTER

Acronyms

ADIOS	Automated Data Inquiry for Oil Spills
AIS	Automatic Identification System
API	American Petroleum Institute
ARD	Assessment and Restoration Division
ASPECT	Airborne Spectral Photometric Environmental Collection Technology
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AVIRIS	Airborne Visible Infrared Imaging Spectrometer
AVIRIS NG	Airborne Visible Infrared Imaging Spectrometer Next Generation
BRI	Bubbleology Research International
BSEE	Bureau of Safety and Environmental Enforcement
CA DFW	California Department of Fish and Wildlife
CALIOP	Cloud-Aerosol Lidar with Orthogonal Polarization
CGA	Clean Gulf Associates
COP	Common Operating Picture
COTP	Captain of the Port
CRRC	Coastal Response Research Center
DMSC	Digital Multi-Spectral Camera
DWH	Deepwater Horizon
ERD	Emergency Response Division
ERMA®	Environmental Response Management Application
FOSC	Federal On Scene Coordinator
FOSTERRS	Federal Oil Spill Team for Emergency Response Remote Sensing
FSU	Florida State University
GIS	Geographic Information System
GNOME	General NOAA Operational Modeling Environment
GPS	Global Positioning System
HD	High Definition
HICO	Hyperspectral Imager for the Coastal Ocean
HSRL	High Spectral Resolution Lidar
ICS	Incident Command System
IPIECA	International Petroleum Industry Environmental Conservation Association
IR	Infrared
ISODATA	Iterative Self-Organizing Data Analysis Technique Algorithm
KSAT	Kongsberg Satellite Services
LWIR	Long Wave Infrared
MARPLOT	Mapping Application for Response, Planning, and Local Operational Tasks
MDA	MacDonald Dettwiler & Associates Ltd
MODIS	Moderate Resolution Imaging Spectroradiometer
MPSR	Marine Pollution Surveillance Reports
MSRC	Marine Spill Response Corp
MWIR	Mid Wave Infrared
NASA	National Aeronautics and Space Administration
NCP	National Contingency Plan

NESDIS	National Environmental Satellite Data and Information Service
NOAA	National Oceanic and Atmospheric Administration
NRDA	Natural Resource Damage Assessment
NRL	Naval Research Laboratory
NRMRL	National Risk Management Research Laboratory
OCAP	On-Call Acquisition Planner
OEDA	Oil Emulsion Detection Algorithm
OGP	Oil and Gas Producers Association
Ohmsett	Oil and Hazardous Materials Simulated Environmental Test Tank
ORR	Office of Response and Restoration
OSPO	Office of Satellite and Product Operations
OSRL	Oil Spill Response Limited
OSRO	Oil Spill Response Organization
SAR	Synthetic Aperture Radar
SMART	Special Monitoring of Applied Response Technologies
SOP	Standard Operating Procedure
SPSD	Satellite Products and Services Division
SWIR	Short Wave Infrared
TCNNA	Texture-Classifying Neural Network Algorithm
TIR	Thermal Infrared
TM	Thematic Mapper
TRACS	Tactical Rapid Airborne Classification System
UAF	University of Alaska Fairbanks
UAS	Unmanned Aircraft System
UAVSAR	Uninhabited Aerial Vehicle Synthetic Aperture Radar
UNH	University of New Hampshire
USCG	United States Coast Guard
USEPA	United States Environmental Protection Agency
USF	University of South Florida

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George Graettinger, NOAA ORR, ARD, Spatial Data Branch
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Nancy Kinner, CRRC, UNH
Jeffrey Lankford, NOAA ORR, ERD, Technical Services Branch

ORR is NOAA's primary office charged with responding to oil spills, hazardous material releases, and marine debris. ORR is tasked with providing the science and information needed to support the USCG during spills and coordinating with federal, state, and tribal natural resource trustees to restore coastal resources damaged by those spills. ORR maintains an interdisciplinary team to forecast the movement and behavior of spilled oil and chemicals, evaluate the risk to resources, and recommend protective and cleanup actions. The office also provides training, prepares and tests spill response contingency plans, and conducts research to improve response capabilities.

The workshop was facilitated by Dr. Nancy Kinner, the UNH Co-Director of the CRRC (www.crrc.unh.edu). CRRC focuses on issues related to All Hazards, and has extensive experience with hydrocarbon spills. The Center is known for its independence and excellence in environmental engineering, marine science, and ocean engineering in regards to spills and other hazards. CRRC has conducted numerous workshops bringing together researchers, practitioners, and scientists of diverse backgrounds (government, academia, industry, and non-governmental organizations) to address issues in spill response, restoration and recovery.

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Gordon Staples, MDA
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*A list of Acronyms is provided on Page 1 of this report.

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1.0 Introduction

Since 2010, the National Oceanic and Atmospheric Administration (NOAA) and the National Aeronautics and Space Administration (NASA) have provided satellite-based pollution surveillance in United States waters to regulatory agencies such as the United States Coast Guard (USCG). These technologies provide agencies with useful information regarding possible oil discharges. Unfortunately, there has been confusion as to how to interpret the images collected by these satellites and other aerial platforms, which can generate misunderstandings during spill events. Remote sensor packages on aircraft and satellites have advantages and disadvantages vis-à-vis human observers, because they do not “see” features or surface oil the same way. In order to improve observation capabilities during oil spills, applicable technologies must be identified, and then evaluated with respect to their advantages and disadvantages for the incident. In addition, differences between sensors (e.g., visual, IR, multispectral sensors, radar) and platform packages (e.g., manned/unmanned aircraft, satellites) must be understood so that reasonable approaches can be made if applicable and then any data must be correctly interpreted for decision support.

NOAA convened an Oil Observing Tools Workshop to focus on the above actions and identify training gaps for oil spill observers and remote sensing interpretation to improve future oil surveillance, observation, and mapping during spills. The Coastal Response Research Center (CRRC) assisted NOAA’s Office of Response and Restoration (ORR) with this effort. The workshop was held on October 20-22, 2015 at NOAA’s Gulf of Mexico Disaster Response Center in Mobile, AL. Attendance at the workshop was by invitation only. Invitees were determined by consensus of the workshop organizing committee based on the expertise each could bring to the workshop discussion. Participants at the workshop included representatives of industry, government, and academia on regional, national, and international levels who have a wide array of experience related to oil observation tools (Participant list in Appendix B).

The expected outcome of the workshop was an improved understanding, and greater use of technology to map and assess oil slicks during actual spill events. Specific workshop objectives included:

- Identify new developments in oil observing technologies useful for real-time (or near real-time) mapping of spilled oil during emergency events.
- Identify merits and limitations of current technologies and their usefulness to emergency response mapping of oil and reliable prediction of oil surface transport and trajectory forecasts. Current technologies include: the traditional human aerial observer, unmanned aircraft surveillance systems, aircraft with specialized senor packages, and satellite earth observing systems.
- Assess training needs for visual observation (human observers with cameras) and sensor technologies (including satellites) to build skills and enhance proper interpretation for decision support during actual events.

The workshop consisted of plenary sessions, a series of hands-on training stations, and group breakout discussions (Agenda in Appendix A). It commenced with initial introductions and presentations on the need for oil observing in response, and current operational programs, oil observing tools, and data analysis. The participants were divided into groups for hands-on training on (1) traditional high resolution photography and video, (2) synthetic aperture radar (SAR), (3) Landsat/Tactical Rapid Airborne Classification System (TRACS), (4) balloons and vessels, and (5) night vision. Day 2 began with plenary presentations on new technologies and applications. The participants returned to groups for breakout sessions, identifying needs and gaps in oil observing technology, and subsequently performing a gap analysis on selected topics. The discussions/answers from each breakout group were summarized and presented to all participants during the following plenary sessions. Day 3 began with each individual ranking priorities for future oil observing tools, developments, and next steps (the potential solutions identified in the gap analyses the previous day). Then, the breakout groups discussed recommendations for a job-aid that could be developed regarding oil observing. The workshop concluded with breakout groups reporting on their discussions and several individuals were asked to summarize the workshop.

2.0 Plenary Sessions

A summary of each presentation from the workshop is provided below. Slides for the presentations are available in Appendix D.

