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Attachment A. Abt Ohmsett Report

Ohmsett In Situ Data Report

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November 18, 2016

1. Introduction

In July 2016, we conducted a simulated oil spill in a controlled environment to develop methods for oil slick detection and characterization. This included synoptic collection of remote sensing data [from satellite, helicopter, and unmanned aircraft system (UAS)], oil slick samples, and underlying oil-contaminated water. We conducted these tests in an open-air tank at the National Oil Spill Response Research & Renewable Energy Test Facility (Ohmsett) at the Naval Weapons Station Earle Waterfront in Leonardo, New Jersey. The Ohmsett tank is 203 m long by 20 m wide by 2.4 m deep, holding 9.8 million liters (2.6 million gallons) of saltwater. On July 14, 2016, our research team added 1,500 liters (400 gallons) of fresh Hoover Offshore Oil Pipeline System (HOOPS) oil to the tank. For four days, the oil weathered on the surface of the tank. On the morning of July 18, wave generators were activated to create wave energy, mixing the surface slick into the water column and creating oil-water emulsions at the surface. We collected in situ surface oil thickness data and water column sampling starting on July 16, 2016 before the wave generators were turned on, and we continued collecting these data through July 22, 2016. This report presents results from the in situ data collections, including bulk oil sample collection, oil sheen/slick thickness measurements, discrete water sampling, fluorescence measurements, and ultraviolet (UV) light attenuation data.

2. Objectives

The first objective of the in situ sampling at Ohmsett was to characterize surface oil thickness. In general, this sampling was conducted concurrently with overhead imaging activities to allow slick thickness to be related to imaging data. In addition, we used the Ohmsett experiment as an opportunity to practice, fine-tune, evaluate, and compare the different slick thickness characterization methods. Finally, to aid in data interpretation, we collected other physicochemical properties of the surface oil, including oil-water ratio, viscosity, density, and chemistry [total petroleum hydrocarbon (TPH) and polycyclic aromatic hydrocarbon (PAH) concentrations].

The second objective of the in situ sampling was to develop methods for characterizing oil exposure in the water column. We collected grab samples from different depths and analyzed the samples for TPH concentrations. In addition, we collected fluorescence measurements from each of the discrete water samples as well as from within the tank during water sampling activities. Finally, we conducted UV light attenuation measurements under slicks of different thicknesses.

3. Methods

3.1 Surface Oil Characterization

3.1.1 Dip Plate Method

At each sampling event, we collected 2–5 areas of oil slick or sheen modified using a method described by Svejkovsky and Muskat (2006). To sample the oil slick, we slowly lowered a small clear acrylic plate in the vertical position into the water to the line where the plate was marked, at approximately a 14.8-cm depth, and then we slowly pulled it out of the water (Figure 1). We then transferred the dip plate to a pre-weighed plastic storage container, and scraped the adhered oil from the dip plate to the plastic container using a rubber spatula (Figure 1). After transferring as much of the oil as possible from the dip plate to the plastic container, we placed a lid on the container and stored it in a cool, dry place until we brought it to the onsite laboratory to weigh.

Figure 1. Sampling an oil slick using a dip plate (left) and transferring oil from the dip plate to a pre-weighed, plastic container (upper and lower right).



After we determined the mass of oil from each dip plate, we used measured density of the oil collected that same day to convert oil mass to oil volume. Then, dividing volume by the sampled surface area, we determined slick thickness. Based on laboratory studies (Svejkovsky and Muskat, 2006), the oil slick from the surrounding area generally adheres to a plate as it is submerged and retrieved from the water. Thus, we assumed that the surface area sampled by the dip plate was equivalent to twice the surface area of the oiled portion of the plate.

3.1.2 Sorbent Pad Method

At each sampling event, we collected 1–3 oil slick or sheen samples using 3M T-151 sorbent pads (modified from a method described by Daling and Leirvik, 2002). Before arriving at Ohmsett, we cut the 3M sorbent pads into 43 cm by 48 cm rectangles and decontaminated the pads with methylene chloride. The pads were allowed to dry overnight in a chemical fume hood before being transferred to re-sealable plastic bags for storage until use.

Just before sampling, we removed an individual pad from its plastic bag and clipped it to a polyvinyl chloride (PVC) sampling buoy. Using a grab pole or other similar device, we slowly lowered the sampling pad buoy with the sorbent pad onto the water surface, ensuring the pad sat flush with the surface (Figure 2). As we deployed the sorbent pad, we photographed the sample

area (with one or more photographs) to visually capture the oil slick or sheen being sampled. We allowed the sorbent pad to sit on the water surface for at least 30 seconds to permit adsorption of oil onto the pad. We then pulled the pad off the water using the grab pole and carefully unclipped the pad from the PVC buoy, using clean, gloved hands or clean, large metal tongs to grab the pad. We folded the oiled pad with the oiled side inward and transferred it to a pre-cleaned, 500-mL sample jar for TPH analysis by ALS Environmental.

Figure 2. Sampling an oil slick using a sorbent pad buoy with a sorbent pad.



3.1.3 WaterMapping Method

Figure 3. WaterMapping sampler.



Dr. Oscar Garcia of WaterMapping, LLC developed a novel method of measuring slick thickness, and he tested this new method at the Ohmsett facility. Dr. Garcia deployed a device with a cylindrical collection tube mounted horizontally so that the tube intersects the water surface (Figure 3). He closed each end of the tube with two plugs activated by a radio remote control (see the WaterMapping, LLC draft report in Appendix A). In this report, we compare the data from this WaterMapping method with data collected using the other methods of slick thickness measurement.

3.1.4 USGS "Fishing Pole" Method

Figure 4. USGS fishing pole sampler.



Dr. Gregg Swayze and a team at the U.S. Geological Survey (USGS) developed a "fishing pole" method of slick thickness measurement (see Dr. Swayze's report, submitted separately). They tested this method at the Ohmsett facility in conjunction with the other methods. This method involves a cylindrical collection tube deployed vertically into the slick (Figure 4) and then plugged using a rope strung through the tube. The tube is then retrieved and the thickness of the oil captured in the tube is measured using a ruler. In this report, we compare slick thickness data from this USGS method to data from the other methods of measuring slick thickness.

3.1.5 Bulk Oil Sampling

Ohmsett staff collected bulk oil samples daily by skimming oil off the surface of the tank using a sampling container attached to a sampling pole (Figure 5). Skimmed oil samples were then transferred to a large separatory funnel to separate water from the bulk oil sample. Ohmsett staff analyzed bulk oil samples for oil-to-water ratios, viscosity, and density. From three of these oil samples, they transferred oil to a pre-cleaned, 100-mL sample jar and sent the sample to ALS Environmental for TPH and PAH analysis.

Figure 5. Bulk oil sampling.



3.2 Water Column Characterization

3.2.1 Discrete Water Sampling

On days 3 and 5 (7/16/2016 and 7/18/2016), we collected discrete water column grab samples at four depths below the slick, at approximately 0.1 m, 0.2 m, 0.5 m, and 1.0 m. Discrete water samples were collected using high-purity, polyethylene tubing and a peristaltic pump. At each sampling depth, we first flushed the sample tubing with approximately 1 L of water. We then collected a 250-mL whole water sample and sent the sample to ALS Environmental for TPH analysis.

To minimize contamination during deployment of the sample tubing through the slick, we deployed the tubing through a large-diameter-PVC tube that was capped as it was lowered into the water through the slick (Figure 6). The cap was then removed by tapping it with a sampling pole, and the tubing was deployed to the desired sample depth.

3.2.2 Fluorescence Sampling

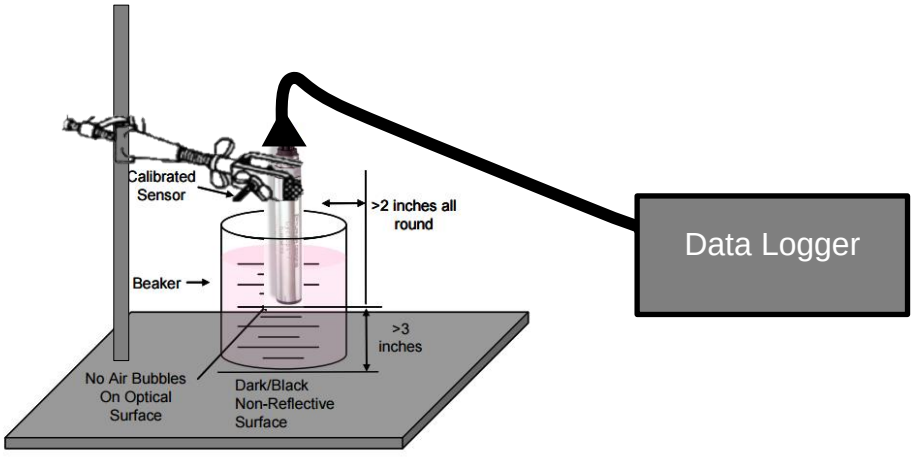
Alongside the collection of the discrete water samples, we collected fluorescence measurements in the water column using a handheld Turner Cyclops-7 fluorometer with a crude oil-specific sensor. In addition, we collected subsamples from each water sample and analyzed the subsamples for fluorescence in the onsite Ohmsett laboratory (Figure 7).

As with the water samples, we deployed the fluorometer through a capped, large-diameter PVC tube to minimize cross-contamination (see Figure 6). The cap was then removed by tapping it with a sampling pole.

Figure 6. Large-diameter PVC pipe with cap being removed by sampling pole after pipe is deployed through the surface slick (top left), deployment of water sample tubing and fluorometer through PVC pipe (right), and water column sampling at desired depth after deployment (bottom left).



Figure 7. Sampling stage for fluorescence measurements.



3.2.3 UV Light Attenuation Sampling

To determine UV light attenuation under different slick thicknesses, we deployed a Biospherical radiometer at the Ohmsett facility under thin sheens, rainbow sheens, and thick emulsions. The radiometer was deployed one of two ways. First, the radiometer was deployed to a fixed depth of 0.5 m and then towed from thin sheens through rainbow sheens to thick emulsions to determine the relative change in UV intensity under different slick thicknesses. In addition, under different slick thicknesses, we collected a profile of UV intensity versus depth by slowly lowering the radiometer from just below the water surface to the bottom of the tank and then slowly raising the radiometer back to the surface. From these profiles, we calculated UV attenuation coefficients under different slick conditions.

4. Results and Discussion

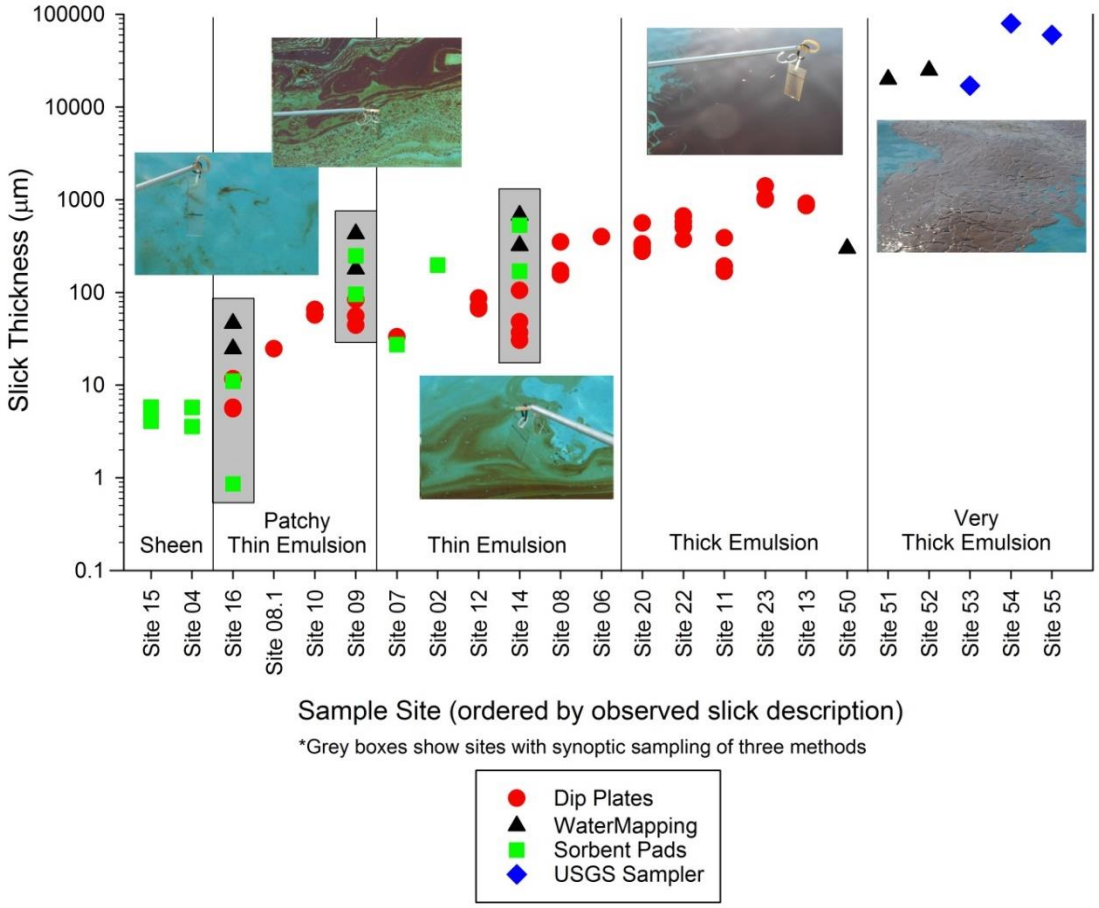
4.1 Slick Thickness

The thin sheen covering much of the tank generally ranged from 3 to 5 µm thickness, while the thickest sections in the middle of the main slick were up to 8-cm thick (Figure 8). Small areas around the edge of the main slick contained slicks with thicknesses in between these two extremes. Given the edges of the main slick contained areas with the greatest range of slick thicknesses, our measurements mostly focused on these areas. Images in Figure 8 show the visual appearance of the different slick areas we sampled as well as highlight the heterogeneity of the slick areas being sampled.

At three of the sampling sites, highlighted by grey boxes in Figure 8, we collected co-located slick thickness data using the dip plate, sorbent pad, and WaterMapping methods (the USGS method was not available until the last day of testing). We know from previous laboratory research (Forth et al., 2015) that oil slicks are highly heterogeneous on minute spatial scales, with slicks that appear uniform in a beaker having measured thicknesses that vary by 1–2 orders of magnitude. The photographs from the collections (Figure 8) indicate that the slicks being sampled were not visually uniform. We would expect oil thicknesses to vary by more than two orders of magnitude in patchy areas. Thus, we were pleased that all three methods produced similar estimates of slick thickness (i.e., within 1–2 orders of magnitude) for the co-located samples.

However, some results suggest potential biases in the methods. For instance, except for one outlier, the dip plates generally represented the lowest end of the thickness range, suggesting this method may be biased slightly low. This low bias could be the result of several factors. First, the method assumes that the dip plate collects the oil slick as it is submerged into the water and again as it is pulled out of the water. However, if the area sampled by the dip plate is actually smaller than our assumed area (e.g., the slick is only collected when the dip plate is submerged into the water), then our results would be biased low. In addition, the dip plate method involves the transfer of oil from an acrylic plate to a pre-weighed container, which can be inaccurate when small amounts of oil stick to the plate and the transfer tools. Given that the transfer of oil is expected to include a certain amount of loss, it is expected that the results would reflect this loss.

Figure 8. Slick thickness measurements from four different measurement methods.

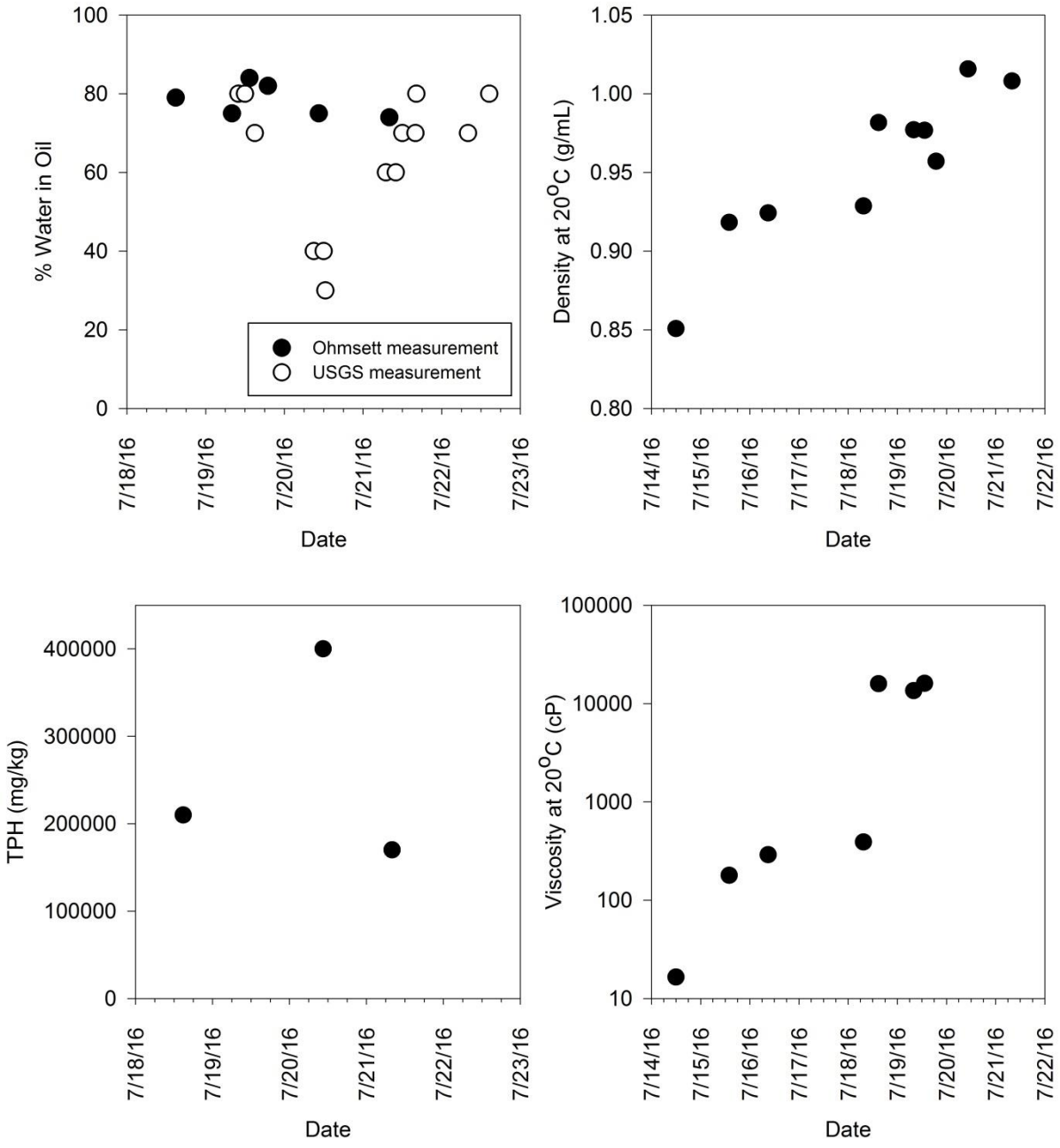


On the other hand, measured thicknesses from the WaterMapping method always fell in the highest end of the thickness range measured by the three methods, suggesting that this method may be biased slightly high. It is possible that the smearing of oil across the inside of the tube may be the cause of this slight bias.

4.2 Bulk Oil Characterization

Our results show that both oil density and viscosity increased over time, with the two largest increases occurring after the first day (7/13/2016 to 7/14/2016) and on the fifth day (7/18/2016) when the wave generators were turned on (Figure 9). The initial increase in density and viscosity is a result of the rapid loss of volatile compounds, a common weathering process when crude oil is released into the environment. The second sharp increase in both oil density and viscosity occurred between the morning and the afternoon of 7/18/2016, which reflects the physical changes to the oil as emulsifications started to form after the generation of waves. By the afternoon of the fifth day, the bulk oil already contained 80% water, indicating the rapid formation of emulsified oil. A high water percentage in the surface oil was maintained throughout the rest of the study, except for a sudden dip on the seventh day (7/20/2016), after the wave generators had been turned off for several hours. On that day, we saw a corresponding increase in the bulk oil TPH concentration, corroborating the decrease in the water percentage in the surface oil.

Figure 9. Changes in physicochemical properties of slick oil over time.



4.3 Water TPH Concentrations

Oil droplets mixed into the water column after the wave generators were started (Figure 10). As a result, TPH concentrations in the water increased four-fold between the third day (7/16/2016), before the wave generators were turned on, and the fifth day (7/18/2016), just after the wave generators were turned on (Figure 11). From underwater viewing windows, we observed oil droplets mixed through the water column to the bottom of the tank, which is more than 2.3 meters below the surface (Figure 12). Water TPH concentrations, along with TPH concentrations estimated from our fluorescence measurements (see Section 4.4), corroborated the observed mixing of oil droplets in the water column (Figure 11). In fact, instead of a decrease in concentration with depth, as expected by oil dispersion theory (Delvigne and Sweeney, 1988), we observed an increase. This increase with depth was observed with samples collected both before and after wave generation; however, it was more pronounced after wave generation. One explanation for this observed increase in concentration with depth could be boundary effects from the tank sides and bottom. However, the observed increase in concentration started with samples collected from 0.2 m, which is well above the tank bottom, and all samples were collected from the middle of tank almost 10 m away from the tank sides. These data suggest that petroleum hydrocarbons mix into the water column below a slick regardless of whether there is wave action, but the mixing is more pronounced when waves are present.

4.4 Fluorescence

One of the secondary goals of the in situ sampling at Ohmsett was to evaluate the potential to use fluorescence spectroscopy to estimate dispersed oil concentrations in the water column in real time. In this study, we measured fluorescence in subsamples from each discrete water sample and examined the relationship between the measured TPH concentration in the water sample and the fluorescence signal in the subsample (Figure 13). On the right axis of Figure 13, we also show the estimated total polycyclic aromatic hydrocarbon (TPAH) concentrations for each water sample, to aid in the comparison of the fluorescence results collected at Ohmsett to other fluorescence studies that report TPAH instead of TPH.

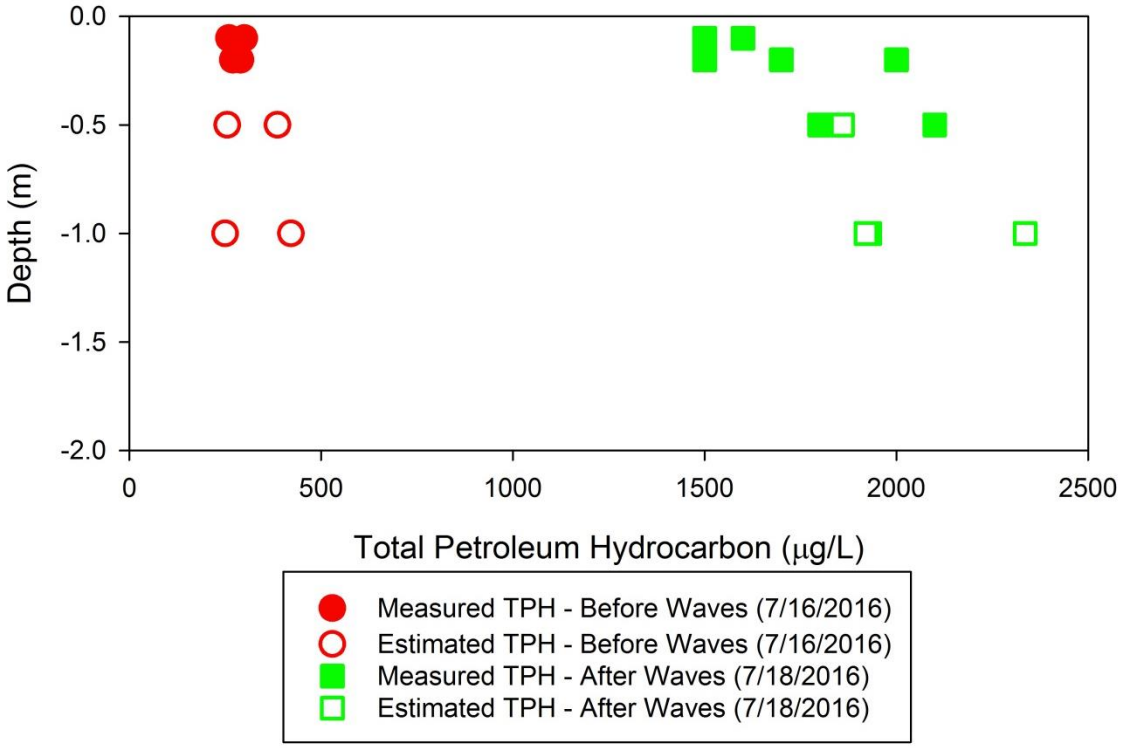
TPAH is often the metric of choice for fluorescence measurements because the aromatics fluoresce. In the bulk oil sample collected on 7/18/2016, the TPAH to TPH ratio was 0.010156 (i.e., about 1% of the total hydrocarbon was PAH). To estimate the TPAH concentrations from the measured TPH concentrations in the water samples, we multiplied the measured TPH concentration of each water sample by the TPH:TPAH ratio from the 7/18/2016 oil sample.

Generally, we found a linear relationship between fluorescence and TPH concentration across a wide range of samples. This linearity was evident before we initiated the waves, where the oil concentrations in water were mainly due to dissolution from the slick, and it was also evident after we initiated the waves, where the water column was inundated with dispersed oil droplets. Within the concentrations tested, this indicates that the fluorometer signal generally maintains linearity irrespective of the oil phase. Although the tank did not have naturally fluorescing compounds or plankton, the data from Ohmsett confirm that fluorometers detect PAHs in water, with a stronger fluorescence signal when more PAHs are present.

Figure 10. Oil droplets mixing in the water column at Ohmsett following initiation of the wave generators.



Figure 11. Measured and estimated TPH concentrations (µg/L) before and after wave generation versus sample depth (m). Measured TPH concentrations were reported by an analytical laboratory and estimated TPH concentrations were developed from a fluorescence measurement using the regression reported in Section 4.4.



4.5 UV Light Attenuation

UV attenuation increased exponentially with slick thickness (Figure 14). The maximum attenuation of UV light for profiles collected under four visually different slick thicknesses (e.g., thin sheen, rainbow sheen, thin emulsion, and heavy emulsion) ranged from 60% under thin sheen to 100% under thick emulsions. Because slick thickness was not measured concurrently with the UV profiles, we used the measured thicknesses collected during the rest of the study to determine the median and range of thicknesses for the four visual thickness categories.

Figure 12. Dispersed oil droplets mixing into entire water column of the Ohmsett tank, as seen through an underwater viewing window.

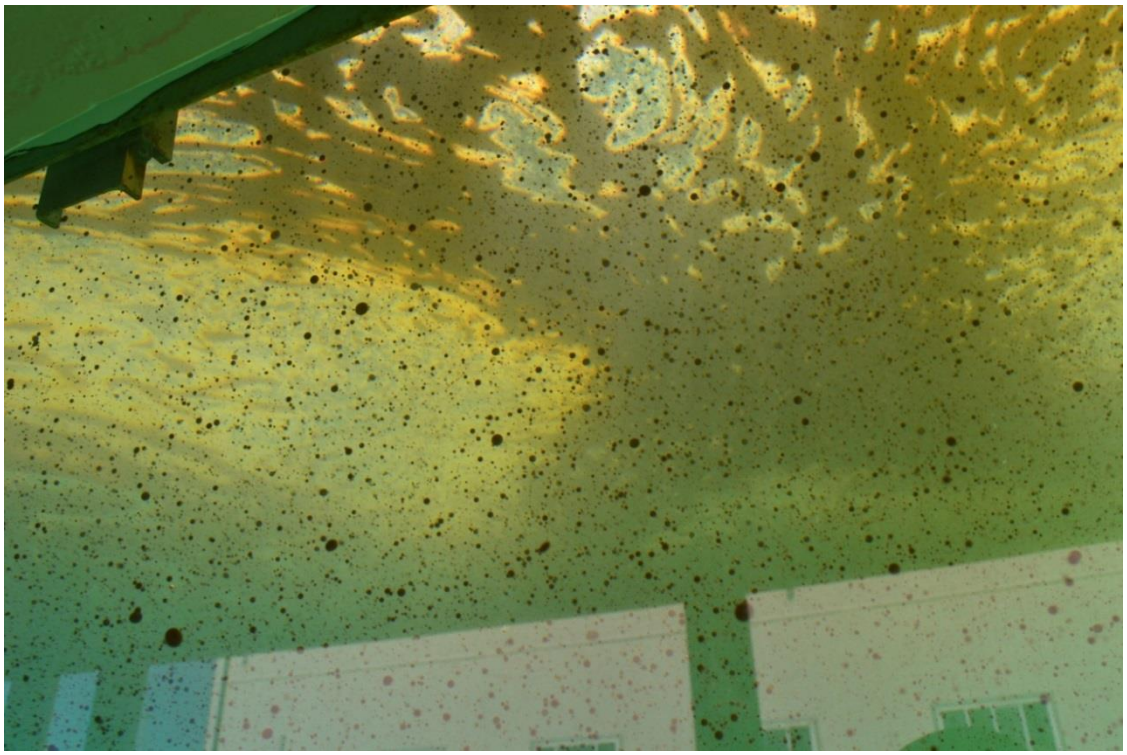


Figure 13. Water TPH concentrations (µg/L) and estimated TPAH concentrations (µg/L) versus fluorescence signal (mV). TPAH concentrations were estimated from the TPH concentrations using the TPAH to TPH ratio measured in the bulk oil sample collected on 7/18/2016.

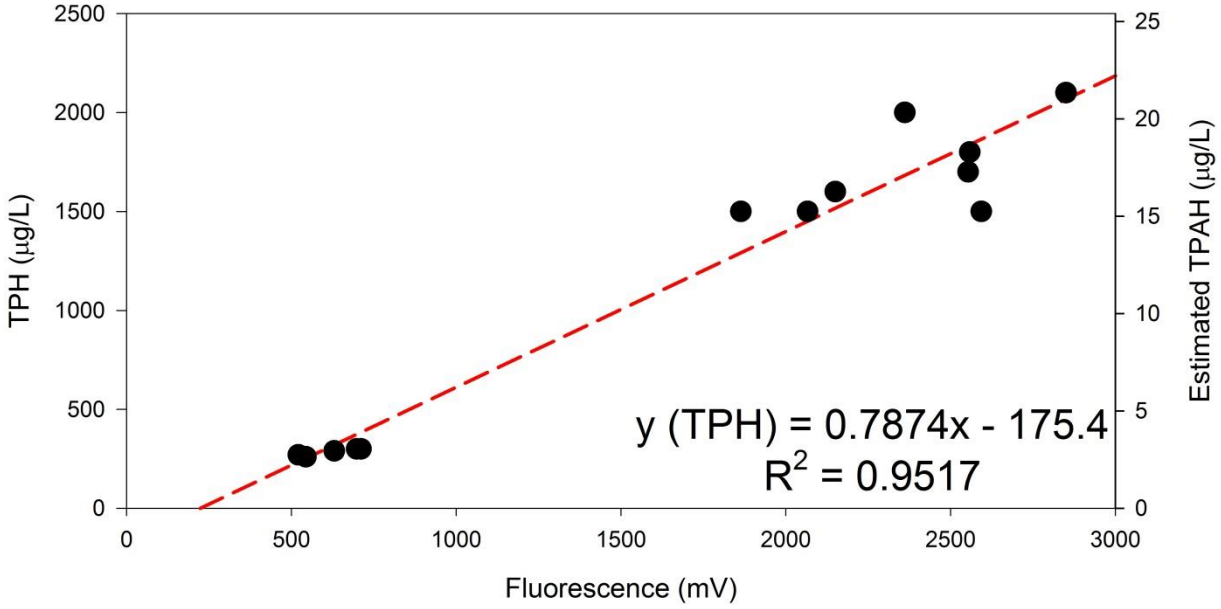
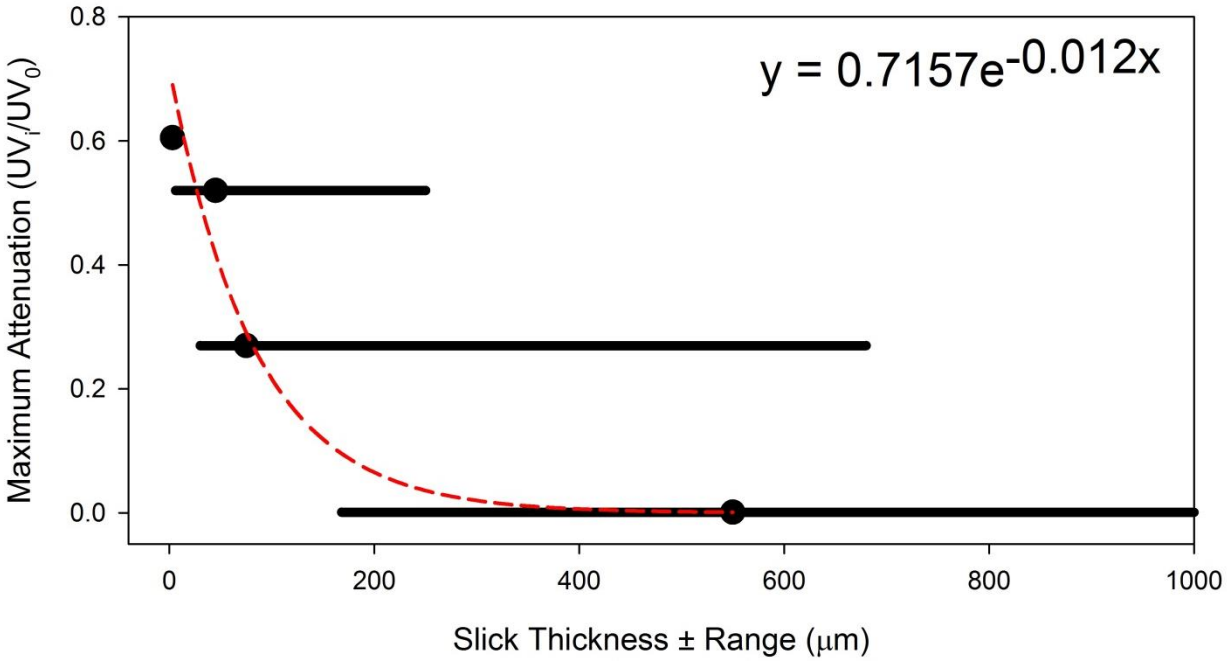


Figure 14. Attenuation of UV light versus slick thickness. The "maximum attenuation" is the ratio of UV intensity under the slick at the bottom of the tank (UV_i) to UV intensity just above the water surface (UV_0). A ratio of 0 means that UV was fully attenuated (i.e., no UV light penetrated the slick).



5. Conclusions and Lessons Learned

The primary purpose of the Ohmsett study was to develop methods for collecting data at oil spill sites. We tested four different methods for measuring the thickness of oil slicks or sheens. In addition, we further developed methods for measuring oil concentrations in water using individual grab samples and fluorescence spectroscopy. Finally, we deployed a UV radiometer to measure changes in UV attenuation in the water column with slick thickness. We implemented several changes to the protocols that were in place when the sampling at Ohmsett began, and we have provided recommendations for additional changes in the future (Table 1).

Table 1. List of recommended changes for methods tested at Ohmsett

Method	Changes implemented at Ohmsett	Future recommended changes
Dip plate	- Reduced the dip plate size to make plates more manageable. - Used a gravimetric-based measurement of oil versus the original volumetric-based measurement to improve method sensitivity.	- Weigh dip plate and container together before and after slick collection to eliminate oil transfer step.
Sorbent pad	- Deployed sorbent pad using a PVC sampling frame to improve consistency of deployment and surface area sampled.	
WaterMapping	- Used Tub O' Towels wipes (or similar product) to minimize oil adhering to the sampling tube.	
USGS fishing pole	- Used Tub O' Towels wipes (or similar product) to minimize oil adhering to the sampling tube.	
Water sampling by peristaltic pump	- Used a large-diameter PVC pipe with cap to minimize contamination of tubing ends by surface oil when deployed into the water.	- Use a 4-channel peristaltic pump so that water from all four sample depths can be collected simultaneously.

Table 1. List of recommended changes for methods tested at Ohmsett

Method	Changes implemented at Ohmsett	Future recommended changes
Fluorescence	- Used a large-diameter PVC pipe with cap to minimize contamination of tubing ends by surface oil when deployed into the water.	- Display and record all fluorescence data using the raw signal without calibration or background subtraction.

5.1 Slick Thickness

Oil slicks are highly heterogeneous on any spatial scale. In a study conducted for the *Deepwater Horizon* natural resource damage assessment, Forth et al. (2015) found that uniform sheens in a beaker varied in thickness by up to two orders of magnitude when measured with a laser. Slick thickness cannot be precisely quantified, particularly where oil is clearly patchy (see Figure 8). However, even with a precision of 1–2 orders of magnitude, slick thickness measurements can be a helpful metric for describing an oil slick and relating remote sensing data to water column PAH data.

For the slick thickness measurements at Ohmsett, we found that the four methods tested were complementary to each other, allowing for a greater range of thicknesses to be measured than with only using one method. Furthermore, each method had advantages and disadvantages depending on the oil slick or sheen being sampled. For example, the dip plate method was limited to the moderate thicknesses; the plates did not successfully collect oil sheens off the water, and they were not able to retain all of the oil if the slick was thicker than several millimeters. Also, when we used multiple methods in the same location, the dip plates consistently provided lower thickness estimates than the other methods, suggesting a bias toward underestimating thickness. On the other hand, the dip plates were very simple to make and deploy, allowing several measurements to be taken in very quick succession. Also, the measurements were easy to complete in the field, which provided us with immediate results.

The dip plate method was greatly improved during our testing at Ohmsett when we reduced the size of the dip plate, allowing us to capture all of the oil in a plastic container immediately after the plate was pulled from the water. In addition, switching from a volumetric-based measurement to a gravimetric-based method greatly increased the sensitivity of the method and reduced the sample processing time and sample transfer error. In the future, we recommend modifying the method so that the dip plate and container are weighed together before the dip plate is deployed, and transferring the dip plate with oil to the same container to be weighed after the slick sample is collected. The dip plate can then be cleaned and reused after it is weighed.

In contrast to dip plates, sorbent pads did not appear to have any bias (high or low) compared to the other methods. In addition, the sorbent pad method was the only method of the four tested that could successfully measure the thickness of sheens. However, each measurement required that a sample be analyzed at an analytical laboratory, which was costly, and the results were not available for days or even weeks.

The original sorbent pad method used a thin bar or pipe attached to a sampling pole. The bar or pipe had two clips that attached to one side of the sorbent pad. The pad was then lowered down in a vertical position, and carefully set on the surface of the water. This method suffered from two major issues. The first issue was that the pad and bar were both light and, thus, if there was any wind it was difficult to control the sorbent pad when placing it on the water surface. The

second issue was that the pad was not protected from surrounding oil; if the frame and pad drifted, it could sample oil from an area far greater than the area of the pad. To address these two issues, we constructed a PVC frame to enclose the pad while reducing the likelihood of sampling oil outside the frame. The frame also added weight to the pad, making deployment easier, keeping the pad horizontal, and making it easier to place the pad flush on the water surface.

The WaterMapping sampler measured the broadest range of slick thicknesses, from 25 µm to over 20 cm (see Figure 8). After initial setup, the WaterMapping sampler has a low per-sample cost. However, this sampler required considerably more time to mobilize and demobilize than did the dip plate, thus limiting the number of samples that could be collected at each site. The method also suffered from oil smears sticking to the inside of the tube, in some cases making it challenging to determine thickness of the settled oil. Wiping the inside and outside of the tubes with Tub O' Towels wipes before deployment appeared to alleviate this issue. In addition, Dr. Garcia will be modifying the design of this sampler so that it collects samples in a vertical tube rather than a horizontal tube, which may reduce the smearing problem.

Finally, the USGS fishing pole sampler was the best method for sampling the thickest slicks. Each measurement cost little to collect, and the device was simple to deploy if two people were available to operate the sampler. As with the WaterMapping sampler, the USGS sampler also struggled with oil smears sticking to the inside and outside of the tube. Again, wiping the tube with the Tub O' Towels wipes before deployment greatly improved the method.

5.2 Water Column Oil Concentrations

Sequential collection of samples from four different depths was overly time-consuming, such that the slick would often drift away before all four samples were collected. In the field, this would confound interpretation of results, since samples from the same profile would be collected under different slick conditions. Therefore, for future sampling, we plan to utilize a four-channel peristaltic pump so that four depths can be sampled simultaneously. This will allow for quicker sampling, producing a more accurate PAH concentration profile in the water column.

When at Ohmsett, we quickly realized that the surface slick interfered with our ability to collect water samples and fluorescence data under the slick. We developed and implemented a method for deploying the water sample tubing and the fluorometer into the water without contaminating the ends with the slick oil on the water surface. For this method, we routed the tubing and fluorometer through a large-diameter PVC pipe that was capped on one end. The PVC with cap was then deployed through the slick into the water and the cap removed by lightly tapping the outside edge. The tubing and fluorometer could then be lowered to the desired depth without direct contact with the slick. In the future, we will attempt to deploy the tubing and fluorometer through clean water before we enter the slick at a site; however, if this method is not available, we will use the capped PVC pipe cover as an alternative.

Finally, our data from the Cyclops 7 fluorometer were consistent with the water sampling data, suggesting that the fluorometer can be used to estimate oil concentrations in the water column. Furthermore, our data show the Cyclops 7 can detect oil concentrations that are in the low, single-digit µg/L of TPAH. Originally, we displayed the fluorescence signal as relative fluorescence with background fluorescence subtracted. At Ohmsett, we found that the background signal may change from day to day or site to site. Thus, we recommend that all data

be initially displayed and reported as the raw fluorescence signal (mV) to avoid issues with incorrect background subtraction and/or erroneous calibrations.

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Attachment B. Water Mapping Ohmsett Report

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3010 Coral Strip Pkwy
Gulf Breeze, FL 32563

Deepwater Horizon (DWH) Lessons Learned Studies: Detection of Oil Thickness and Emulsion Mixtures using Remote Sensing Platforms

Technical Report for Abt Associates

By

Oscar Garcia-Pineda, PhD
Water Mapping LLC

October 27, 2016

Revised July 31, 2017

"The findings and opinions expressed in this report are solely those of the authors and do not necessarily reflect the views and policies of the Bureau of Safety and Environmental Enforcement, nor does mention of the trade names or commercial products constitute endorsement or recommendation for use."

Water Mapping LLC
3010 Coral Strip Pkwy
Gulf Breeze, FL 32563

Executive Summary

During and after the 2010 Deepwater Horizon oil spill (DWH), remote sensing provided critical data that guided day to day operations and damage assessment decision-making. Remote sensing data were foundational for response search area identification, oil extent mapping and forecasting, and oil thickness and volume characterizations directly supporting injury assessment. In this context, Water Mapping LLC (WM) has been an important participant as part of the efforts leaded by NOAA and Abt Associates to advance our understanding on how we can exploit remote sensing technology.

Aligned with BSEE and NOAA objectives to capture lessons-learned from DWH and advance our understanding for oil spill preparedness, WM joined NOAA, BSEE, Abt, and other recognized oil spill industry participants on a comprehensive set of experiments at the National Oil Spill Response Research and Renewable Energy Test Facility (Ohmsett). These experiments occurred starting on July 14 and concluding on July 23, 2016. After the tests at Ohmsett, WM analyzed the data collected; this report presents the results of the analyses.

During the Ohmsett experiments, WM obtained high-resolution synthetic aperture radar (SAR) imagery from RADARSAT-2 and TerraSAR-X. The results of these data acquisitions verified that SAR can detect emulsified oil, although for slicks in the confined area of the Ohmsett tank, the oil emulsions were only detectable when the highest resolution beam mode was used and the incidence angle was less than 30 degrees. Higher-resolution satellite imagery from DigitalGlobe (Worldview-2 and -3) provided clear pictures of floating oil on the tank but little information on slick thickness/volume per unit area.

Additionally, WM collected visible and thermal infrared data using a camera and FLIR sensor attached to an unmanned aerial system (UAS, or drone). The imagery from the UAS clearly showed the distribution of oil in the tank, and the infrared data from the FLIR outlined the areas with the thickest oil.

WM also developed and tested a new in situ oil sampler designed for quantifying slick thickness. The floating remote-controlled sampler collected samples in a horizontally-mounted tube, with the sample collection triggered by the remote. A high-resolution macro camera subsequently photographed the sample, and a computer algorithm calculated the slick thickness based on the number of oiled pixels in the image. While this prototype is still under development, the work at Ohmsett demonstrated the utility of collecting a sample using a remote-controlled sampler and subsequently calculating the oil thickness using high-resolution photography.

Finally, WM combined synoptic oil thickness data with FLIR thermal infrared data to produce an initial estimate of slick thicknesses within the tank. While this oil quantification method was a proof of concept and will require additional development, the UAS is a promising new tool for oil spill detection and quantification.

The Ohmsett testing shows promising new techniques for assessing oil slicks in the field. Operationally, the UAS can be used not only to detect oil slicks in the vicinity of the operator, but also to discern between thicker actionable oil and thinner sheens. The WM oil slick sampler provides a method of creating a point estimate of oil slick thickness. With sufficient data, it may be possible to estimate average thickness or oil volume per unit area using these techniques.

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1. Introduction

As part of the project engaged between NOAA and BSEE, this technical report contains the results of the work performed by WM during the Phase 1 of the project carried out at Ohmsett from July 14 to July 23, 2016. The purpose of this work is centered on the utilization of Synthetic Aperture Radar (SAR) imagery for detection of oil emulsions on oil spills, and the support of a UAS with high resolution visual and thermal cameras as an observing platform. The results obtained by an oil sampler device developed by WM are also shown here.

The most technically challenging aspect of oil spill response operations and surface oil remote sensing monitoring has not been the actual detection of oil presence/absence or the oil slick size, but rather the quantification of the surface oil slick thickness (or volume). Over the past five years, the DWH NRDA pursued many studies looking specifically at the detection and characterization of oil thickness for fresh and emulsified oils using both active and passive remote sensing platforms and sensors.

SAR has been used for many years for the detection of oil on the ocean surface. The areas of low backscatter are commonly exploited as a means to delineate the oil and to use this information to support oil spill response (Garcia-Pineda et al. 2009, 2013A). From an oil-spill responder perspective, however, it is crucial to identify actionable (i.e. can be contained, dispersed, burned, recovered) versus non-actionable (cannot be controlled) oil within the overall spatial extent of the oil spill. In broad terms, actionable oil tends to be thick or emulsified oil, and non-actionable is thin, sheen-like oil.