2.1 Need for Oil Observing in Response

2.1.1 Scott Lundgren, NOAA ORR, ERD

Scott Lundgren discussed the need for oil observing in response primarily from the perspective of NOAA's ERD. For example, he discussed ERD's role in scientific support coordination reporting directly to the Unified Command, and the Environmental Unit of the Planning Section. He noted the associated oil observation needs to perform those roles and identified five key questions that need to be answered during a response: (1) What happened? (2) Where could the oil go? (3) What could it affect? (4) What harm could it cause? and (5) What can be done to help minimize the damage? Oil observations during a response are critical to help inform and answer questions #2 and #5 in terms of developing oil spill trajectory projections and determining what can be done to address the situation and reduce impacts. In order to do that effectively, information regarding oil observations needs to be accurate and timely. The oil detection information can be used to create a Common Operating Picture (COP), perform trajectory modeling, identify resources at risk, and provide on-water response support. Lundgren briefly reviewed some of the existing resources, tools, and technologies available to responders, and reminded the group that the majority of spills are relatively small scale spills where more basic technology is used. However, technology is moving quickly and the Deepwater Horizon (DWH) spill allowed for technology to expand into new arenas and for new technologies to be tested, as most spills are orders of magnitude below the volume and flow of the DWH spill.

2.1.2 James Litzinger, Gulf Strike Team, USCG

The USCG can act as the Federal on Scene Coordinator (FOSC) and Captain of the Port (COTP) during a spill. Litzinger explained the applicable regulations and authorities that could apply in an oil spill response. The National Contingency Plan (NCP), which gives the FOSC certain authorities, has four general priorities: (1) give safety and human health top priority, (2) stabilize the situation in order to prevent the event from worsening, (3) use all necessary containment and removal tactics in a coordinated manner to ensure timely, effective response, and (4) take action to minimize further environmental impact from additional discharges. The goals of the emergency response are to minimize the adverse impacts of the incident and to maximize public confidence and stakeholder satisfaction (by doing a good job and communicating well). USCG officials need oil observation information during a response to perform their duties as FOSC and COTP. They use a lot of information from aerial observations, NOAA's Environmental Response Management Application (ERMA®), and USEPA to make decisions during a spill. Remote sensing oil observations provide the COP, without which the odds of a successful response are lower. Oil observing is used to develop the best strategies and tactics to respond to the threat and minimize adverse impacts. For example, a plane cannot put dispersants on an area of oil, or a boat place boom to catch the leading edge of a spill, without knowing where the oil is going. The USCG also uses oil observations when choosing the best enforcement action(s).

2.1.3 Lisa DiPinto, NOAA ORR, ARD

Lisa DiPinto presented information on how oil observation data are important during response from the damage assessment and restoration perspective. Under the Oil Pollution Act (1990), Natural Resource Damage Assessment (NRDA) must: (1) determine the amount of injury to natural resources and lost services from the time of the incident through recovery of resources, (2) develop and oversee implementation of restoration plan(s) to compensate the public and natural resources for injuries and lost services, and to ensure the polluters pay for assessment and restoration. To perform injury assessments, oil observations are needed to assess: (1) surface oiling "footprints" of exposure, (2) percent cover of oil within the footprint, (3) persistence of surface oiling for exposure duration, and (4) surface oil thickness. Even sheens must be observed and documented because they may be toxic. In some cases, qualitative information is sufficient, but in many cases detailed information such as thickness and percent water in the slick are required. NOAA has used synthetic aperture radar (SAR) and aerial imagery together to document oiling for NRDA, which provided additional information regarding exposure in the nearshore environment that they would not have had otherwise. Ideally, future field sampling would collect many types of samples at once (e.g., satellite, overflight, surface water, subsurface water gradient, air gradient, slick thickness) so that as complete a picture as possible can be generated.

2.2 Current Operational Programs

2.2.1 NOAA ORR Oil Observing Program and Tools – Jeff Lankford, NOAA ORR, ERD

Jeff Lankford discussed NOAA ORR's current oil observing program. A large component of this involves human observers in airplanes or helicopters documenting their findings with notes and photographs. Overflights collect a variety of information related to the spill: location and size of the oil slick, oceanographic features (e.g., currents, convergence lines, rip tides), environmental conditions (e.g., winds, currents, visibility), and presence of wildlife in the vicinity. Human observations can also help identify false positives (e.g., kelp beds, sargassum, cloud shadows, natural slicks) and validate or recalibrate models. An overflight map is created using the observer's notes, photographs, and Global Positioning System (GPS) trackline. The map is available approximately one hour after the flight is completed. The advantages of human observation include: a fast turnaround for results, real-time decisions regarding where the aircraft should go, fairly accurate detection of the size of the spill by trained observers, the ability to conduct multiple flights per day and deploy tracking devices, and flexibility for use in rivers and lakes. Factors that can limit or prevent flights or observations include: poor weather conditions, equipment failure, limited pool of trained observers (i.e, there are not many available), use only during daylight hours, limited distance and time from home base, or delays encountered in generating the post-flight map. Flights are limited to 2 to 3 hours due to time restrictions and fuel capacity, and observations are limited to where the plane traveled. Lankford provided a list of equipment needed for overflights, and noted that observers bring backup equipment (e.g., GPS, cameras). He expects that future needs will be constrained by time and funding, but suggests a hand-held data tracker (e.g., tablet) would be useful to speed availability of information to decision makers. In addition, there is a lot of bureaucracy to address prior to flying an aircraft and using human observers (e.g., contracts, agreements, approvals). If these were streamlined, it could occur more quickly, more often, and would facilitate training additional observers. It was noted during the Q&A period that NOAA does not have a formal protocol to standardize aerial observations and photography.

2.2.2 NOAA NESDIS-MPSR and Remote Sensing for Surface Oil Assessment – Davida Streett, NOAA NESDIS OSPO SPSD Satellite Analysis Branch

Davida Streett discussed the Marine Pollution Program operated within the NOAA NESDIS Satellite Analysis Branch. The NESDIS program operates continuously (24, 7, 365) and provides satellite imagery and analysis for a variety of hazard mitigation programs. Marine Pollution Surveillance Reports (MPSR) provide spill and dumping monitoring for huge areas, and can be the first warning of a spill. A variety of ancillary data are used to reduce false results. NESDIS data can be used to (1) provide input to oil spill trajectory models, (2) compare results from various models, (3) verify areas that do not need spill response (i.e., there is no oil), (4) reassure the public that areas are being monitored daily, (5) determine where overflights should be performed, (6) provide coverage when aircraft cannot fly due to weather, and (7) provide resources for use by the media during high profile spills. NESDIS data are often the primary means of developing a synoptic picture of very large spills.

The biggest limitation for routine monitoring (e.g., releases from ships) is lack of available imagery, which is especially limited at night and under cloud cover when most of these events occur. For moderate spills, there is a little more imagery available (with some delay). The possibility of having the National Geospatial-Intelligence Agency task commercial satellites to collect such data would be a big improvement. During large spills, an International Disaster Charter is activated, so member countries provide imagery for free. While the amount of imagery vastly increases, challenges still remain in how to integrate this information into the response, because it is unfamiliar and has format issues. Streett identified the need for (1) more imagery in a timely manner (2) a quick/approximate method of determining oil thickness (distinguish sheens from recoverable oil) (3) experience/algorithms/ collaborative framework/user interactions/education to eliminate false results, particularly in the Arctic where there is little experience.

Ongoing collaborations (e.g., Federal Oil Spill Team for Emergency Response Remote Sensing [FOSTERRS]) encourage interagency cooperation to ensure that during a spill oil observing techniques and imagery can be quickly, effectively, and seamlessly used to support the response. FOSTERRS is interested in ensuring that new technologies are developed where existing ones do not meet responders' needs.

2.2.3 USEPA ASPECT – Mark Thomas, USEPA

Mark Thomas discussed the current capabilities and proposed enhancements to the USEPA's Airborne Spectral Photometric Environmental Collection Technology (ASPECT) remote oil detection system. It provides 24/7 emergency response capability and is activated with one phone call. An aircraft takes off within one hour of activation, and can collect chemical, radiological, and imagery data. Once data are collected, it takes approximately 5 minutes to process onboard and provide oil location and relative thickness to first responders. ASPECT products are provided in Google Earth/Maps and ESRI formats. ASPECT costs $1,300 per flight hour. Due to difficulties with traditional aerial photography (e.g., low oil to water contrast, high glare/glint contamination, day light dependent, difficulty in interpretation), the open ocean detection system uses multispectral infrared imaging systems (which also allows for nighttime use). An Iterative Self-Organizing Data Analysis Technique Algorithm (ISODATA) method is useful and permits various levels of oil content/water content to be contoured. Shallow water oil detection is complicated by the thermal environment of near shore waters, and therefore requires the use of multispectral multivariate methods. The program has found that spectral pattern recognition is most effective in this case. More information on ASPECT sensors, systems, methods, coverage areas, resolution, and speed of coverage can be found in the presentation slides (Appendix D). Mr. Thomas also reviewed planned upgrades to ASPECT, including the imaging sensors (expected March 2016) and software (expected late 2016). The software should be able to support oil spill response efforts ranging from tropical waters to Arctic ice.