During DWH, as presented by Garcia-Pineda et al. (2013B), on an empirical way we observed how SAR was able to detect oil emulsions that were also detected by other platforms. The detection of oil on the ocean surface is a well-proven SAR application that fundamentally

depends on the discrimination of the ocean-surface backscatter and the backscatter from the oil (Garcia-Pineda et al., 2009, 2010, 2013A, 2013B). Two of the three key-parameters that define ocean-surface backscatter are wind speed and SAR incidence angle: the backscatter increases with increasing wind speed, and decreases with increasing incidence angle. The detection of oil is enhanced at small incidence angles and for wind speeds roughly between 3 m/s and 12 m/s (Brekke and Solberg, 2005; Garcia-Pineda et al., 2009; Ivanov et al. 2002; Staples and Garcia, 2016; Staples and Rodrigues, 2013). A third parameter that dictates SAR oil detection is the polarization state of the radar. It is generally accepted that the co-polarization state, VV, provides stronger backscatter from the ocean surface than HH polarization. Cross-polarized radar returns (HV or VH) from the ocean surface are inherently low.

For this project, based on our theoretical understanding and our empirical observations made during the DWH using SAR, we wanted to test our hypothesis if SAR could actually detect heavy oil emulsions under specific set of conditions. We attempted this test by scheduling acquisitions by RADARSAT-2 ultra-fine spotlight and TerraSAR-X spotlight beam modes over the Ohmsett tank. The plan was to use the Ohmsett tank capabilities to release 400 gallons of crude oil and progressively expose the oil through the emulsification process while different SAR snapshots (variable in wavelengths, resolution, and incidence angle) were collected.

In addition to the collection of SAR snapshots during the emulsification process, we would acquire different direct measurements with our WM sampler and we would monitor the progression of the emulsions also with our UAS platform.

2. Chronology

From the beginning of the operations at the Ohmsett facilities, WM in coordination with BSEE, Ohmsett personnel, and all the other project participants met every morning with a detailed safety meeting and a daily plan of the activities. All the participants were coordinated primarily based on the satellite acquisition schedule and with the progression of the emulsification of the oil released in the tank. Starting on day 1 (July 14th), 400 gallons of oil were released and we were able to start testing our sampling device. The first satellite image was acquired on the early morning of July 16th by Radarsat-2. UAS operations started as well that same day, and were continued every day at different times in coordination with the other project participants.

Table 1 is a timeline summary of the activities in which WM took part during the Ohmsett tests.

Table 1. Chronology of the activities at Ohmsett

Day Number	Date	Activities
1	14-Jul	Oil Release, Initial tests with WM sampler
2	15-Jul	WM sampler adjustments and calibration
3	16-Jul	First UAS flights, First SAR Satellite Image Collected, WM sampler used
4	17-Jul	World View Image collected. No activities over the tank.
5	18-Jul	Radarsat-2 and Optical images collected. UAS operations and WM sampling
6	19-Jul	TerraSAR-X, UAS thermal, visual, and WM sampling
7	20-Jul	Calibration of UAS thermal and tests with WM sampler
8	21-Jul	TerraSAR-X, UAS thermal, visual, and WM sampling
9	22-Jul	Radarsat-2 and Optical images collected. UAS operations and WM sampling
10	23-Jul	Data gathering, clean up, and end of operations

3. Satellite Data

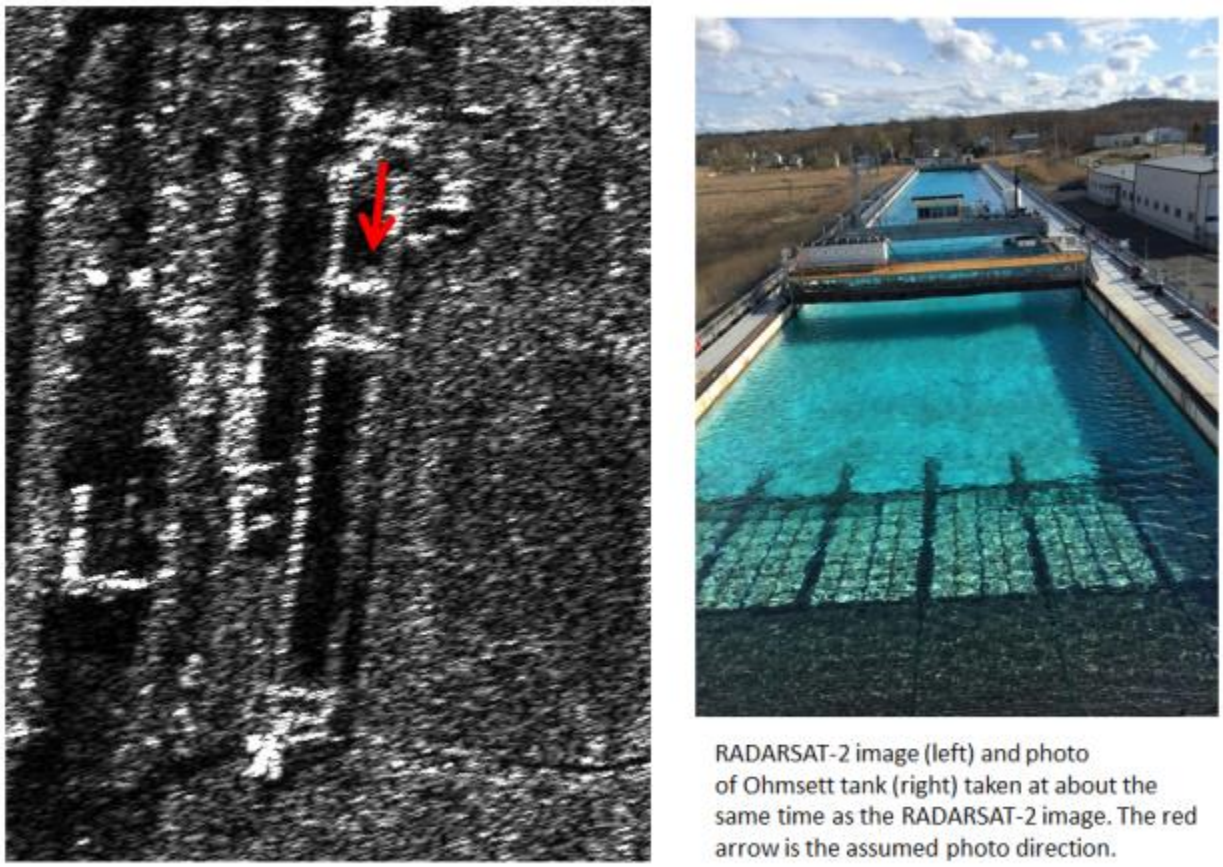
Since 2014 WM has had a data sharing agreement with MDA Corporation, the operator of RADARSAT-2. MDA is also in parallel agreement with Airbus, which is the satellite operator of TerraSAR-X. Because of these agreements, we were able to obtain satellite SAR imagery at a nominal cost of less than 20% of the regular commercial price of the imagery. Additionally, NOAA/NESDIS requested 4 images from the WorldView-2 and WorldView-3 satellites (Table 2).

Table 2. Summary of Satellite Data

Satellite	Number of Images	Satellite Wavelengths	Resolution
RADARSAT-2	3	C-Band	1m
TERRASAR-X	2	X-Band	40cm
Worldview-2	2	Visual	1m
Worldview-3	2	Multispectral	1m

For SAR satellite imagery, satellite operators adjusted the beam configuration for the specific request of aiming the tank. This beam mode is not a very common request. Usually for oil spills, SAR images cover a greater area with a pixel resolution of about 10-25m per pixel, compared to the small area of the Ohmsett tank with pixel resolution of one meter or less.

Once the image is acquired by the satellite the next step was to conduct a calibration process on the satellite data to generate a digital version of the image collected. In order to get a control dataset, previous to this exercise, we acquired an image from RADARSAT-2 in April 7, 2016. This satellite image shown below (Figure 1) was a good example that allowed us to see how many 'interference-free' pixels we could obtain inside the tank. At the time of this snapshot, the tank did not have any thick oil present.



RADARSAT-2 image (left) and photo of Ohmsett tank (right) taken at about the same time as the RADARSAT-2 image. The red arrow is the assumed photo direction.

Figure 1. Background images of the Ohmsett tank.

3.1. Satellite Imagery Gallery

Figures 2 and 3 show a summary of all the satellite imagery collected during the experiments. A detailed description of the satellite imagery datasets can be seen on Appendix A. Each of the maps on Appendix A shows a close up to the area of interest (the Ohmsett tank) and the footprint coverage of the entire image.

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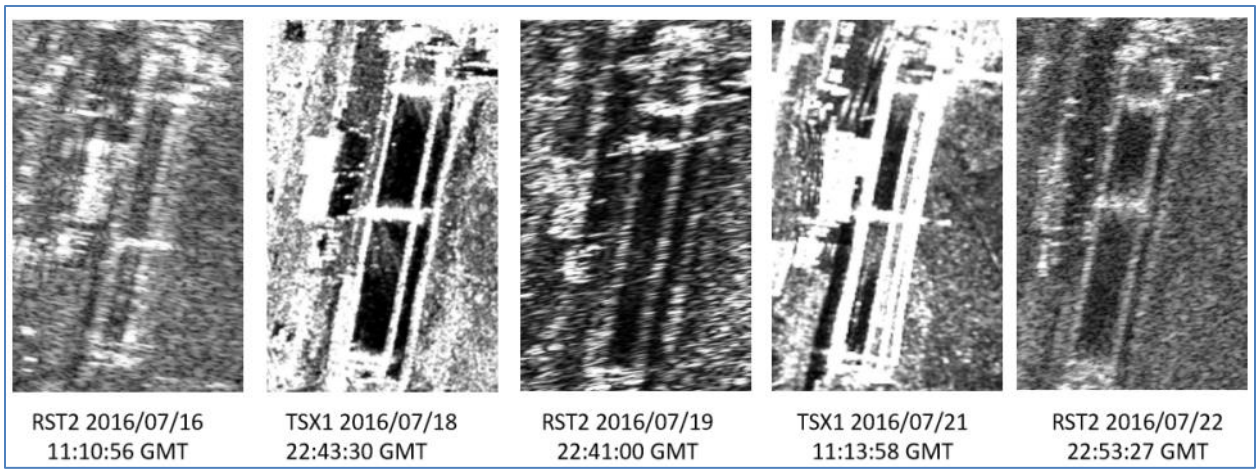

Figure 2. SAR Imagery over Ohmsett



Figure 3. WorldView Imagery over Ohmsett

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4. Oil Thickness Measurements with WM sampler

For several years WM has been developing technology for sampling oil and for measuring oil thickness on water. For this phase at Ohmsett, WM designed and built a floating apparatus that carries a tube to collect an oil sample. The tube was suspended horizontally and centered on the waterline to allow the oil to flow freely in/out the tube (Figure 4). This apparatus is the second operational prototype that WM has produced and is called the WM-OSS2 (Water Mapping Oil Spill Sampler 2).

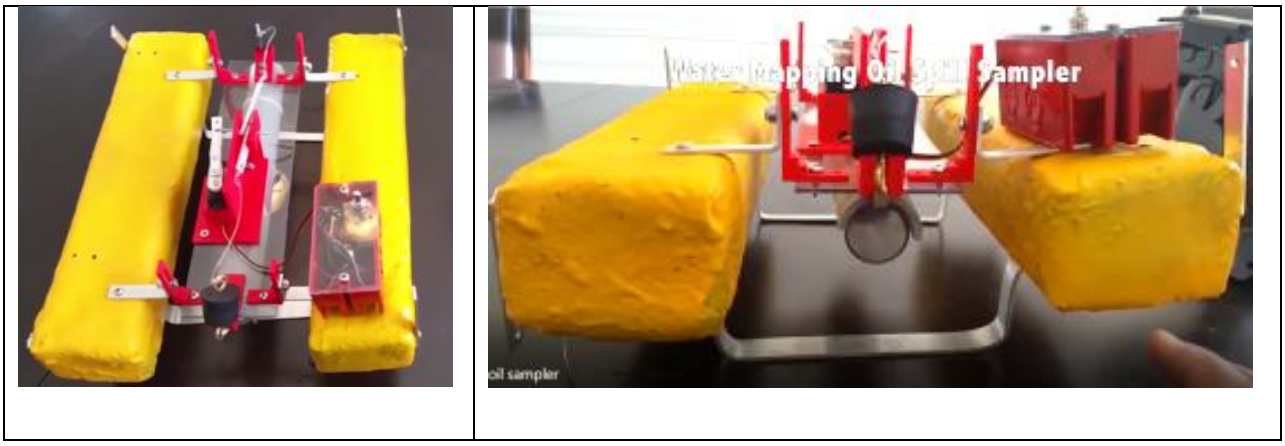

Figure 4. WM Oil Spill Sampler

The WM-OSS2 can be deployed on water, attached to a line or a cable. This device is operated via a radio remote control. A triggering mechanism holds a safety pin that the operator releases using the remote control. In addition, we mounted a camera aligned with the tube and a second underwater camera that looked from underneath. Figure 5 shows stills from the video collected while in operation.

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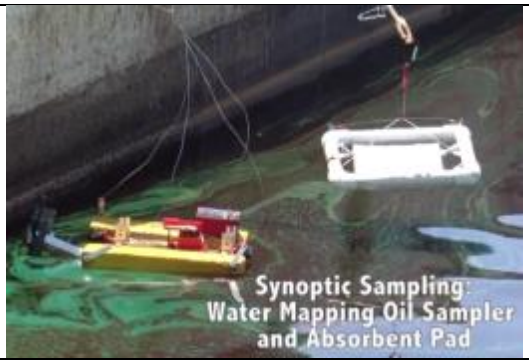
View during oil-water sampling	View after trigger activation sample secured
	
	
	

Figure 5. Water Mapping Oil Spill Sampler-2 Operation.

For this particular test, the collections of the samples were secured on a 12 inch long polycarbonate tube with an inner diameter of 1.25 inches. Samples were then taken into a portable photo-lab for analysis (Figure 6). The camera uses a 5x macro-lens that takes a high resolution photo of the sample.



Figure 6. Portable photo-lab

The high resolution photo of the sample was then analyzed in a custom Graphical User Interface (GUI) developed by WM in Matlab. This GUI allows the measuring of the oil thickness by quantifying the length in pixels of the floating oil inside the tube.

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The thickness measurement was obtained by measuring the length (in pixels) of the diameter of the tube, and then measuring the distance (in pixels) of the oil line (Figure 7). By dividing the known diameter of the tube (1.25 inches) by the number of pixels, we determined the size of each pixel in inches, which we converted to meters.

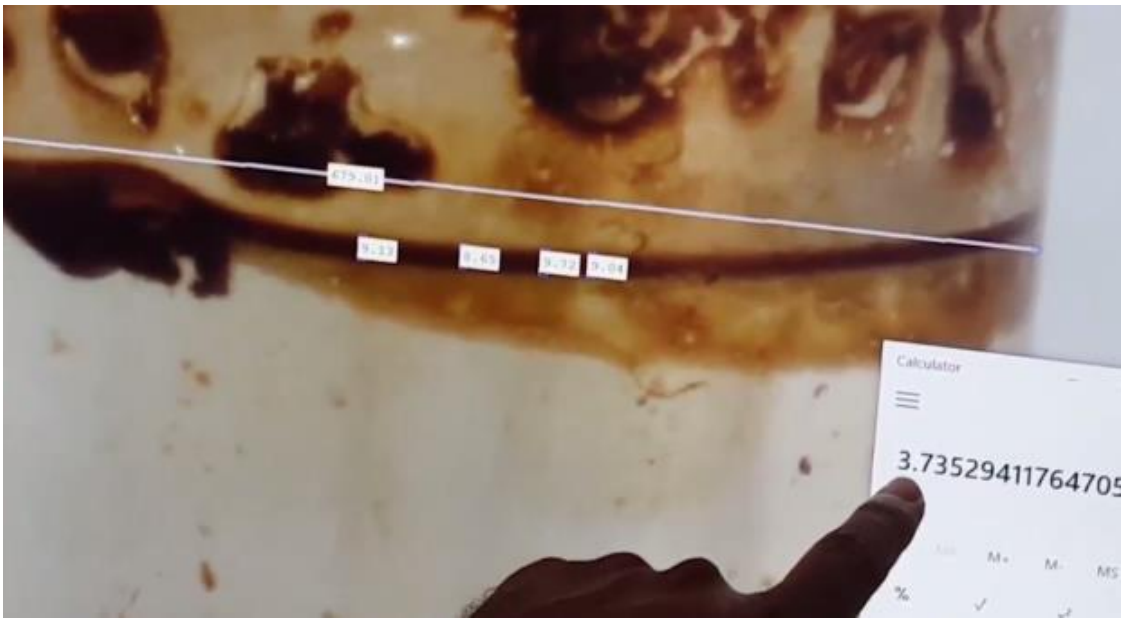

Figure 7. Image Processing for thickness measurement.

Once the pixel size (Pz) was determined, then we multiplied Pz by the length of the oil line (Pq). This provided thickness concentrated over the area of the inner diameter of the tube, which was then divided by the horizontal area of the tube.

The equation to resolve thickness is:

$$Th = (Pq * Pz)\ \frac{Vertical\ Circular\ Area\ Tube}{Horizontal\ Area\ Tube}$$

Where Th = Thickness, Pq is the quantity of pixels of the oil line, Pz is the pixel size (in meters).

Figure 8 shows some of the most representatives samples collected during the experiment showing the full range of thicknesses. A detailed report of each sample is available as Appendix B. In each case we include a photo taken at the moment of the sample with the location of tank.

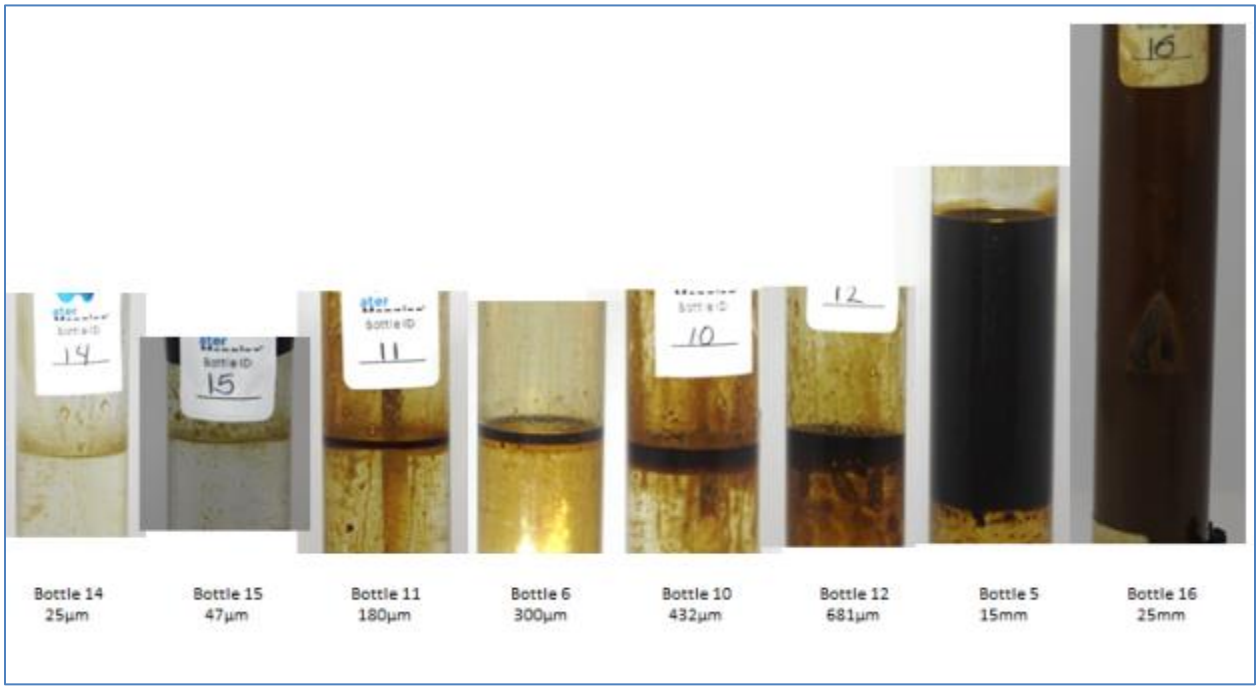

Figure 8. Oil Samples collected at Ohmsett

5. UAS operations

To provide support and validation of the observations, WM used an unmanned aerial system (UAS) during the Ohmsett experiments. The UAS carried a high definition (HD) real time transmission video and a FLIR thermal infrared sensor. This UAS system recorded the evolution and weathering of the oil emulsion so it could be correlated with the satellite data. The UAS also helped with the selection of targets of oil of different categorical thicknesses.

The UAS platform consisted on an octocopter with a payload capability of 24 lbs. This platform allowed us to mount an HD camera and FLIR on independent gimbals (Figure 9).



Figure 9. WM UAS System

One of the advantages of this UAS system configuration is its 'Lightbridge' video system (Figure 9, bottom right) that enables multiple monitors to receive the video signal 'live' from any of the UAS cameras on high definition. This signal has been tested to remain strong within a 2 mile range.

We collected high resolution photos during the UAS flight (Figure 10) every 4 seconds. All of the photography and telemetry information was then ingested into software that handles the orthographic information of the UAS (Figure 11) to generate a photo mosaic (Figure 12).

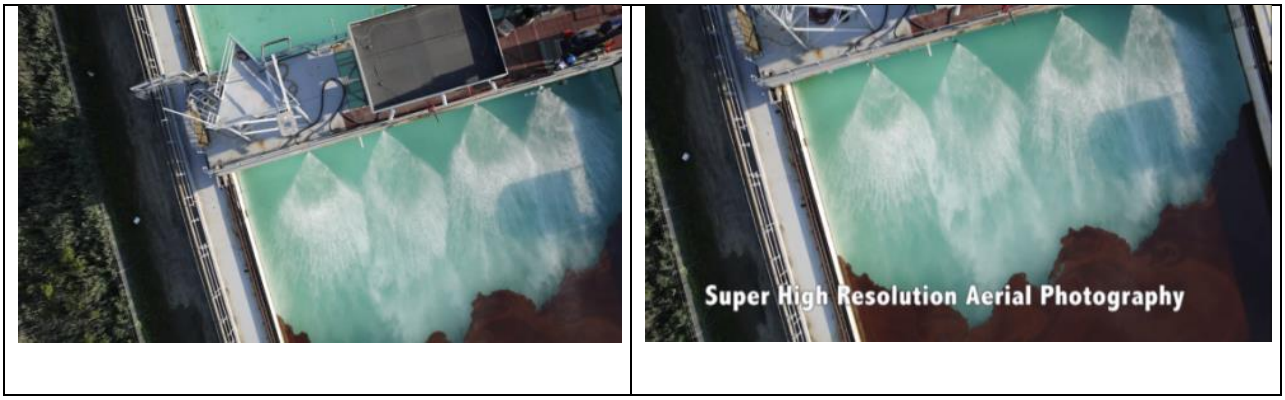

Figure 10. UAS photography examples

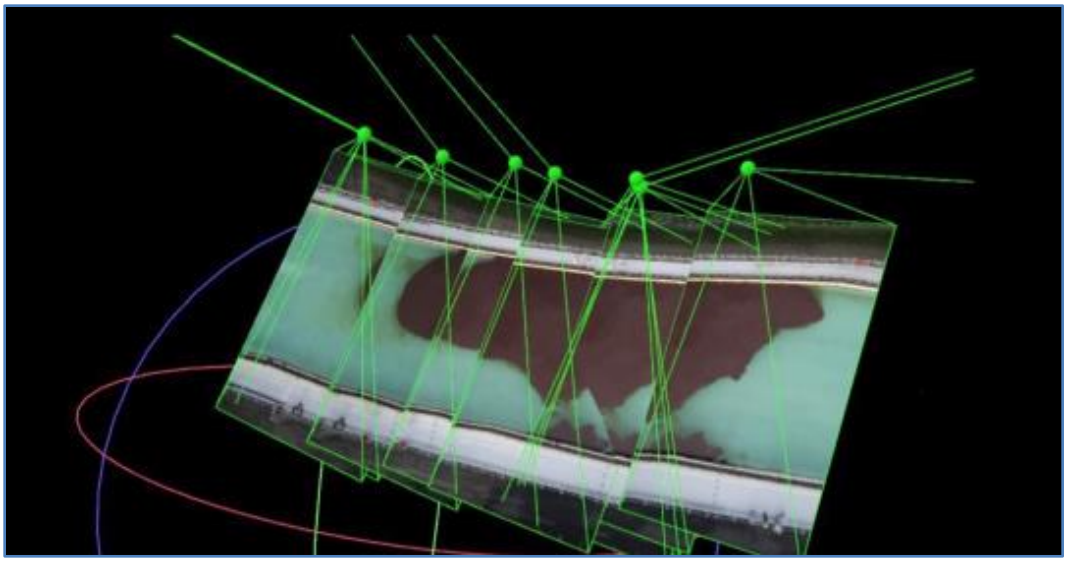

Figure 11. UAS imagery orthomosaic process

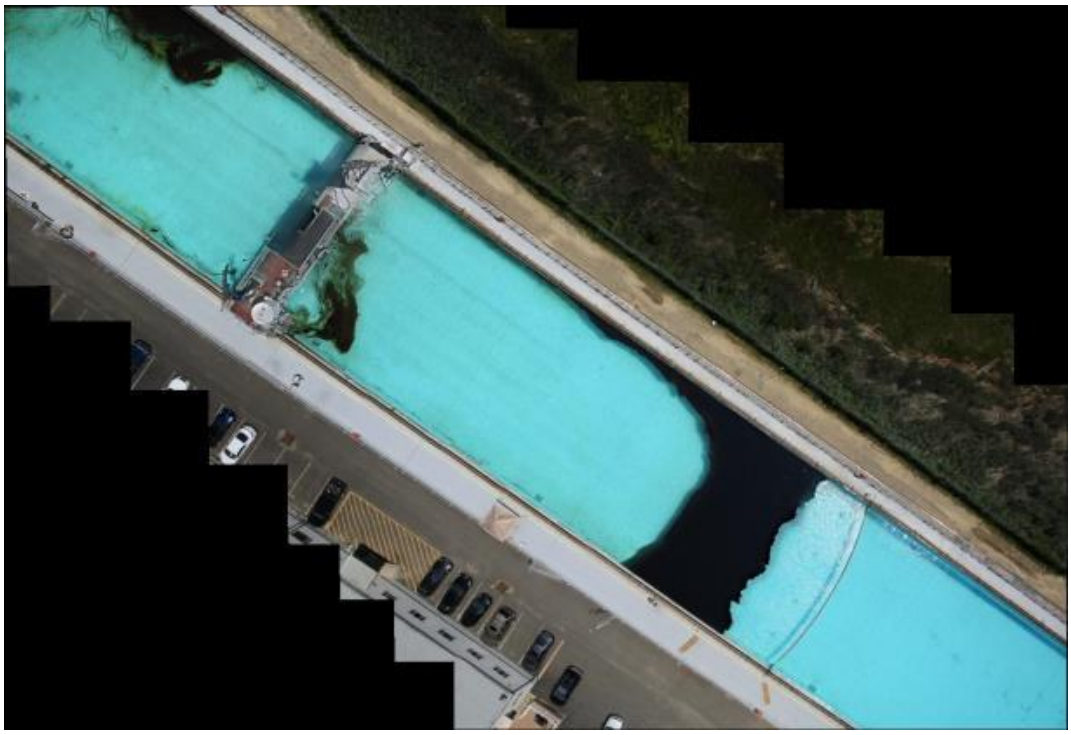

Figure 12. Final aerial photo mosaic.

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The photomosaic in Figure 12 was generated from flight data collected on July 16th. For each flight, all of the UAS control data points were recorded (Figure 13).



Figure 13. Flight telemetry data

Flight records are useful for generating the photo-mosaics as well as for compliance of the FAA rules.

At the altitude flown at Ohmsett, the photographs had a very high resolution of 5mm per pixel. Figure 14 is a final photomosaic produced from a flight on July 18. Figure 15 shows a close-up view of the blue square in Figure 14, demonstrating the resolution of the original photograph.



Figure 14. UAS high Resolution Full Size

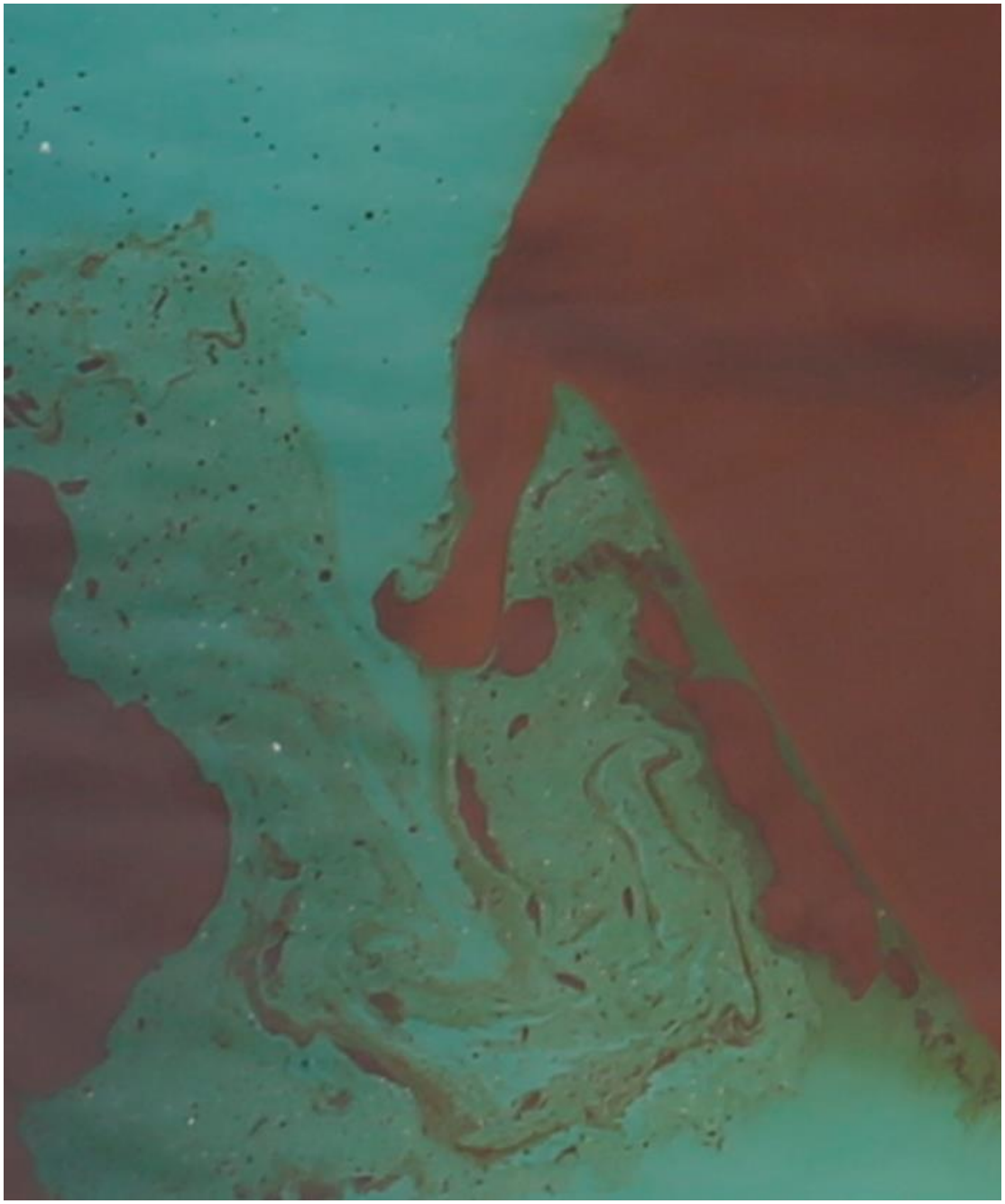

Figure 15. Full resolution (5 millimeter pixel resolution UAS photography)

A summary of the UAS photomosaics is shown on Figure 16. High resolution photography was used to correlate the observations of the satellites and other sensors.

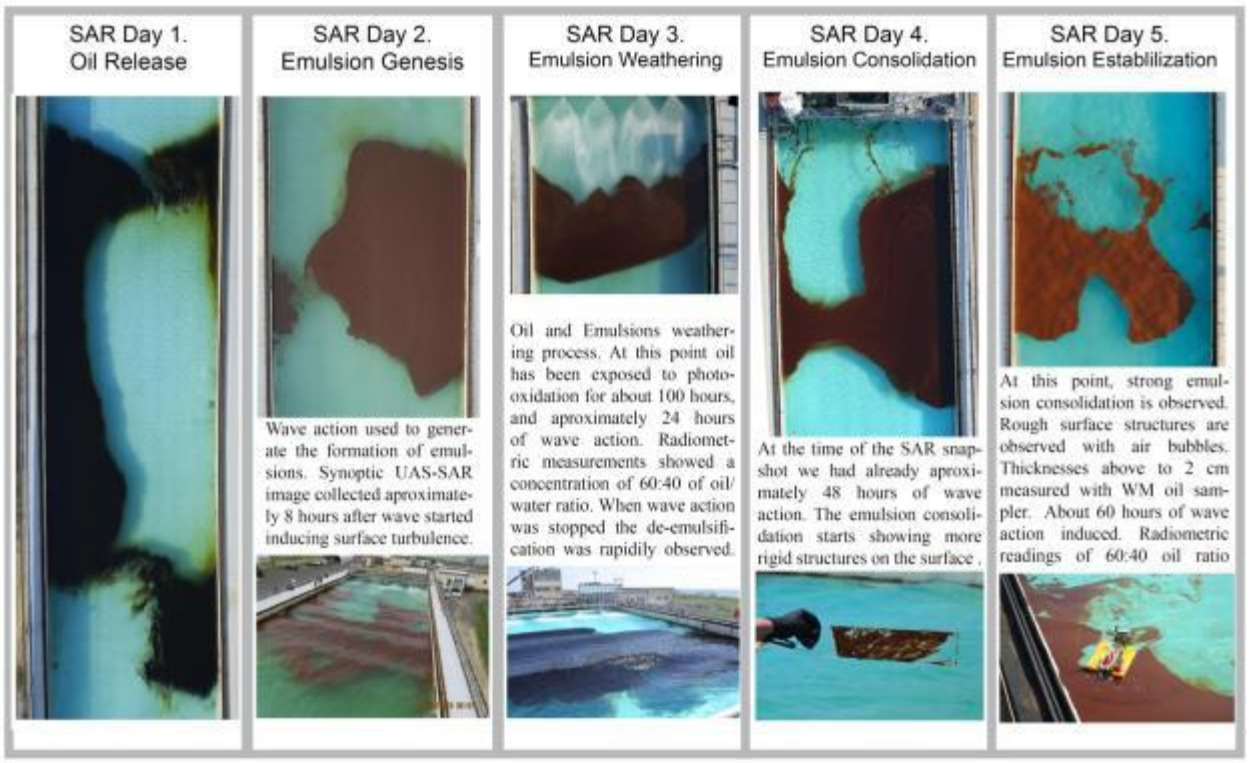

Figure 16. Daily synoptic UAS-SAR observations at Ohmsett.

Collecting both optical and infrared images at the same time revealed structures that were not visible to the human eye (Figure 17). This real time imaging system allow us to detect spots of specific thicknesses within the tank; field sampling personnel could target specific areas of oil thickness, guided by these images in real time.

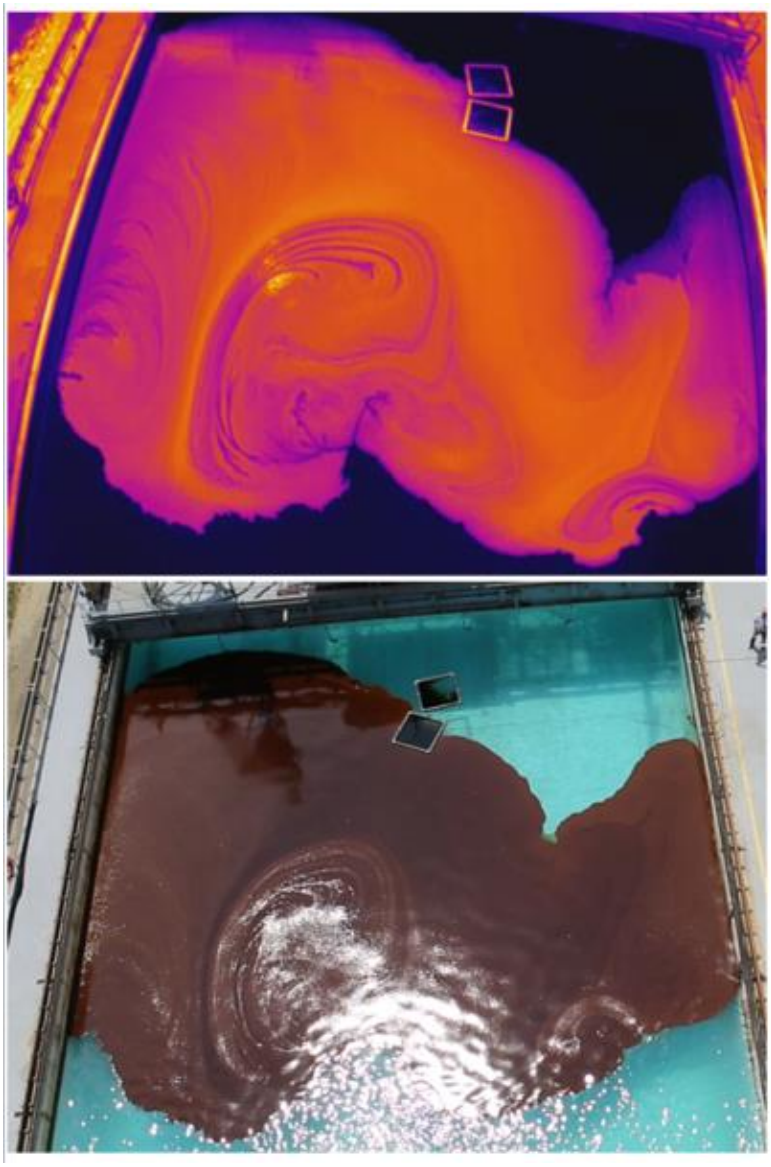

Figure 17. Synoptic view of both UAS cameras (FLIR and HD Optical)

During the experiments at Ohmsett we were able to display on a screen the real time video as seen by the Infrared camera. Figure 18 shows an example of synoptic views from the visual and the thermal cameras. While the visual HD video (inset top left) showed an even black surface, the thermal infrared detected different oil thickness signatures.

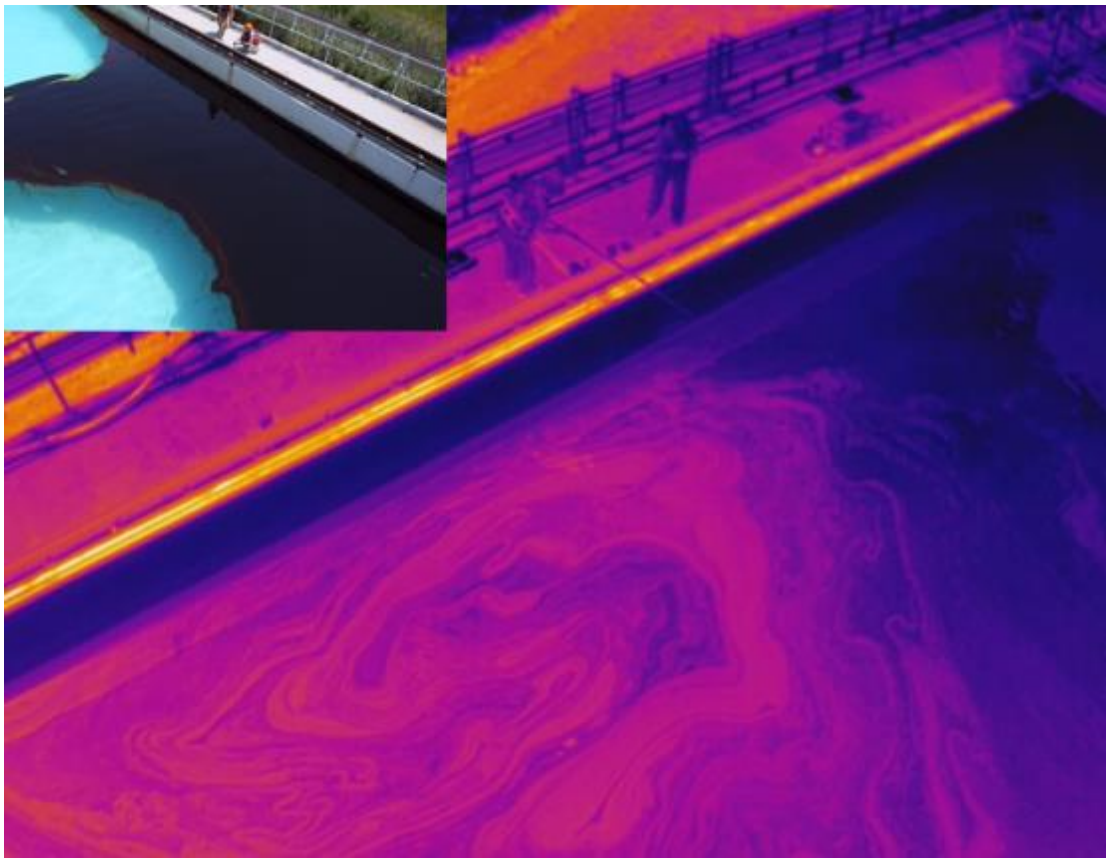

Figure 18. UAS-Thermal for Sampling

The UAS-FLIR system provided a unique resource to observe the progression of the emulsion and the distribution of the relative thickness of the oil in the tank. A 'Fusion' color map was chosen after performing different tests as it shows the highest contrast between thin and

thickest layers. Figure 19 shows the data collected by the thermal (top left) and visual (bottom left) cameras on the UAS. These snapshots can be processed and georeferenced to match the exact location.

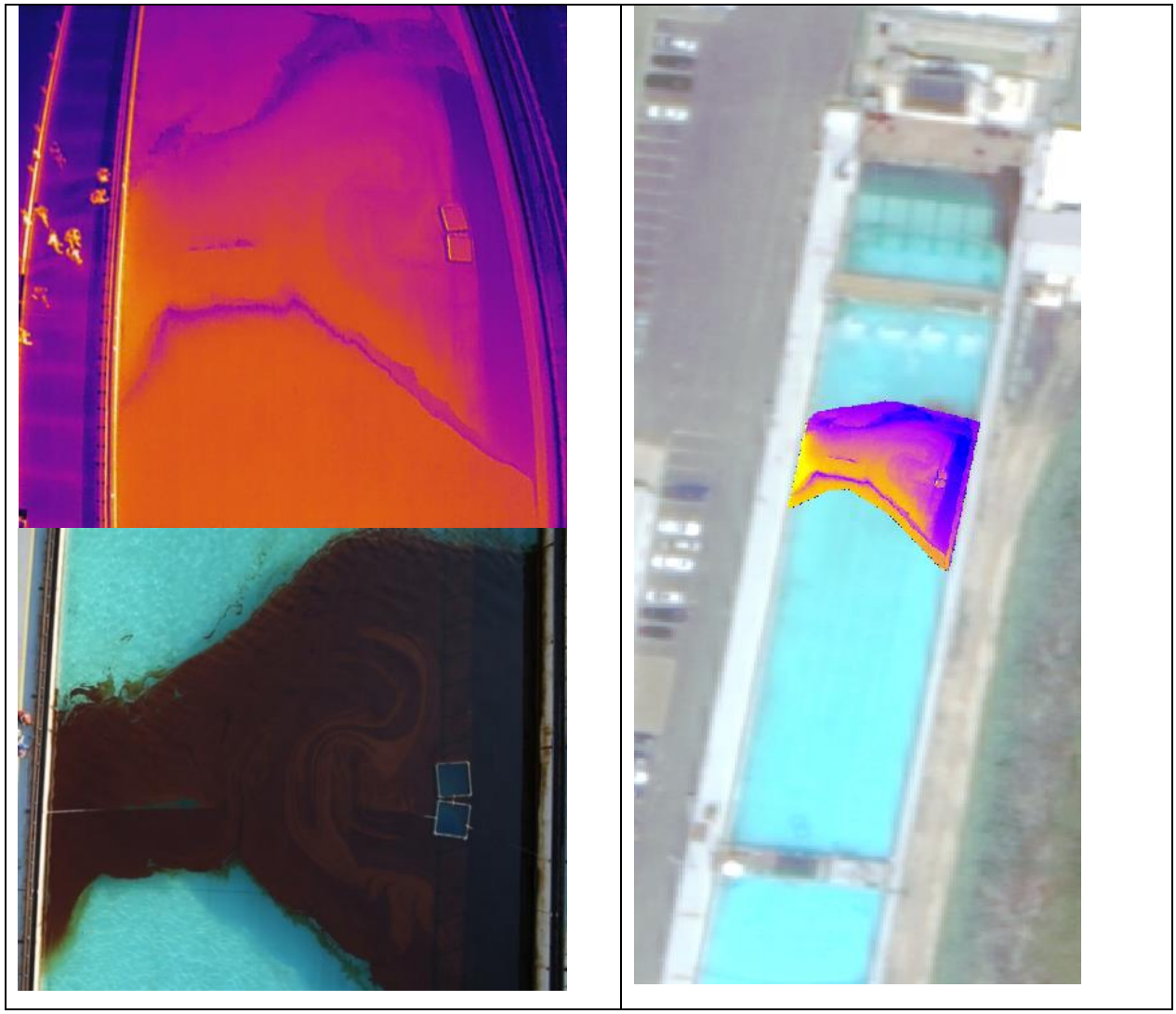

Figure 19. Projection of FLIR on Ohmsett

Figure 19 (right) shows the location of the data collected by the FLIR after being geo-rectified. The brightest colors (yellow-orange) correspond to the warmest areas on the oil inside the tank. That layer is correlated with the thickest areas of emulsions (Figure 20).

For oil spill monitoring, an important parameter is oil-water contrast. This is usually defined as the signal from a patch of oil less the signal from surrounding water divided by the signal from the water. When the contrast is 0, oil cannot be detected; negative or positive contrast allows the oil to be detected if the contrast is greater than the noise level of the instruments.

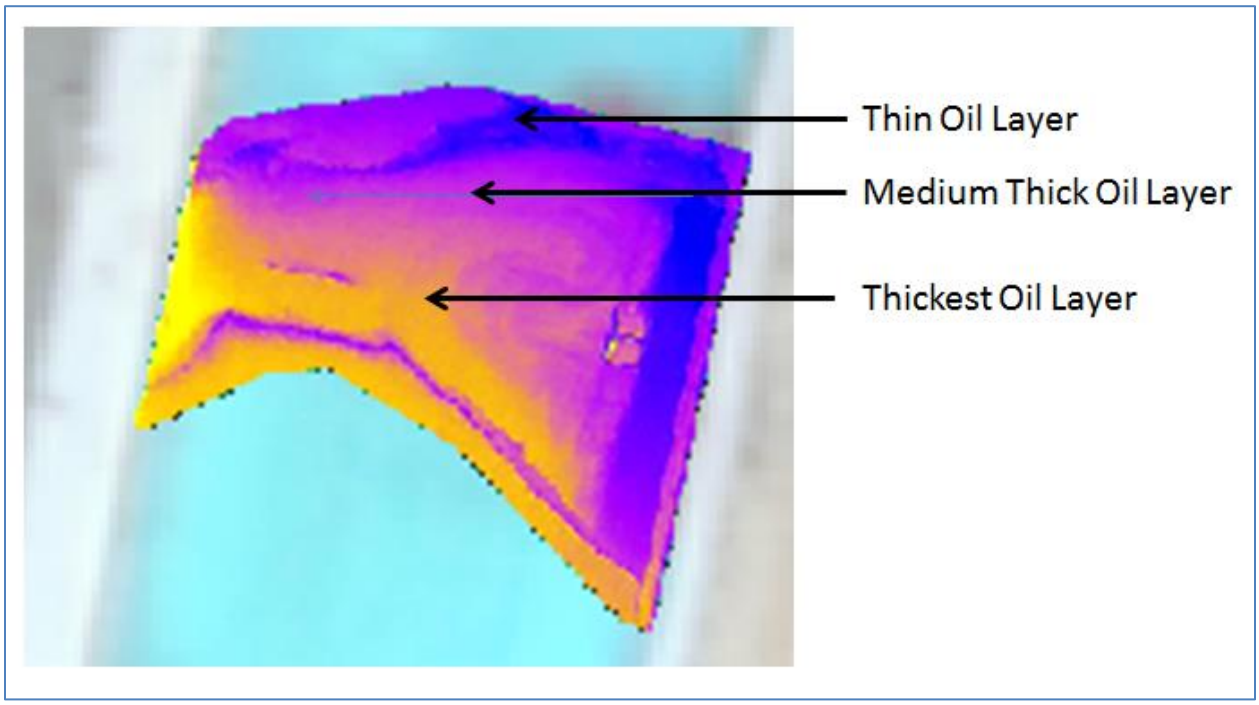

Figure 20. Categorical oil thickness detected by the Thermal UAS

Detection of surface oil in thermal data is based on different physical principles from those responsible for oil water contrast in the UV part of the spectrum. Oil is detectable in thermal images for two reasons:

- The thermal emissivity of oil is lower than that of water.
- The temperature of surface oil is often different from the temperature of the surrounding water.

It is important to point out that the thermal emissivity will be affected by the incidence angle of the thermal sensor. Figure 21 shows two examples of thermal views georectified over the Ohmsett tank. These two datasets were collected less than 30 minutes apart.

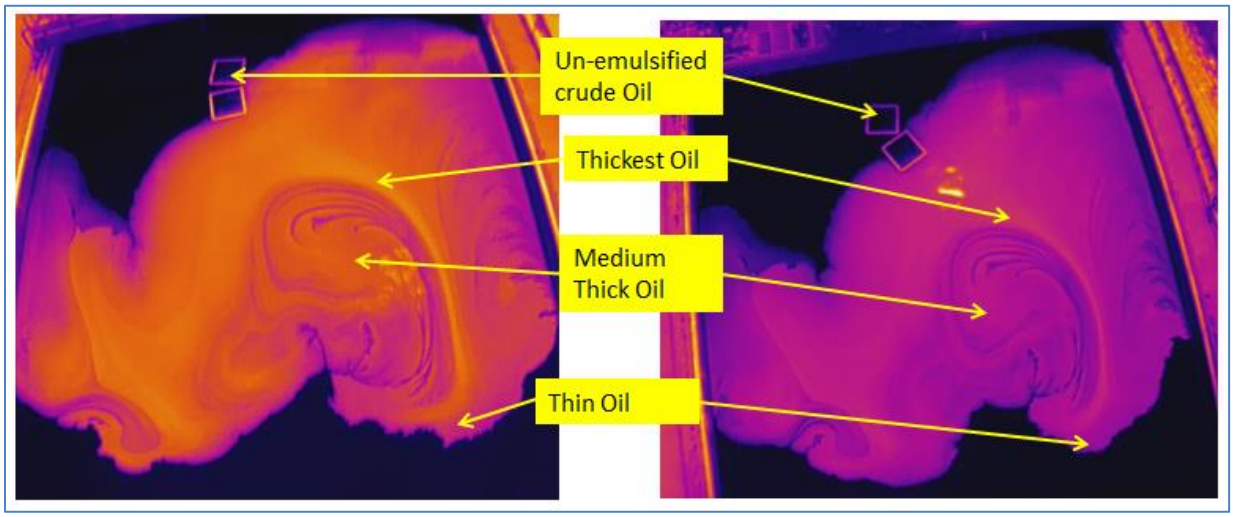

Figure 21. Thermal imagery from different viewing angles.

In Figure 21, the detected emissivity of the oil changes depending on the viewing angle of the camera. However, the features related to the thickest oil are still detectable and match the location in both cases. Figure 21 (left) was taken at 45 degrees oblique (from nadir) and Figure

21 (right) was taken at 30 degrees oblique (from nadir). Figure 22 shows a projection of the thermal infrared data over the Ohmsett tank.

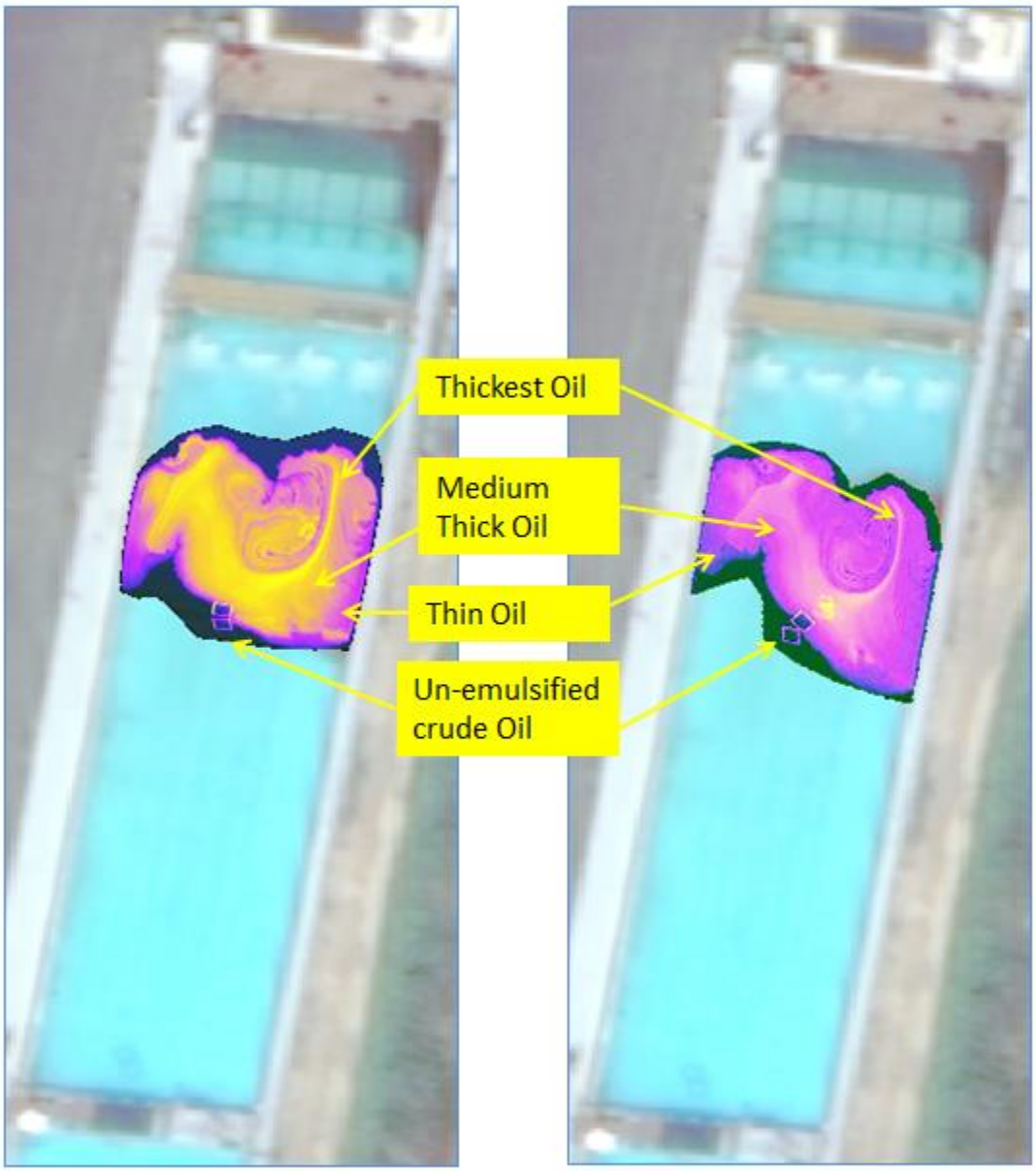

Figure 22. Projection of UAS-Thermal over Ohmsett

By performing a calibration of the thermal imagery collected from the UAS with the thickness measurements collected by the WM-OSS, we produced a thickness map classification of the oil on the Ohmsett tank (Figure 23).

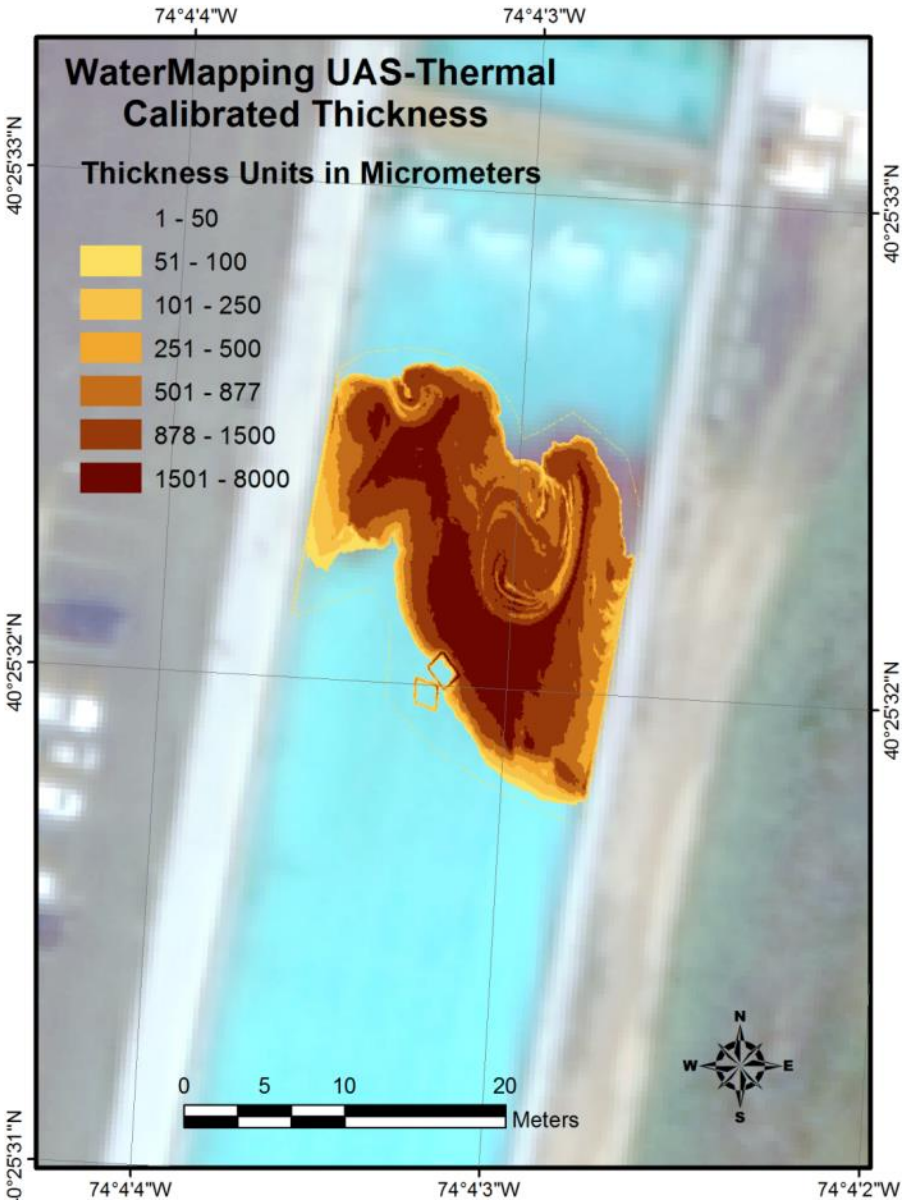

Figure 23. Calibrated thickness classes.

6. SAR Analysis

The main purpose of obtaining the SAR data was to confirm that oil emulsions could generate significant backscatter that can be discerned from the surrounding un-emulsified oil (Garcia-Pineda et al., 2013). This concept was the foundation to generate the Oil Emulsion Detection Algorithm (OEDA) which was used on many of the SAR images collected during the DWH. Figure 24 shows an example of features imaged synoptically by optical and SAR imagery on May 24, 2010. The location, scale, distribution, and size of this features suggested that they corresponded to heavy thick oil emulsions.

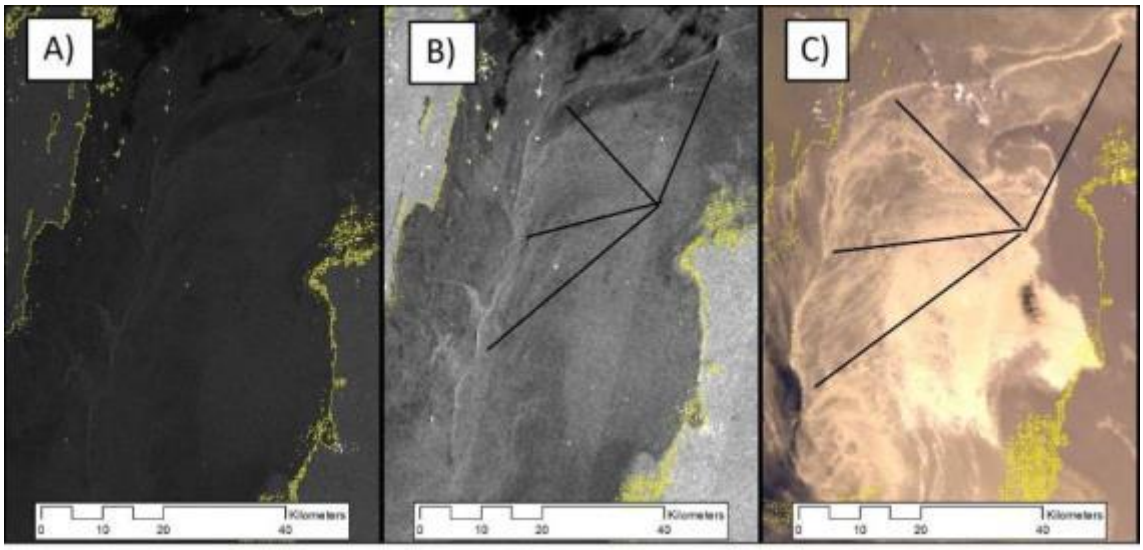

Figure 23. Synoptic SAR (ALOS) and optical (MERIS) satellite data over DWH. Raw SAR data (A) can be used to delineate the extent of the slick. Post-processed SAR data (B) can be used to enhance features associated with thick oil emulsions that also can be observed on optical data (C). Source: Garcia-Pineda et al., 2013B

One of the challenges during the Ohmsett experiments was to acquire the SAR imagery with the appropriate incidence angles. The SAR images collected during the Ohmsett sampling did not

have optimal incidence angles. Most oil spills do not occur during optimal weather or when passing satellites have optimal viewing satellite angles. In this situation, we had make do with the satellite data available during the week of the tests at Ohmsett.

We knew in advance that the best possibilities for getting good results were during the acquisitions on July 18 and 21. These two SAR configurations represented the best incidence angles that we could get to image oil emulsions inside the tank. The image collected on July 18 by TerraSAR-X had great quality. However at the time of this acquisition the operations at Ohmsett were at a stage where we did not had generated emulsions yet. Because of that, the image collected on the 18th did not show any distinctive features.

The satellite image collected on July 21st is outstanding (Figure 24). This image corroborated the concept suggested on Garcia-Pineda et al. (2013B). The image processing steps and conclusions are presented in the following section.

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TERRASAR-X Spotlight Acquired on July 21st, 2016



Figure 24. SAR footprint of TerraSAR-X July 21st. This spotlight image had a nominal resolution of 40 cm and an incidence angle of 24 degrees from nadir.

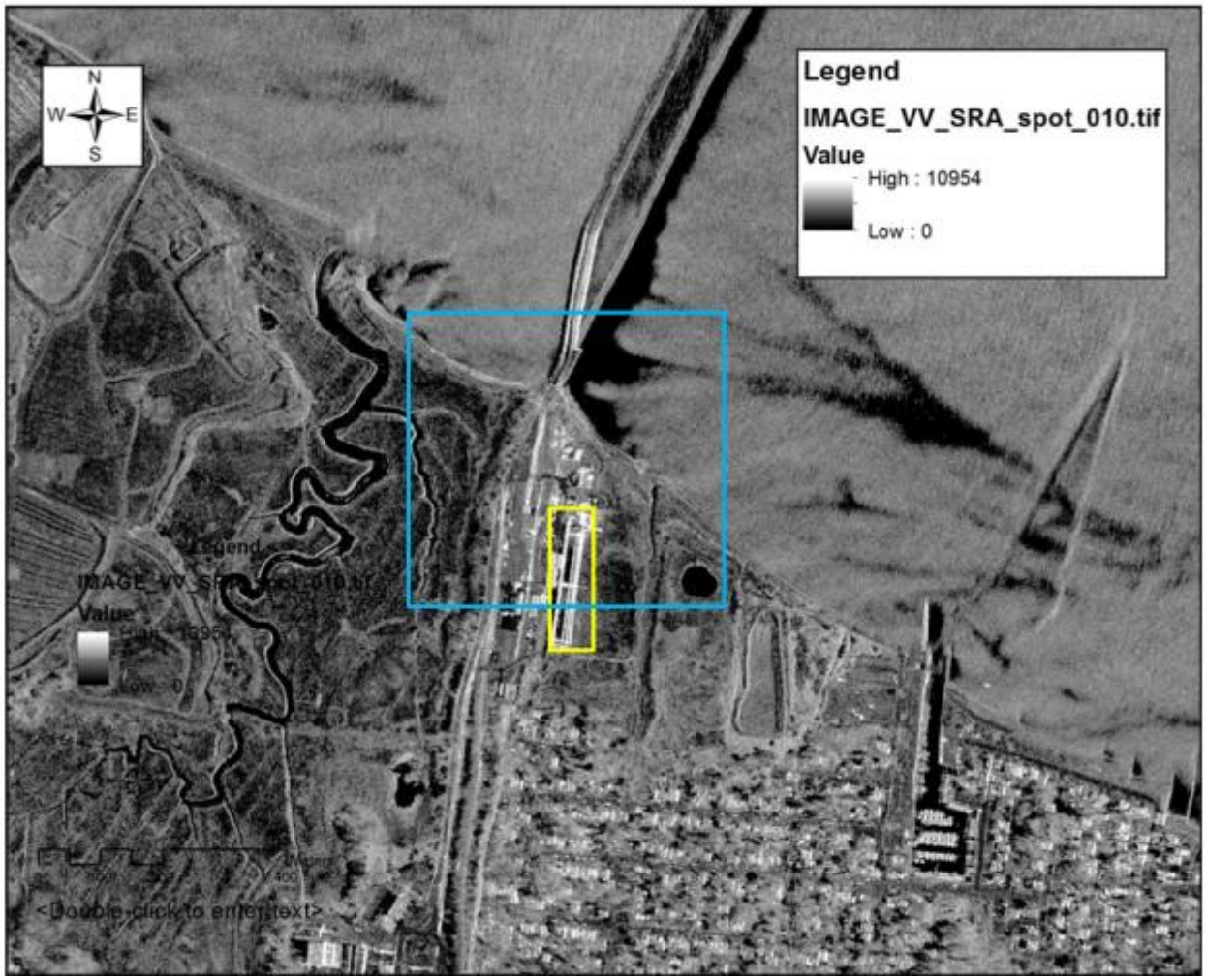

Figure 25. SAR image of Ohmsett and the adjacent bay. The two sub-scenes of the SAR image (blue and yellow rectangles) are described in the following analysis.

We used image enhancement on two SAR sub-scenes to show how the pixel values changed across the image particularly on areas of the Bay where there is no oil present. This exercise allowed us to see the floor noise and the speckle noise of the image. We then compared the pixels inside the tank with pixels on open water on the bay (Figures 26, 27, and 28).

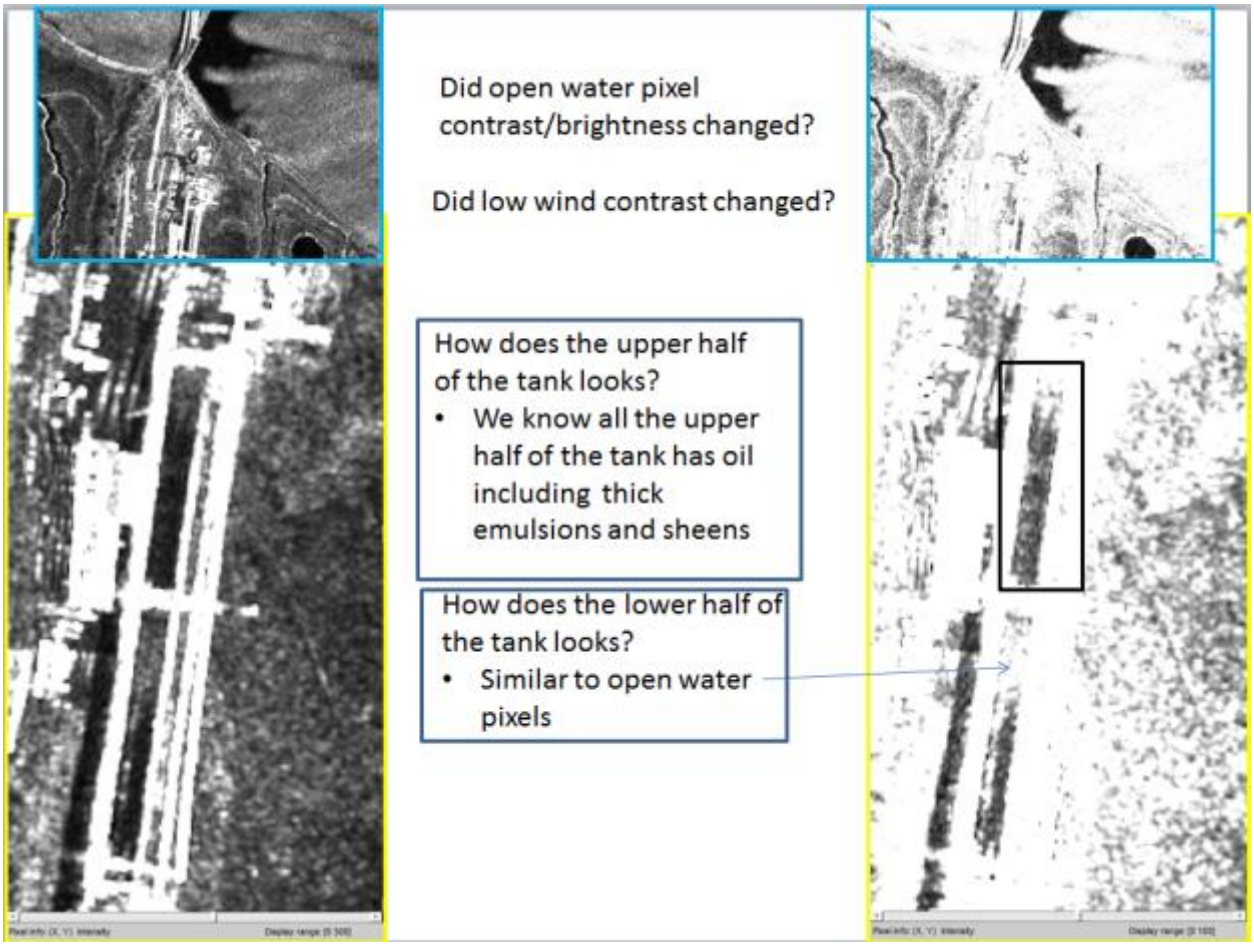

Figure 26. Backscatter of Ohmsett compared to open water.

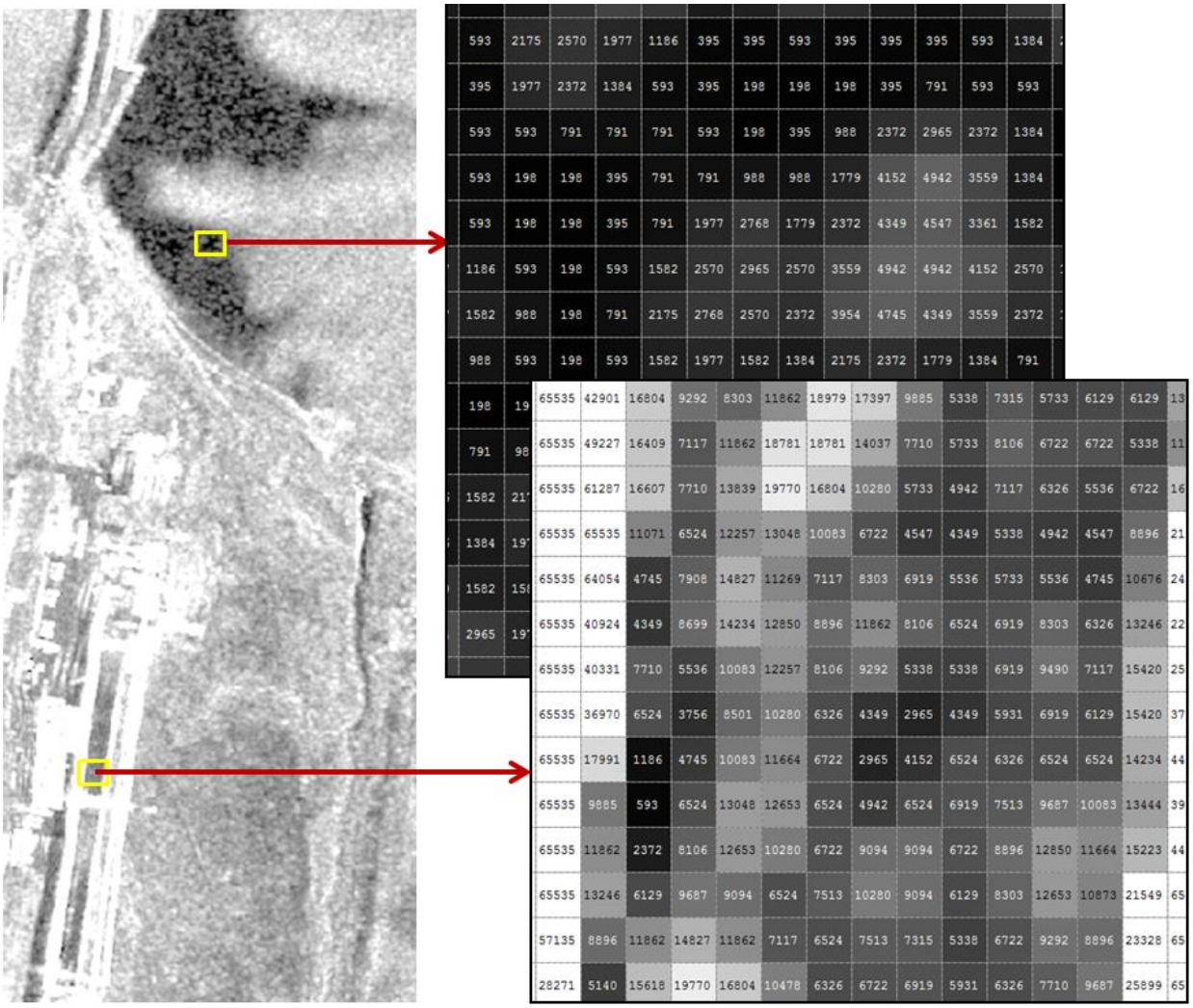

Figure 27. Comparison of low backscatter pixel values inside the tank vs open water bay.

By looking at the low-backscatter areas in the bay and then comparing the pixel values with the low backscattering inside the tank, we observed that areas covered with oil sheen (inside the tank) had a stronger backscatter than areas with low wind cells (created by the land obstruction) in the bay. This demonstrates that the low floor-noise ratio for this satellite configuration is good enough to distinguish between low wind and oil. In other words, generally speaking, low wind cells in the bay look 'darker' than the thin oil inside the tank. This is of great importance because the SAR beam modes that are normally used during oil spill operations cannot perform this distinction. We conclude that using a sub-meter resolution beam mode is the main reason of why in this case we can make this distinction of oil vs low wind.

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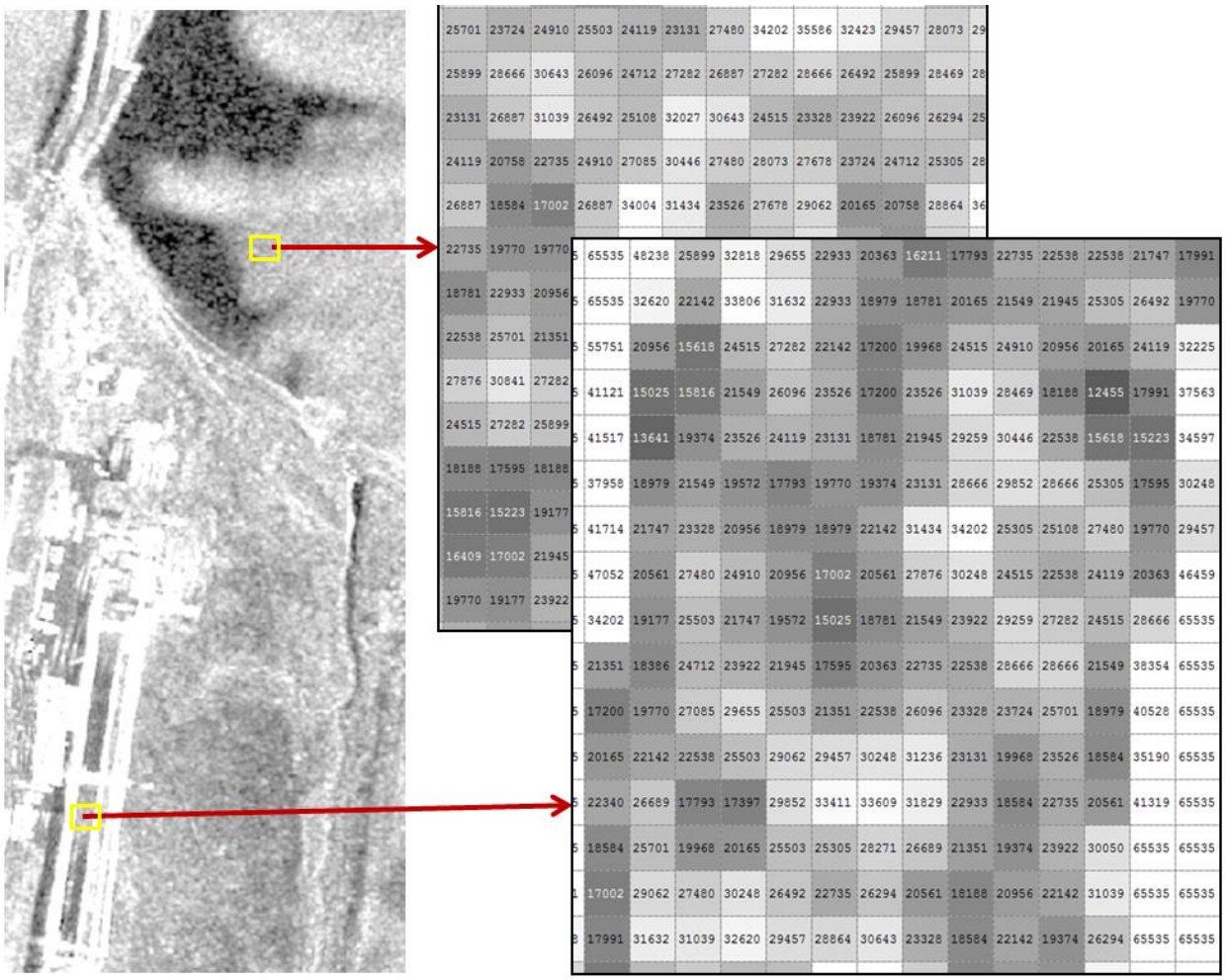

Figure 28. Comparison of high-backscatter pixel values (tank vs clean water at the bay).

When we look at the pixels inside the tank that have the highest pixel values (south section of the tank) we can find similar pixel values in many different areas in the open water inside the bay. The pixel values of the south portion of the tank (divided by the bridge with the containment/spraying system) are higher than the north side of the tank. Figure 28 shows that pixels values of areas of clean open water in the bay are similar to the highest pixel values inside the south portion of the tank. Therefore, we conclude that the south portion of the tank likely had no oil sheens. We never observed oil on the south portion of the tank visually nor with any other sensor.

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Based on our previous knowledge about the location of the emulsions inside the tank, we looked for pixel value changes that might correspond to the emulsions. Without any post-processing of the pixel values, we observed a difference on the backscatter on an area that matches the location of the emulsions at the time of the SAR snapshot (Figure 29).

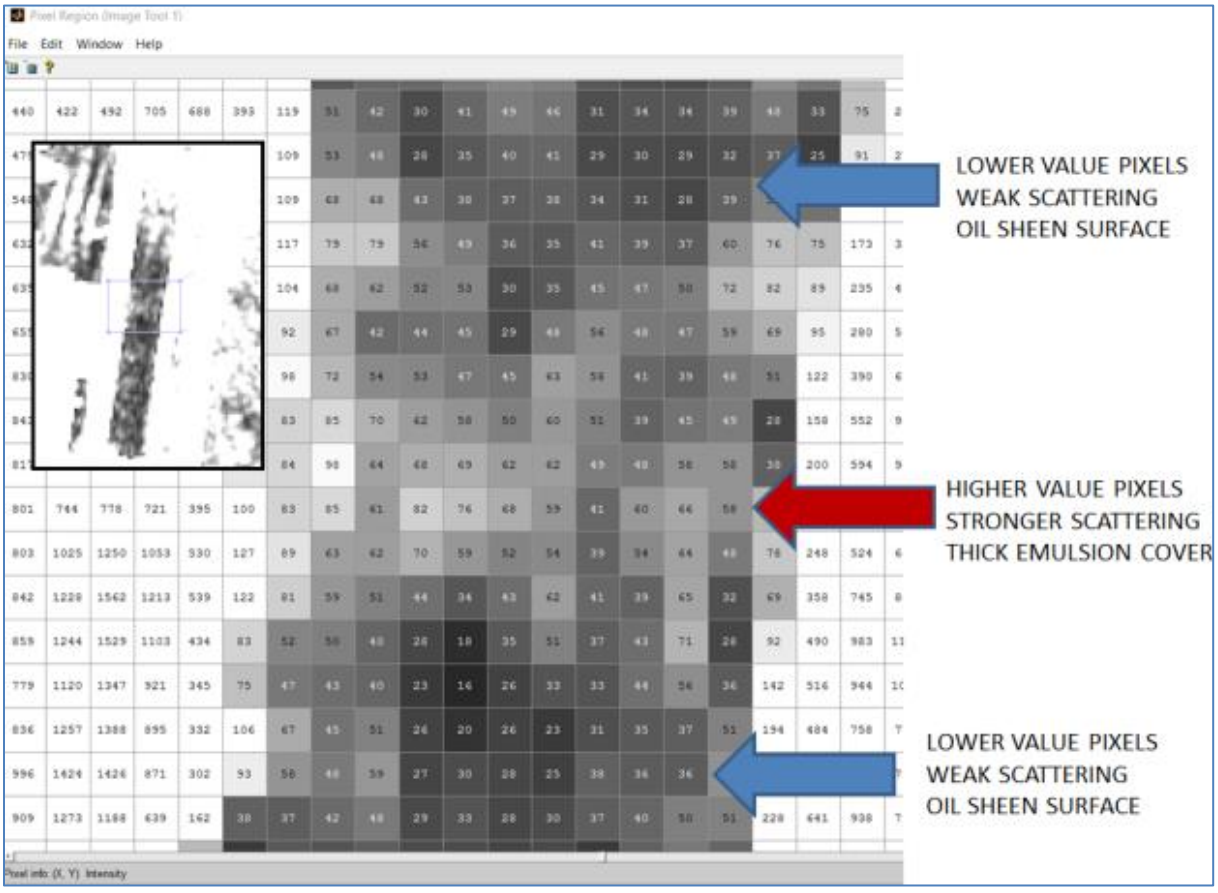

Figure 29. SAR image processing

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We then maximized the contrast between the pixel values (Figure 30).

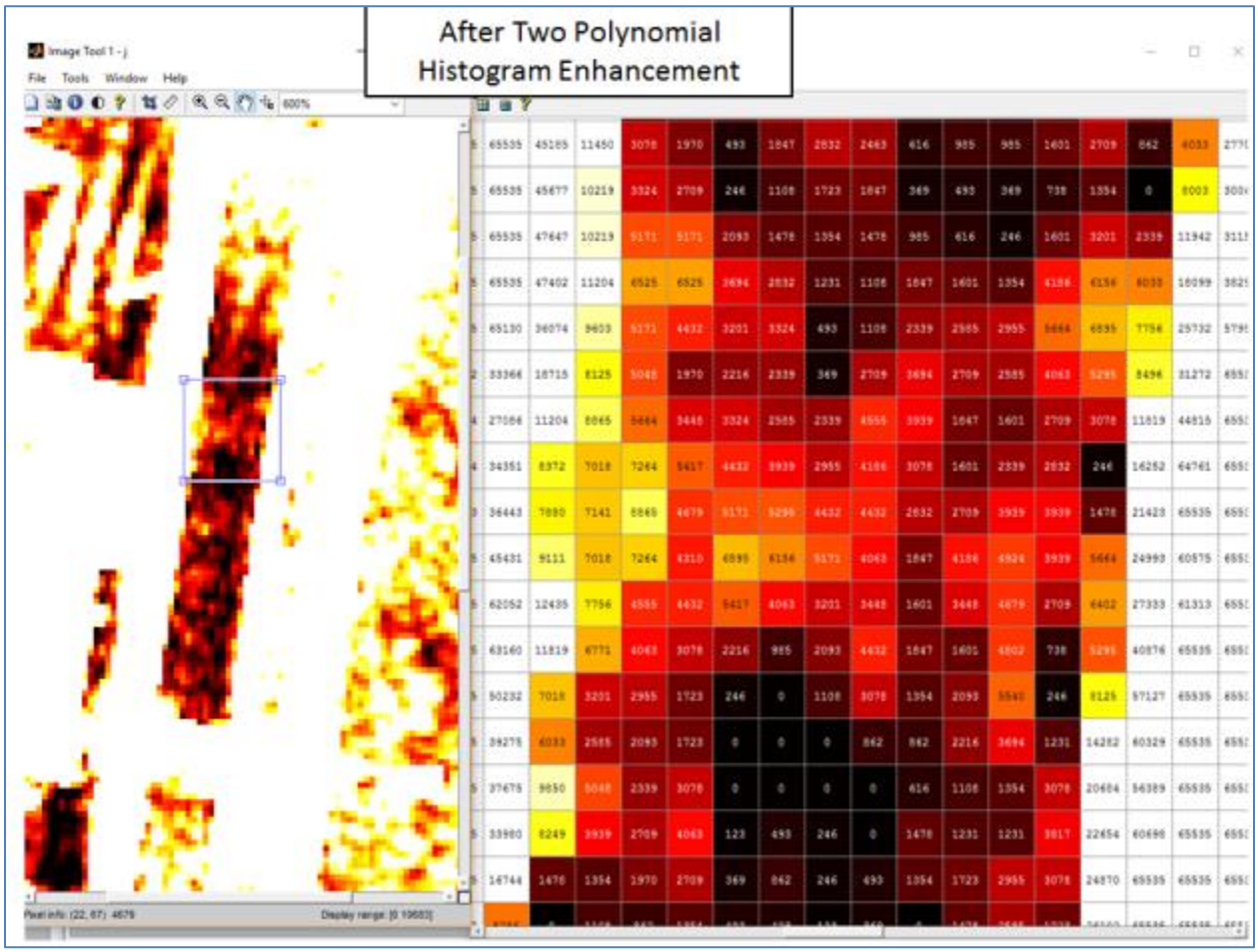

Figure 30. Oil emulsion detection on SAR after pixel value enhancement.

The location of the emulsions shown in UAS images were then related to the features observed on the SAR image. The SAR pixels with higher backscatter suggesting the location of the emulsions matched the UAS imagery (Figure 31)

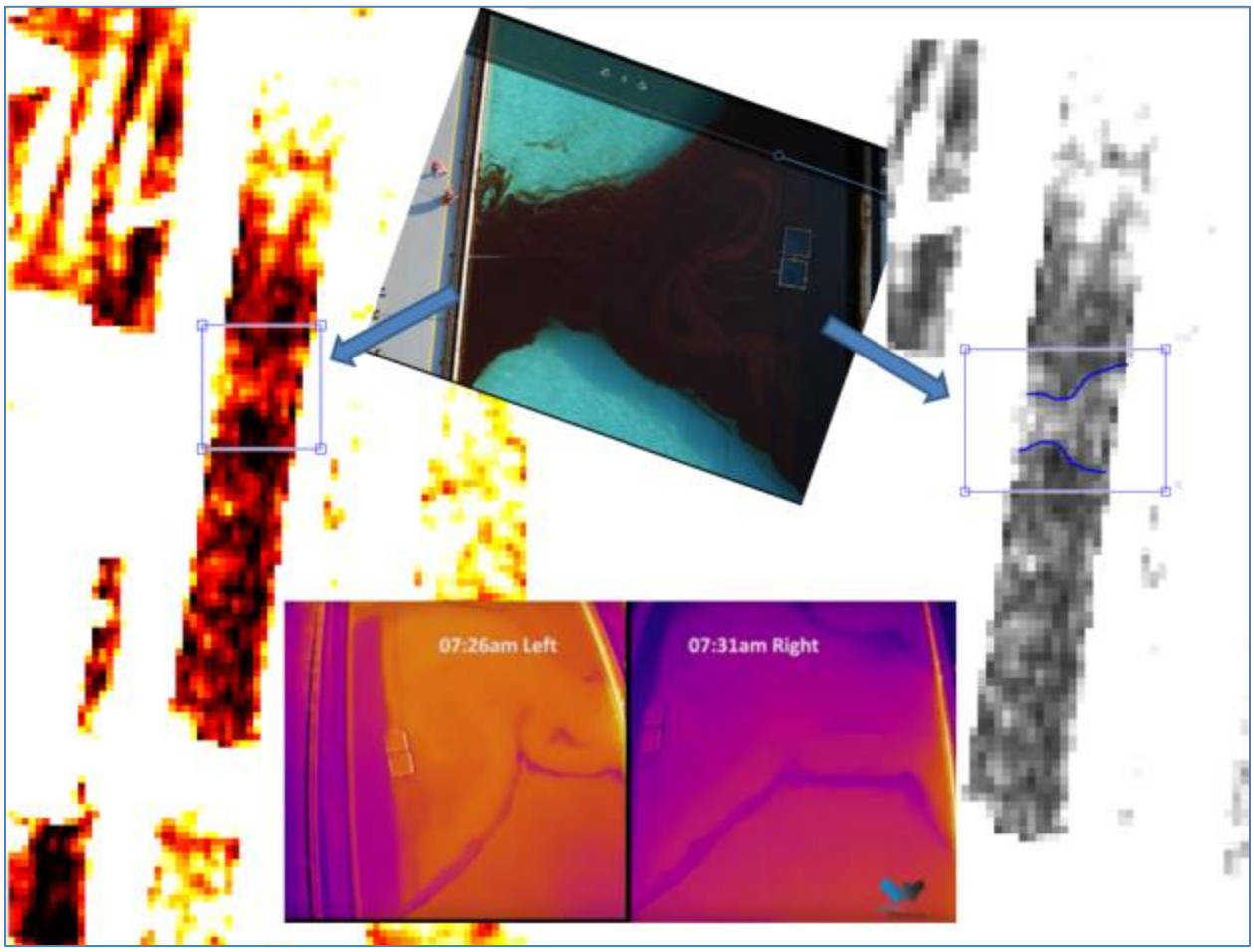

Figure 31. Comparison of SAR vs UAS-Thermal and UAS-Visual.

7. Conclusion

One outcome from Phase 1 at Ohmsett is the proof of concept obtained by the SAR capability to detect oil emulsions as hypothesized in Garcia-Pineda et al. (2013B). Although even with the highest resolution beam mode, a SAR satellite image will only contain a handful of pixels corresponding to a small tank, the experiment provided evidence that SAR can detect stable emulsions. Aligned with the theoretical physical understanding of the microwave backscattering, it is possible for SAR to detect oil emulsions under specific combinations of viewing angles and oil compositions. The combination of variables and conditions are given by:

1) Oil emulsion stabilization.
2) SAR viewing angle
3) Pixel resolution
4) Noise floor and interference

Oil emulsion stabilization. By damping the short gravity and capillary waves, crude oil will have the same effect of creating a specular reflector of the water surface regardless of the oil's thickness. In order to create oil emulsions, oil needs to be exposed to natural weathering processes such as waves, wind, oxygen, sunlight, and other factors. The emulsification process takes time depending on the intensity of the weathering process. At Ohmsett we observed this process by turning on/off the wave generator on the tank. It was not until July 20th (7th day of the experiments) when we observed oil emulsions reaching a level of stabilization similar to what we have observed on the field. The next SAR image that captured the tank (on July 21st) was able to detect differences between oil and the area where all the emulsions were concentrated (see Figure 29). None of the SAR images collected before July 21st could detect emulsions. The result supports the conclusion that emulsions must be well developed and stable before SAR can readily detect them.