2.2.4 NASA Programs – Cathleen Jones, NASA Jet Propulsion Laboratory

Cathleen Jones gave an overview of current NASA programs on oil observation including a table showing existing spaceborne instruments and satellites (Moderate Resolution Imaging Spectroradiometer [MODIS], Advanced Spaceborne Thermal Emission and Reflection Radiometer [ASTER], Multi-Angle Imaging SpectroRadiometer [MISR], Hyperspectral Imager for the Coastal Ocean [HICO], Cloud-Aerosol Lidar with Orthogonal Polarization [CALIOP]) and details of each (e.g., bands, resolution, swath). MISR combines different viewing angles/directions and bands to help detect false positives (e.g., distinguish oil from clouds). Jones provided a similar table of airborne sensors (Airborne Visible Infrared Imaging Spectrometer [AVIRIS], Uninhabited Aerial Vehicle Synthetic Aperture Radar [UAVSAR], High Spectral Resolution Lidar [HSRL]) along with images from each technology. During the DWH spill, NASA analysts were able to quantitatively map thickness of oil using AVIRIS. UAVSAR is NASA's L-band synthetic aperture radar. UAVSAR is very good for monitoring oil spills because it has a very fine resolution, quad polarization, and a high signal to noise ratio. It "sees" through clouds, fog, and storms, and data collected during the DWH spill was used to develop a method to quantify the oil volumetric fraction. It can distinguish where oil has landed on beaches and along vegetated shorelines in wetlands, and can be used to identify newly oiled areas overnight.

Oil can be difficult to distinguish from new/thin sea ice using SAR, however, recently published work (Brekke, 2014) has yielded promising methods. NASA is interested in developing this capability further to study and respond to oil on ice spills. With respect to logistics, UAVSAR flight cost is $3,000/hour for NASA-approved users. NASA is working with other agencies to facilitate rapid response using UAVSAR. If the UAVSAR aircraft is available, the instrument can be deployed within 24 hours. NASA recommends that NOAA communicate ahead of time if they may want to use UAVSAR. The instrument is designed for portability to different platforms, and products are usually available in 24 hours. NASA participated with UAVSAR in a Norwegian oil-on-water spill exercise in June 2015 that involved controlled releases of oil in the North Sea. Goals included: (1) studying slick development, transportation, and weathering; (2) characterizing volumetric oil fraction of slicks using polarized SAR; (3) differentiating mineral oil spills from biogenic slicks using SAR; and (4) evaluating onboard processing capability. This research will advance the use of SAR for spill response.

Q&A

Some of the discussion emphasized the need for oil remote sensing to identify “recoverable oil”. The term “recoverable oil” depends on what method of response is used (e.g., in situ burning, skimming, dispersant application) and the resources available (e.g., the grade of the skimming equipment). In some cases, knowing where the heaviest oil is located is sufficient (without detailed measurements). In other cases, knowing the oil volume per pixel (or another related measurement) would be ideal.

2.3 Current Oil Observing Tools and Data Analysis

2.3.1 SAR – Gordon Staples, MDA and Oscar Garcia, Water Mapping LLC

Gordon Staples discussed spaceborne radar capabilities, and data acquisition, processing, and delivery. Spaceborne radar is an established tool for emergency response that can provide situational overview, broad coverage area, relatively low cost, easy deployment, and all-weather day and night imaging. Oil slicks are detected from the images using a combination of analyst knowledge and algorithms. Data can be provided in many formats (e.g., Geo TIFF, PDF, SHP, KML) and provide information on surface area of the spill, wind speed and direction, and locations of vessels and infrastructure. Spaceborne radar analysis can be integrated into ERMA® and combined with other data to form a COP. The time from the initial request until delivery of the product varies, but can be obtained in four hours during an emergency.

Oscar Garcia presented his work using satellite remote sensing to study the 11 year old Taylor Energy oil leak in the Gulf of Mexico. He presented a table of current and future sources of SAR data, and images from four sensors for the same oil slick conditions. He stressed that an aerial observer should always confirm the SAR data. Garcia believes that SAR can detect the presence/absence of oil and emulsions, including relative thickness. He recommended using the Taylor Energy site to test/compare oil remote sensing technologies, as well as experiments at the Bureau of Safety and Environmental Enforcement’s (BSEE) Oil and Hazardous Materials Simulated Environmental Test Tank (Ohmsett) facility.

2.3.2 Landsat/TRACS – Mark Hess, Ocean Imaging and Kevin Hoskins, MSRC

Mark Hess and Kevin Hoskins stressed the importance of multi-level, tactical remote sensing to efficiently put response resources in the best location (day and night) to recover oil. In past spill experience, responders have been less interested in a numerical value of oil thickness vs. knowing the location of "recoverable" oil. In order to do this, real-time tactically-oriented information is needed quickly (e.g., identifying and tracking actionable oil). The Ocean Imaging-Marine Spill Response Corp (MSRC) "ABC" (Aircraft-Balloon-Close-in) remote sensing strategy was developed specifically for this purpose. Rapidly deployable portable tools, based on multiple sensors and platforms, provide an oil spill mapping system that combines thickness estimates from visual oil spill surveys with digital capabilities (e.g., thermal imaging) for real-time direction of recovery assets as well as near-real-time input into the COP. This combination provides greater spatial detail and uses wavelengths outside those in the human range. Combined visible multispectral and thermal-infrared (IR) imagery provided by Ocean Imaging's TRACS system improves thickness measurements, oil characterization, and location capability. One challenge is getting information distributed to the on-water responders quickly and efficiently. Ocean Imaging and MSRC are researching technologies that can provide efficient, moderate-cost air-to-ground communication links to deal with this challenge. The "B" and "C" components of the ABC system allow the responding vessels to further hone in on the oil deemed most actionable oil.

2.3.3 AVIRIS Next Generation – Ira Leifer, BRI, presented by Chuanmin Hu (USF)

Chuanmin Hu presented Ira Leifer's information on AVIRIS Next Generation (AVIRIS NG) and its use in the Refugio Incident Spill. AVIRIS NG has better geolocation, finer resolution, and an improved signal to noise ratio than AVIRIS. While AVIRIS NG was used during the Refugio spill, it was not until several days into the incident, when oil slicks were minimal. AVIRIS NG maps contaminated areas by matching target spectra (e.g., the spectral signature from a laboratory oil) to observed spectra (actual observed spectral signature of oil in environment). Other materials besides floating oil, such as sargassum or debris/trash, can also be identified by their spectra, helping to identify false positives. The primary application demonstrated for AVIRIS NG in the spill was beach tar mapping. AVIRIS NG had a spatial resolution of 30 cm at the altitude flown and can map 30 km of beach in 30 minutes, and provide real-time data telemetry to Incident Command.

2.3.4 Oil Spill Response Limited (OSRL) – Jean Teo, OSRL

Oil Spill Response Limited (OSRL) is an industry-funded international (outside the U.S.) organization that provides oil spill preparedness and response services. Jean Teo gave an overview of OSRL's oil observing tools including satellite imagery, tracking buoys, trained observers, and aviation platforms. CarteNav AIMS is a software that overlays key information to assist with response tasking. It quantifies the extent of the oil slick and relays real-time information (e.g. images, slick perimeter) to ground stations. For satellite imagery, OSRL and MDA work together to provide radar imaging and optional visual capability. On average, there are two satellite overpasses globally per day. Buoys are used to track and monitor surface oil using a bi-directional iridium satellite system. Trained observers use a camera and GPS, and employ quantification tools such as the Bonn Agreement Oil Appearance Code. OSRL combines different technologies (e.g., oil spill modeling, satellite imagery, digital mapping) to increase the usefulness of the visual observation reports. In 2014, OSRL participated in an exercise which released oil and diesel fuels into United Kingdom waters. Various vessels, equipment, technologies, and overflights monitored movement of the oil, its recovery, and dispersant effectiveness. Lessons learned included that surveillance and modeling are essential for effective containment and dispersant operations, and that integrating numerous data sources into useful intelligence is extremely valuable, but requires significant planning to ensure timely and comparable data.