Based on observations made by Ohmsett personnel, the oil:water ratio during the July 21st SAR snapshot was 60:40, which is consistent with what we observe in the field when SAR detects the oil emulsion features. Figures 32 and 33 show the emulsions present at the time of the TerraSAR-X snapshot. The roughness and texture of the emulsions as shown in these pictures is similar to what we observe on the field when thick emulsions are present. However, in the field, other factors such as particulate matter or the addition of surfactants can affect the timing, viscosity, and consistency of stable emulsions. The experiment at Ohmsett provides an example of the time required to form stable emulsions in clean sea water in a controlled setting; in the field, we expect less time is required for stable emulsions for form on the ocean surface.

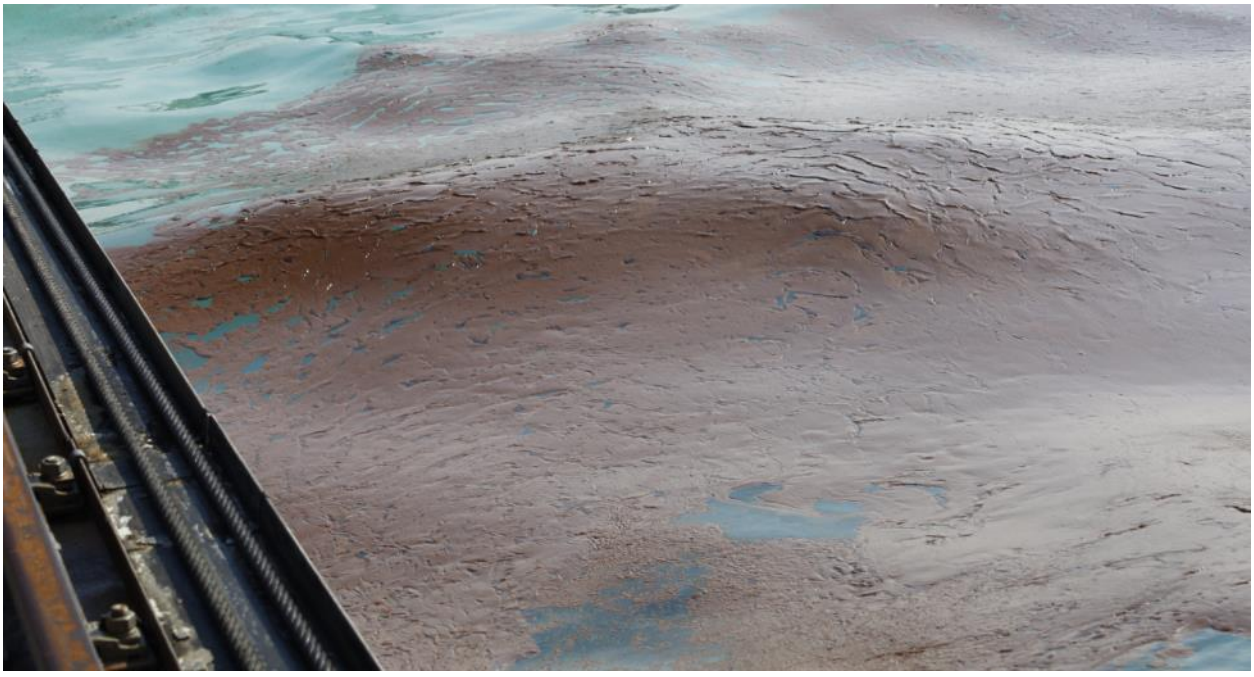

Figure 32. Stable oil emulsion. Photo captured on July 21st at the Ohmsett tank.

This Ohmsett experiment supports the hypothesis that SAR detects stable emulsions at a given range of oil:water ratios because the viscoelastic strength of the emulsion is sufficient to generate distinctive surface roughness. We believe that the increment on the dielectric conductivity of the emulsion might also be a factor that increases the backscatter, however, it is likely that the main reason SAR detects floating emulsions is the subtle changes in the geometry of the surface roughness.

SAR satellites and viewing angles. The only available satellites with the requisite beam mode and viewing angle to view the oil in the Ohmsett tank at the time of the experiment were TerraSAR-X and RADARSAT-2. One of these satellites covered the area of the tank almost daily using the highest resolution beam mode available (40cm and 1m resolution, respectively). Each satellite pass had slightly different viewing angles, ranging from 21 to 34 degrees and resulting in slightly different imagery each day (see Figure 2).

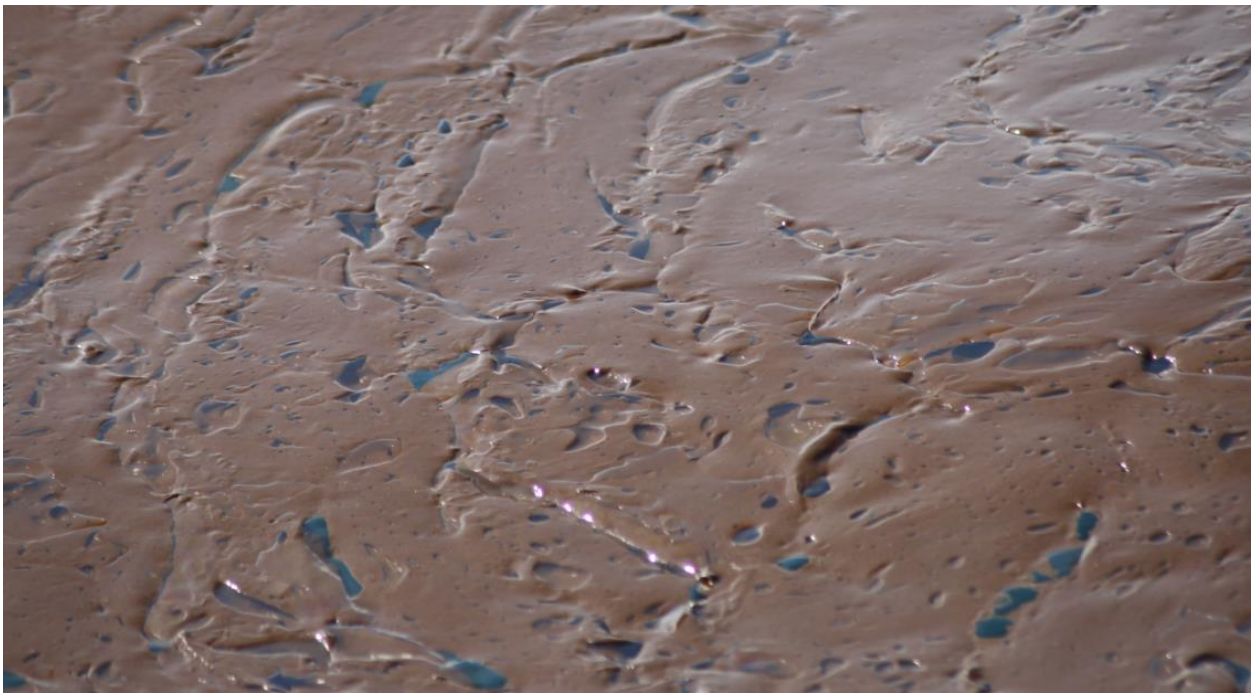

Figure 33. Surface roughness generated by the stable oil emulsion.

Theoretically, based on the geometrical conditions of the tank size and orientation, the optimal viewing angle to image the confined area of oil inside the tank is less than 30 degrees from nadir. This was confirmed during the Ohmsett experiment. The best acquisition that showed distinction of oil vs emulsions was captured on July 21st by TerraSAR-X , with an incidence angle of 24 degrees. On the last day of the experiment, when the emulsions were most apparent, RADARSAT-2 collected an image, but the incidence angle was 34 degrees, and as a result, the emulsions were not detectable. It is likely that emulsified oil on open water covering an area larger than a tank would be detectable at an incidence angle greater than 30 degrees. However, for this particular experiment in the highly confined area of a tank, the emulsions were only detectable in the TerraSAR-X image with an incidence angle under 30 degrees. As shown in Figures 27 through 31, the advantage of using a satellite beam mode with such a high spatial resolution is a factor on the ability to detect oil emulsions. As we were able to only observe oil emulsions inside the tank on only one SAR image (mainly due to the incidence angles and the maturity of emulsions at the time of imaging), future work is needed to compare the capacity among different SAR sensors to detect the emulsions.

Oil thickness measurements and calibration of the UAS-thermal. By linking the measurements of UAS-thermal observations with the physical measurements of thickness using WM-OS2, we produced maps depicting approximate average oil thickness (Figure 34). The technique of using field-collected calibration data to classify remote sensing data is well understood. However, we are not aware of any previous attempts to calibrate FLIR data from a UAS with data from a novel method of collecting oil in a graduated cylinder and measuring thickness photogrammetrically. The method shows promise for use in the field, with the caveat that a single measurement or even a single estimate of average thickness is unlikely to capture the heterogeneity of oil on water.

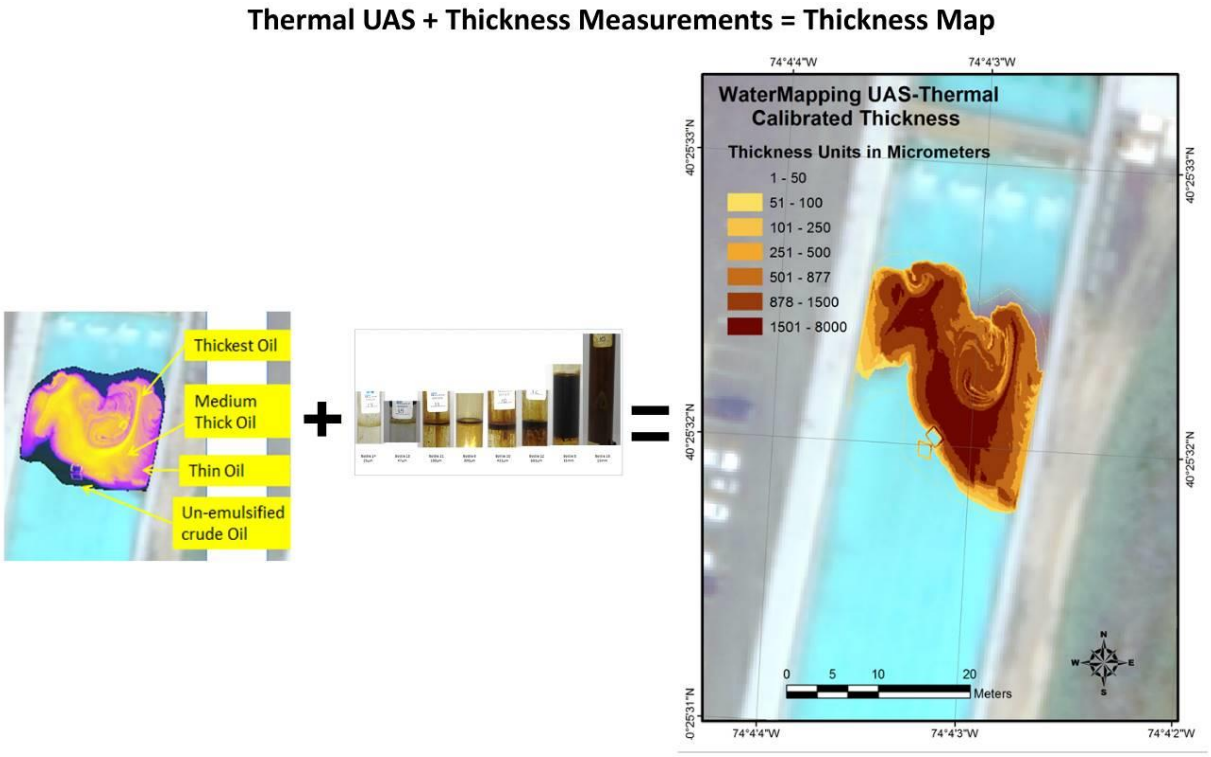

Figure 34. Combination of Thermal UAS with Thickness measurements from WM-OS2.

Areas of improvement for this experiment. Based on this Phase 1 experiment, we suggest the following three areas of focus for improvement in future studies:

1) **Satellite schedule**. Ideally, oil thickness and concentration data should be collected when satellites with appropriate viewing angles and beam modes will be passing overhead. In Phase 1, we only obtained one SAR image that could detect the emulsified oil. In the future, we would ideally have multiple images over multiple days, allowing us to investigate the ability of SAR imagery to detect different emulsion states and oil:water ratios at different incidence angles. If experiments could be scheduled around the timing of satellite imagery, we would pick a week where multiple polarimetric images would be collected at incidence angles less than 30 degrees.

2) **Synoptic thickness measurements**. This Phase 1 experiment included multiple techniques (in addition to WM-OS2) for estimating oil thickness. Collecting data using multiple techniques synoptically in time and space would allow us to present a statistical estimate of mean, median, and range of thicknesses. This would allow cross-calibration of the methods as well as allow some quantification of the variability of thickness on a small scale.

3) **Multiple oil states.** For the remote sensing analysis, particularly SAR analysis, it would be useful to have emulsified oil in one part of the tank and fresh/un-emulsified oil on the other side of the tank. This would allow us to determine how emulsification state affects the ability of the remote sensors to detect the presence of oil generally and thick/actionable oil in particular on the water surface.

8. References

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Staples, G. and O. Garcia (2016). Detection of emulsified oil in the Gulf of Mexico. In *Proceedings of the IEEE Geoscience and Remote Sensing Symposium*, Beijing, China.

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APPENDIX A

Water Mapping, LLC
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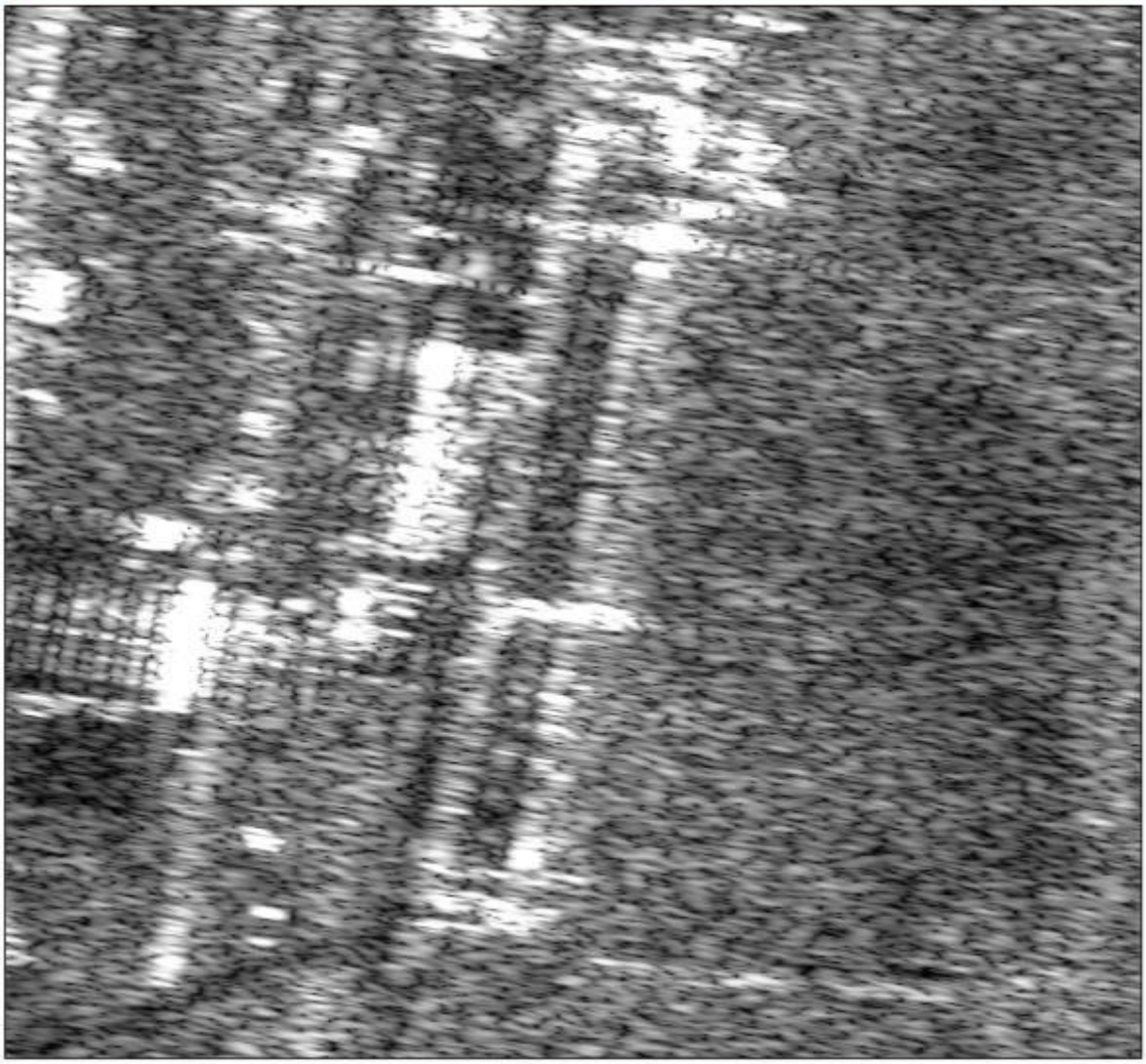
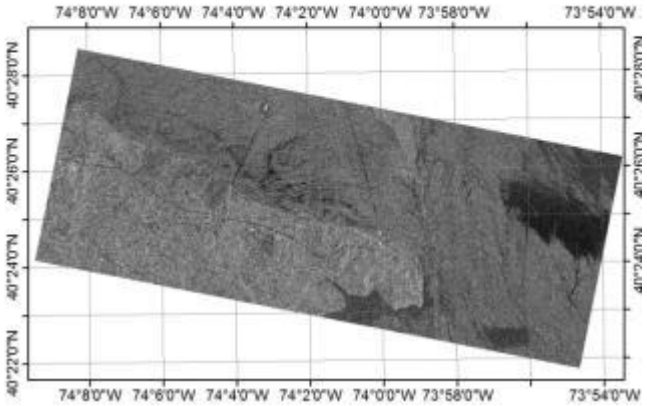
RST2-20160716_111056



RADARSAT-2
Date: 2016/07/16
Time: 11:10:56 GMT

Resolution 1m
Wavelength C-Band
Polarization Vertical



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WV3_20160716_1604Z_Pansharpen_tif.tif



WorldView 3
Date: 2016/07/16
Time: 16:04 GMT

Wavelength Multispectral



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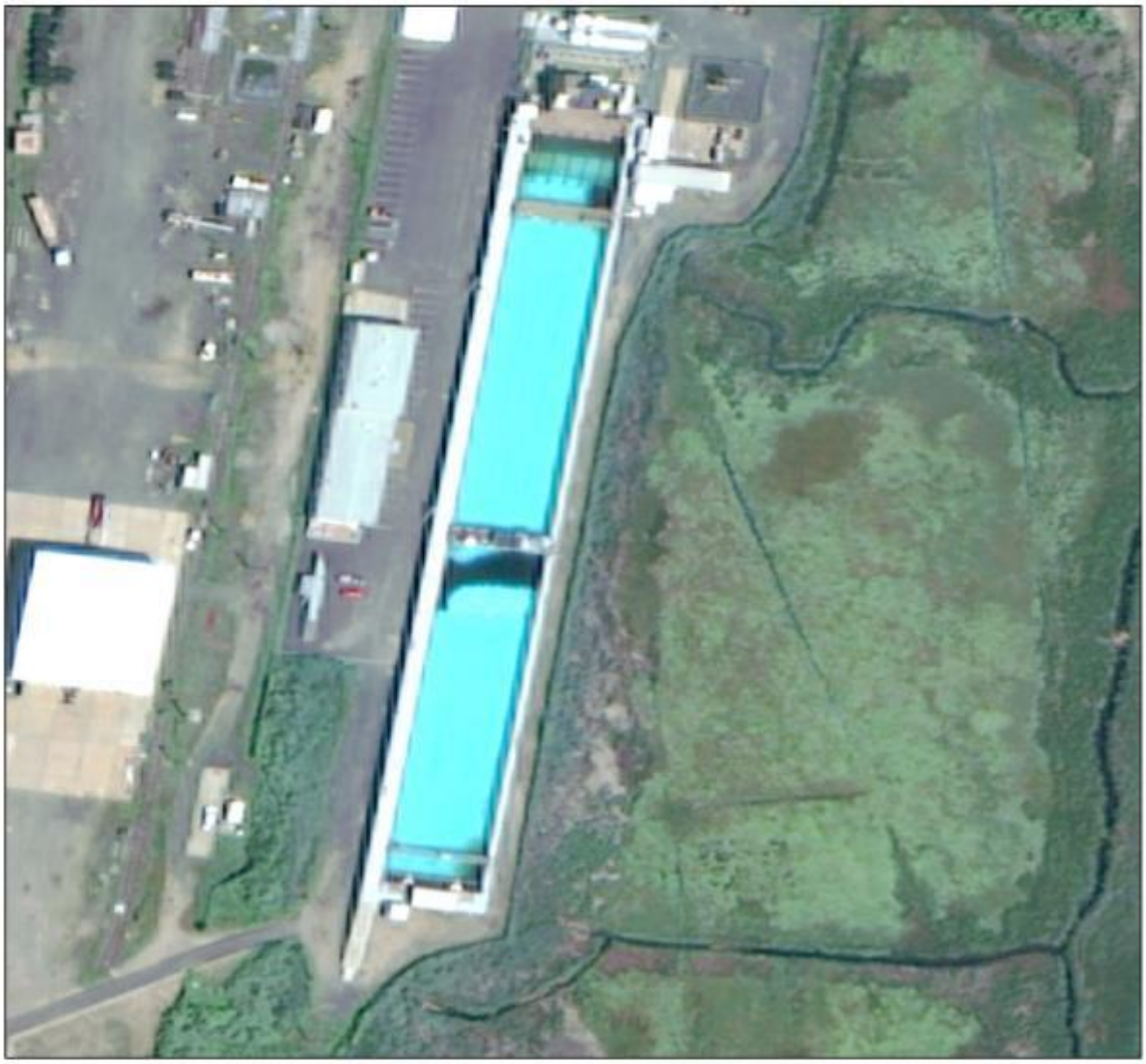
WV3_20160717_1619Z_Pansharpen_tif.tif



WorldView 3
Date: 2016/07/17
Time: 16:19 GMT

Wavelength: Multispectral



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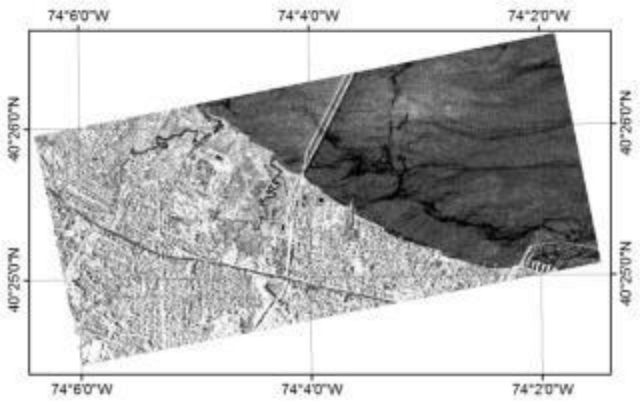
Tallahassee, Florida. 32312

IMAGE_VV_SRA_spot_024.tif



TerraSAR-X
Date: 2016/07/18
Time 22:43:30 GMT

Resolution 40cm
Wavelength X-Band
Polarization Vertical
Look Angle 24



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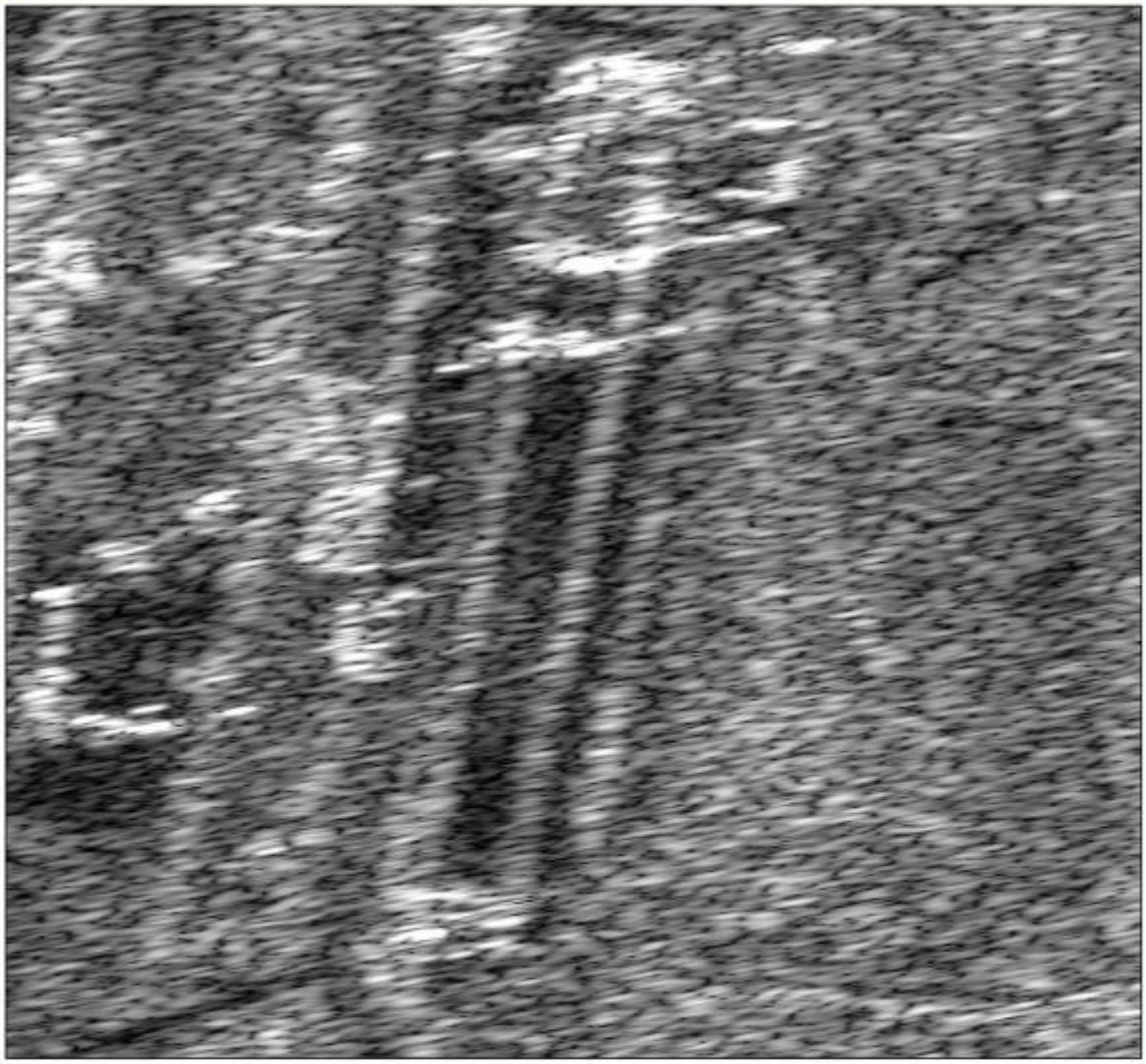
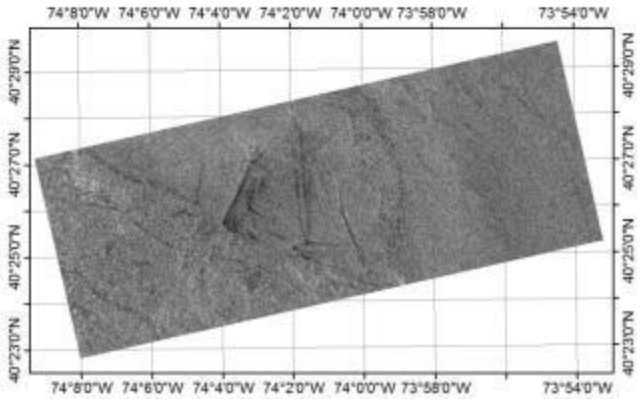
RST2-20160719_224100



RADARSAT-2
Date: 2016/07/19
Time: 22:41:00 GMT

Resolution 1m
Wavelength C-Band
Polarization Vertical



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WV2_20160719_1553Z_Pansharpen_tif.tif



WorldView 2
Date: 2016/07/19
Time: 15:53 GMT

Wavelength: Visual



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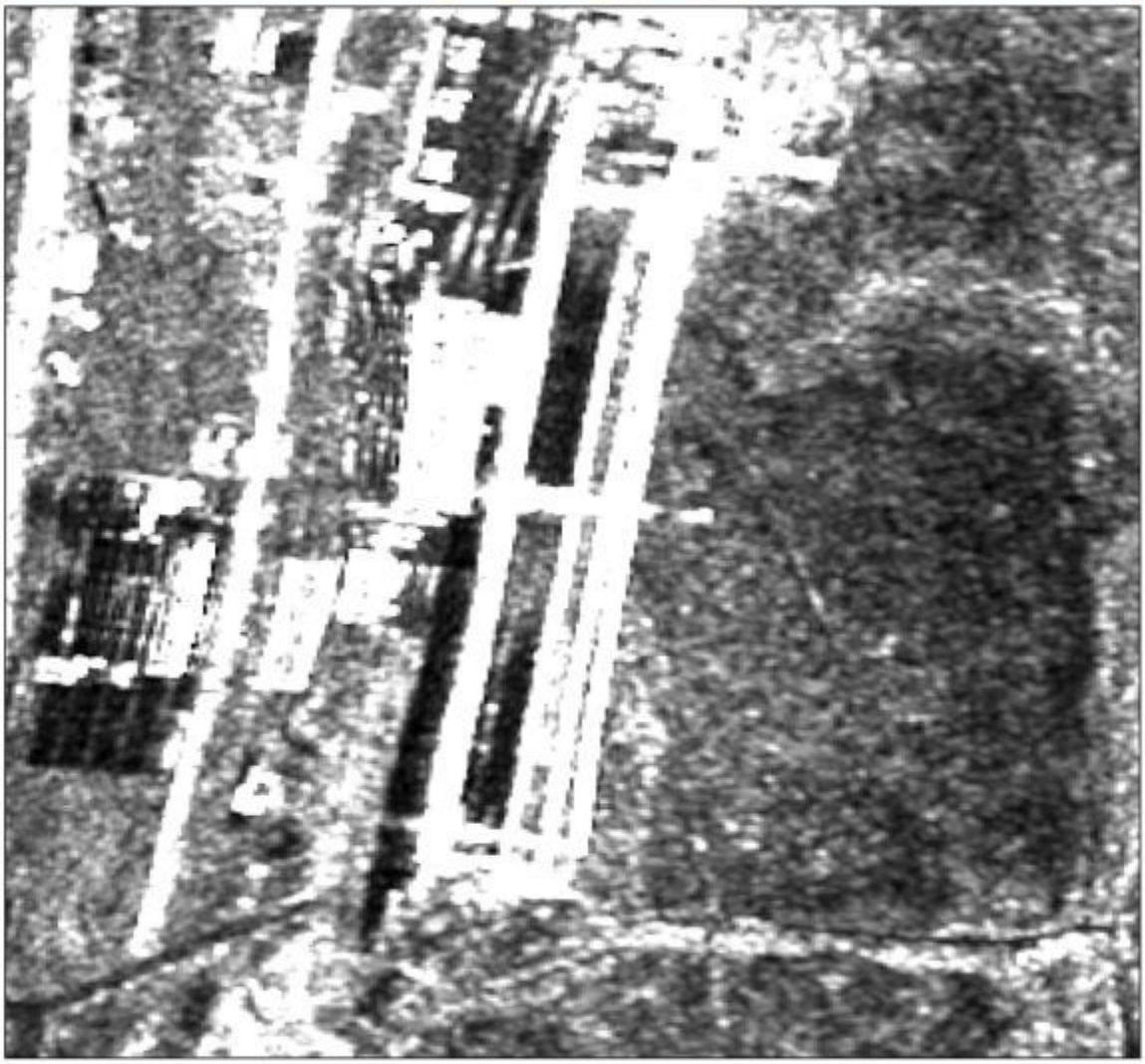
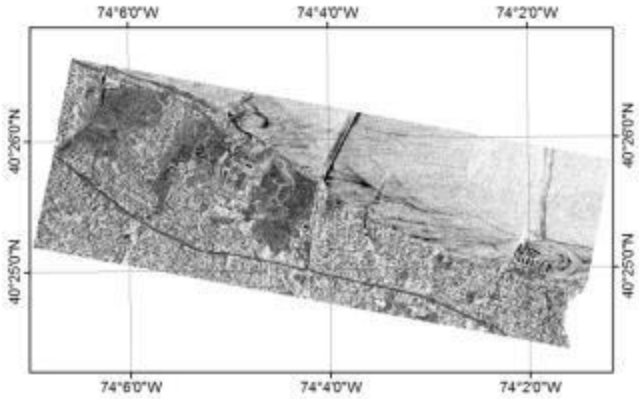
IMAGE_VV_SRA_spot_010.tif



TerraSAR-X
Date: 2016/07/21
Time 11:13:58 GMT

Resolution 40cm
Wavelength X-Band
Polarization Vertical
Look Angle 10



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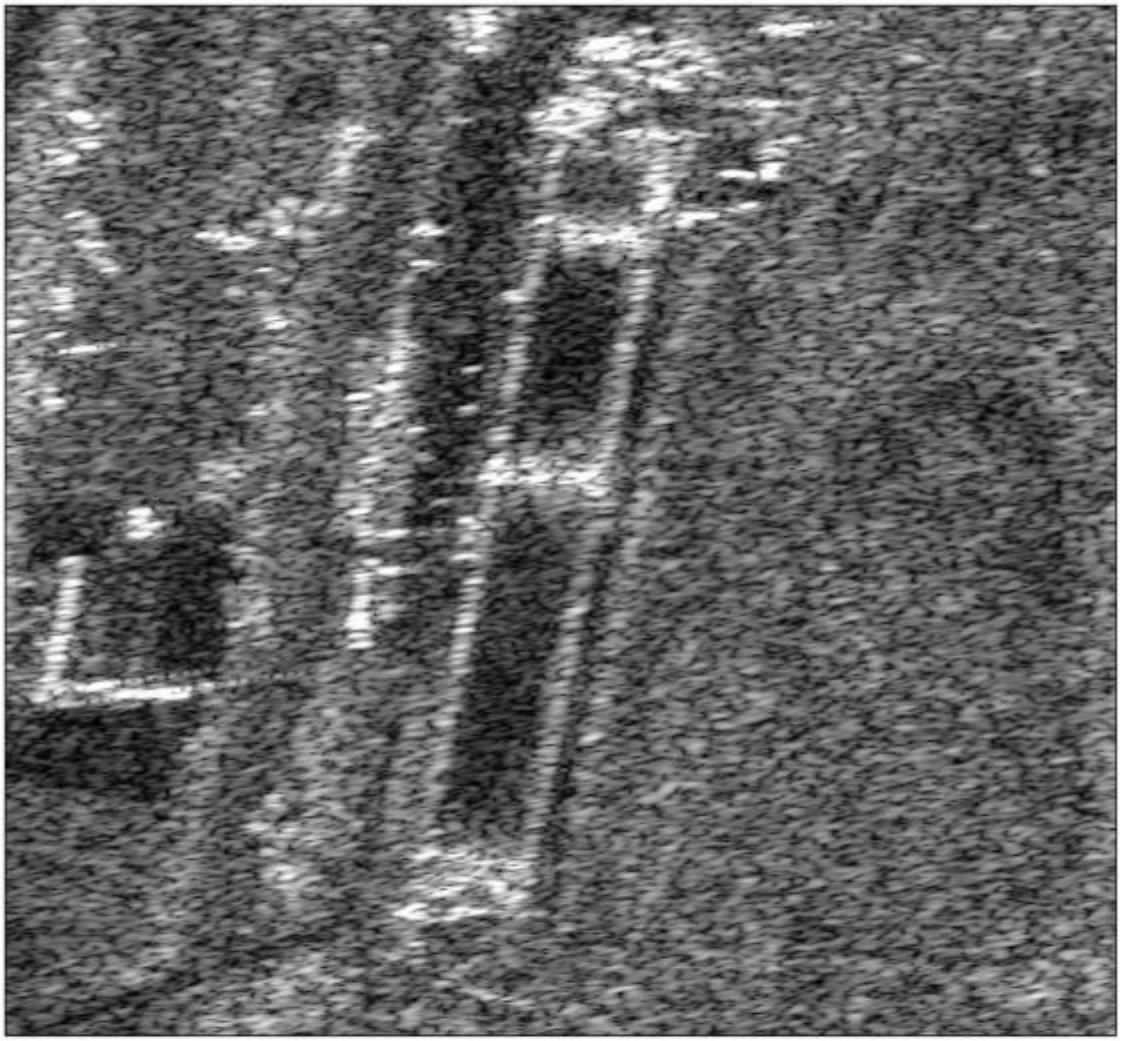
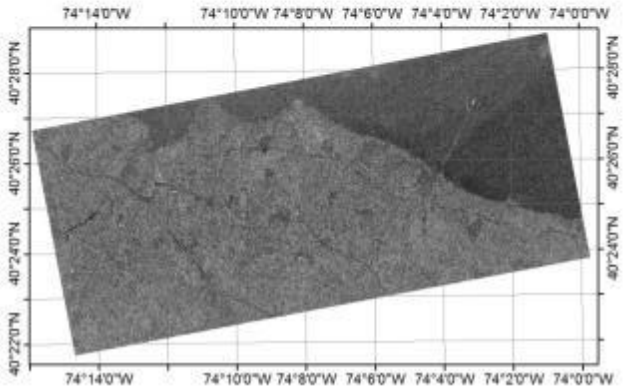
RST2-20160722_225327



RADARSAT-2
Date: 2016/07/22
Time: 22:53:27 GMT

Resolution 1m
Wavelength C-Band
Polarization Vertical



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WV3_20160722_1601Z_Pansharpen_tif.tif



WorldView 3
Date: 2016/07/22
Time: 16:01 GMT

Wavelength: Multispectral



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Tallahassee, Florida. 32312

APPENDIX B

Water Mapping, LLC
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Tallahassee, Florida. 32312

Oil Spill Trap Sampler

Bottle ID: 1

Date/Time: 07/13/2016 10:35 am

Tank Location: North side of the tank

Sample Description: Initial test with oil remainings

Oil Spill Trap Sampler

Bottle ID: 1

Date/Time: 07/13/16 10:35am

Tank Location: North side of the tank

Sample Description: Initial test with oil remainings



Calculated Thickness 310µm



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Oil Spill Trap Sampler

Bottle ID: 2

Date/Time: 07/13/2016 1:37 pm

Tank Location: North side of the tank

Sample Description: Initial test with oil remainings





Calculated Thickness 329µm



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Oil Spill Trap Sampler

Bottle ID: 3

Date/Time: 07/13/2016 1:39 pm

Tank Location: North side of the tank

Sample Description: Initial test with oil remainings

Oil Spill Trap Sampler

Bottle ID: 3

Date/Time: 07/13/16 1:39 pm

Tank Location: North side of the tank

Sample Description: Initial test with oil remainings



Calculated Thickness 555µm



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Oil Spill Trap Sampler

Bottle ID: 4

Date/Time: 07/13/2016 1:43 pm

Tank Location: North side of the tank

Sample Description: Initial test with oil remainings

Oil Spill Trap Sampler

Bottle ID: 4

Date/Time: 07/13/16 1:43pm

Tank Location: North side of the tank

Sample Description: Initial test with oil remainings



Calculated Thickness 502µm



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Oil Spill Trap Sampler

Bottle ID: 5

Date/Time: 07/15/2016 11:26 am

Tank Location: West side of the tank

Sample Description: Fresh crude oil

Oil Spill Trap Sampler

Bottle ID: 5

Date/Time: 07/15/16 11:26am

Tank Location: West side of the tank

Sample Description: Fresh crude oil



Calculated Thickness 15mm



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Oil Spill Trap Sampler

Bottle ID: 6

Date/Time: 07/16/2016 11:05am

Tank Location: South boundary of the slick

Sample Description: First trial after first drone flight

Oil Spill Trap Sampler

Bottle ID: 6

Date/Time: 11:05 am 7/16

Tank Location: South Boundary of the slick

Sample Description: First trial after first drone flight

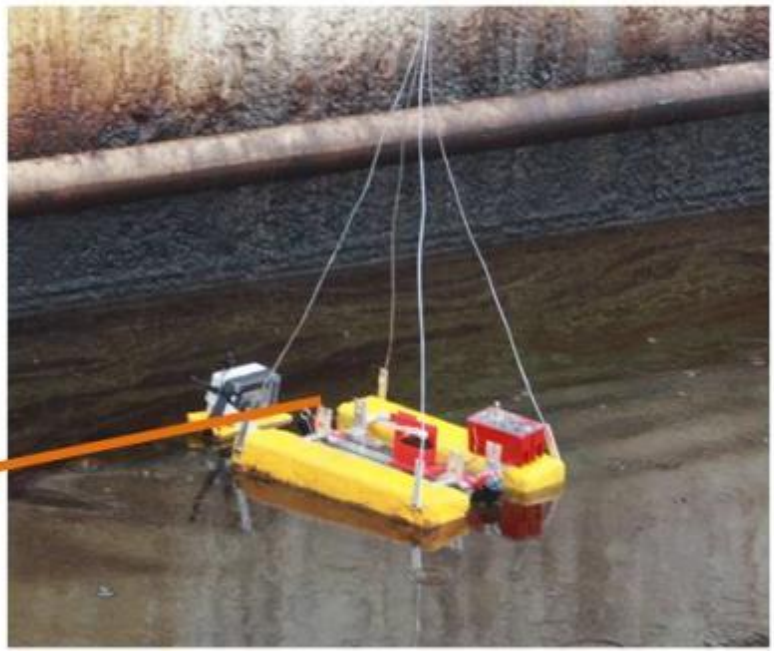
Ambient Conditions

Other Samples Simultaneous

Calculated Thickness 300µm







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Oil Spill Trap Sampler

Bottle ID: 8

Date/Time: 07/19/2016 10:25 am

Tank Location: South West side of the tank

Sample Description: Waves generator, clear sky

Oil Spill Trap Sampler

Bottle ID: 8

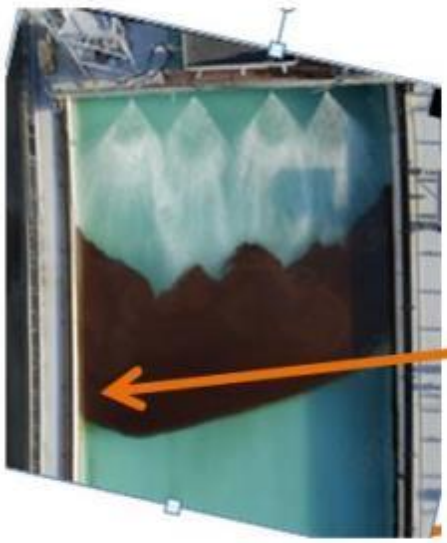
Date/Time: 7/19/16 10:25am

Tank Location: _____

Sample Description: Waves generator clear sky



Calculated Thickness 20 mm





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Oil Spill Trap Sampler

Bottle ID: 10

Date/Time: 07/20/2016 11:48am

Tank Location: Northeast side of the slick

Sample Description: Pin metal

Oil Spill Trap Sampler

Bottle ID: 10

Date/Time: 07/20/16 11:48

Tank Location: NE side

Sample Description: pin metal



Calculated Thickness 432µm





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Oil Spill Trap Sampler

Bottle ID: 11

Date/Time: 07/20/2016 11:56am

Tank Location: Northeast side of the slick

Sample Description: Pin Plastic





Calculated Thickness 180µm





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Oil Spill Trap Sampler

Bottle ID: 12

Date/Time: 07/21/2016 8:35am

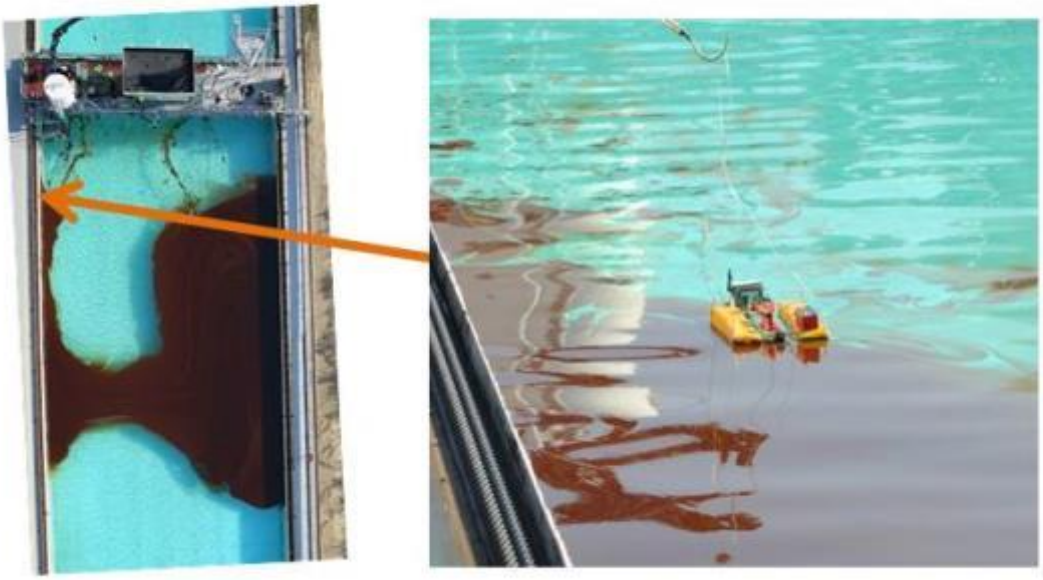
Tank Location: North West side of the tank

Sample Description: Very thick. Need wider tube





Calculated Thickness 681µm



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Oil Spill Trap Sampler

Bottle ID: 13

Date/Time: 07/21/2016 8:45am

Tank Location: North West side of the tank

Sample Description: Very thick. Need wider tube

Oil Spill Trap Sampler

Bottle ID: #13

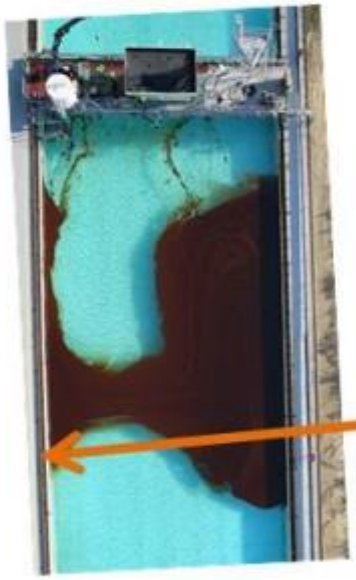
Date/Time: 7/21/16 8:45

Tank Location: _____

Sample Description: _____



Calculated Thickness 322µm





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Oil Spill Trap Sampler

Bottle ID: 14

Date/Time: 07/22/2016 8:17 am

Tank Location: North West side of the tank

Sample Description:


Oil Spill Trap Sampler

Bottle ID: #14 | #15 | #16

Date/Time: 8:17 | 8:24 | 8:44

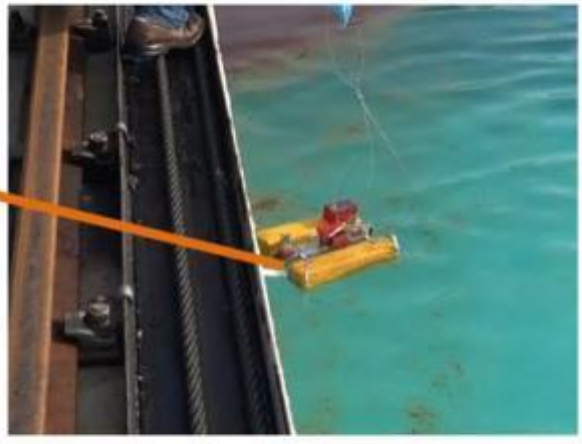
Tank Location: _____

Sample Description: _____



Calculated Thickness 25µm





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Oil Spill Trap Sampler

Bottle ID: 15

Date/Time: 07/22/2016 8:24 am

Tank Location: North West side of the tank

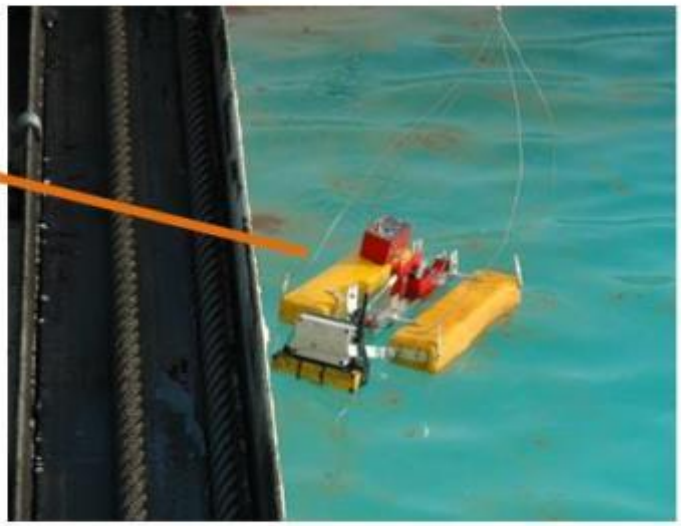
Sample Description:





Calculated Thickness 47µm





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Oil Spill Trap Sampler

Bottle ID: 16

Date/Time: 07/22/2016 3:20 pm

Tank Location: South East side of the tank

Sample Description: Very thick emulsions


Oil Spill Trap Sampler

Bottle ID: #16 16

Date/Time: 3:20pm 07/22/16

Tank Location:

Sample Description: Thick



Calculated Thickness 25mm





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APPENDIX C

Water Mapping, LLC
1240 Greensward Dr.
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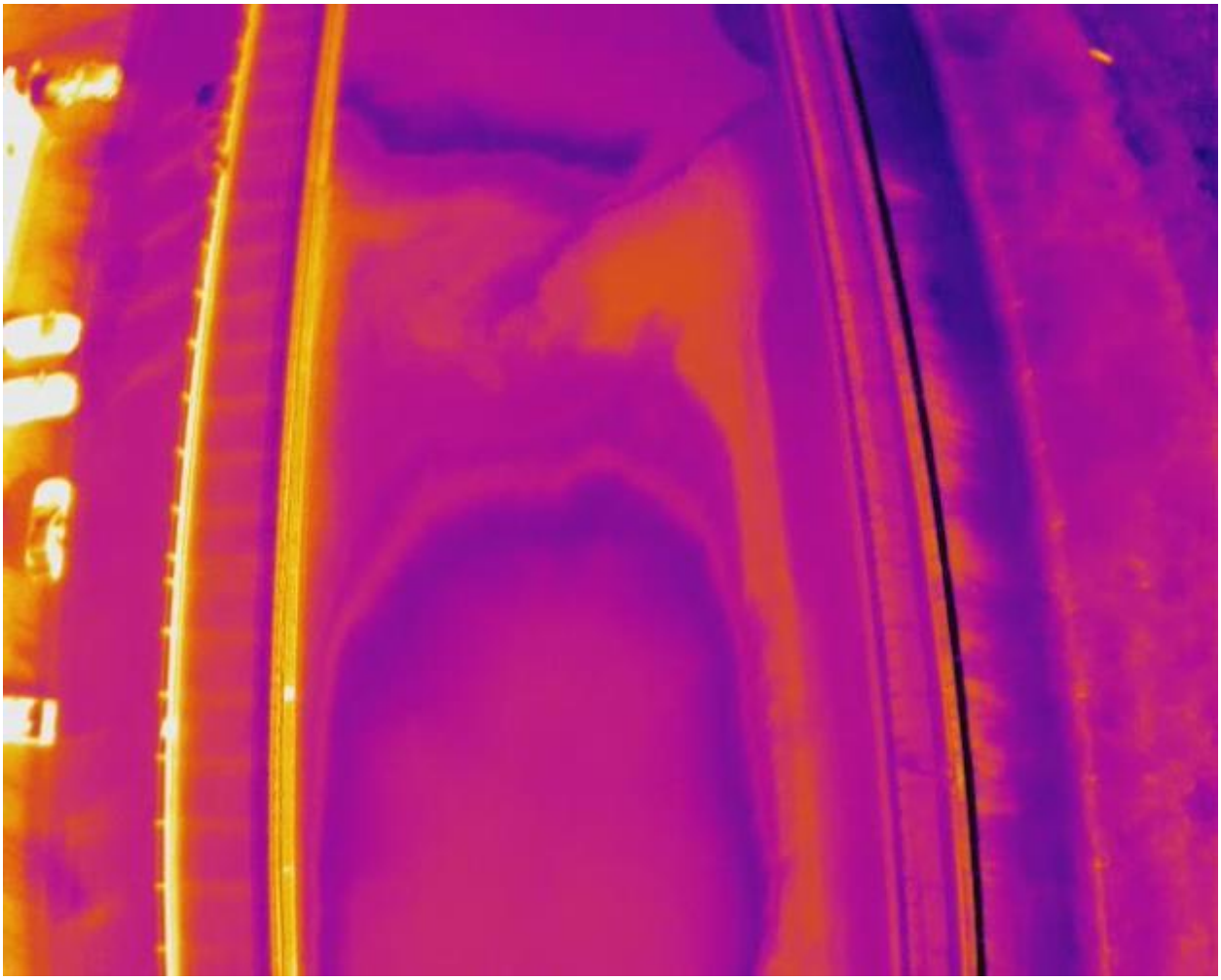
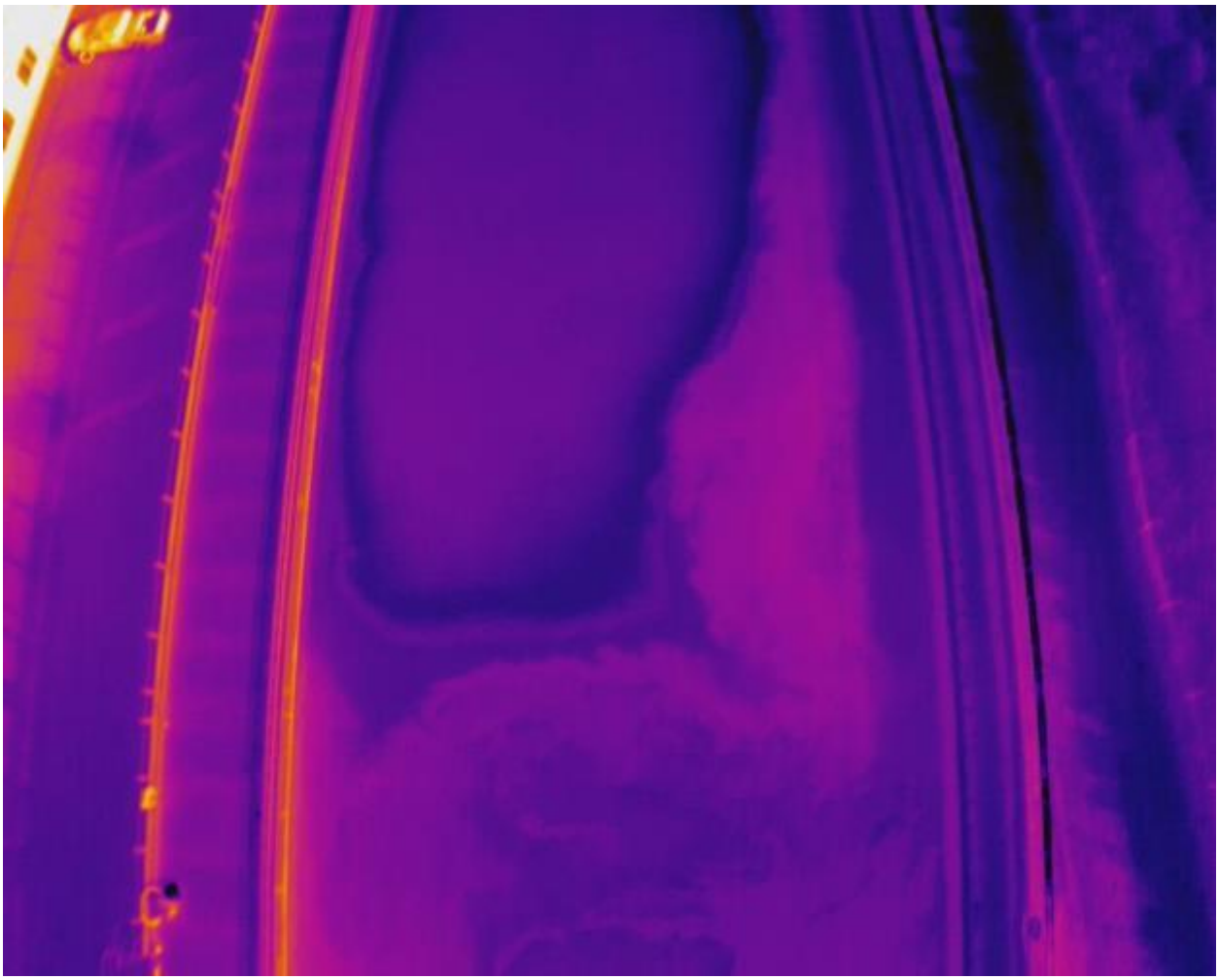
FLIR COLLECTED ON 2016/07/16
FLIGHT TIME: 07:35:12
VIDEO STILL: H264.00_02_17_27.Still002



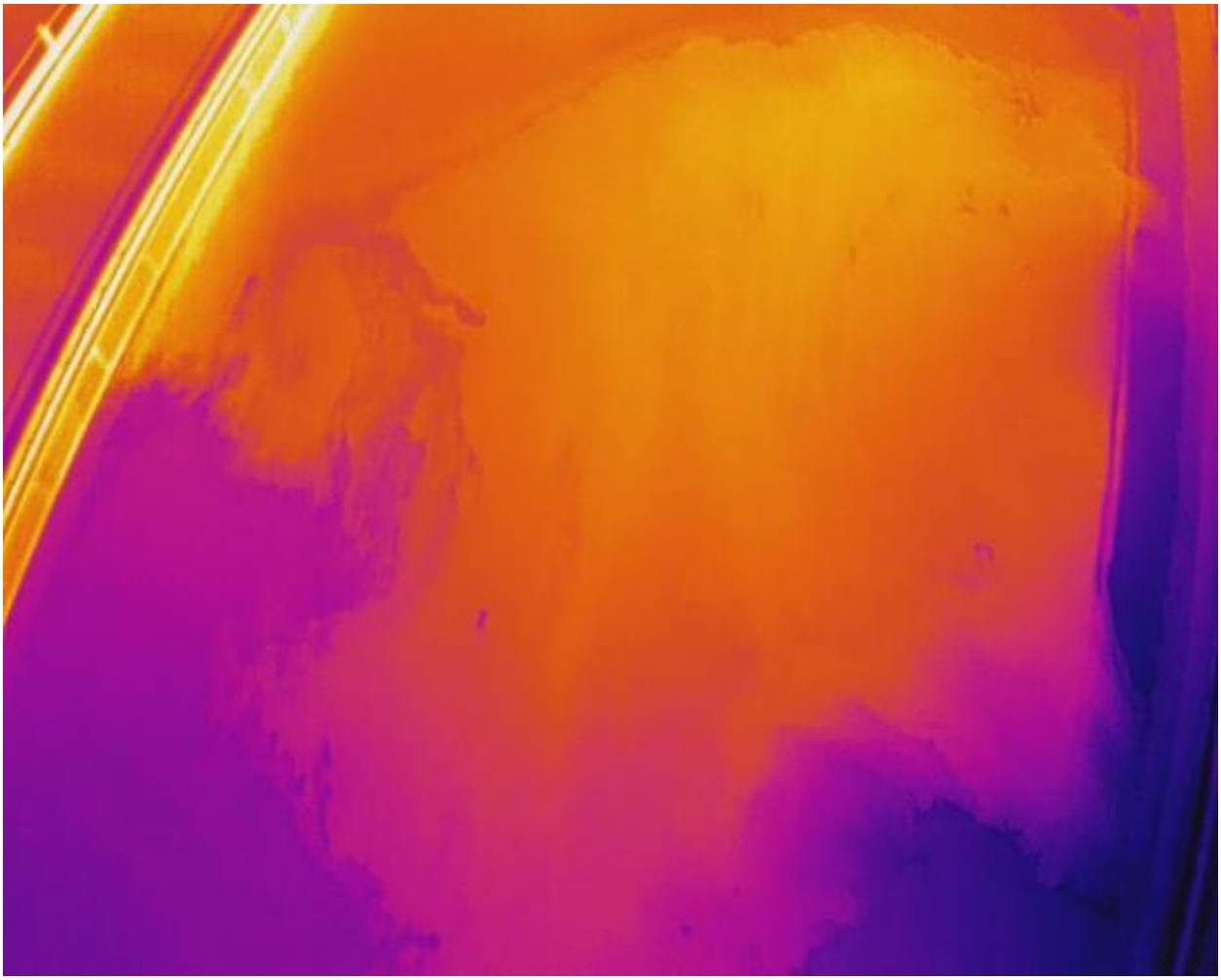
Water Mapping, LLC
1240 Greensward Dr.
Tallahassee, Florida. 32312

FLIR COLLECTED ON 2016/07/16
FLIGHT TIME: 07:35:12
VIDEO STILL: H264.00_02_23_28.Still003



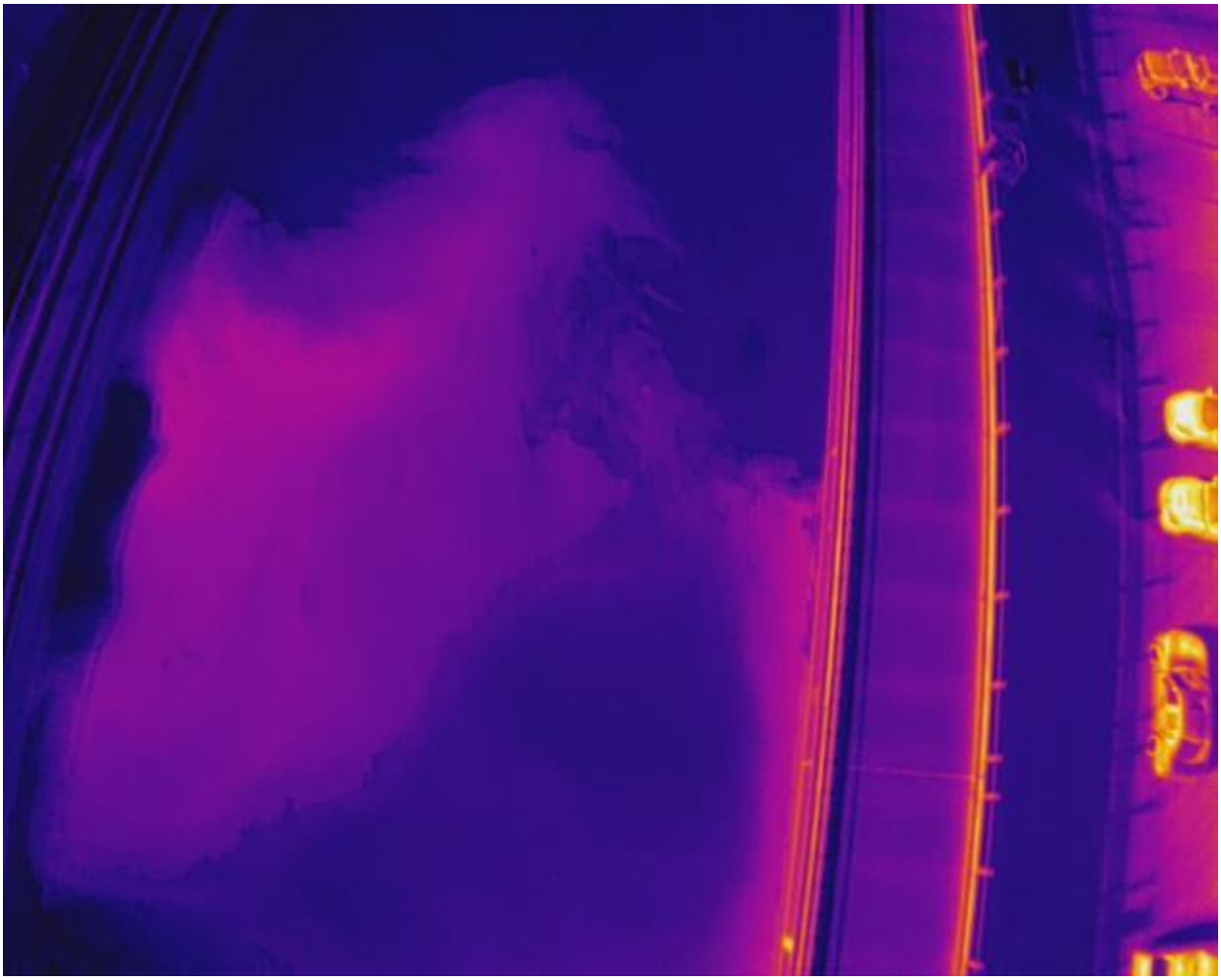
Water Mapping, LLC
1240 Greensward Dr.
Tallahassee, Florida. 32312

FLIR COLLECTED ON 2016/07/16
FLIGHT TIME: 07:58:22
VIDEO STILL: H264.00_07_33_26.Still001



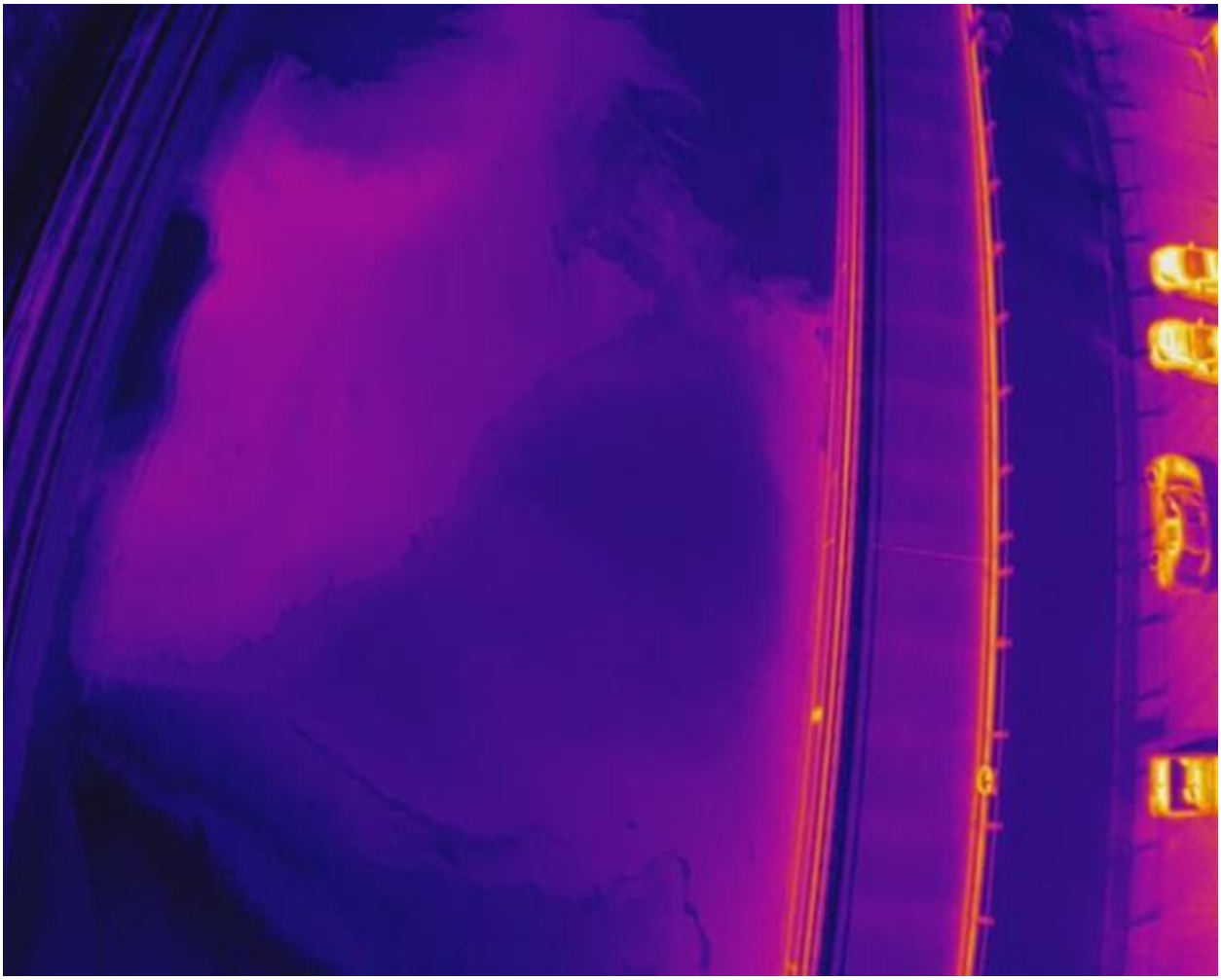
Water Mapping, LLC
1240 Greensward Dr.
Tallahassee, Florida. 32312

FLIR COLLECTED ON 2016/07/16
FLIGHT TIME: 07:58:22
VIDEO STILL: H264.00_09_03_08.Still002



Water Mapping, LLC
1240 Greensward Dr.
Tallahassee, Florida. 32312

FLIR COLLECTED ON 2016/07/16
FLIGHT TIME: 07:58:22
VIDEO STILL: H264.00_09_04_28.Still003



Water Mapping, LLC
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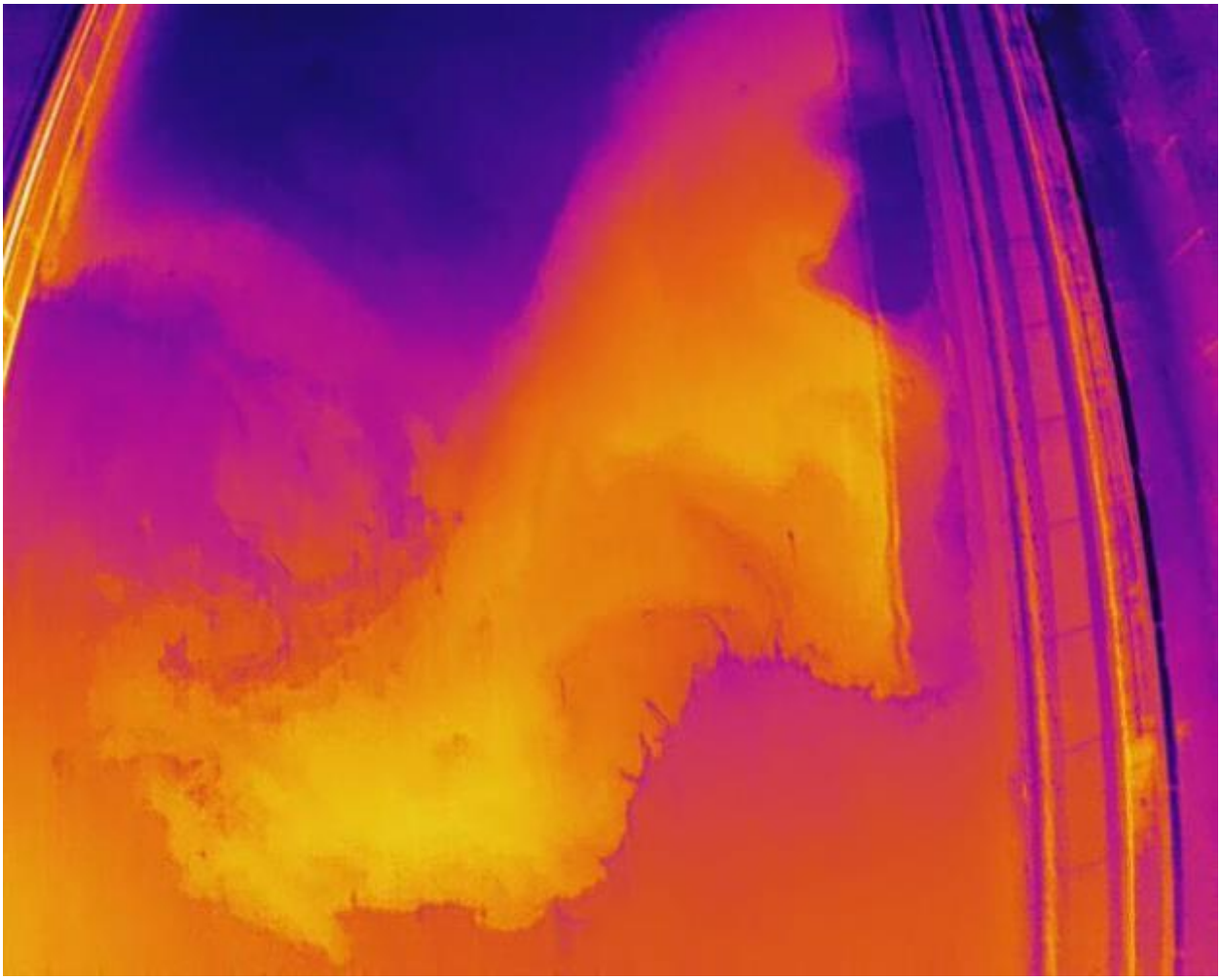
Tallahassee, Florida. 32312

FLIR COLLECTED ON 2016/07/16
FLIGHT TIME: 07:58:22
VIDEO STILL: H264.00_10_38_09.Still005



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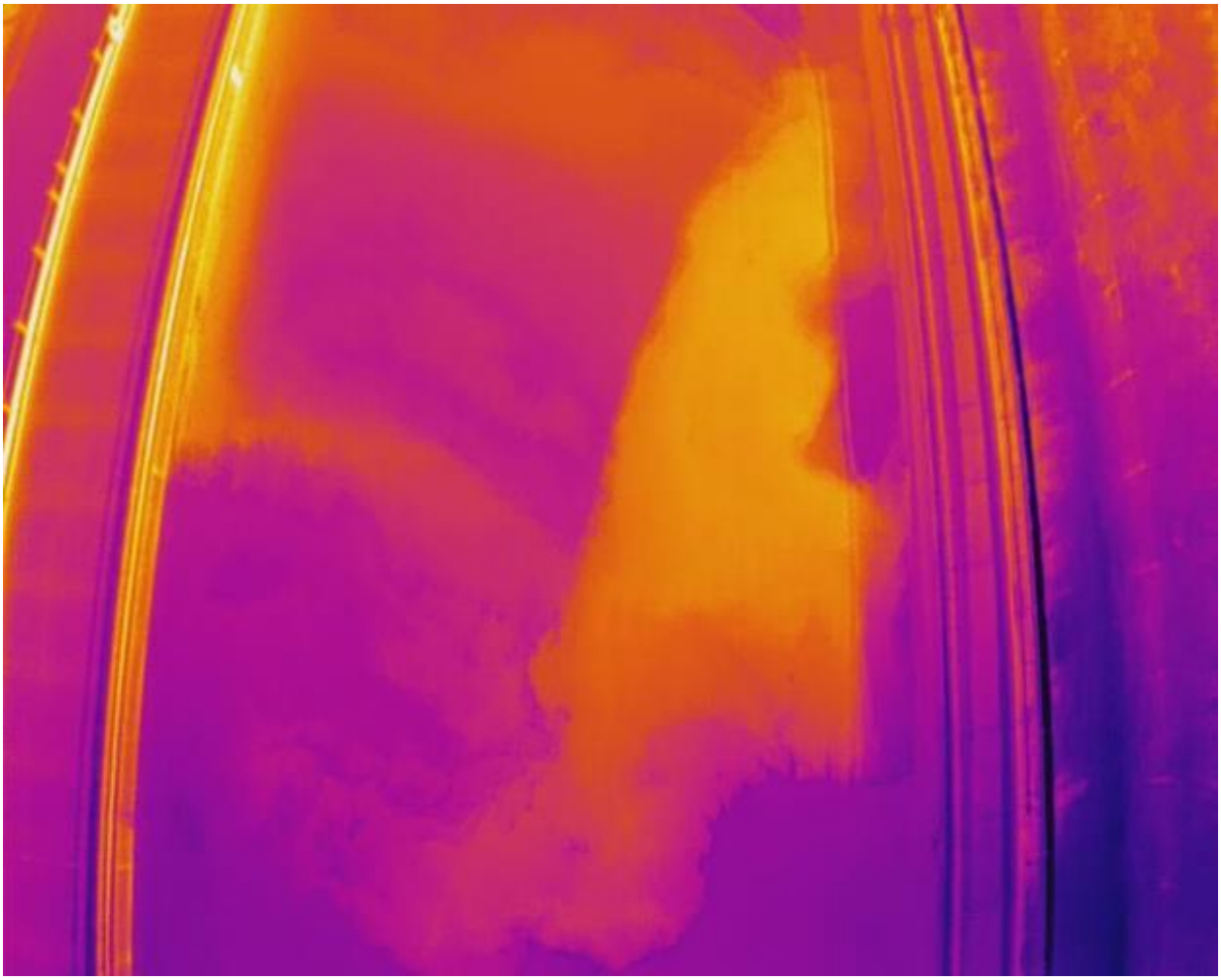
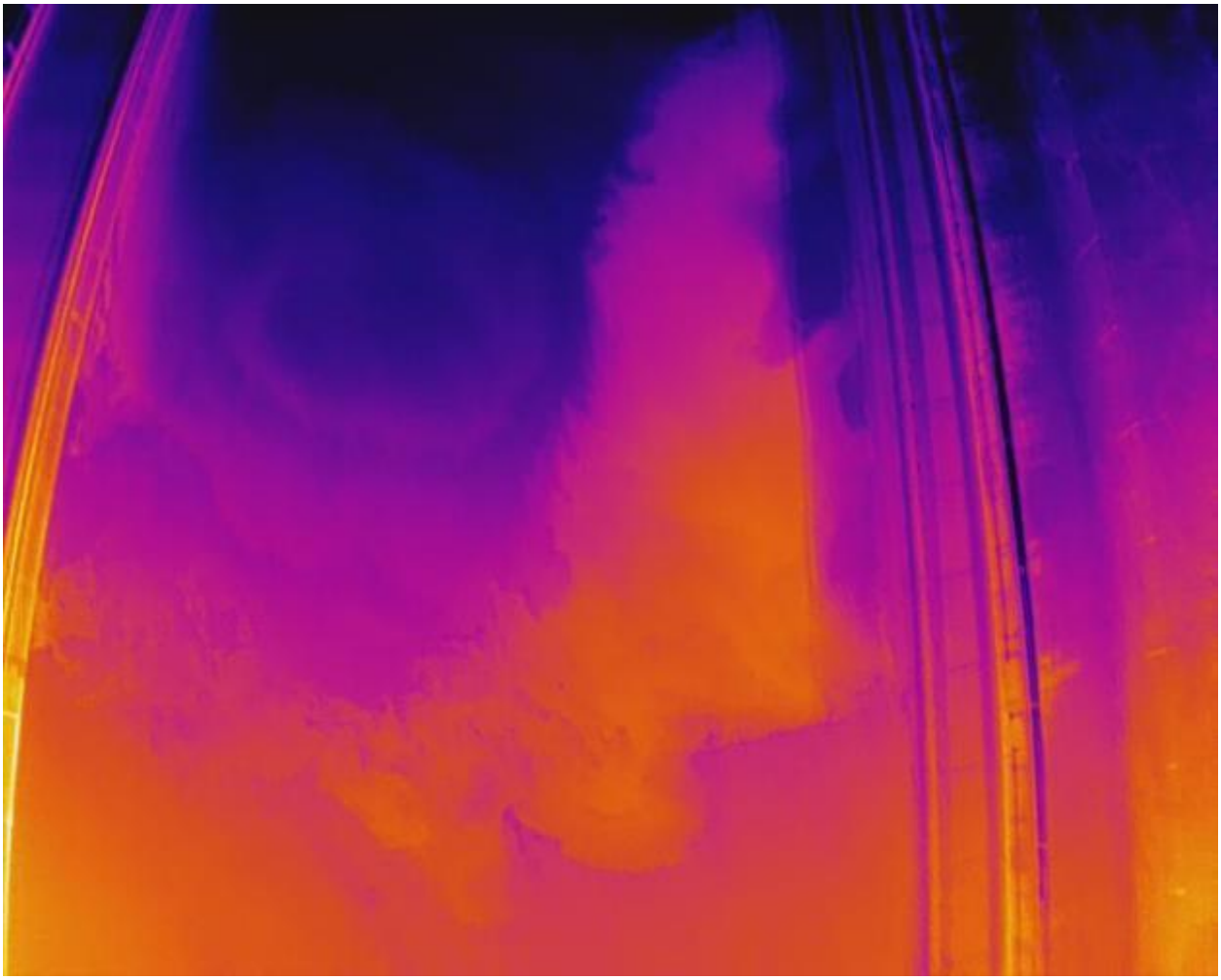
Tallahassee, Florida. 32312

FLIR COLLECTED ON 2016/07/16
FLIGHT TIME: 07:58:22
VIDEO STILL: H264.00_11_11_19.Still006



Water Mapping, LLC
1240 Greensward Dr.
Tallahassee, Florida. 32312

FLIR COLLECTED ON 2016/07/16
FLIGHT TIME: 07:58:22
VIDEO STILL: H264.00_12_56_19.Still007



Water Mapping, LLC
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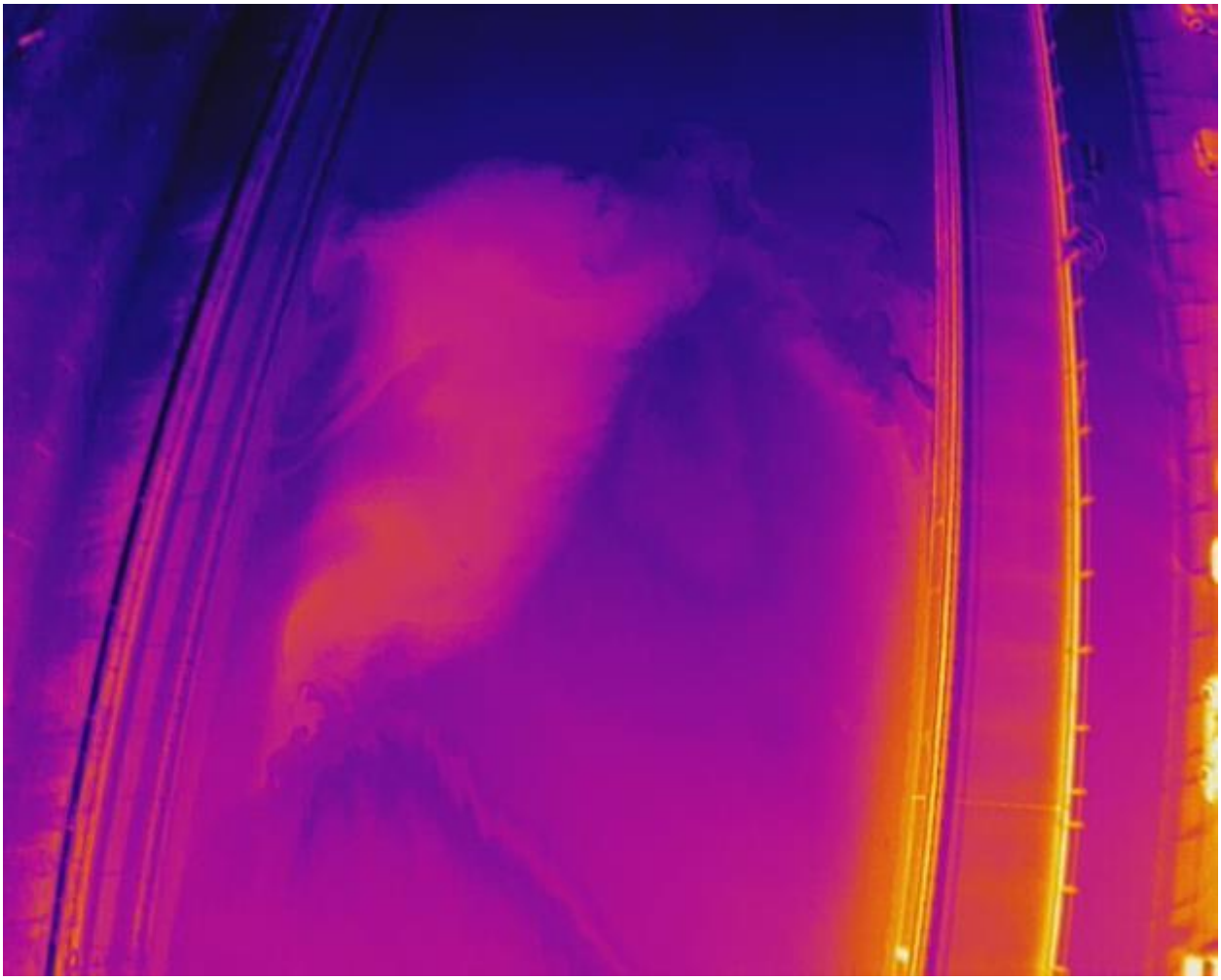
Tallahassee, Florida. 32312

FLIR COLLECTED ON 2016/07/16
FLIGHT TIME: 07:58:22
VIDEO STILL: H264.00_15_01_29.Still008



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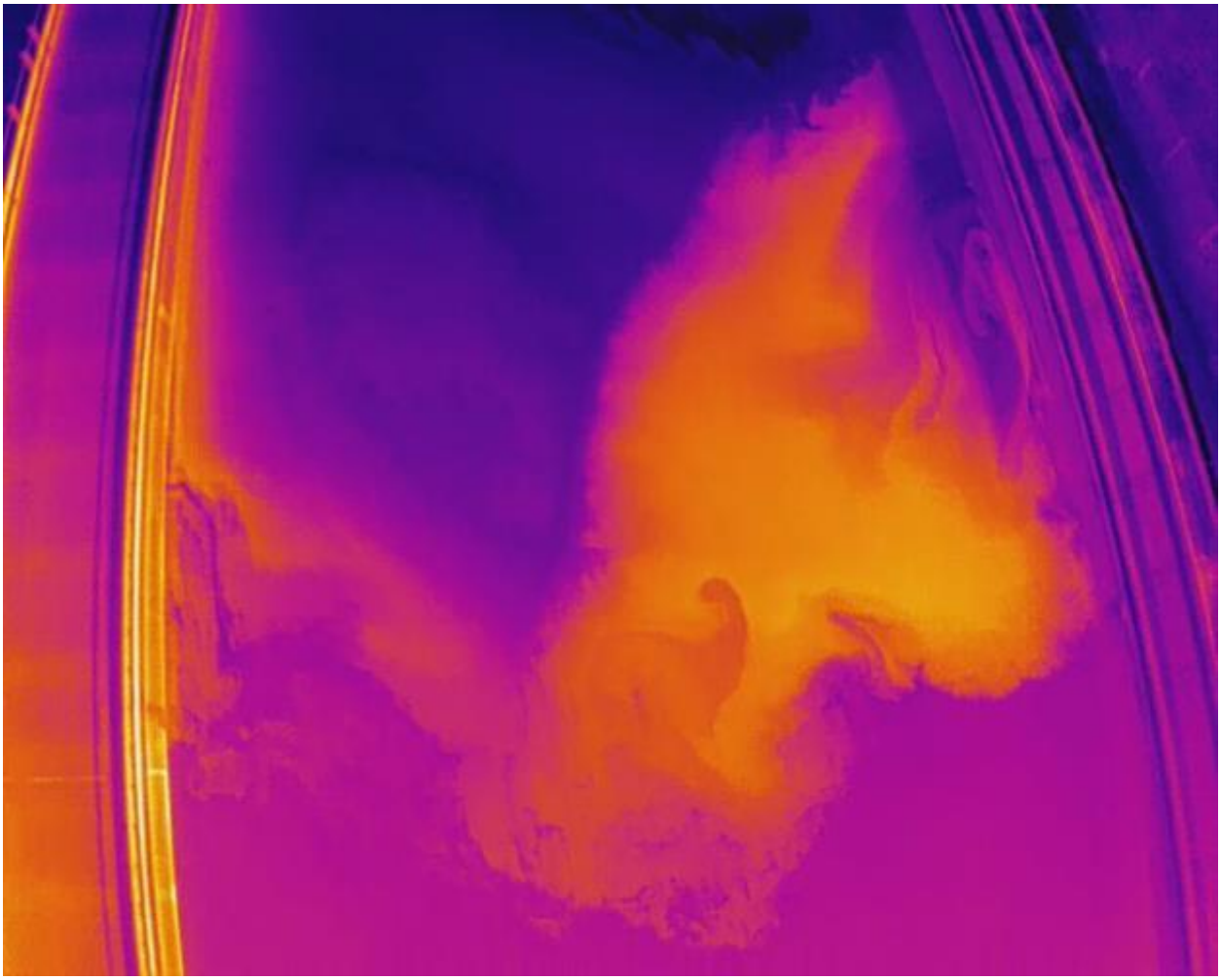
Tallahassee, Florida. 32312

FLIR COLLECTED ON 2016/07/16
FLIGHT TIME: 07:58:22
VIDEO STILL: H264.00_16_43_15.Still009



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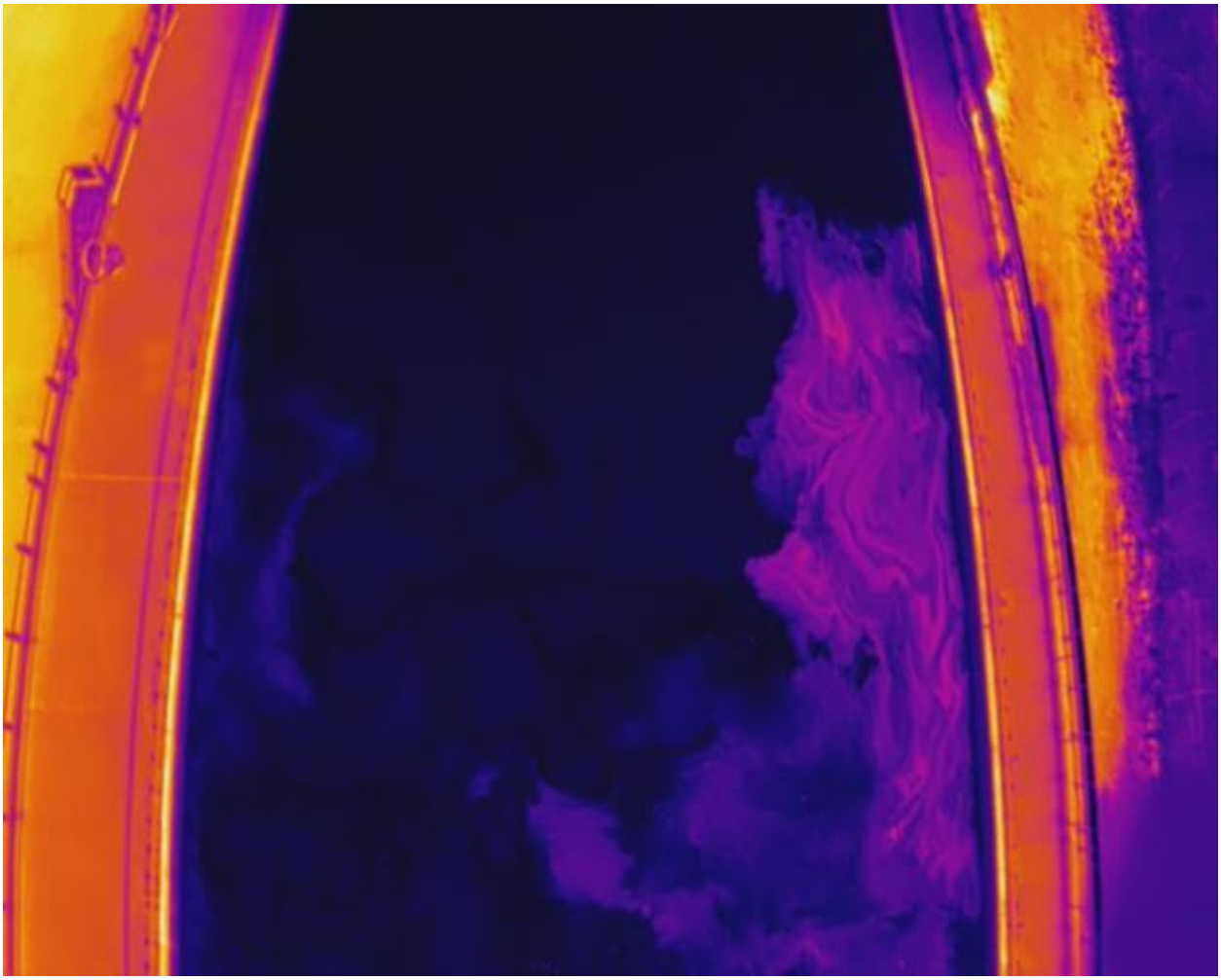
Tallahassee, Florida. 32312