2.3.5 Night Vision Applications – Mark Roberts, U.S. Army

Mark Roberts discussed available night vision (infrared) applications the U.S. Army and BSEE are developing that could allow oil spill response operations to be more effectively conducted in low light environments. Near infrared is what is most commonly referred to as “night vision”, with the signature green hue. Lower quality but very effective analog-based night vision goggles are even available at stores (e.g., Walmart). Digital technologies have advantages over analog, such as allowing for post processing, and information can be sent directly to a command post for evaluation. Currently for low light and degraded environments, sensor technology is available in near infrared, short wave infrared (SWIR), mid wave infrared (MWIR) and long wave infrared (LWIR). Using SWIR, water appears opaque so the viewer sees what is on top of it. SWIR is expensive and still a relatively new sensor but from an airborne platform it is very useful to distinguish false positives (e.g., vegetation). MWIR, used mostly in aircraft, offers higher resolution in degraded environments, but is expensive because the detectors require cooling. LWIR technology shows the most promise for oil detection, identification, and thickness estimates. LWIR can be used in less than ideal weather conditions, and uncooled sensors allow for smaller and lower cost sensors. Overall, a multispectral approach with real-time post processing is the most promising for oil observation during spill response. However, he did not feel a true hyperspectral sensor is needed due to cost and the few wavelengths that are actually needed to detect and quantify oil on water during a spill response.

2.4 New Technologies/New Applications

2.4.1 NASA Out-Year Planning & Expectations – Sonia Gallegos, NASA, presented by Cathleen Jones, NASA

Cathleen Jones presented information from Sonia Gallegos on NASA out-year planning and expectations. All information from NASA is summarized in Section 2.2.4.

2.4.2 NRDA/Assessment Use: DWH Multi-sensor Assessment - Jamie Holmes, Stratus Consulting

Jamie Holmes discussed how data integration from multiple sensors was used for the DWH damage assessment. SAR provides the greatest sensor coverage (i.e., northern Gulf of Mexico nearly every day). MODIS offers advantages such as high spatial and temporal coverage, and published methods for detecting oil. However, MODIS has coarse resolution and is subject to weather limitations. Landsat Thematic Mapper (TM) has a relatively high resolution, but has limited temporal coverage (i.e., one image every 8 days during DWH) and also has weather limitations. AVIRIS has high resolution and is hyperspectral, though has narrow flight lines (i.e., limited spatial coverage), limited temporal coverage (i.e., only one day during DWH), and weather limitations. Ocean Imaging's Digital Multi-Spectral Camera (DMSC)/Thermal Infrared (TIR) imager has a high resolution and almost daily imagery, but does have weather limitations and narrow flight lines. Thick oil could be discerned using the high resolution sensors (AVIRIS and DMSC) and thick oil could be inferred in the more coarse satellite data using similar spectral relationships similar to those in the high resolution imagery. There is also a SAR analysis method for detecting emulsions. The Oil Emulsion Detection Algorithm (OEDA) was used during the DWH NRDA to delineate thick, heavy oil emulsions. A multi-sensor integrated model was developed for the DWH NRDA to create a single integrated product using the best available data and provide a rough thickness assessment, although the model was not completed before the DWH settlement occurred. For future incidents, more synoptic sampling and ground-truthing of remote sensing imagery should be collected. Overall, using remote sensing data to estimate adverse impacts on biota is a challenge (due to low resolution of the data) but has significant potential going forward.

2.4.3 NRDA/Assessment Use: DWH SAR Applications – George Graettinger, NOAA ORR, ARD

George Graettinger discussed the application of SAR for NRDA. A NRDA assessment requires demonstration of causality (i.e., the oil causing injury). A key component of this is determining exposure, and SAR can help with this assessment by documenting the extent of surface and potential shoreline oiling. SAR oiling features can also add value to traditional assessment techniques and modeling (e.g., SCAT, pre/post oiling screening). NOAA NESDIS created oil footprints for almost every day of the response, primarily using SAR data. During the DWH response SAR oiling extent assessment was performed manually by NESDIS analysts. However, during the DWH Damage Assessment a semi-automated approach was developed and deployed. This automated approach, known as the texture-classifying neural network algorithm (TCNNA) pre-processes images prior to final assessment by the analyst. This process produced more consistent delineations in a more timely fashion. NESDIS and a team from Florida State University (FSU) jointly developed TCNNA and first published the method in 2009. SAR TCNNA derived sensor products include daily composites, a cumulative composite, cumulative days of oiling, days of shoreline oiling, and time of oiling. Images of these products were shown during the presentation. Days of shoreline oiling defines initial near shore exposure dates, and characterizes the duration and persistence for potentially exposed shorelines. A time of oiling shoreline grid allows water and sediment samples (characterizing chemical concentrations) to be rapidly filtered for pre/post oiling conditions. The use of SAR data helps prioritize NRDA assessment efforts for habitats and species assemblages at the greatest risk of exposure. Current and emerging applications of SAR data will provide significant support to the NRDA process in future incidents. Because medium to large response and assessment efforts often rely on SAR data, it is important to coordinate between the Unified Command and Agency technical experts to ensure that the use of these data are understood and then to collect, analyze, and deliver the appropriate information efficiently.

2.4.4 UAS Potential Use & Limitations – Michele Jacobi, NOAA ORR, ARD

Michele Jacobi presented on Unmanned Aircraft Systems (UAS) potential uses and limitations. UAS can be helpful for response and assessment data by accessing areas that may be difficult to reach (e.g., issues of distance or safety). A UAS survey could collect a variety of information including: oil coverage/extent, convergence zones, sensitive habitats, targeted species, socio-economic impacts, marine debris, ephemeral data collection, and images for use in public outreach. A UAS has similar weather limitations to manned aircraft. NOAA has tested UAS deployments for oil observing and resources observations, as well as during the Refugio (CA) oil spill. The NOAA Puma UAS covered a large portion of the spill area during the Refugio incident in a single day, but the resolution was not adequate and outputs could not be spatially rectified. The Puma High Resolution Nadir camera also was tested and produced a high resolution geo-rectified image for Refugio. Ideally, Geo Tiffs would be available for input into the ERMA® COP within 30 minutes of the end of the flight and derived products within four to six hours. That delivery specification has proved difficult, (though industrial representatives said this was possible). Working through all the logistics of flying a UAS can be challenging, involves a high degree of coordination for approvals, and may not be practical if other manned air operations are occurring during an incident. A contracting vehicle is needed so that funding within the appropriate Incident Command System (ICS) structure can occur quickly. Further evaluation is needed regarding UAS collection platforms, mission needs, and improved information flow. Jacobi presented a table outlining mission requirements. Again, the improvement of information flow and pre-planning between ERD and ARD is essential.

2.4.5 KSAT – Multi-Mission Near Real-Time Satellite Imagery – Carles Debart, KSAT

Carles Debart presented about the Multi-mission and Near Real-Time satellite data delivery and services available through KSAT. KSAT has an extensive network of ground stations including one in Svalbard Island, a unique location near to the North Pole from which to access data from polar orbiting satellites. This provides the shortest possible acquisition-to-delivery time globally (≤ 2 hours), accessing 85 satellites and 20,000 passes per month. In North America, the expected delivery time from KSAT SAR satellite's portfolio is about one hour from acquisition. Debart showed a spreadsheet of the satellites that would be available for an example oil spill scenario off Mobile, AL, including when each satellite image would need to be ordered to ensure the satellite can be tasked before cut-off times, and when the images and oil spill detections would be distributed to the response teams.

3.0 Hands-On Training Stations

Five stations were available for attendees during the hands-on training session.

3.1 Traditional High Resolution Photography and Video – Jeff Lankford, NOAA ORR, ERD

Jeff Lankford, with the help of Lexter Tapawan (NOAA ORR ERD Geographic Information System [GIS] staff), gave an overview on making an overflight map. The trained aerial observer takes a camera, GPS, notebook, and perhaps a basemap on the flight and collects photographs, notes, and GPS coordinates. Upon return, the observer gives the GPS unit, camera, and field notes to an information manager.