FLIR COLLECTED ON 2016/07/18
FLIGHT TIME: 12:32:02
VIDEO STILL: H264.00_05_44_14.Still001



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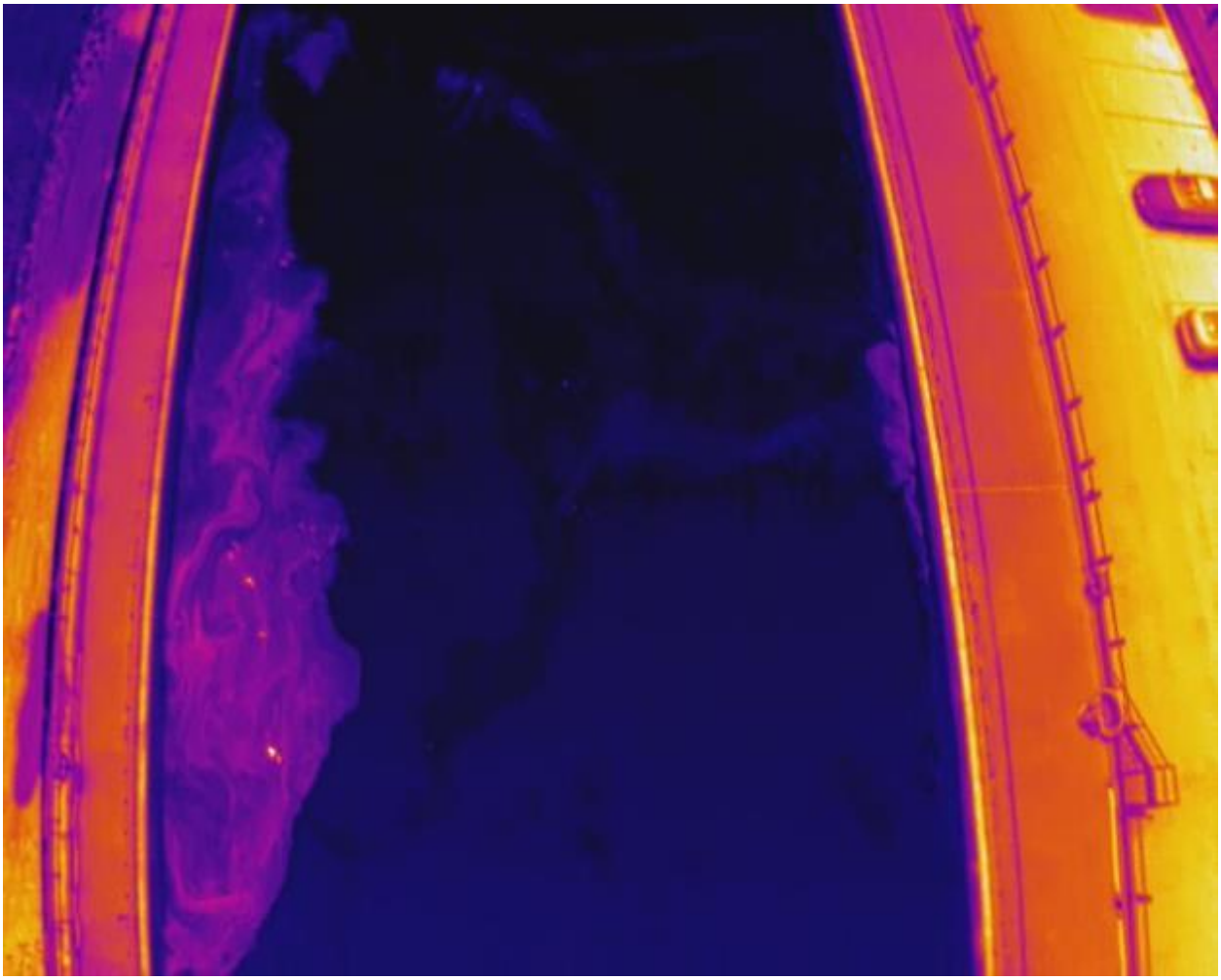
FLIR COLLECTED ON 2016/07/18
FLIGHT TIME: 12:32:02
VIDEO STILL: H264.00_07_46_11.Still002



Water Mapping, LLC
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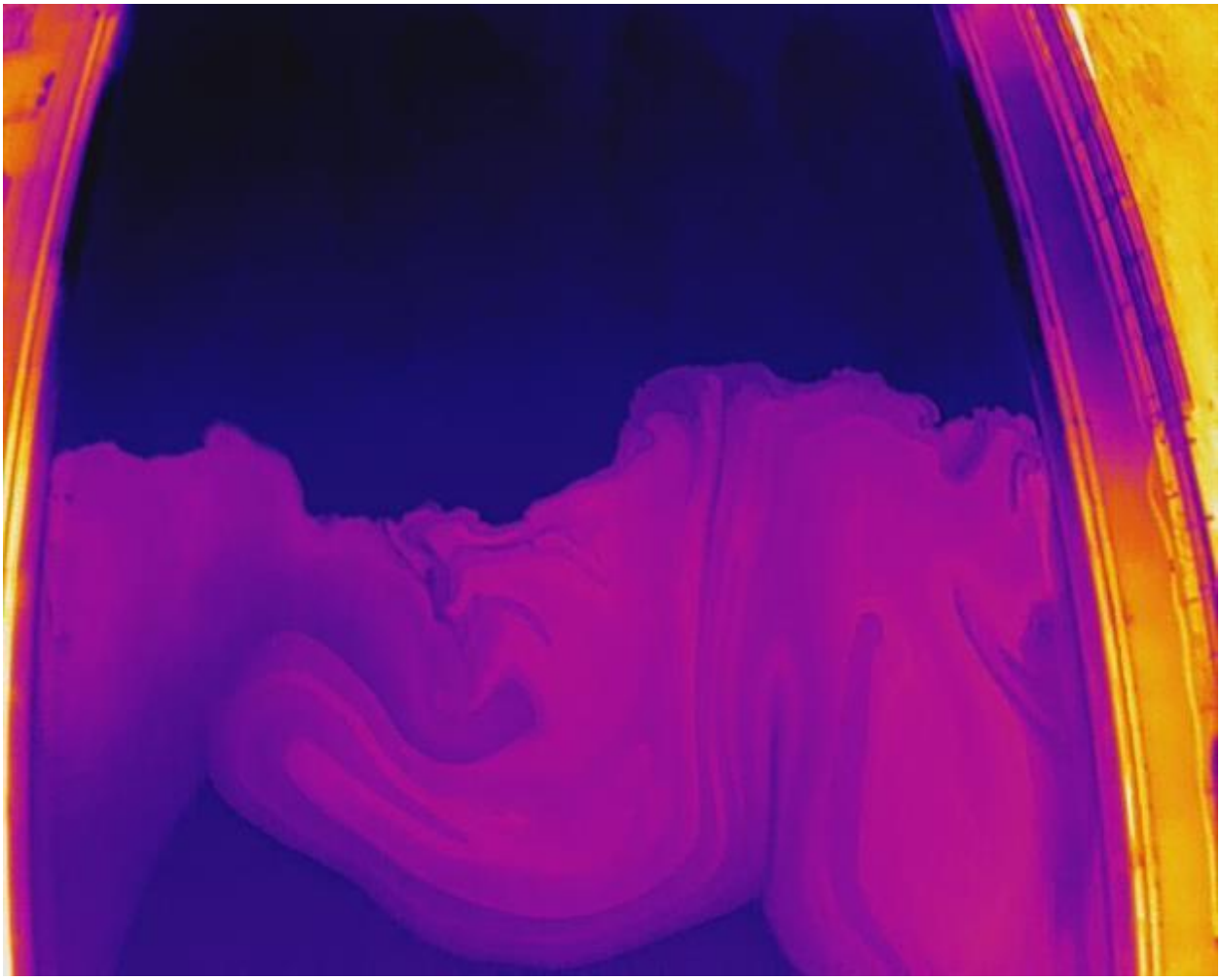
Tallahassee, Florida. 32312

FLIR COLLECTED ON 2016/07/18
FLIGHT TIME: 15:44:10
VIDEO STILL: H264.00_12_17_19.Still001



Water Mapping, LLC
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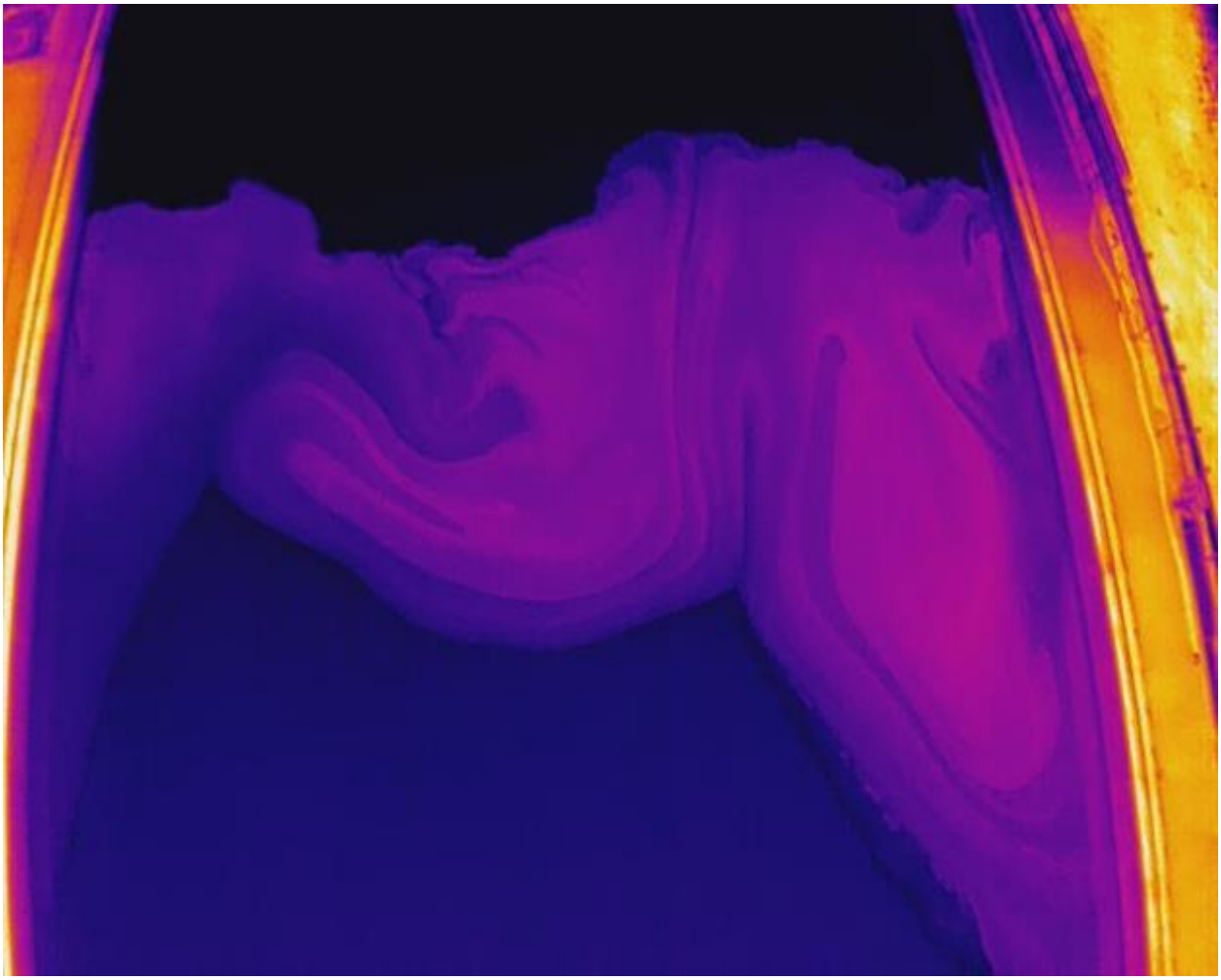
Tallahassee, Florida. 32312

FLIR COLLECTED ON 2016/07/18
FLIGHT TIME: 15:44:10
VIDEO STILL: H264.00_12_20_01.Still002



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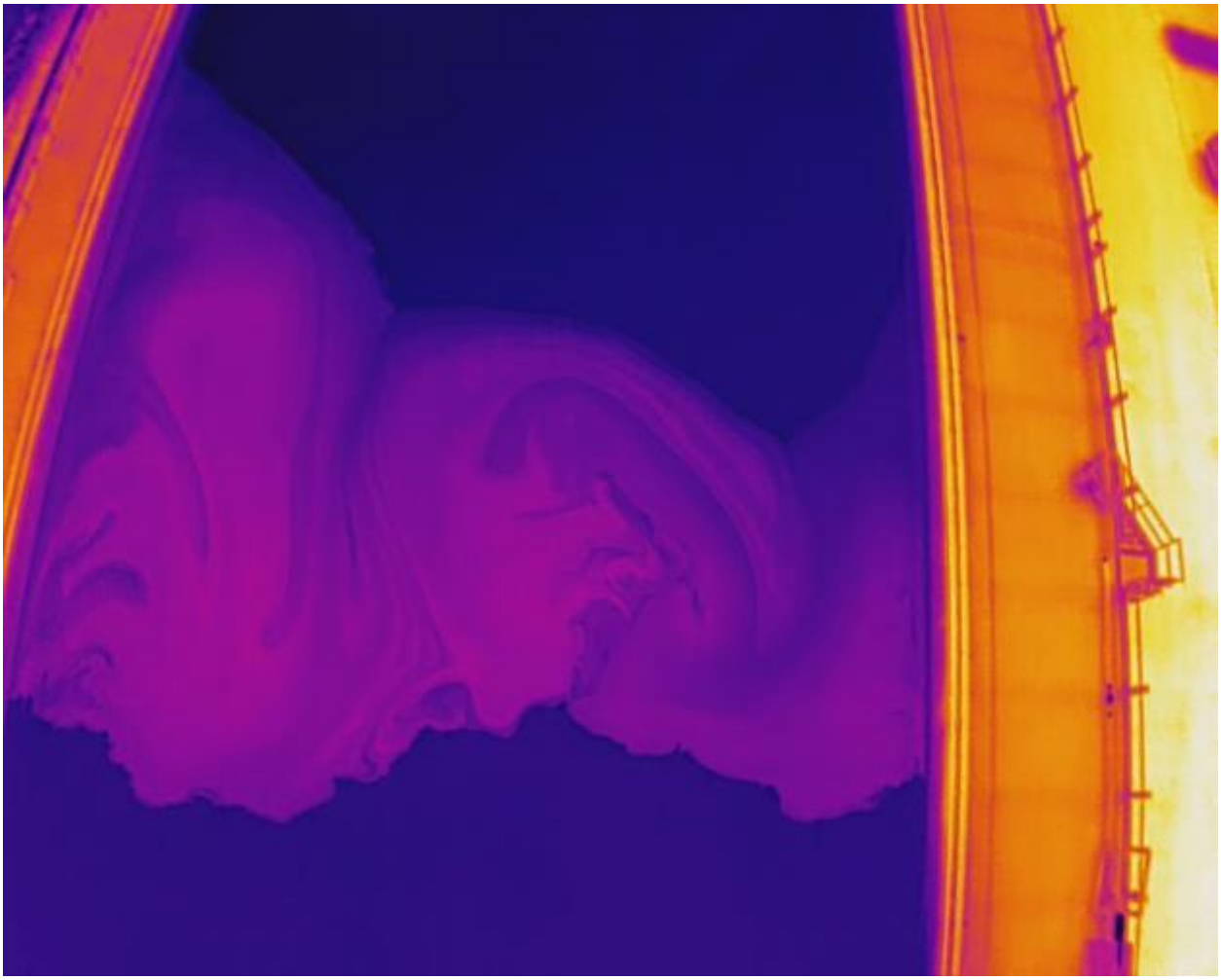
Tallahassee, Florida. 32312

FLIR COLLECTED ON 2016/07/18
FLIGHT TIME: 15:44:10
VIDEO STILL: H264.00_13_54_23.Still004



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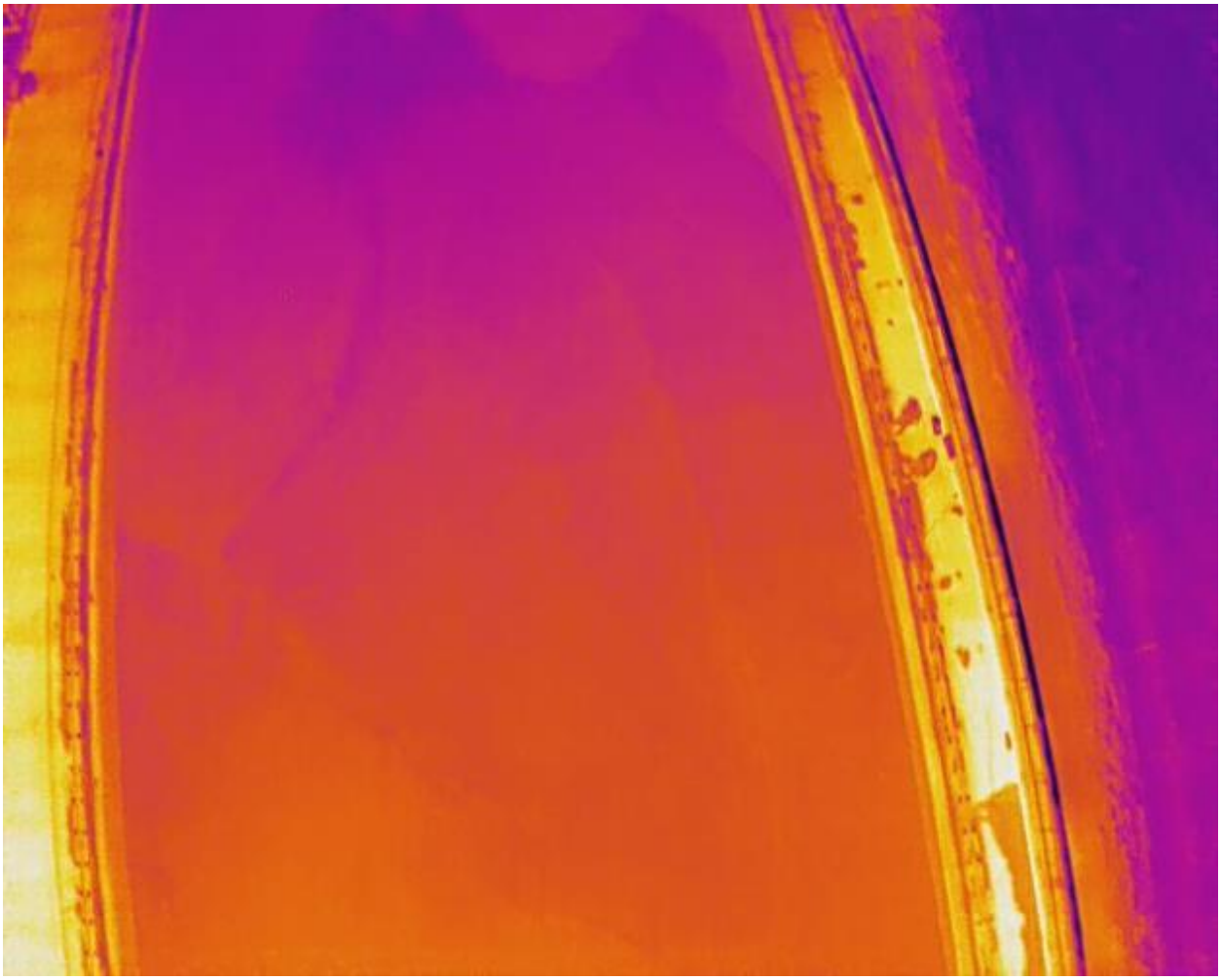
FLIR COLLECTED ON 2016/07/18
FLIGHT TIME: 18:40:23
VIDEO STILL: H264.00_07_17_10.Still001



Water Mapping, LLC
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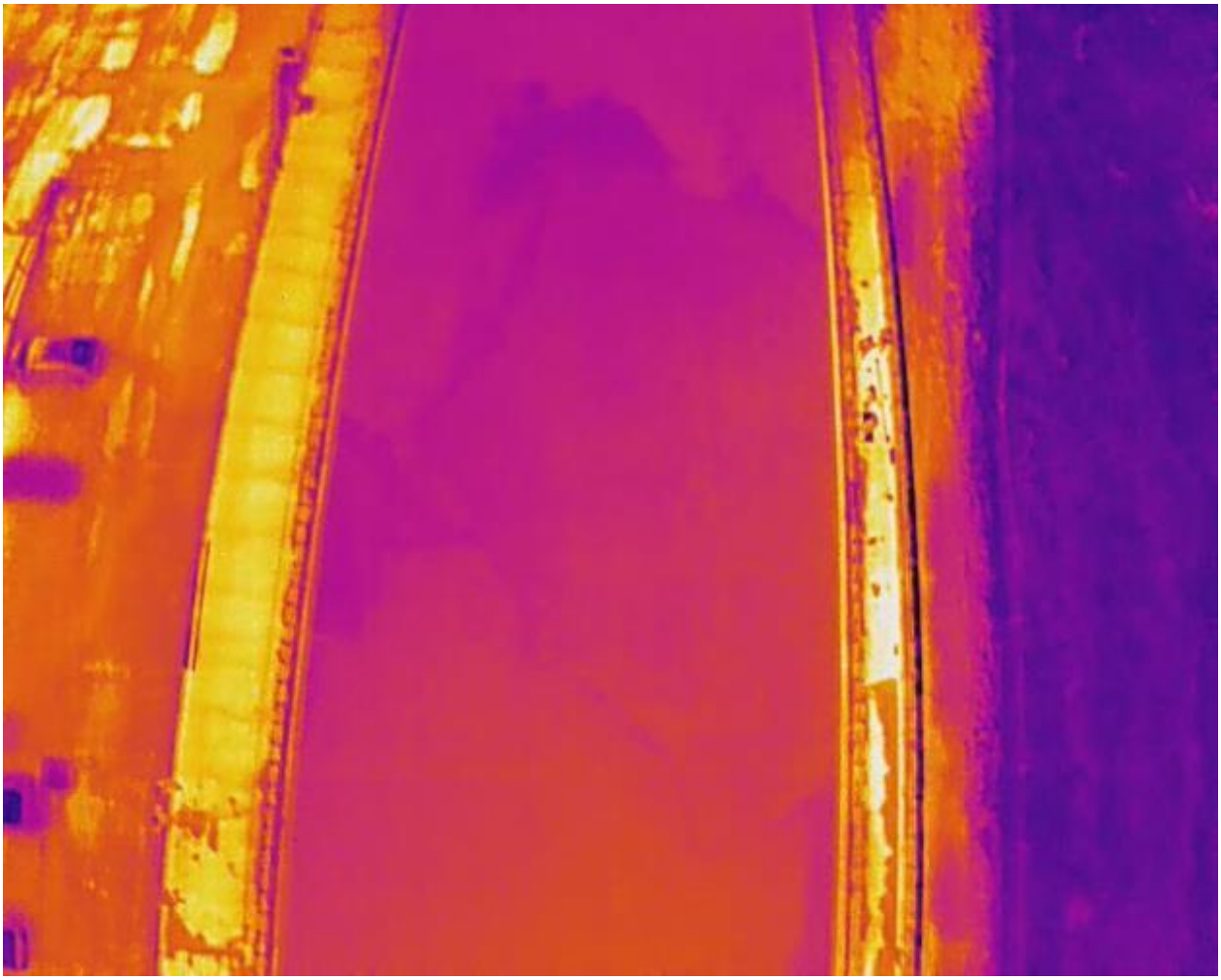
Tallahassee, Florida. 32312

FLIR COLLECTED ON 2016/07/18
FLIGHT TIME: 18:40:23
VIDEO STILL: H264.00_09_18_07.Still002



Water Mapping, LLC
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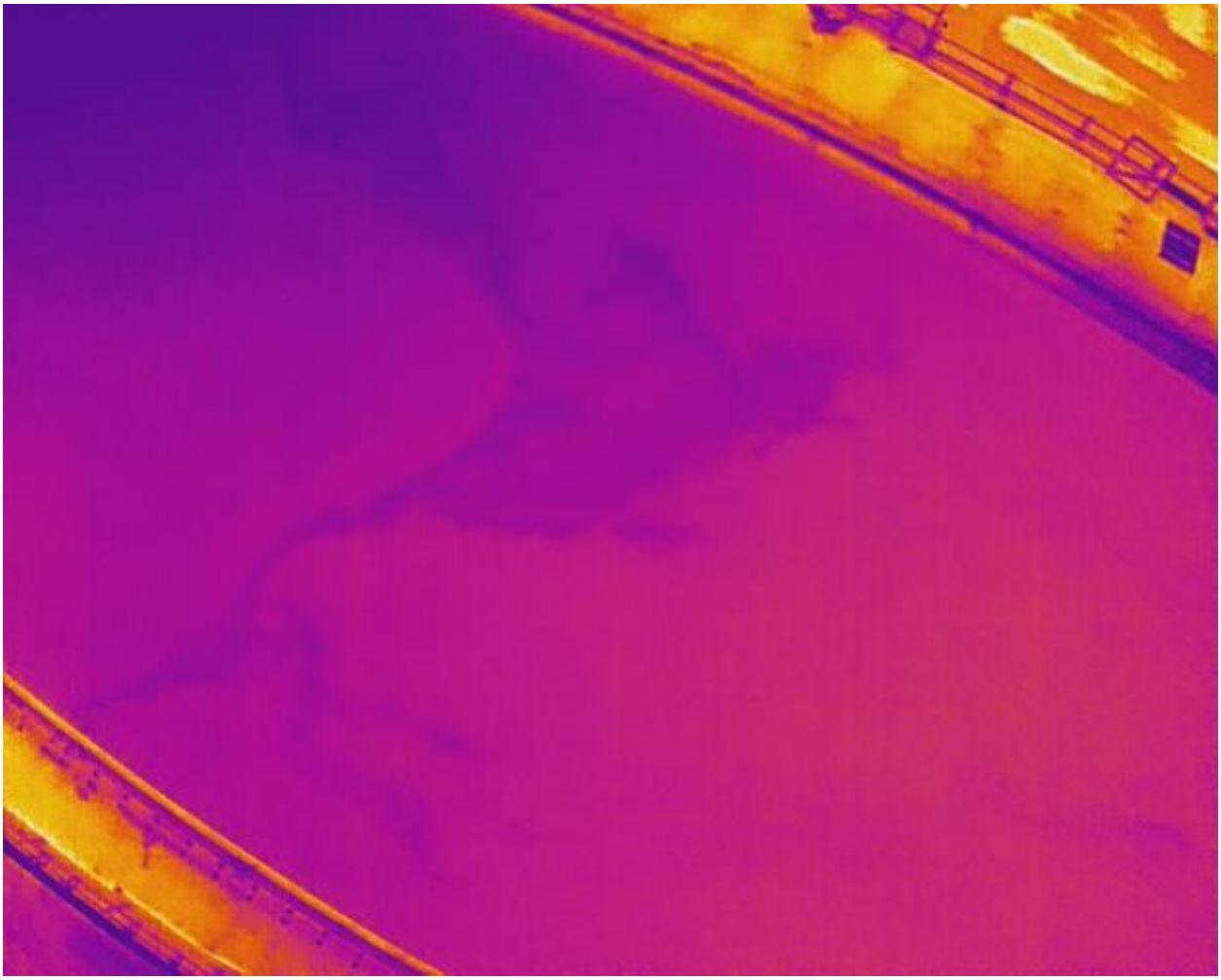
Tallahassee, Florida. 32312

FLIR COLLECTED ON 2016/07/18
FLIGHT TIME: 18:40:23
VIDEO STILL: H264.00_11_12_08.Still003



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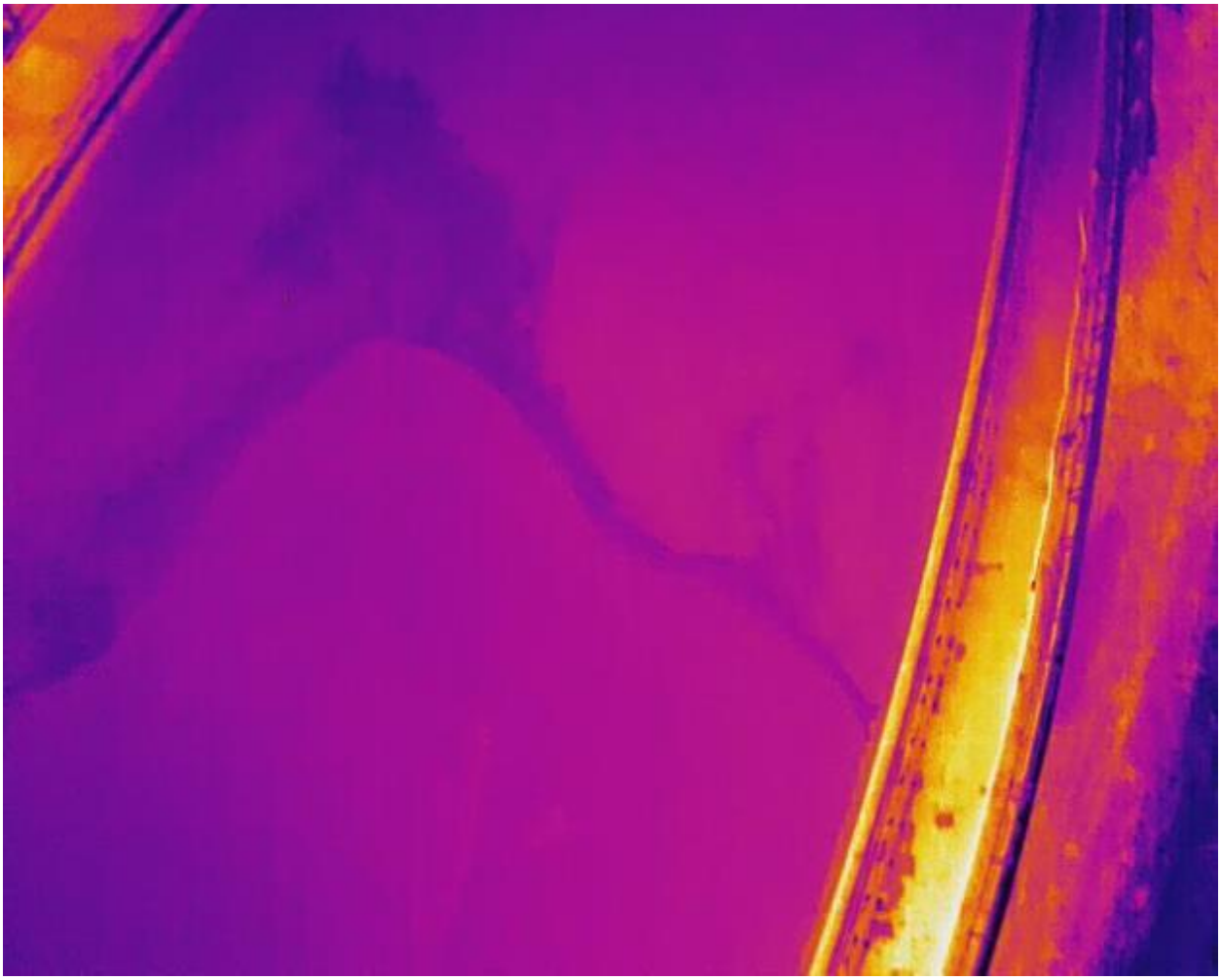
Tallahassee, Florida. 32312

FLIR COLLECTED ON 2016/07/18
FLIGHT TIME: 18:40:23
VIDEO STILL: H264.00_11_40_03.Still004



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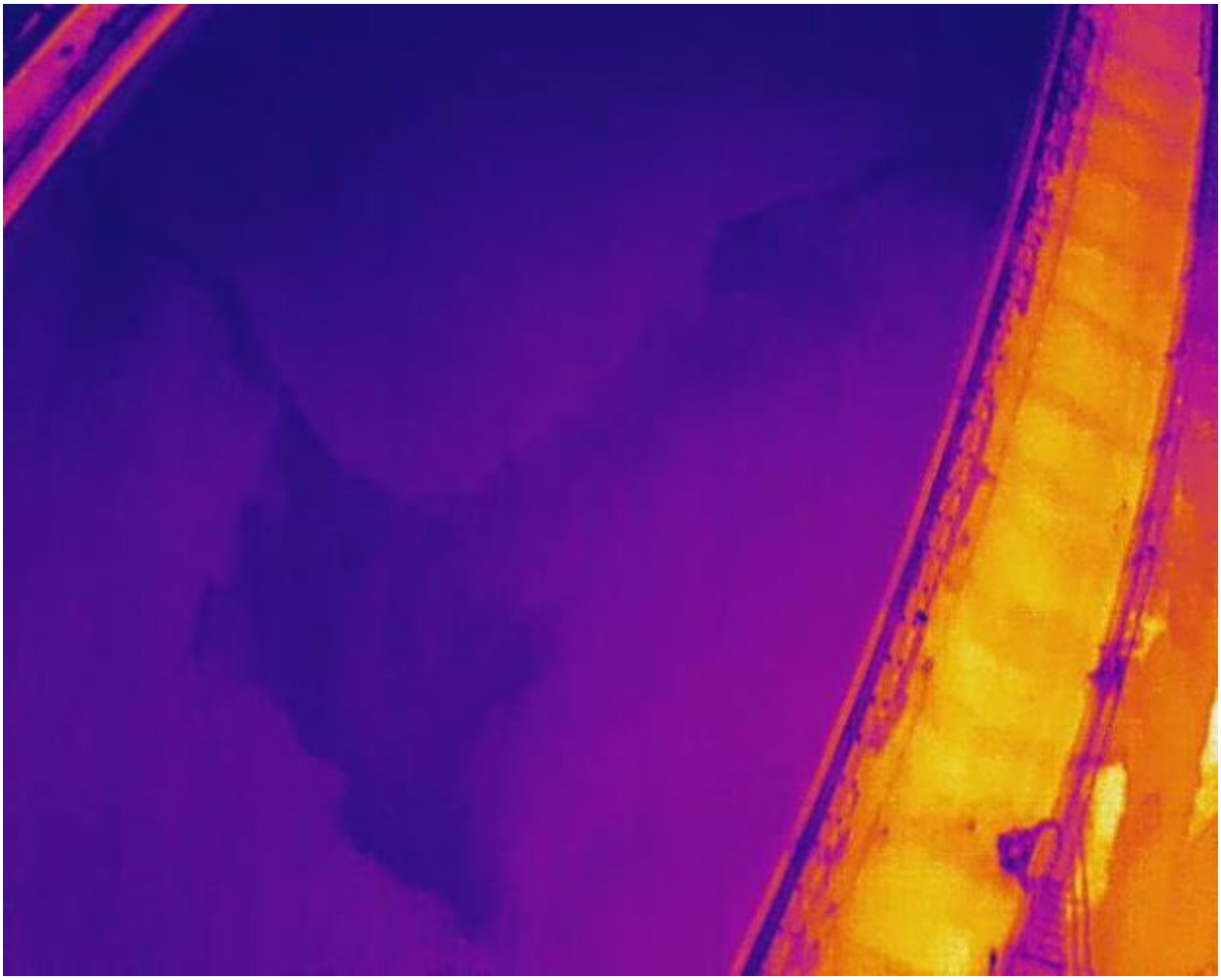
1240 Greensward Dr.
Tallahassee, Florida. 32312

FLIR COLLECTED ON 2016/07/18
FLIGHT TIME: 18:40:23
VIDEO STILL: H264.00_11_55_23.Still005



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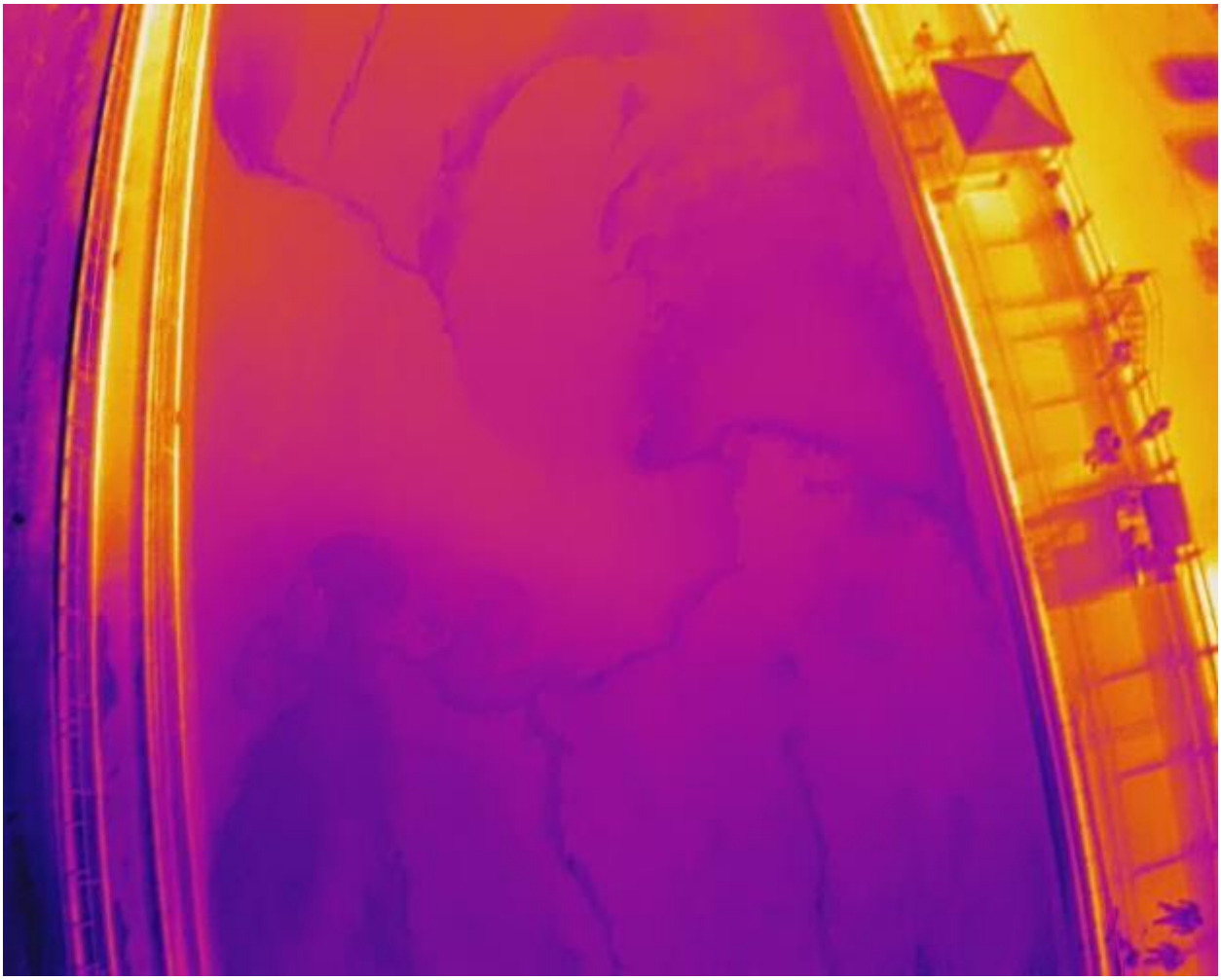
Tallahassee, Florida. 32312

FLIR COLLECTED ON 2016/07/19
FLIGHT TIME: 18:19:18
VIDEO STILL: H264.00_01_22_18.Still001



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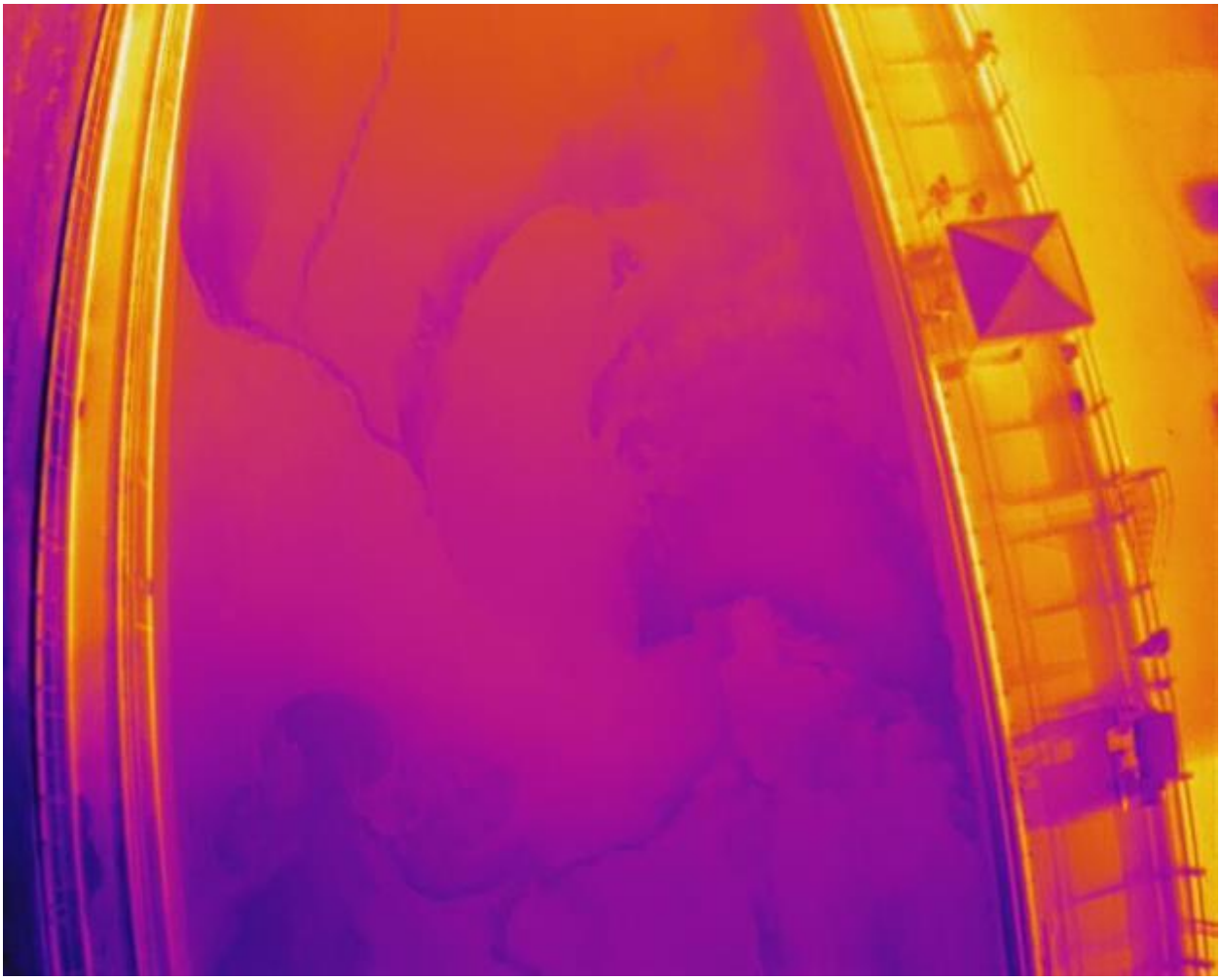
Tallahassee, Florida. 32312

FLIR COLLECTED ON 2016/07/19
FLIGHT TIME: 18:19:18
VIDEO STILL: H264.00_01_30_21.Still002



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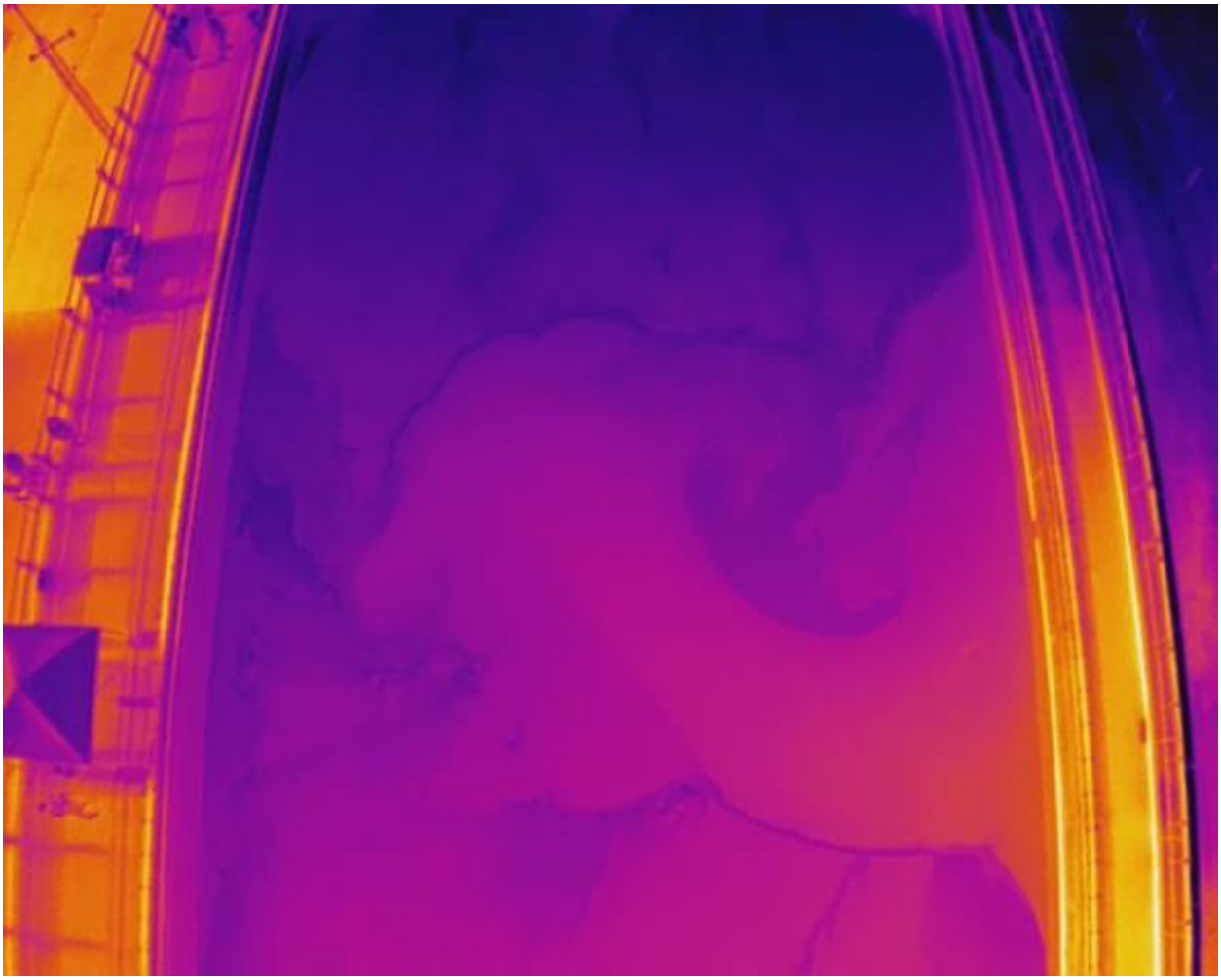
Tallahassee, Florida. 32312

FLIR COLLECTED ON 2016/07/19
FLIGHT TIME: 18:19:18
VIDEO STILL: H264.00_02_37_22.Still003



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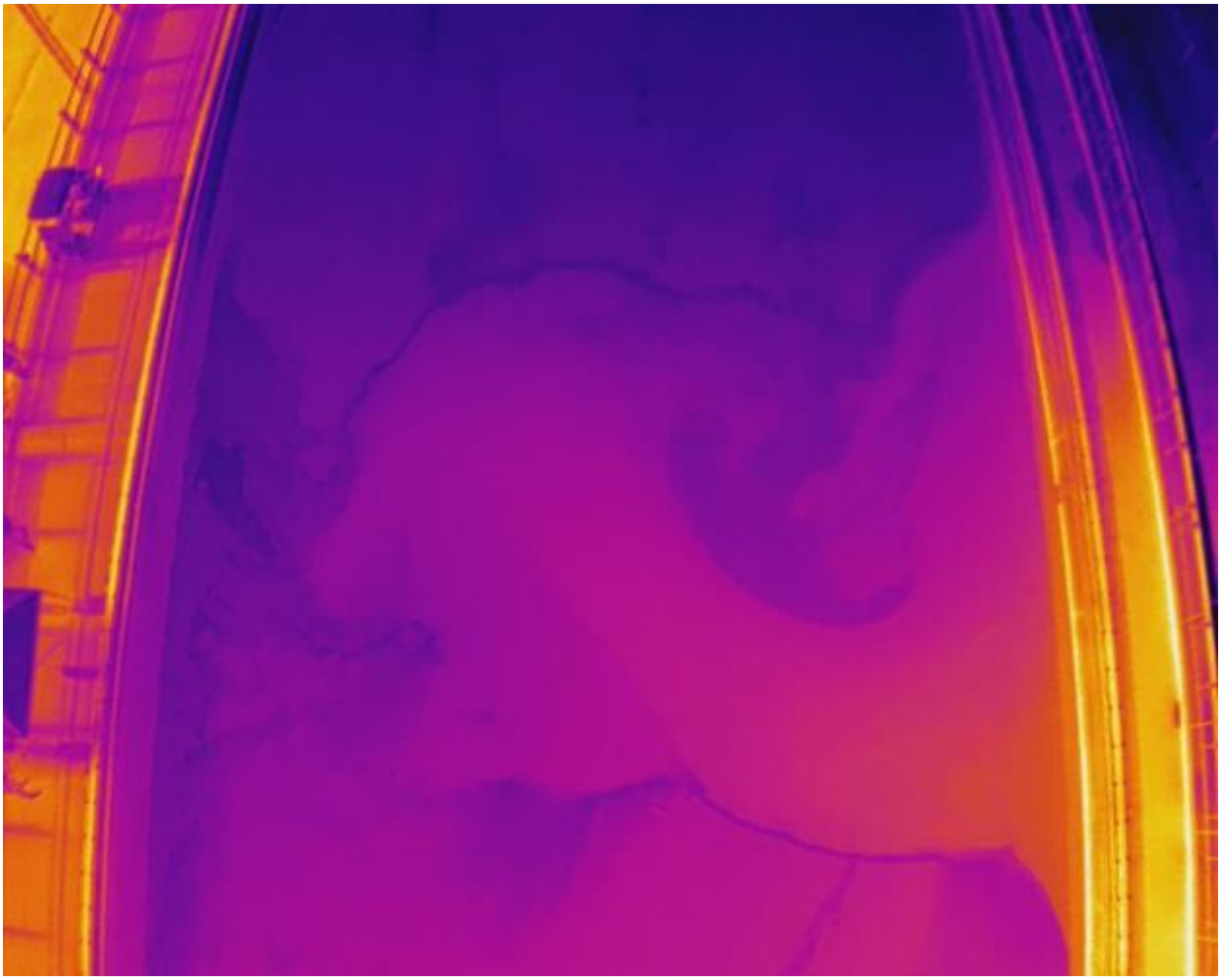
Tallahassee, Florida. 32312

FLIR COLLECTED ON 2016/07/19
FLIGHT TIME: 18:19:18
VIDEO STILL: H264.00_02_43_13.Still005



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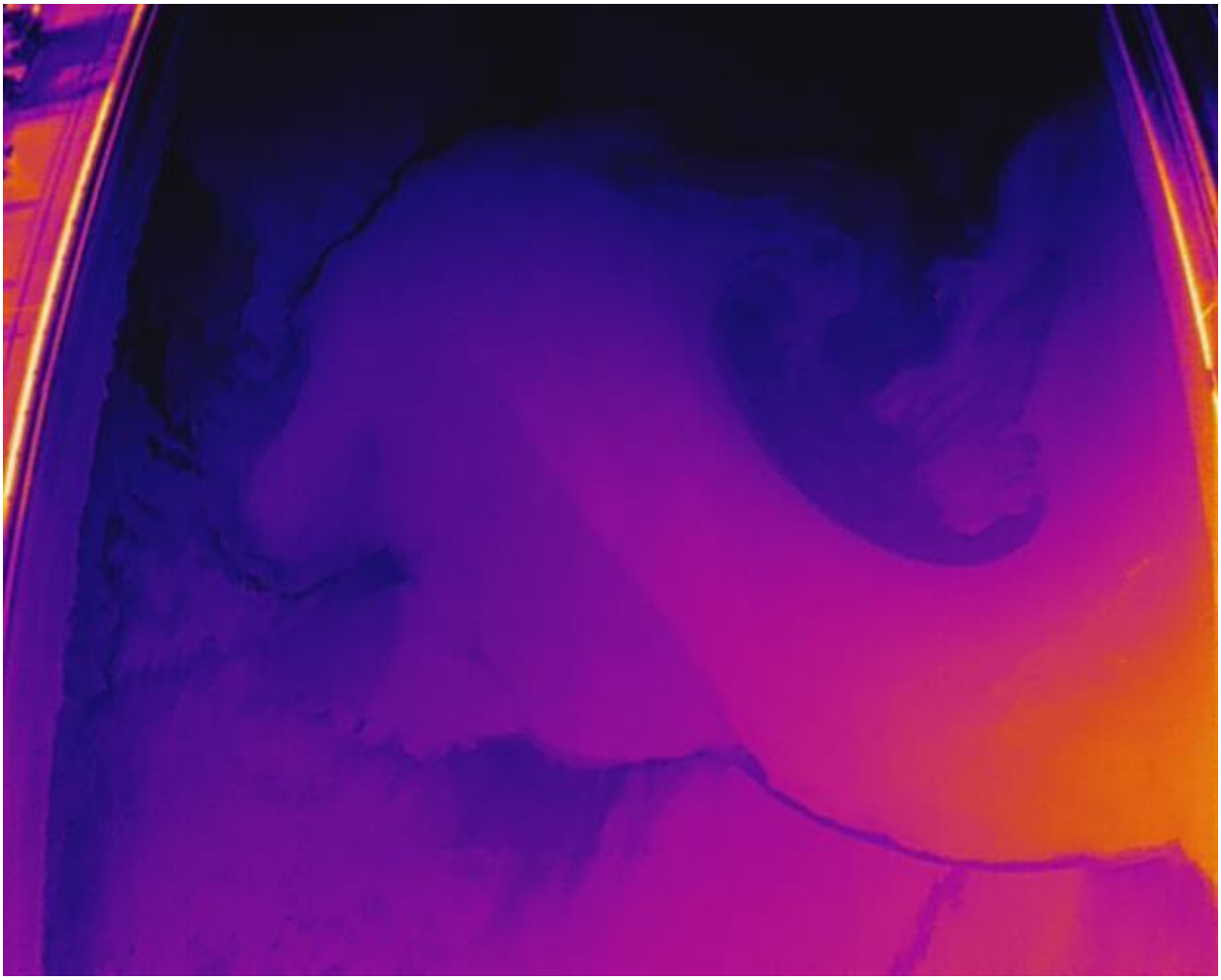
FLIR COLLECTED ON 2016/07/19
FLIGHT TIME: 18:19:18
VIDEO STILL: H264.00_02_50_00.Still004



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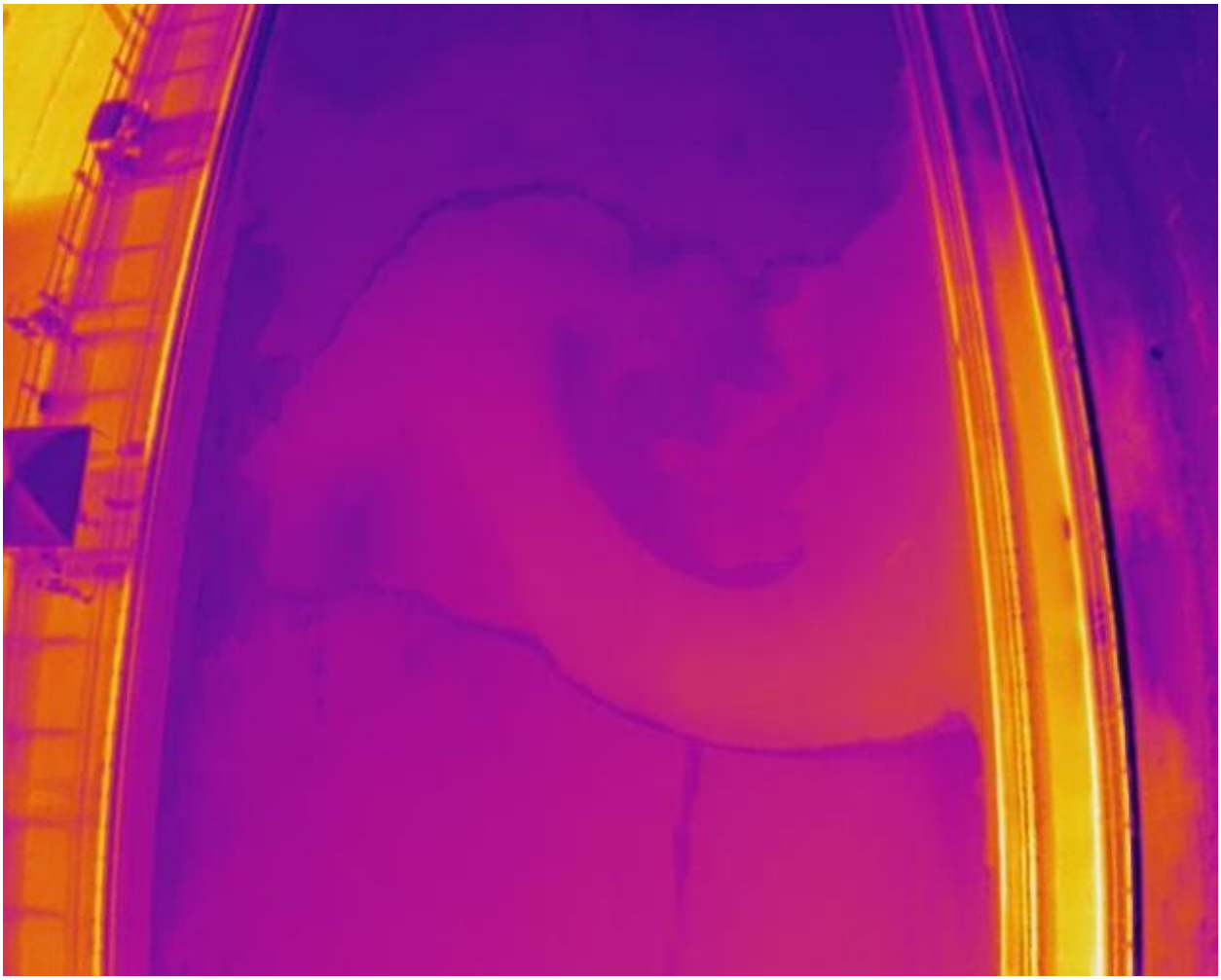
Tallahassee, Florida. 32312

FLIR COLLECTED ON 2016/07/19
FLIGHT TIME: 18:19:18
VIDEO STILL: H264.00_03_48_14.Still006



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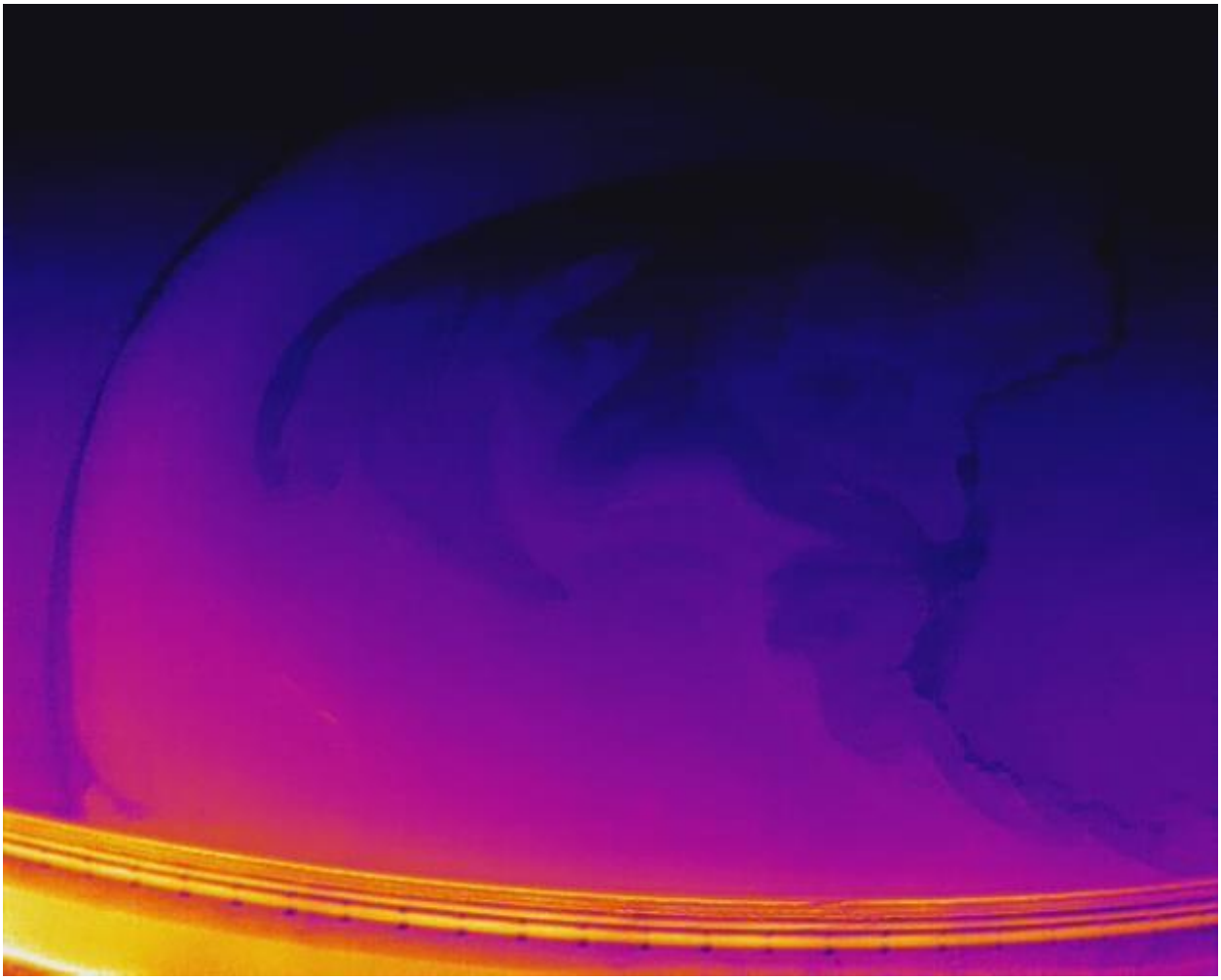
Tallahassee, Florida. 32312

FLIR COLLECTED ON 2016/07/19
FLIGHT TIME: 18:19:18
VIDEO STILL: H264.00_05_46_22.Still007



Water Mapping, LLC
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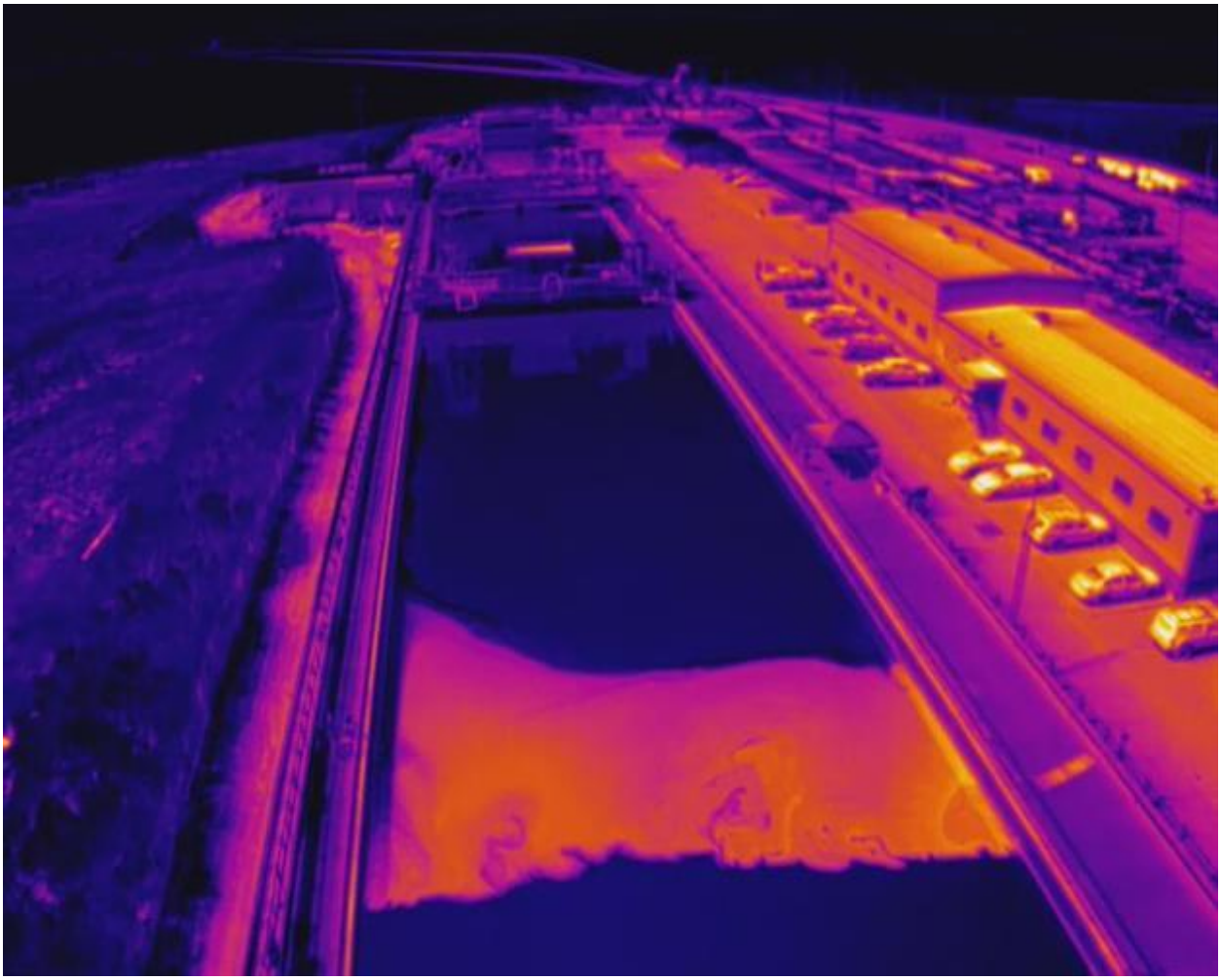
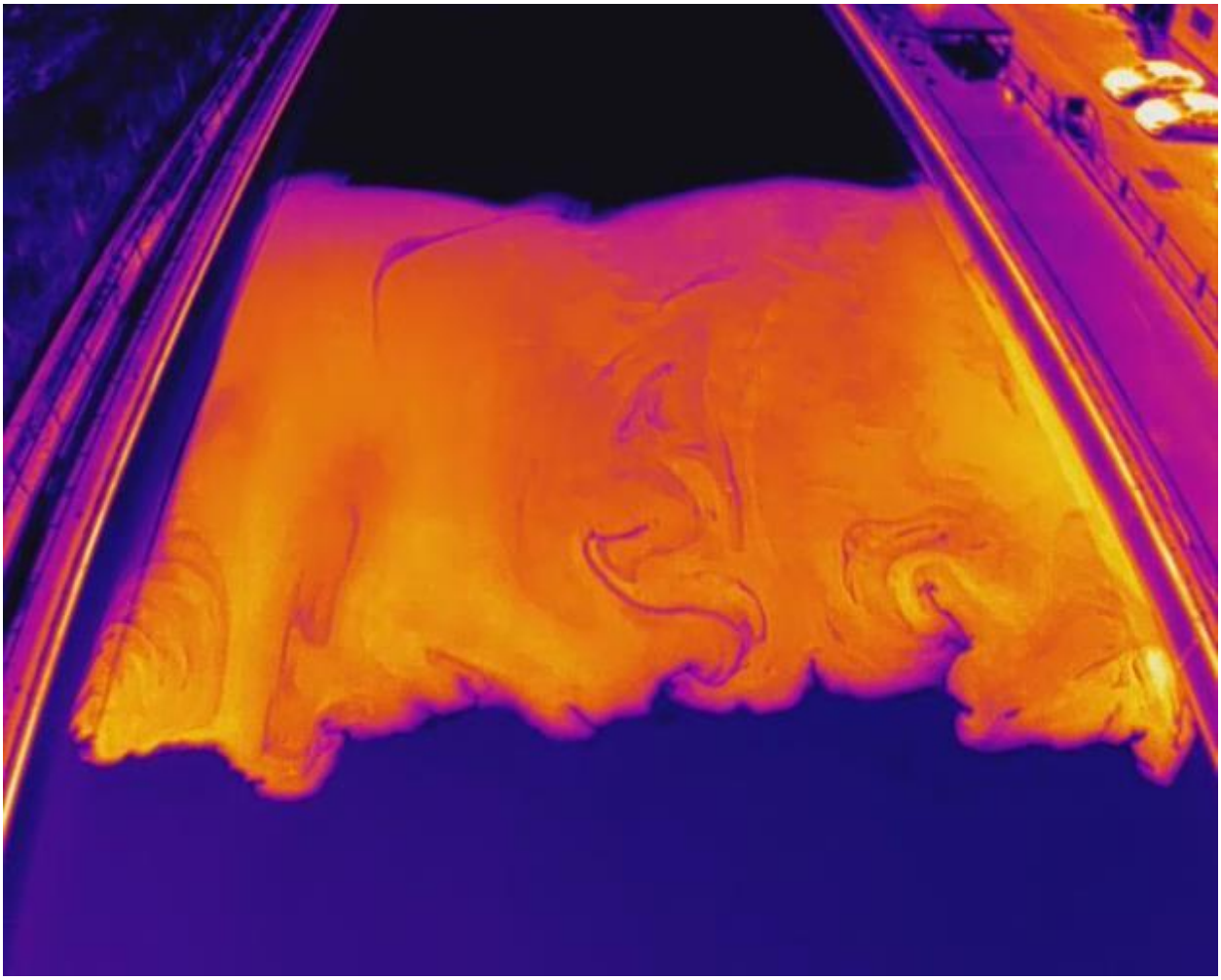
FLIR COLLECTED ON 2016/07/20
FLIGHT TIME: 10:18:40
VIDEO STILL: H264.00_02_30_20.Still002



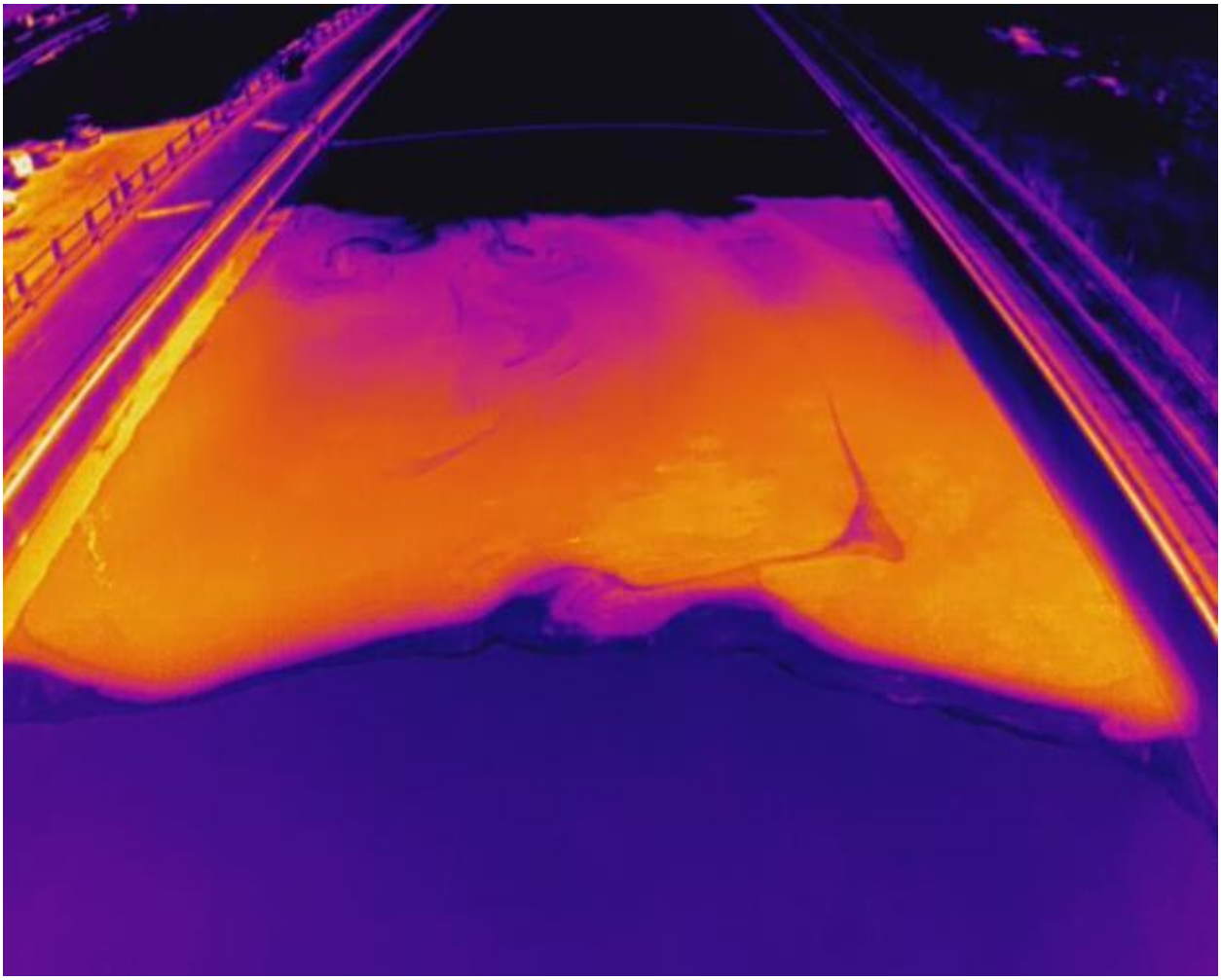
Water Mapping, LLC
1240 Greensward Dr.
Tallahassee, Florida. 32312

FLIR COLLECTED ON 2016/07/20
FLIGHT TIME: 10:18:40
VIDEO STILL: H264.00_07_25_15.Still008



Water Mapping, LLC
1240 Greensward Dr.
Tallahassee, Florida. 32312

FLIR COLLECTED ON 2016/07/20
FLIGHT TIME: 10:18:40
VIDEO STILL: H264.00_09_21_18.Still009



Water Mapping, LLC
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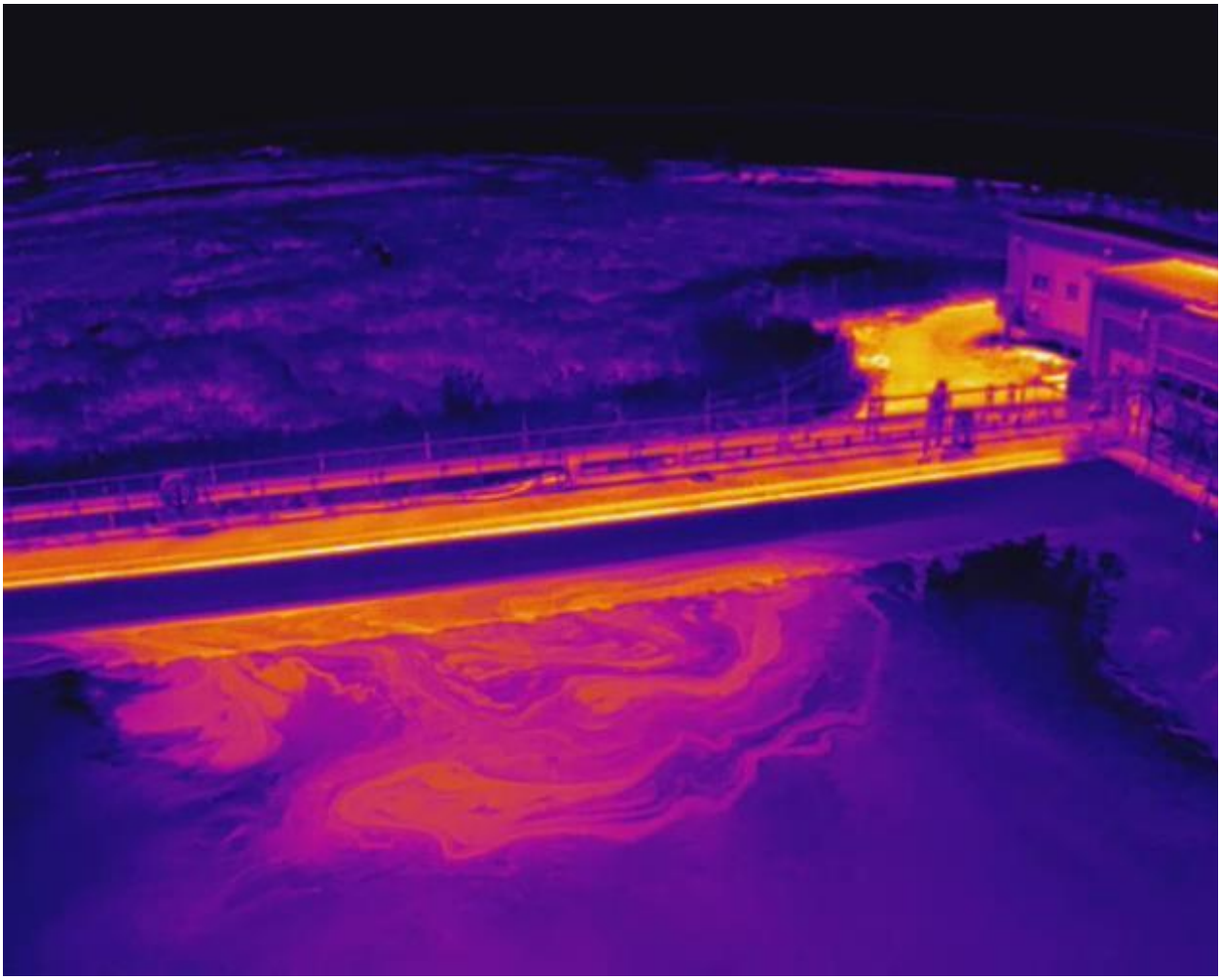
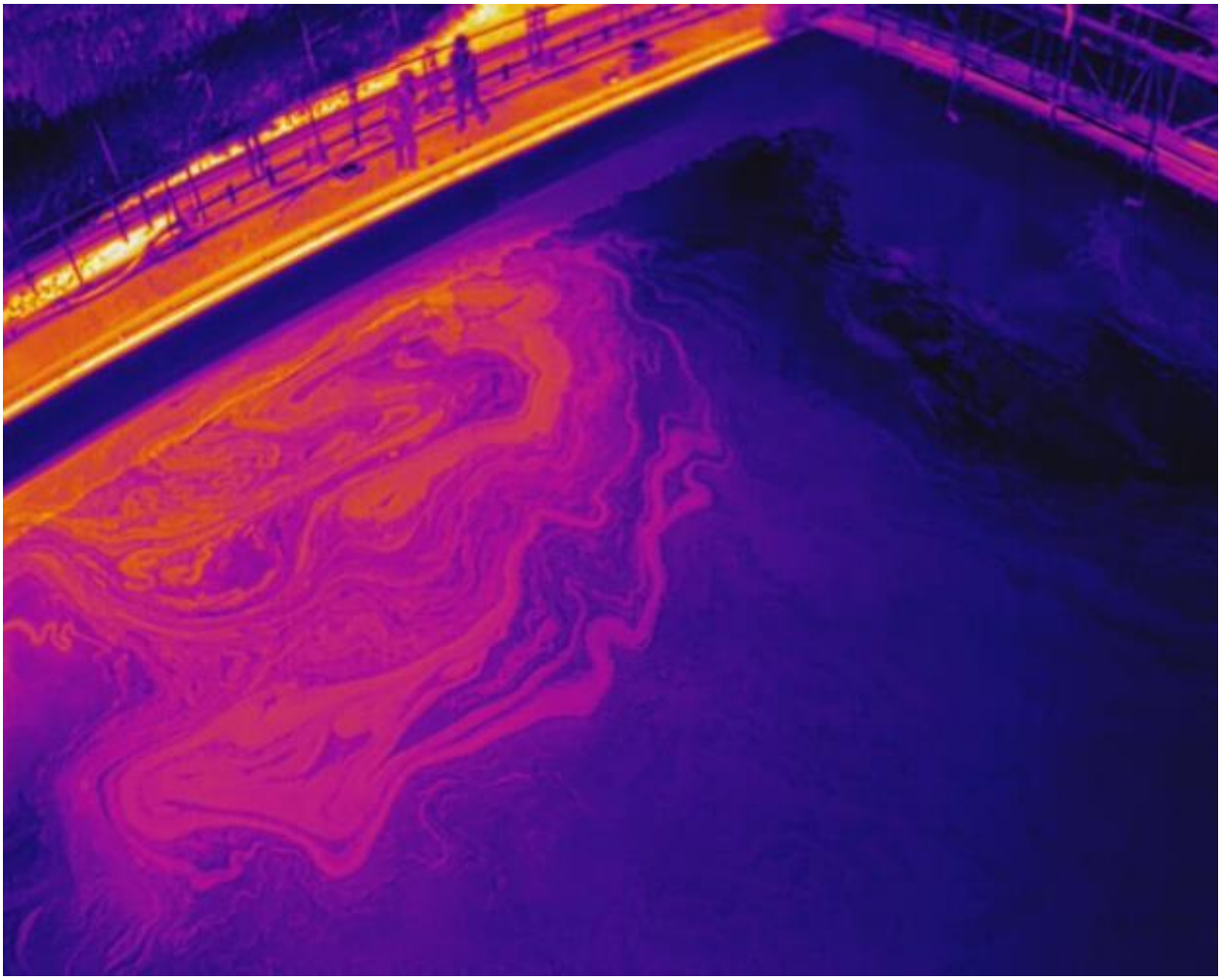
Tallahassee, Florida. 32312

FLIR COLLECTED ON 2016/07/20
FLIGHT TIME: 12:12:11
VIDEO STILL: H264.00_02_39_16.Still001



Water Mapping, LLC
1240 Greensward Dr.
Tallahassee, Florida. 32312

FLIR COLLECTED ON 2016/07/20
FLIGHT TIME: 12:12:11
VIDEO STILL: H264.00_03_22_08.Still002



Water Mapping, LLC
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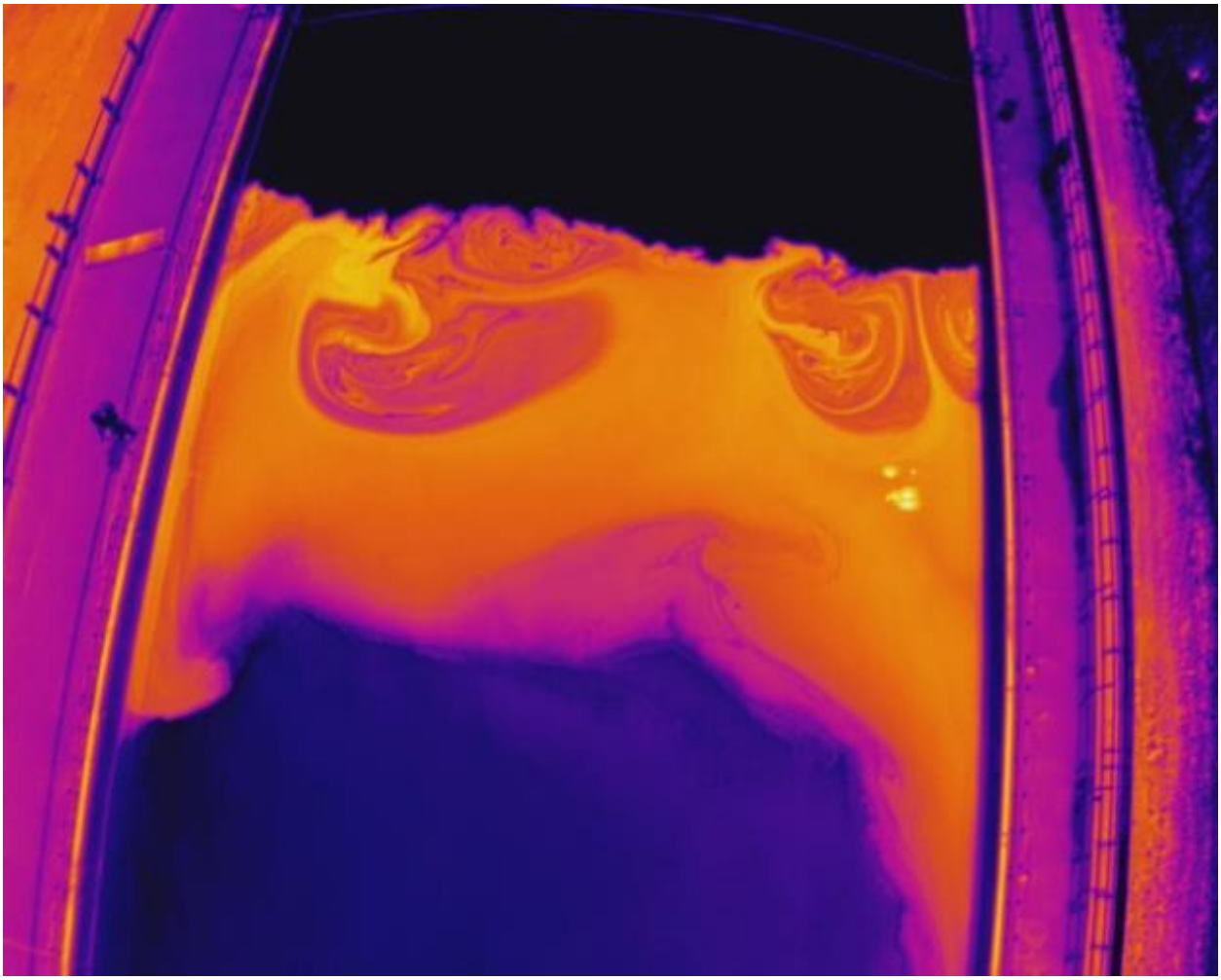
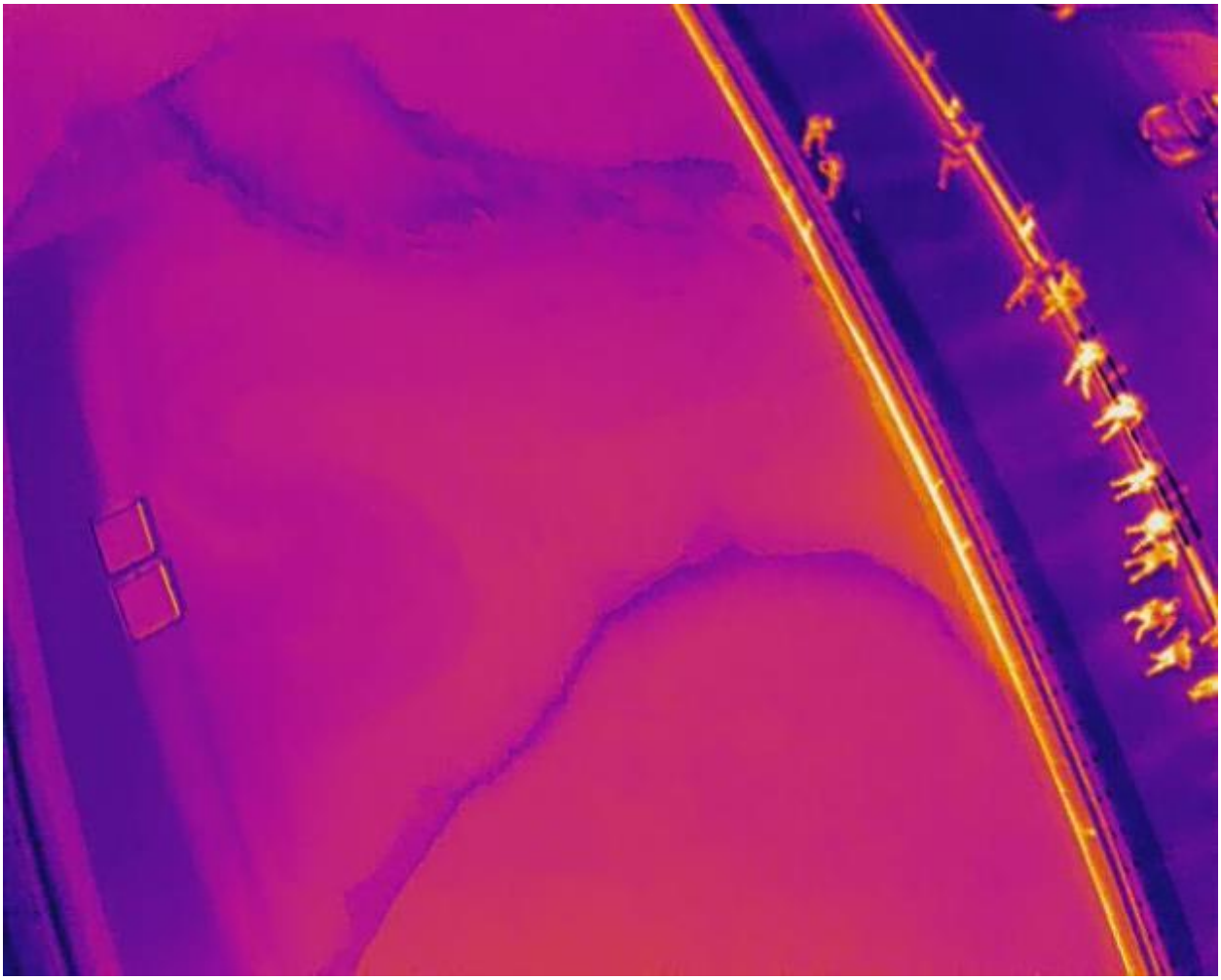
Tallahassee, Florida. 32312

FLIR COLLECTED ON 2016/07/20
FLIGHT TIME: 12:12:11
VIDEO STILL: H264.00_09_00_16.Still011



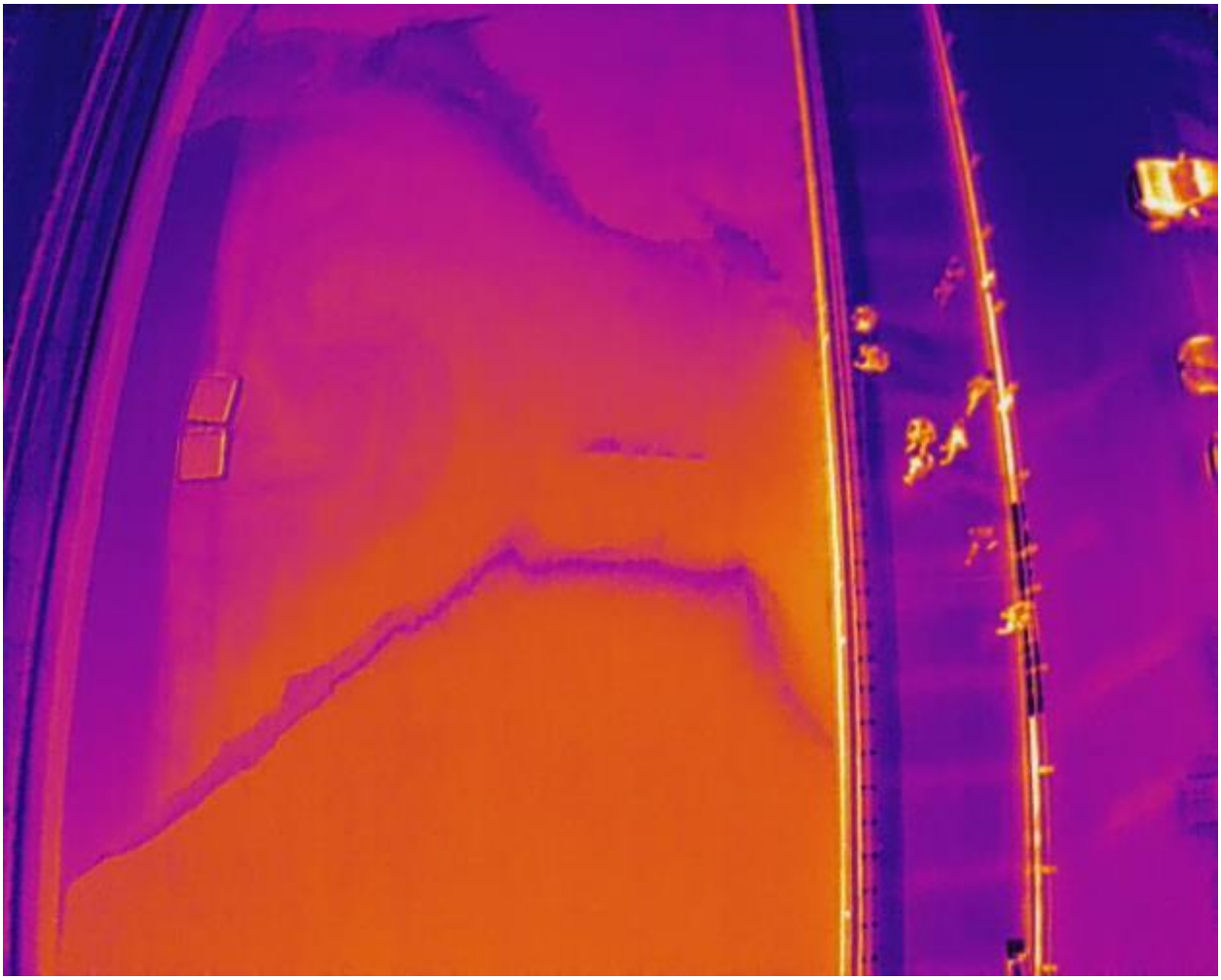
Water Mapping, LLC
1240 Greensward Dr.
Tallahassee, Florida. 32312