Garmin MapSource software is used to extract waypoints and track logs from the GPS unit. Three files are exported: gpx file (the primary file used for map creation) and gdb and txt (backup files). Mapping Application for Response, Planning, and Local Operational Tasks (MARPLOT) is used as a platform for the gpx file, where some edits are made. Ideally, the information manager and overflight observer have a post-flight briefing. The information manager goes through each waypoint with the overflight observer to generate notes corresponding to a particular waypoint/observation. Electronic data capture could help address the difficulty of a face-to-face briefing during an actual spill. The shapefile is then brought into a template in ArcMap and notes are added as text boxes. Photo points can also be added. The map is reviewed by the overflight observer and then exported into various formats and distributed. Because the process is tied to ArcMap it is not possible to create this map without GIS staff. In the future, NOAA ARD and ERD need to coordinate, perhaps by having a Standard Operating Procedure (SOP), so that the data collected during overflights can be used for NRDA (e.g., noting the presence of sargassum).

3.2 SAR - Gordon Staples, MDA

An MDA On-Call Acquisition Planner (OCAP) (available 24/7) is given the location and approximate size of the spill, and availability of spaceborne radar services is accessed. A contract must be in place to request an order; the U.S. government and most large oil companies have these. MDA has three direct downlink locations in North America. The practical minimum time from the initial request to acquisition is 12 hours. Four hours is possible, but only for large-scale emergencies. Once the image is acquired, analysis time and data delivery typically take less than two hours. There can be conflicts if a satellite is already tasked for another acquisition. Sometimes conflicts can be resolved to obtain the image as quickly as possible, but not always. Staples presented an example oil spill scenario in the Gulf of Mexico, for which an oil spill outline and oil tracker report (via email) and processed SAR data (via ftp site) would be delivered within 18 hours after notification. False positives (if detected) are delineated and wind speed and direction. Confidence intervals are assigned based on the imagery along with knowledge of the area. MDA has worldwide coverage (accessing many satellites) except for a part of the Arctic and Antarctic and some countries (e.g., Iran). The larger the swath width, the lower the resolution (the most common is 50 m resolution for a 300 km swath which provides 90,000 sq km of coverage in a single image).

3.3 Landsat/TRACS – Mark Hess, Ocean Imaging

Mark Hess discussed TRACS, aerial mission planning, data acquisition for tactical use, oil classification, and data delivery strategies. There are many considerations to take into account:

- Aircraft (e.g., understand differences between mounting unit and flying in a non-pressurized vs. pressurized aircraft, FAA certification, portholes have to be right size, maximum allowed altitude).
- In order to quickly locate to site of the incident and utilize aircraft of opportunity, camera technology should be portable and be able to be checked onto commercial aircraft without being damaged.

- Visual observers are still very important. They are not eliminated by this technology (i.e., they determine what images to collect).
- Consider time of day of overflights - flights in morning and afternoon are best to avoid sun glint.
- The intended purpose of the acquired data must be known to optimize mapping, recovery, and monitoring.
- Consider flight altitude in order to maximize efficiency of overflights and data collection based on size of spill.
- Know your target area. Open ocean data acquisition is very different from coastal. For example, the rocky intertidal zone is one of the most difficult areas to monitor because biota growing on the rocks are black and absorb heat.
- TRACS system can be used in multiple ways. 1) direct tactical information communicated to responder vessels, 2) creation of 'quick view' image mosaics sent down to boats to provide them a picture of the situation and 3) further classification of the incident imagery to generate oil type and thickness classification maps for ingestion into the COP.
- A good internet connection is critical to upload/offload data (e.g., a poor internet connection required 2 hours to transfer data during the Refugio spill).
- A combination of multispectral and thermal data is best to identify what type of oil is present (i.e. thicker oil vs. sheen, fresher oil vs weathered and emulsified oil). Multispectral and thermal data can be co-located where one appears on top of the other in order to improve the efficacy of the classification process and the information products generated.

3.4 Night Vision Applications - Mark Roberts, U.S. Army

The night vision training was held in a dark area, so workshop participants could try the technology. The U.S. Army can loan these to other Federal agencies, but not private entities. However, they can offer support with collection assistance to any potential user. Raw video footage that was taken from a helicopter at pre-dawn demonstrated the user could see a lot of detail. With night vision technology, thicker areas of oil can also be determined because those areas appear cooler (depending on the settings of "black hot" or "white hot" these areas would appear brighter or darker than other areas). The best times to use night vision technology are pre-dawn (complete lack of solar energy) and mid-day (complete overwhelming solar energy), resulting images are reversed in these cases. The worst times of day are at thermal cross-over just after dawn and evening pre-sunset (in these cases there will be no thermal diversity). The cost of night vision technologies varies: devices cost $60,000 to $100 (i.e., excellent to adequate resolution). Cooled sensors are higher resolution but are some of the more expensive options. Some technologies integrate directly to an iPhone or Android. A multispectral approach helps to distinguish false positives.

3.5 Balloons and Vessels – Kevin Hoskins, MSRC

Kevin Hoskins discussed aerostat systems, which may be deployed from a vessel or the shoreline in support of day and/or night operations. Aerostats may be flown at altitudes up to 500', which provides a much broader view of the response area given the high height of eye, therefore enhancing the ability to identify and stay in the most actionable oil. The sensing unit on the balloon contains gimbal mounted High Definition (HD) and TIR cameras, as well as an Automatic Identification System (AIS) repeater. The sensing unit equipment is powered by a 12 VDC battery, which is incorporated into the balloon's kite assembly. The balloon can be flown in winds up to 34 knots. The viewer terminal allows the operator to control the camera view and identify the coordinates of potential targets. This positioning information can be overlaid onto a sea chart for further clarity. The operator also has the ability to see images in 100% optical or 100% IR, or any combination thereof. This is a very useful feature in determining if targets are actionable or may be false positives. The IR camera can be switched from white hot to black hot modes depending on conditions. Finally, both cameras have record capability and the operator can also capture screen shots of the viewer terminal screen.

3.6 Lessons Learned from Hands-On Training – Plenary Panel

Following the hands-on training, a panel of responders discussed lessons learned and practical applications:

Judd Muskat - California Department of Fish and Wildlife

- Radar satellites are fantastic for providing synoptic coverage. They are a great tool for first alert, and can cover hundreds or thousands of miles instantaneously. However, false positives are a problem. The California Office of Spill Prevention and Response uses Ocean Imaging's TRACS system to provide a quick determination of whether oil is present, its condition (e.g., fresh or emulsified), and the thickness distribution within the slick.
- Aerial observers should employ the best achievable technologies such as thermal imaging night vision goggles, similar to those demonstrated during the hands-on session.

Lisa DiPinto – NOAA ORR, ARD

- Oil observing needs are different for small vs. large spills. For small spills, numerous types of sensors, images, and specialists would not be used.
- Because of the potential of litigation, data and analyses have to be of high quality and defensible when collected for NRDA. False positives are a problem. Each oil observation product or technology must be defensible and have stronger validation than is currently available.
- It would be good to standardize overflight maps and make them more "high tech". For the long term NRDA cases, it would make a significant difference if additional information is collected during overflights (e.g., distance to object, camera angle). This could probably be done for not much more cost and not slow up the response people.

Robyn Conmy - USEPA

- Conmy also noted oil observing needs are different for small vs. large spills.
- Needs are also different for short-term vs. long-term monitoring (e.g., immediate response vs. NRDA).

- More trained aerial observers are needed (i.e., NOAA has five observers). Observer techniques could be improved in various ways (e.g., additional handheld instruments, reduce the subjectivity of the process).
- False positives are problematic. In the long term, infrared, SAR, and multispectral technologies are needed to rule out false positives.
- Data transfer to the FOSC is critical (e.g., good connections and platforms to speed information transfer).
- Plumes within the water are important to damage assessment. Methodologies for plume detection need to be incorporated into guidance documents such as the Special Monitoring of Applied Response Technologies (SMART). There are ongoing efforts to do this.
- The detection of a heavier oil released from a pipeline needs to be expanded (e.g., test bed studies at Ohmsett on different types of submerged oils).
- EPA is also responsible for inland waters, so detection in big rivers and lakes must be possible.

James Hanzalik - USCG FOSC (Ret.), CGA

- He reiterated the different needs between incidents of short (hours-days) vs. long (weeks-months) duration.
- Oil observation technologies must help the FOSC determine what resources/response measures to deploy first (e.g., in situ burning, dispersant application, protective boom, skimmers).
- Response decisions are normally based on the oil's trajectory, especially for longer duration incidents. Having the best tools to inform the personnel providing the trajectory (e.g., infrared, visual, or other) is important. As experienced during DWH, often the majority of the oil in the trajectory was sheen that was not recoverable and resources may have been misdirected to respond to those areas.
- There appears to be no lack of oil observing technologies, only a need to integrate them into existing systems.
- While much information can come from these technologies, it is most important that the right information gets to the decision-makers in a timely manner.
- Some technologies that are promising include:
    - Balloon and UAS systems – to deploy cleanup vessels to where the most oil is located. During the DWH spill, vessels were not always in the best locations.
    - Night vision or thermal imaging – can facilitate nighttime operations and 24/7 oil tracking.
    - Geotagging information – is important to locate where the oil is observed.

4.0 Breakout Sessions

4.1 Breakout Session 1 – Needs and Gaps in Oil Observing Technology

During the first breakout session, each group was asked to brainstorm needs that exist in oil observing technology and justify their selections (e.g., quickly need to know where heavy oil is to effectively manage tactical response). Results of each group can be found in Appendix G.

4.2 Breakout Session 2 – Gap Analysis

For the second breakout session, 13 of the needs that were identified in the first session were selected by the organizing committee and considered "gaps" for further analysis by the breakout groups. Needs were selected as gaps if they were complex technical or policy/protocol needs that would benefit from further analysis. Needs that were straightforward action items were not selected for the gap analysis, but are available in Appendix G. Each group was assigned three of the selected gaps to analyze. There was some overlap in the gaps assigned to the groups to gage the diversity of viewpoints. The groups provided the following information about each gap:

- Applicable location
- Technical limitations causing the gap
- Other issues or limitations causing the gap
- Potential technological solution
- Schedule to develop solution
- Cost to adapt technology to oil observing
- Logistics for deployment
- Other notes/considerations

Results from each group are provided in Appendix G.

4.3 Plenary/Breakout Session 3 – Prioritize Needs and Path Forward

At the beginning of Day 3, participants were asked to rank (high, medium, low) in order of priority, the potential solutions that had been identified to address the gaps discussed during Breakout Session 2. Participants did not rank solutions outside their area of expertise. Forty-nine of the participants submitted rankings. Table 1 shows the highest ranked priorities. The table includes whether the solutions are technical or policy/protocol related, short or long term, and relatively high or low cost. The ranking sheet, detailed results, and method of scoring are shown as Appendix H.

In addition, as part of the path forward, the general consensus was that a job aid should be developed on oil observation technology for oil spills. During the third breakout session, participants were asked to discuss who the audiences should be, what the most important sensors are to include, and other things they would like to see included. Results for each group are provided in Appendix G. As part of the session, the job aids developed or being developed by industry and BSEE were presented. American Petroleum Institute (API) published a Remote Sensing in Support of Oil Spill Response Planning Guidance (API, 2013), which includes the following: incorporating remote sensing into oil spill response and mission support planning, establishing a remote sensing team, determining the appropriate technology, deploying the technology, and analyzing and communicating data. An assessment of current research and emerging trends in surveillance technologies for oil spill response is also included. The Naval Research Laboratory (NRL) is currently finalizing a remote sensing selection guide for BSEE, which can be used for a variety of oil spill scenarios. The selection guide is an excel workbook that contains extensive information on sensor capabilities. Based on user input, and pre-loaded data/calculations for a wide

Table 1.

Solutions Prioritized per Workshop Participants*	**Score****	**Category**	**Timeframe**	**Cost**
Georeferenced data with standard format (metadata) (Re: Integration of Synoptic Sampling into Mission Planning)	234	technical	short-term	low
Coordinating remote sensing acquisition with field data collection (Re: Integration of Synoptic Sampling into Mission Planning)	226	Policy/Protocol	short-term	med
Bandwidth - software compression, portable network stations, pre-planning of data demands, satellite communications/infrastructure (Re: Delivery Infrastructure)	223	technical	short-term	med
Accessibility/connectivity - remote site data integration away from ICP (Re: Delivery Infrastructure)	222	technical	short-term	med
On-site testing during exercises (Re: Data Delivery Time)	218	Policy/Protocol	short-term	low
A go kit multi sensor package (SAR, multispectral, infrared, high resolution imagery) (Re: Remote Sensing Operations - skimming, dispersants, burn, night operations)	218	technical	long-term	high
Advancements in/complete on-board processing (Re: Real Time Capture of Data)	218	technical	short-term	med
Standardize human observer methodology and output (Re: Oil Observation)	217	Policy/Protocol	short-term	low
Supplement human observers with digital tools (Re: Oil Observation)	216	Policy/Protocol	short-term	low
Multi sensor approach with **repeated** surveys over time including hyperspectral, SAR, and high resolution visual (Re: Shoreline Oil Data and Habitat)	214	Policy/Protocol	short-term	high
Digital georeferenced photo subjects (Re: Oil Observation)	214	technical	short-term	low
Technology scalability for volume calc that is defensible (Re: Technologies for Oil Thickness)	212	technical	long-term	high
Quad-pol SAR (Re: Technologies for Oil Thickness)	210	technical	short-term	med
Identify standard equipment and training (Re: Oil Observation)	209	Policy/Protocol	short-term	low
AVIRIS (Re: Technologies for Oil Thickness)	204	technical	long-term	high
Thickness: Creating operational systems and validating methods for application of those systems (Re: Flow Rate, Footprint, Thickness)	203	technical	long-term	high
Web-mapping service for data sharing (Re: Data Deliver Time)	200	technical	short-term	low
Microwave-based air-to-ground communications system (Re: Real Time Capture of Data)	200	technical	short-term	med
Calibration events minimum once per incident (Re: Integration of Synoptic Sampling into Mission Planning)	200	Policy/Protocol	short-term	med
Contemporaneous collection (Re: Integration of Synoptic Sampling into Mission Planning)	199	Policy/Protocol	short-term	low
Multiple sensors and platforms in order to fill out the gaps for the required schedule (Re: Shoreline Oil Data and Habitat)	198	technical	long-term	high
Quad-pol UAS SAR (Re: Technologies for Oil Thickness)	198	technical	short-term	med
Better data capture (Re: Other Data)	197	technical	short-term	med
Capture data from multiple observers (Re: Oil Observation)	197	Policy/Protocol	short-term	low
Aerial assets for schedules and resolution (Re: Shoreline Oil Data and Habitat)	196	Policy/Protocol	short-term	low

* There were 4 categories with no solutions ranked as high priority: detection of oil in ice, trajectory modeling, subsurface, and oil/chemical composition.

** The lowest and highest possible scores respectively were 49 (or zero if nobody voted) and 245.

range of parameters (e.g., availability, ownership, deployment time, tool strengths, limitations, data latency, cost), the workbook recommends an appropriate remote sensing tool(s). The workbook will be updated as remote sensing technology develops. Further information is provided in the presentation slides (Appendix D). A number of other existing resources were identified during the workshop that assess remote sensing capabilities (e.g., for airborne remote sensing, the International Petroleum Industry Environmental Conservation Association [IPIECA] and Oil and Gas Producers Association [OGP] have a report titled An Assessment of Surface Surveillance Capabilities for Oil Spill Response using Airborne Remote Sensing [Partington, 2014]). A list of these identified resources is compiled in Table 2.

5.0 Workshop Conclusions and Recommendations

5.1 Specific Workshop Objective Summary

Objective: Identify new developments in oil observing technologies useful for real-time (or near real-time) mapping of spilled oil during emergency events.

The 2010 Deepwater Horizon represented an unprecedented challenge to the oil spill response community. The scope and magnitude of the oil spill demanded creative use of existing technologies and the development of new options for capturing daily operational data to facilitate an effective response. The use of remote sensing was invaluable for understanding the characteristics and location of the surface oil and to predict where it was going. Additionally, many sensor technologies were employed coincidently to capture multi-resolution data to better understand the scale and degree of surface oiling and its potential to cause harm to natural resources.

The use of the NOAA NESDIS daily SAR for oil footprint delineation facilitated daily operational decisions, representing a new reliance on remote sensing that had never before occurred. Additionally, NOAA SAR analysis was further enhanced during the NRDA as a twofold semi-automated process, TCNNA, for footprint creation and further delineation of heavy emulsions (actionable oil) using the OEDA. The TCNNA and OEDA processes for delineation of the oil footprint and heavy emulsified oil represented innovative uses of SAR data that will be evaluated for development and use as operational products for NOAA support at future spills.

The Ocean Imaging (BP contractor) high resolution aerial multispectral and thermal imagery was collected almost daily at the DWH rig site to capture thickness and volume estimations. This effective product was very useful for response source monitoring missions, but this use was limited by the small footprint that these missions could capture in one day, particularly for NRDA. This reality reduced the impact these tools had on the overall response, however, this daily experience allowed the application of methods to medium resolution Landsat data. In doing so, qualitative thickness estimates were generated to support the NRDA and look across a larger area than had been possible during the response itself. The private sector/Oil Spill Response Organization (OSRO) partnership that occurred was an example of a very effective pairing of technology for operational response or assessment. From this work, Ocean Imaging developed the TRACS portable sensor package that can be deployed on platforms of opportunity, support oil observation imagery capture, and deliver data to a Unified Command COP in near real-time. These rapid response capabilities were demonstrated at the 2015 Refugio Pipeline spill response.

EPA ASPECT and NASA AVIRIS sensors were active during the DWH oil spill, however, their data products were not integrated into the COP to the fullest extent possible. The EPA ASPECT high resolution imagery data were underused. This fast response asset has significant application for air monitoring and spill assessment and is well integrated into Agency activities. Indeed, ASPECT data could provide significant support to multiple response and assessment activities, particularly in the identification of actionable oil. The EPA employs rapid capture, on-board processing and near-real time data delivery as the core of the service. ASPECT true color imagery was used as a ground truth source for oil on water characterization as well as for sargassum assessment in the DWH NRDA. The NASA AVIRIS hyperspectral sensor is an extremely high resolution technology that has a published record for surface oil characterization and quantification. Unfortunately, AVIRIS data collection suffers from difficulty of capture (environmental conditions), huge data volume (220 bands of data) and ineffectual data delivery (~1 day lag for DWH). Regardless, these data were very important in adjusting or “tuning” the surface oiling data from SAR and MODIS satellites.

The Workshop provided the opportunity to see the NASA UAVSAR and U.S. Army Night Vision technology and products. NASA is very interested in using the UAVSAR technology to provide more practical support for oil spill response and damage assessment. NASA is working with NOAA to expand the application of these technologies into direct response support. The UAVSAR technology is uniformly accepted by the remote sensing community as an extremely effective SAR sensor. Unfortunately, there are significant costs to deploy UAVSAR and it has long lag times for data delivery.

The U.S. Army Night Vision tools and technology are not widely used or routinely available to the oil spill community. There are some very high costs to the equipment, and there are limitations regarding how these tools can be used. Currently, the night vision tools do not include the laser range finders or measurement support that would make them more useful for feature identification. Regardless, there are real potentials in the technology demonstrated, because it could allow oil spill response work to continue after dark (e.g., 24 hours a day). The application of night vision tools to response should be considered.

There is still much more work to inventory and understand how best to apply all of the technologies to support oil spill response decision-making. It seems clear that there are many platforms and sensors currently in use that will be part of the multi-sensor toolkit identified by the Workshop participants. We need to better: (1) understand what the current strengths and weaknesses of each sensor are, (2) develop experiments to demonstrate how these technologies relate to each other, and (3) develop new and smaller deployment packages to put the most effective sensors in the sky.

Objective: Identify merits and limitations of current technologies and their usefulness to emergency response mapping of oil and reliable prediction of oil surface transport and trajectory forecasts. Current technologies include: the traditional human aerial observer, unmanned aircraft surveillance systems, aircraft with specialized senor packages, and satellite earth observing systems.

Current remote sensing technologies provide significant support to traditional visual oil observing programs. These technologies provide supplemental evidence of oiling and provide additional “eyes” in the sky to move people and equipment to where “actionable” surface oil exists and can be addressed. However, there are still questions regarding the extent to which any remote sensing assessments can be relied upon exclusively. Human observation of surface oiling is still needed for characterization and validation.

As identified by a majority of the workshop participants, a combination of human and technological sensors are required to effectively target “actionable” oil. Furthermore, a combination of sensor technologies increases confidence in the findings via a weight-of-evidence approach. A combination of sensors was used during DWH assessment and provided a strong approach, however, it has still not achieved sufficient community support or necessary validation.

Academics, industry partners, and Agency representatives all identified the need for a robust series of synoptic sampling experiments including detailed requirements and procedures to better quantify the performance of individual sensors or any combination of sensors for realistic qualitative thickness characterization of surface oil. Then, quantitative thickness (or volume) calculation of surface oil may be evaluated. Experiments should be undertaken to capture a series of satellite, aerial, and on water remotely-sensed data, along with in situ surface water/oil sampling. This will allow examination of the relative performance of these sensors and build the understanding of the quality of the data they are providing to the response and damage assessment communities. As a result of the Oil Observing Tools Workshop, BSEE and NOAA are working toward a cooperative series of experiments to examine these questions in open water and controlled tank tests.

Objective: Assess training needs for visual observation (human observers with cameras) and sensor technologies (including satellites) to build skills and enhance proper interpretation for decision support during actual events.

Trained overflight oil observations still appear to be the “gold standard” in surface oil characterization. NOAA’s ORR provided overview training and is actively looking to expand its oil observing program with partner agencies. NOAA is actively developing tools to support the capture of oil observer observations and the delivery of these observations to a COP (e.g., ERMA®), providing decision-making capabilities. Regardless of the ongoing, rapid developments in the remote sensing of surface oil, it is extremely important that a robust Oil Observing Training program continues. It is difficult to maintain a broad base of trained observers. It has been difficult over the past decade to train new aerial observers with the proper skill set that is needed for the long term. Cuts in program funding and the ability to add FTE's has left us with fewer persons available to train as aerial observers. Many potential observers from outside organizations have been trained in half to full day classes that typically cover the fundamental principles for conducting aerial observations. These classroom lectures while valuable are not able to provide the student with the complete skill set needed to go out into the field and capture the information that is needed. The key component that is missing from this training is the practical field experience that can only be gained by observing oil on open water. To observe oil on the water complicates the learning process as there are only a couple of locations where this can easily be done. To make the training truly valuable for those participating, the training sessions need to take place at or near these locations. Another option that has been employed over the years is to use actual spill events as a training opportunity. This option has its own drawbacks such as the aircraft type, available seats, and can usually only accommodate one student observer at a time.

5.2 Workshop Key Themes and Areas of Interest:

Throughout the workshop, the following key needs, themes, and points were repeatedly emphasized. An associated recommendation and action is provided for each one.

Small spills, which are the most common, are significantly different from large scale spills in terms of response time, technologies used, funding, and staffing. Many experiences and considerations related to oil observing are based on the highly atypical very large DWH spill.

> **Recommendation:** Remote sensing may provide limited utility to small spills in selected settings. Remote sensing is effective in supporting evaluation of risk in many, but not all responses or assessments. Understanding when remote sensing should not be used is almost as important as knowing what sensors to choose and where they will help. As UAS and other compact remote sensing solutions become more common, the use of these technologies for small spills will become more and more practical.
>
> **ACTION:** Develop a list of criteria/metrics where remote sensing tools are useful in oil spill response and assessment.

Oil observation consists of three steps characterized as data capture, processing, and delivery.

> **Recommendation:** Data delivery must be stressed whenever data is to support response or assessment. Agencies will often only identify capture and processing requirements without addressing delivery. The process often fails because delivery of observational and analytical data, which is critical, is left unspecified. Delivery requirements must be included for any contracts being written for remote sensing work.
>
> **ACTION:** Develop a short list of delivery requirements that could be included for remote sensing data collections to ensure complete and timely delivery of products.

Human observation is the cornerstone of all oil observation. NOAA needs more trained aerial overflight observers. In addition, observation methodology should be updated and standardized to provide consistency.

> **Recommendation:** NOAA and other agencies should pro-actively train staff for aerial overflight oil identification.
>
> **ACTION:** Continue development of NOAA's Oil Over-flight Observation training program.

The most useful technology to supplement the data obtained by trained aerial observers is a package of all sensors combined. It would be helpful to repackage existing technologies into a deployable "go kit" that is small enough to fit onto a UAS and able to deliver data quickly.

> **Recommendation:** While a combination approach of different sensors cobbled together in some fashion has some use, there is little technology available that brings multiple sensors together in one physical package. This reality is likely to continue for some time. The current solution is to develop a post-processing mash-up of data or deploy a variety of sensors on platforms-of-opportunities including fixed wing, helicopters, and UAS to achieve this combination effect.
>
> **ACTION:** Develop workable combination packages of existing technologies and develop multiple platforms and sensor packages based on the most common response or assessment needs.

Responders need to know where the thick/"actionable" oil is located in order to make the most effective response decisions.

> **Recommendation:** This is the target for operational tools development now. Understanding where we have "no oil", "sheen or thin oil" or "thicker, actionable oil" is the level of characterization that we can and should target with existing/emerging remote sensing technologies while keeping the future goal of supporting more discrete quantification as a future goal.
>
> **ACTION:** Conduct a NOAA/BSEE led diverse synoptic sampling experiment that will validate the qualitative characterization technologies for surface oil developed during DWH. This validated, operational methodology will then allow the use of these data and tools in support of day to day decision-making for response and assessment.

False positives are a significant concern that must be addressed.

> **Recommendation:** During a response, false positives cost time and money. False positive tracking should continue to be a significant task for over-flight observers and analysts. The observer is in a unique position to identify and locate features that can cause responders to mistakenly act. False positive sources should be identified and then be mapped and loaded into

the COP to help prevent additional resource expenditures on a known feature.

ACTION: Develop better methods to identify false positives as part of overflight observation training. False positive sources must be identified and located so that they are "known" and can be used to inform subsequent over-water surveys.

Ground truthing of data is needed, especially a protocol for synoptic sampling.

Recommendation: Remote sensing data supplement what is captured in the field. It is critical to have in situ "truth" for the image analysis products generated to understand the data collected by remote sensing. Standardized synoptic sampling protocols will provide the data necessary to correlate the relative sensor response to specific features.

ACTION: Conduct data collections in situ as part of any remote sensing activity.

Responders need the data delivered quickly to the right people at the right time. Information from more sophisticated technologies often does not make it into the COP or command post before decisions about the response are made. Data delivery should be practiced in training and drills (i.e., conduct drills to simulate Days 4 and 5 of a spill response). Requirements for delivery of data and related time requirements must be included in contracts.

Recommendation: More drill/exercise focus must be placed on data delivery activities. Data delivery mechanisms are an afterthought in training scenarios, while at the same time being one of the most critical activities for success. Collected and even processed data are of little value if they are not delivered in a timely manner to decision makers. This could be the topic of a NOAA lead drill at the DRC in Mobile, AL.

ACTION: Conduct drills emphasizing Days 3 or 4 of a response so as to focus on data delivery.

API, BSEE, and others, have funded and developed guidance to determine appropriate remote sensing technology. The output from these efforts should be developed into an online tool that can become part of NOAA's integrated modules (e.g., General NOAA Operational Modeling Environment [GNOME], Automated Data Inquiry for Oil Spills [ADIOS]) available in the responder's toolbox.

Recommendation: Do not create more guidance documents as good resources are already available. Create an information portal/webpage that allows responders, damage assessors, and developers access to existing information. Additionally, the findings and priorities from this workshop should inform remote sensing controlled and open water/real world testing and experimentation.

ACTION: Build a portal/landing page for API and BSEE work with descriptions of what they have already done. Include other existing resources and reference documents. Keep the information at the site updated.

Data collected during the response needs to be useful to the NRDA process. NOAA ORR ERD and ARD must coordinate better to address the needs of response and assessment.

Recommendation: There is a continuum of data collected from response to assessment to restoration. Data should be managed and shared across this range of activities for an incident and common needs should be considered for data collection activities in situ and via remote sensing. OR&R's ARD and ERD have been working to ensure that data management and data sharing are key components of their cooperative response and assessment strategies. The OR&R "Data Management and Sharing Plan (incident template)" has been developed as part of the OR&R Data Management strategy and represents an effort currently underway.

ACTION: Use the OR&R Data Management and Sharing Plan incident template during events and training to further ensure cooperative data management for response and subsequent NRDA casework.

There must be continued integration between end users and data providers.

Recommendation: There needs to be ongoing coordination and communications between consumers and developers to ensure data needs are identified and appropriate products are generated.

ACTION: Continue recurring discussions between emergency responders, damage assessors, data managers and developers. More regular meetings would help solidify some of the ongoing needs that developers should target. This should be a regular track session at oil spill conferences (e.g., Clean Gulf, IOSC).

Some of the gaps identified, if addressed, could change the usefulness of oil observing significantly. This means that the path forward includes a mix of solutions including some less expensive actions that could advance the state of the art in oil observing, as well as some very high cost ones that may be delayed out of necessity.

Recommendation: With the current technological solutions that exist today, a combination of sensors and platforms will be required.

ACTION: Do not expect a "single solution" tool-box in the near term. Rely on a multi-platform, multi-sensor approach based on settings and conditions.

One major problem is the limited funding to address the gaps in oil observing tools identified. The oil response community must develop a plan to help fund the necessary actions.

Recommendation: Public agencies must work closely with industry to identify the needs and potential funding options to address them. This will be problematic with the current low price of oil. Public and private partnerships will continue to provide more cost-effective comprehensive solutions.

ACTION: Pursue joint agency and industry demonstrations of oil observing tools and focus on flexible funding mechanisms.

5.3 Workshop Portal Page

There is a portal/landing page for Oil Observing Tools at the CRRC website (http://crrc.unh.edu/oil_observing). The portal includes links to this report and other resources, such as the work done by API and BSEE, as well as other job-aids and references. A summary of the information in the portal (as of the final date of this report) is shown in Table 2, however the information on the portal will be updated as new information becomes available.

Table 2. Additional Resources

Title	Author/Source	Year
Remote Sensing in Support of Oil Spill Response, Planning Guidance	API	2013
Standard Guide for Selection of Airborne Remote Sensing Systems for Detection and Monitoring of Oil on Water	ASTM	2015
Standard Guide for Visually Estimating Oil Spill Thickness on Water	ASTM	2006
Standard Practice for Reporting Visual Observations of Oil on Water	ASTM	2008
Remote Sensing Systems to Detect and Analyze Oil Spills on the U.S. Outer Continental Shelf – A State of the Art Assessment	Burrage et al, NRL, funded by BSEE	2016
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	Muskat, Judd	2016 DRAFT Available*
ExxonMobil spill response book	ExxonMobil	2014
Detection, Tracking, and Remote Sensing; Part VII in the Handbook of Oil Spill Science and Technology	Wiley, edited by Merv Fingas	2015
Bonn Agreement	Various	Various
NOAA OR&R Spill Response Job-Aids/One-pagers:		
Open Water Oil Identification Job Aid for Aerial Observation	NOAA	2012
Guide to Delineation of Oil	NOAA NESDIS	2009
OR&R/ERD Job-Aids (e.g., Overflight, Oil Identification, Shoreline Assessment)	NOAA	Ongoing
Reference Documents:		
Discrimination of Oil Spills from Newly Formed Sea Ice by Synthetic Aperture Radar	Brekke et al	2014
State of the Art Satellite and Airborne Marine Oil Spill Remote Sensing: Application to the BP Deepwater Horizon Oil Spill	Leifer et al	2012
The Federal Oil Spill Team for Emergency Response Remote Sensing, FOSTERRS: Enabling Remote Sensing Technology for Marine Disaster Response	Leifer et al	2015
Natural and Unnatural Oil Slicks in the Gulf of Mexico	MacDonald et al	2015
An Assessment of Surface Surveillance Capabilities for Oil Spill Response using Airborne Remote Sensing, provided for International	Partington, Kim	2014

Petroleum Industry Environmental Conservation Association (IPIECA) and Oil and Gas Producers Association (OGP)		
Oil Spill Detection and Mapping in Low Visibility and Ice: Surface Remote Sensing, Final Report 5.1 for the Arctic Oil Spill Response Technology - Joint Industry Programme	Puestow et al	2013

*Draft posted with author's permission.

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7.0 Appendices

Appendix A: Agenda

Appendix B: Participants

Appendix C: Breakout Group Members

Appendix D: Presentation Slides

Appendix E: Plenary Session Notes

Appendix F: Hands-On Training

Appendix G: Breakout Group Results

Appendix H: Priorities Ranking

Appendix I: Technologies for Oil Thickness