FLIR COLLECTED ON 2016/07/21
FLIGHT TIME: 07:14:19
VIDEO STILL: H264.00_10_21_10.Still002



Water Mapping, LLC
1240 Greensward Dr.
Tallahassee, Florida. 32312

FLIR COLLECTED ON 2016/07/21
FLIGHT TIME: 07:14:19
VIDEO STILL: H264.00_12_12_22.Still004



Water Mapping, LLC
1240 Greensward Dr.
Tallahassee, Florida. 32312

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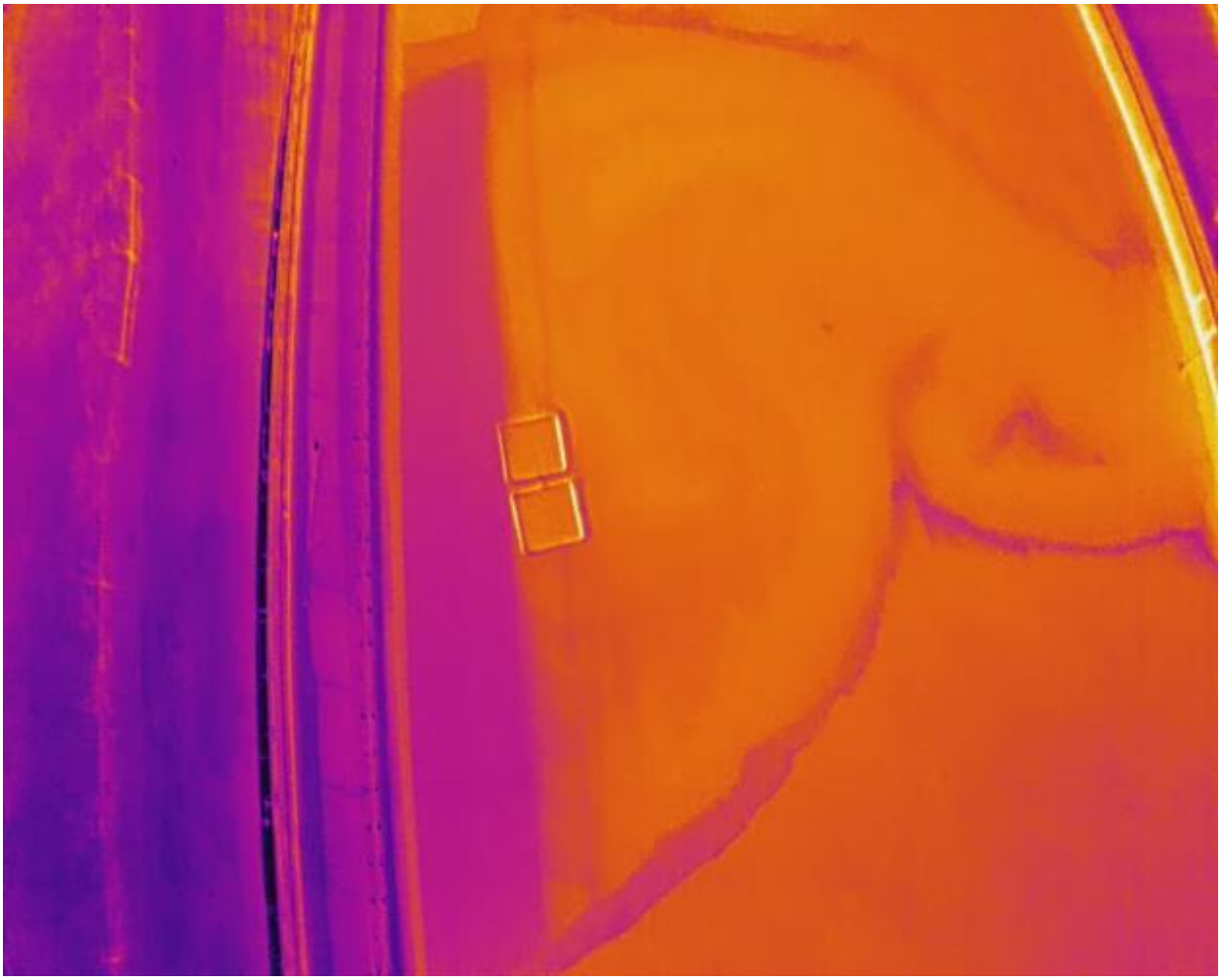

Water Mapping, LLC
1240 Greensward Dr.
Tallahassee, Florida. 32312

FLIR COLLECTED ON 2016/07/21
FLIGHT TIME: 08:13:32
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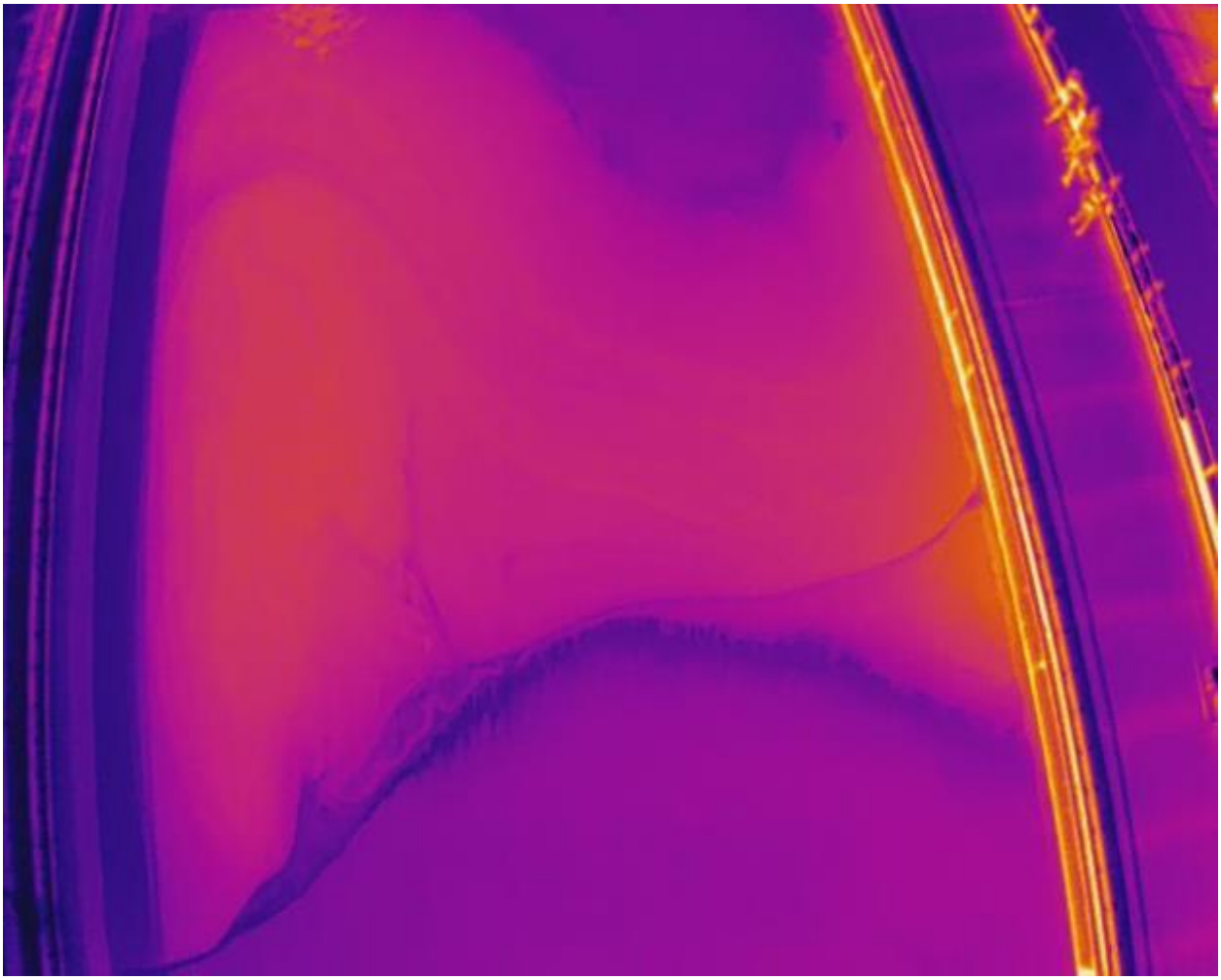

Water Mapping, LLC
1240 Greensward Dr.
Tallahassee, Florida. 32312

FLIR COLLECTED ON 2016/07/21
FLIGHT TIME: 08:13:32
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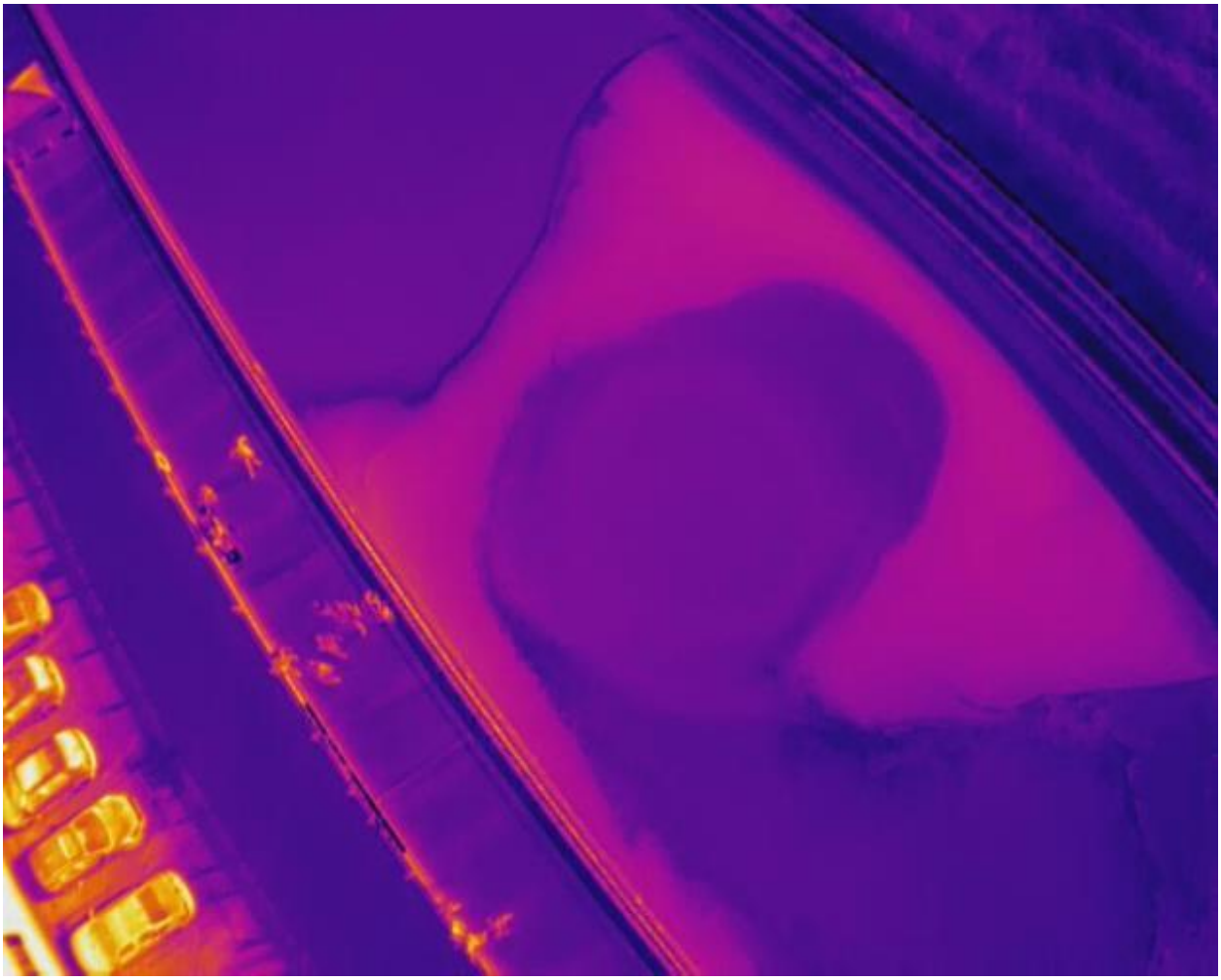
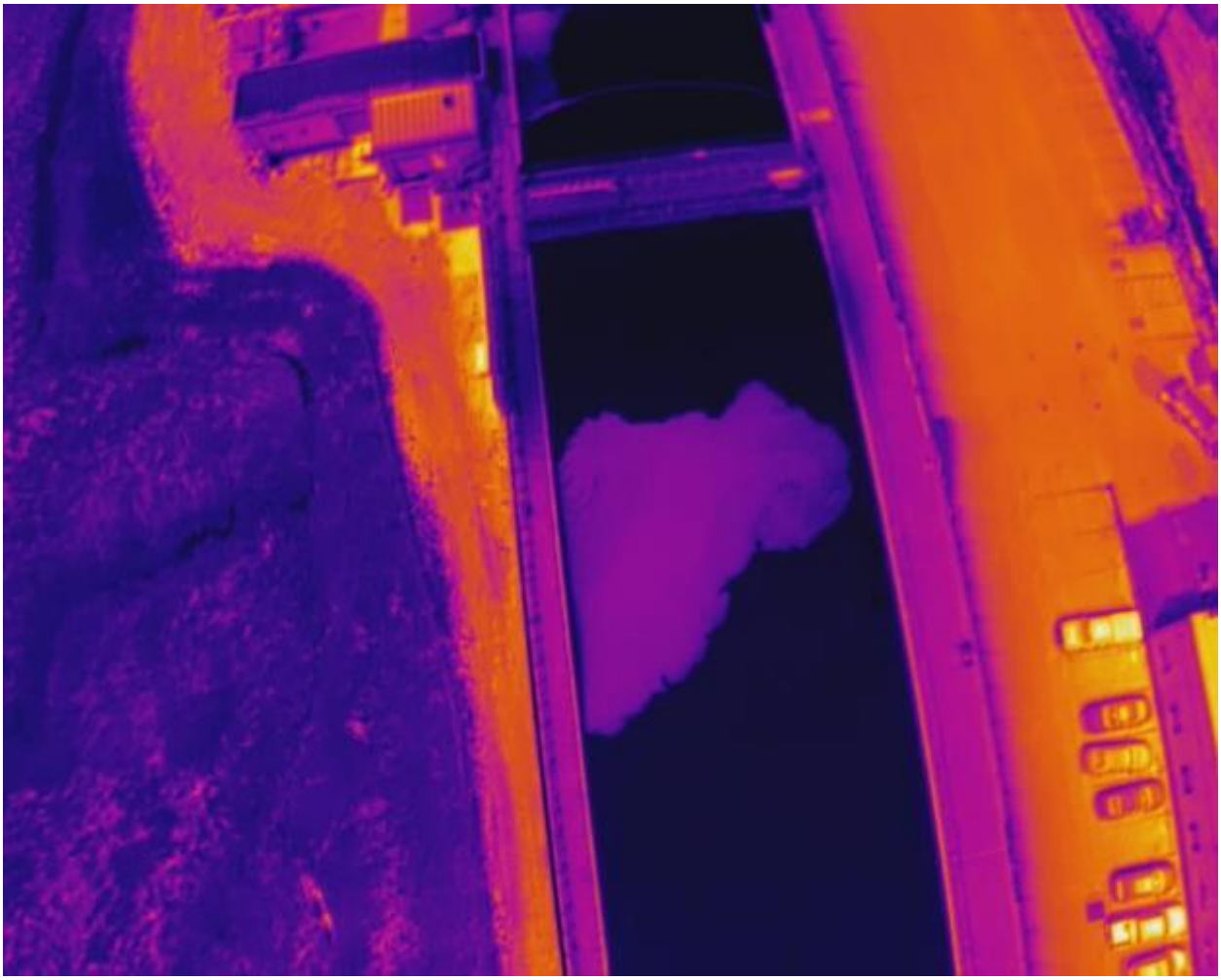


Water Mapping, LLC
1240 Greensward Dr.
Tallahassee, Florida. 32312

FLIR COLLECTED ON 2016/07/22
FLIGHT TIME: 11:59:17
VIDEO STILL: H264.00_07_03_14.Still002



Water Mapping, LLC
1240 Greensward Dr.
Tallahassee, Florida. 32312

FLIR COLLECTED ON 2016/07/22
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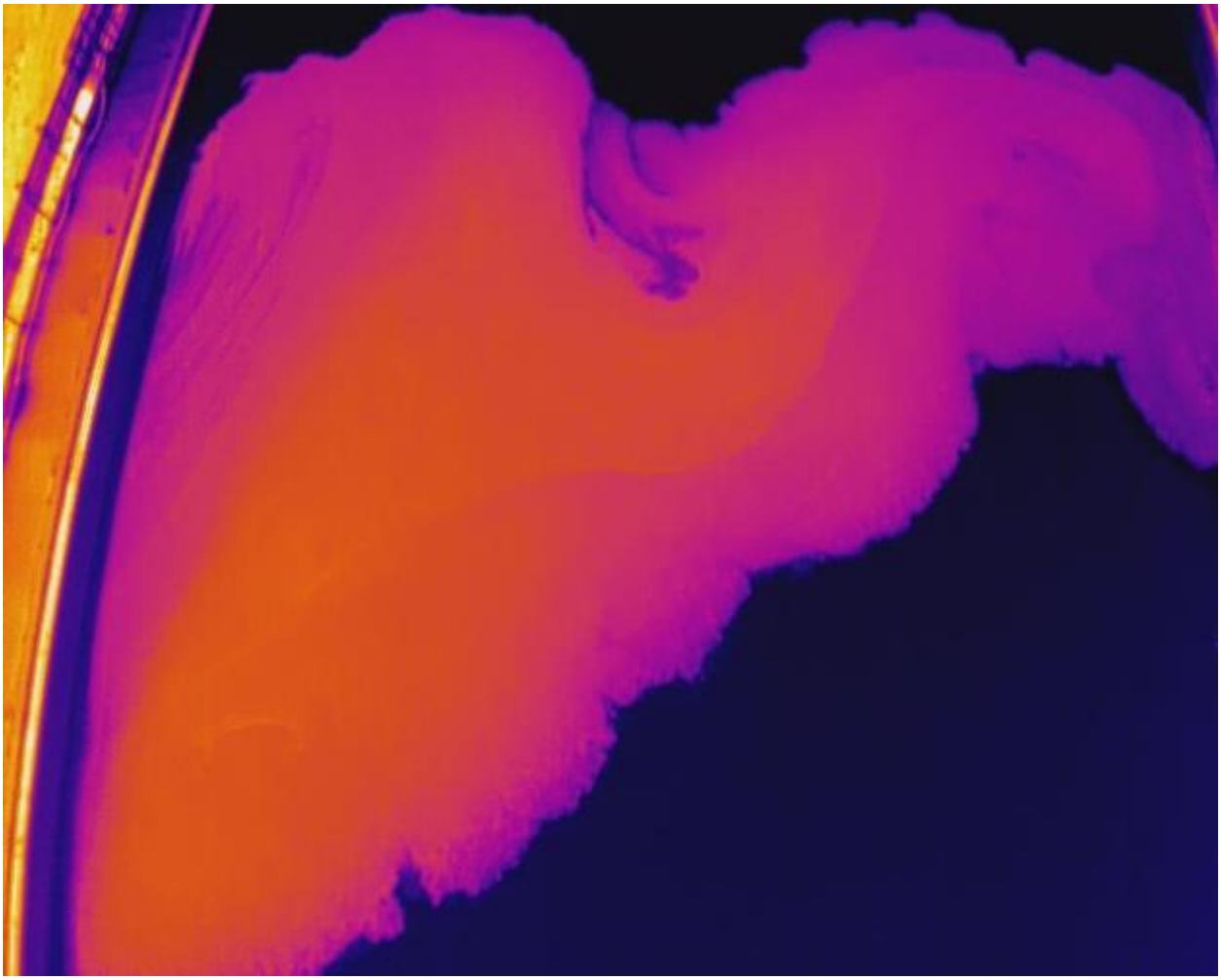

Water Mapping, LLC
1240 Greensward Dr.
Tallahassee, Florida. 32312

FLIR COLLECTED ON 2016/07/22
FLIGHT TIME: 12:40:13
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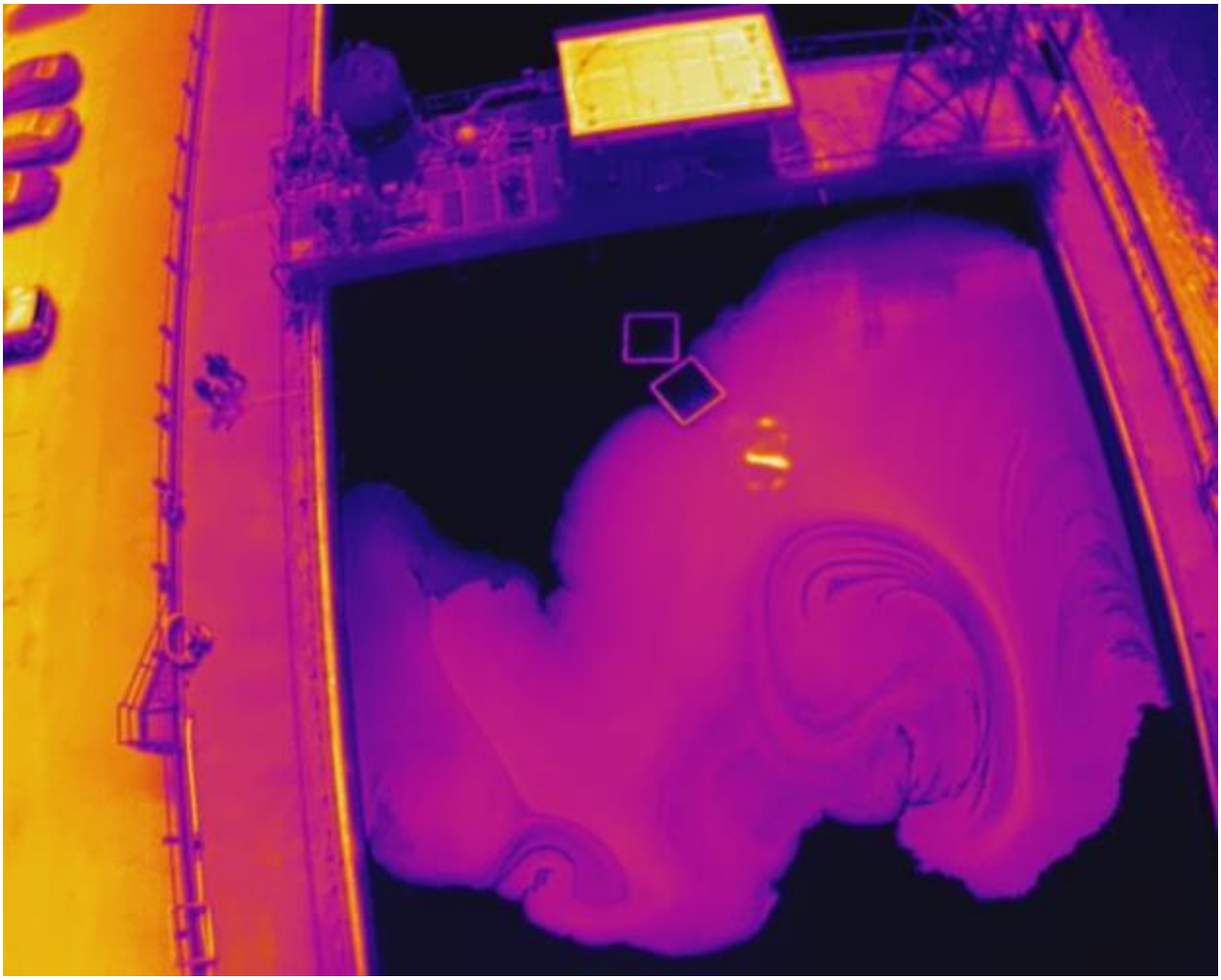
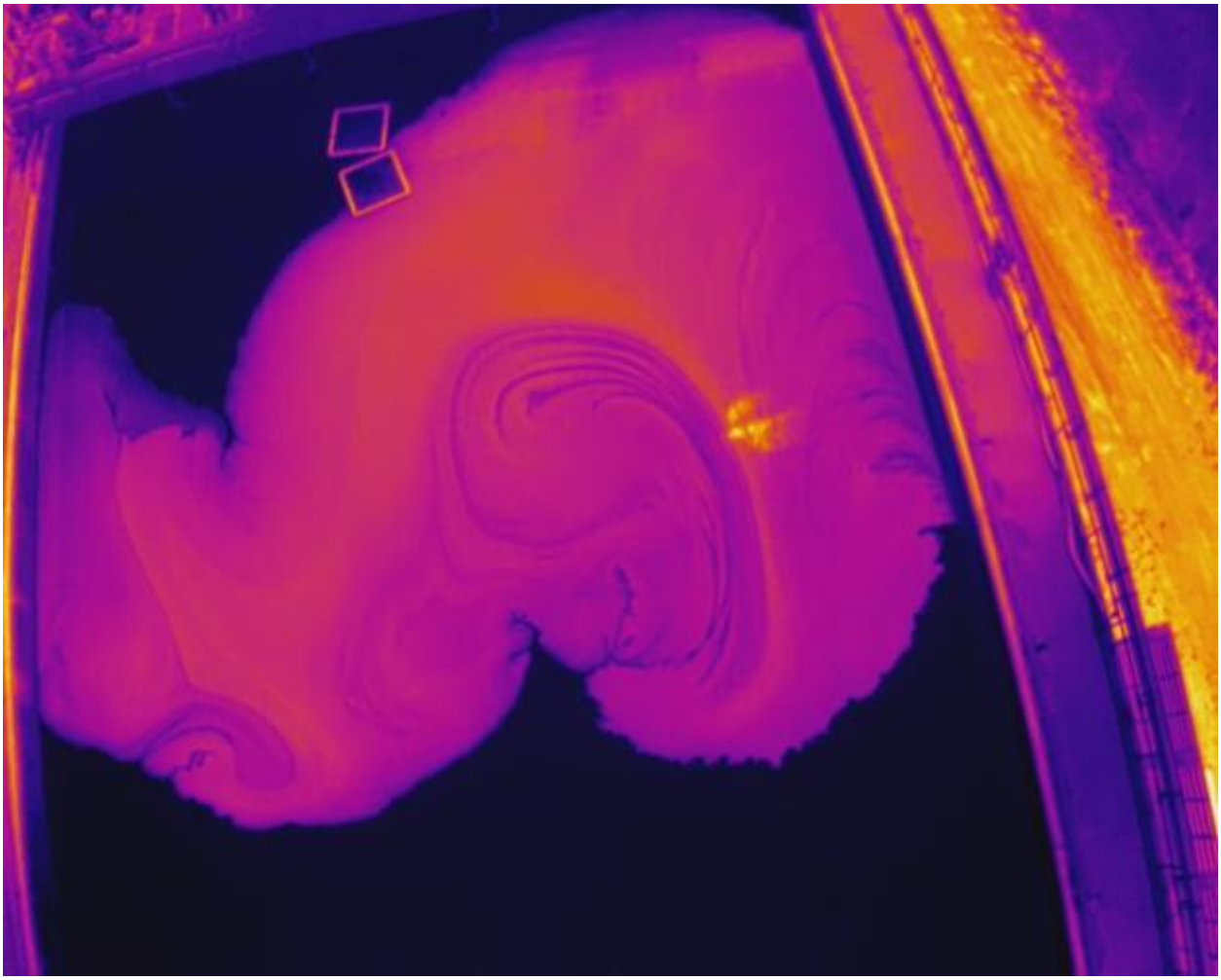


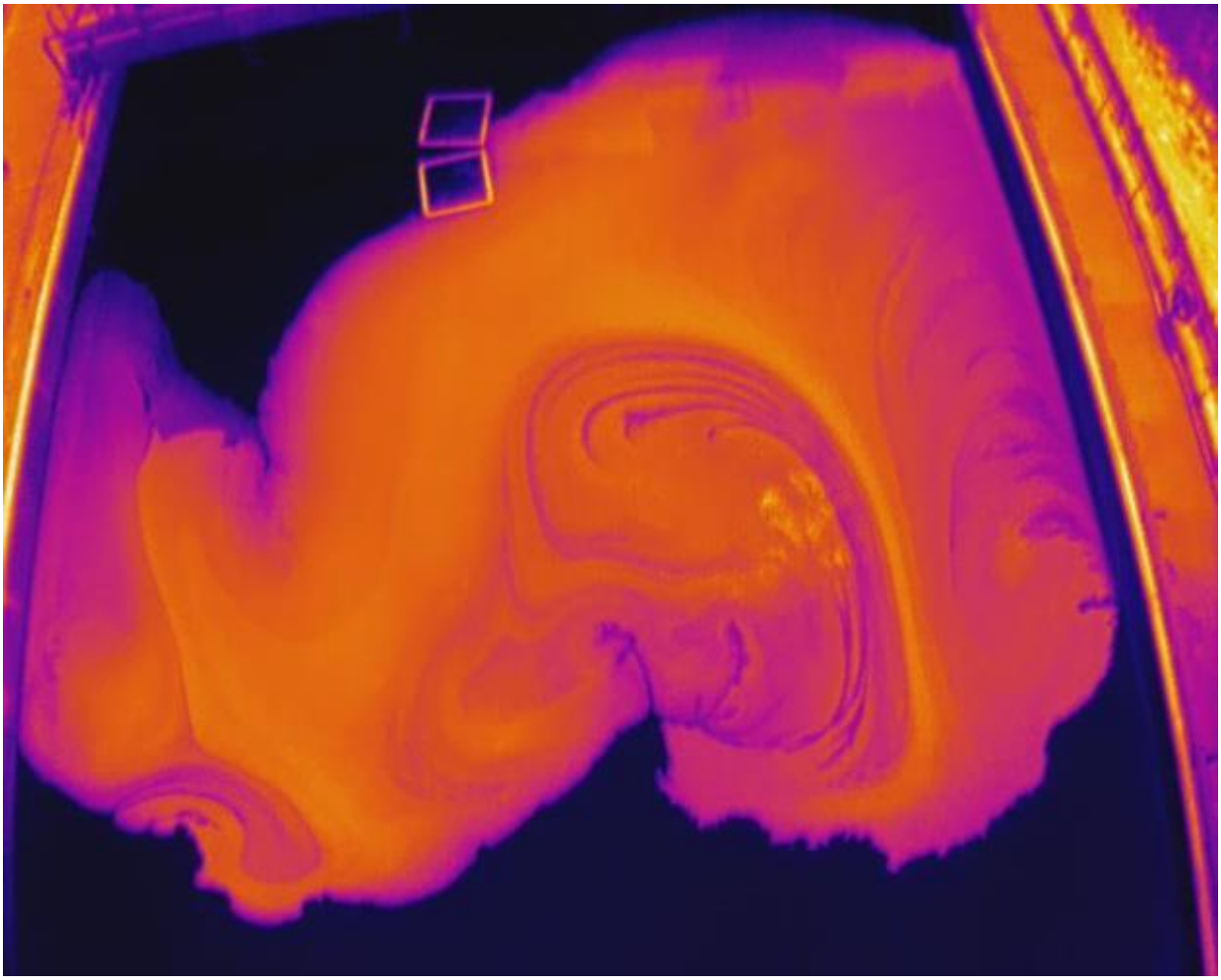
Water Mapping, LLC
1240 Greensward Dr.
Tallahassee, Florida. 32312

FLIR COLLECTED ON 2016/07/22
FLIGHT TIME: 12:40:13
VIDEO STILL: H264.00_03_07_28.Still002



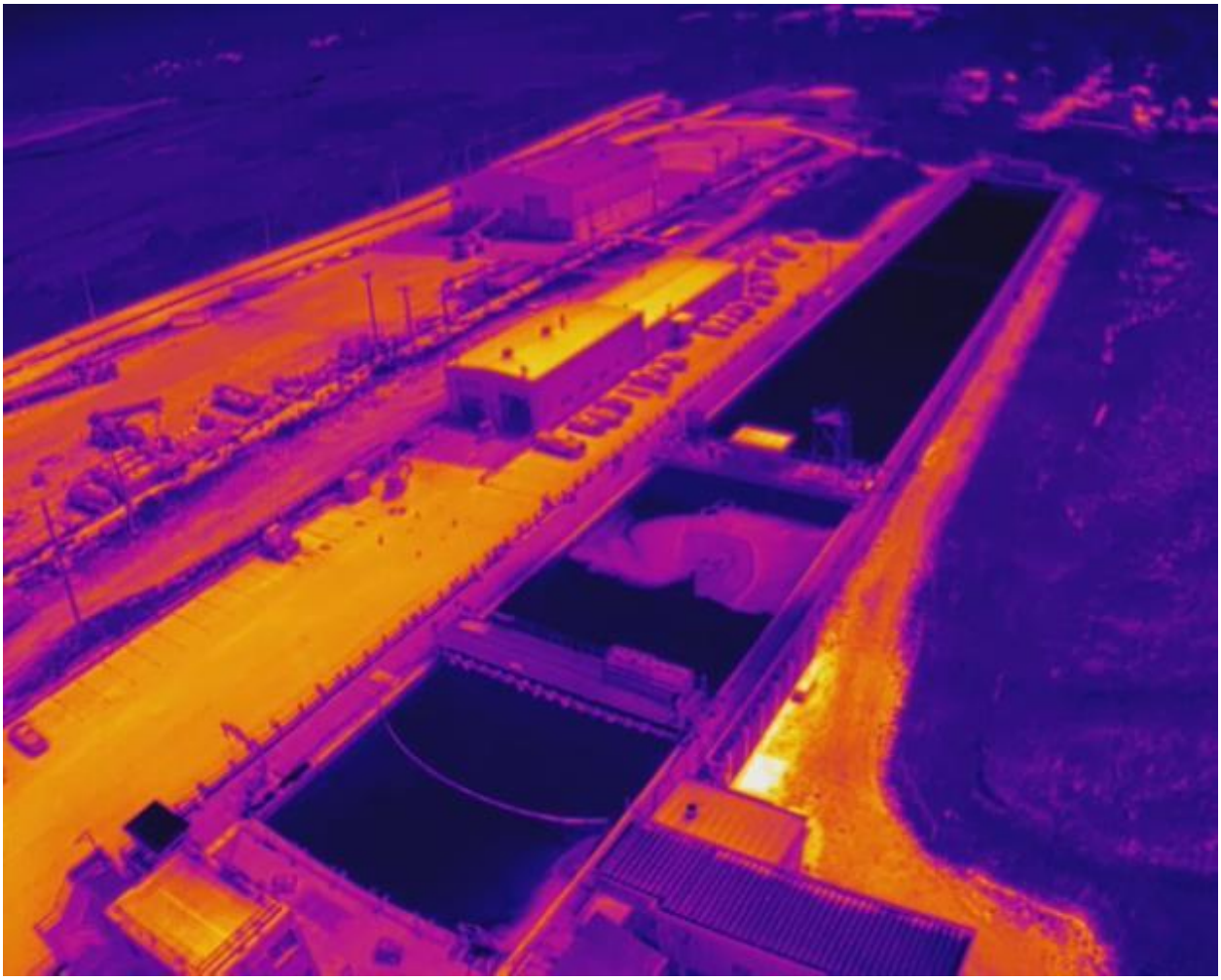
Water Mapping, LLC
1240 Greensward Dr.
Tallahassee, Florida. 32312

FLIR COLLECTED ON 2016/07/22
FLIGHT TIME: 12:40:13
VIDEO STILL: H264.00_03_34_20.Still003



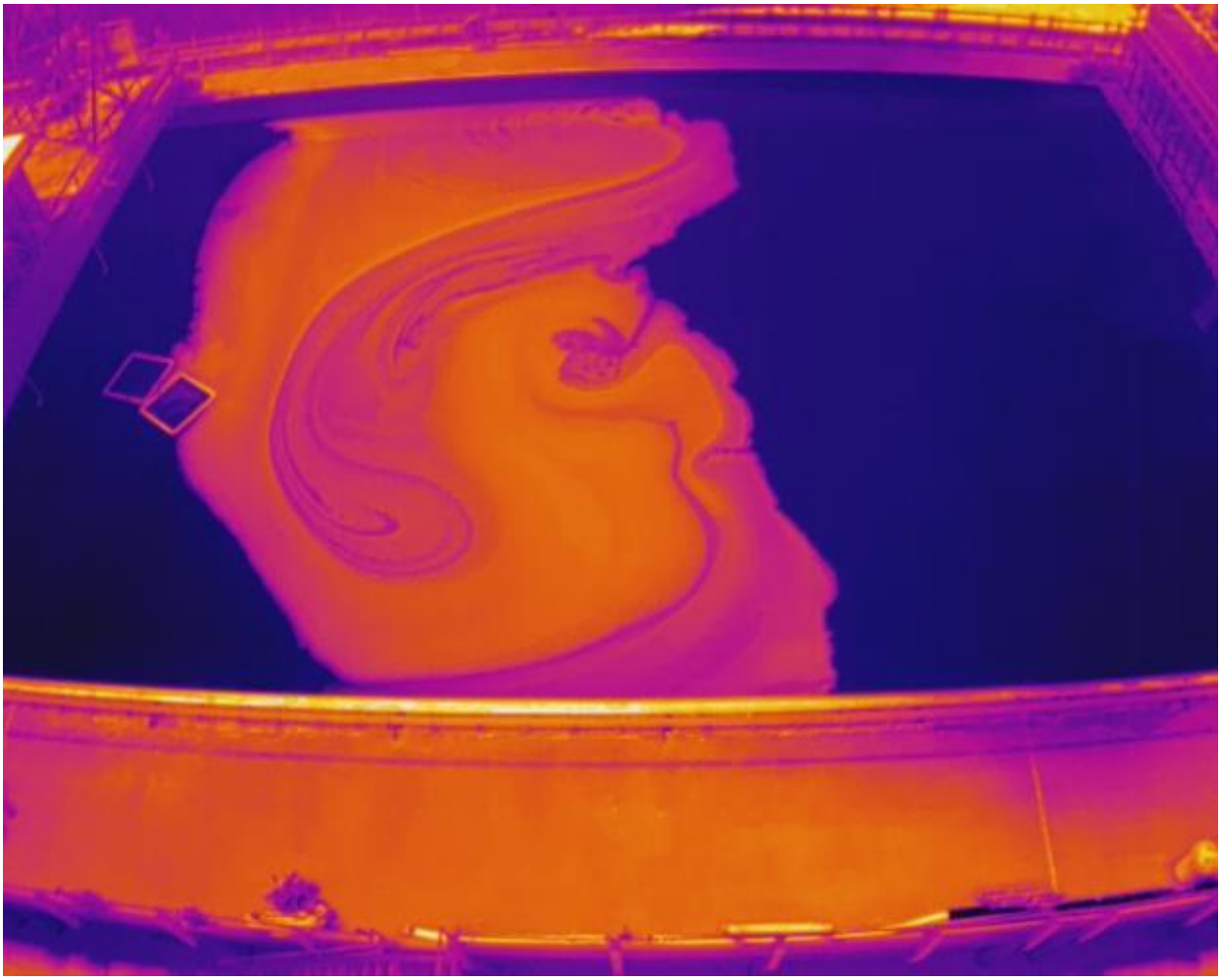
Water Mapping, LLC
1240 Greensward Dr.
Tallahassee, Florida. 32312

FLIR COLLECTED ON 2016/07/22
FLIGHT TIME: 12:40:13
VIDEO STILL: H264.00_07_02_20.Still006



Water Mapping, LLC
1240 Greensward Dr.
Tallahassee, Florida. 32312

FLIR COLLECTED ON 2016/07/22
FLIGHT TIME: 12:40:13
VIDEO STILL: H264.00_12_44_05.Still016



Water Mapping, LLC
1240 Greensward Dr.
Tallahassee, Florida. 32312

FLIR COLLECTED ON 2016/07/22
FLIGHT TIME: 18:47:25
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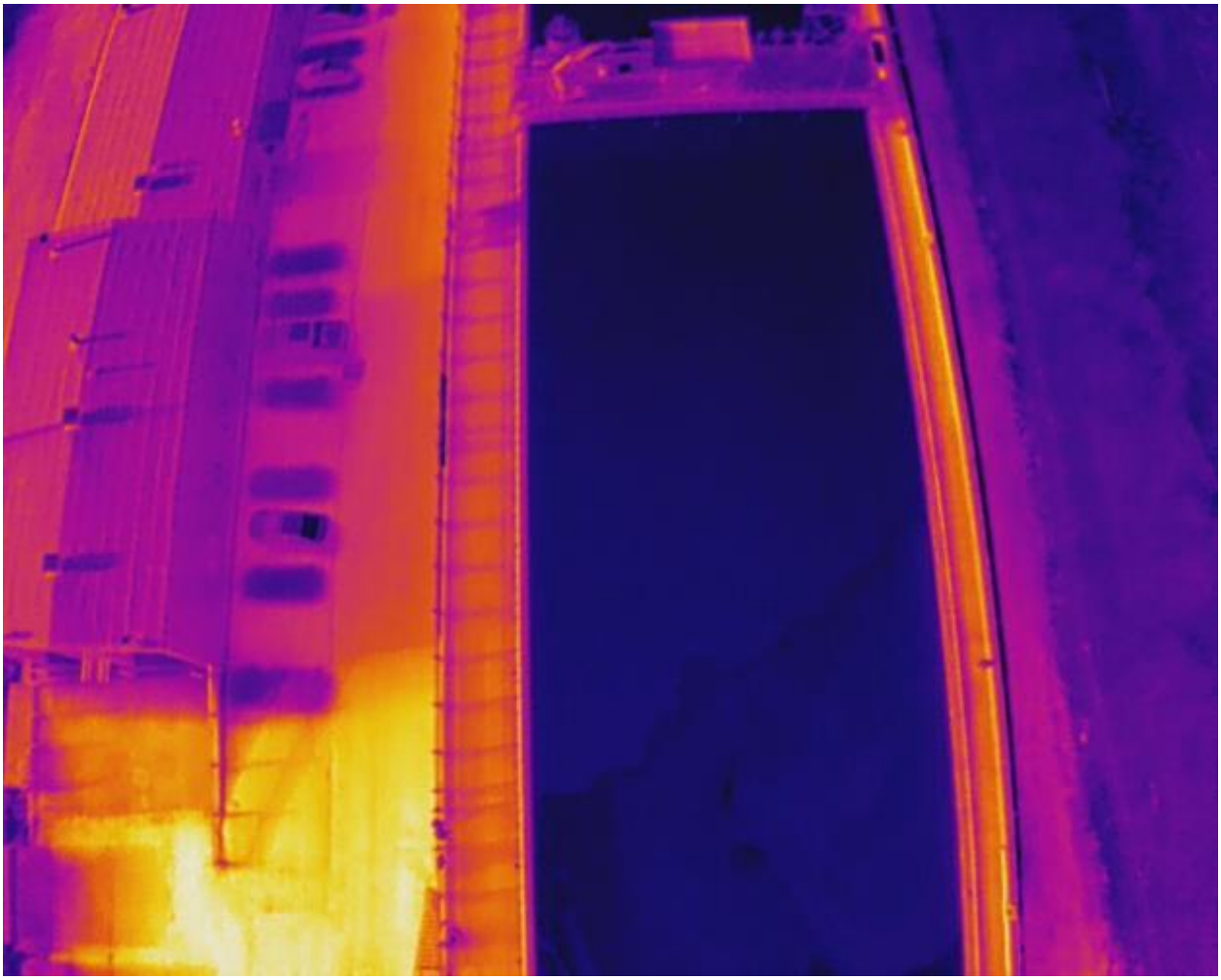

Attachment C. Ocean Imaging Ohmsett Report

Phase I Report

prepared for

Abt Associates, Inc. and National Oceanic and Atmospheric Administration

"Deepwater Horizon Lessons Learned Studies: Detection of Oil Thickness and Emulsion Mixtures Using Remote Sensing Platforms"

Deepwater Horizon Task Order #47094, Subcontract Agreement No. 47087

By

Ocean Imaging Corp.

11/23/16

"The findings and opinions expressed in this report are solely those of the authors and do not necessarily reflect the views and policies of the Bureau of Safety and Environmental Enforcement, nor does mention of the trade names or commercial products constitute endorsement or recommendation for use."

INTRODUCTION

The 2010 Deep Water Horizon (DWH) oil spill presented an unprecedented amount of remote sensing data used as part of the response effort as well as the post-spill National Resource Damage Assessment (NRDA) work. As stated in the original proposal for this project, significant progress has been realized, however, data collected and methods developed during DWH suffer from incomplete control and validation due to the operational timelines and Unified Command's (UC) requirements for operational decision making. Satellite and aerial remotely sensed data acquisition was almost exclusively performed without simultaneous in situ field data or any other form of quality/accuracy determination.

The stated goal of this project is to build upon lessons learned from DWH NRDA application of remote sensing (RS) to:

1) Evaluate remote sensing platforms and sensors for the detection and characterization of surface oil and emulsions,
2) Coordinate simultaneous in situ water and oil collection and characterization for thickness and chemistry and
3) Evaluate and compare surface oil thickness measurement methods.

These objectives all serve the overarching goal to validate and quantify the efforts put forward under the DWH NRDA Oil on Water workgroup and provide BSEE and NOAA the needed methodology and operational tools to assess future oil spills and the ability to monitor and measure more accurately the thickness of surface oil slicks in the marine environment. Phase One of this project was to characterize the detection of known oil thicknesses and oil-emulsions in a controlled environment, performing multiple tests and calibrations for thermal, optical, and microwave sensors at the National Oil Spill Response Research & Renewable Energy Test Facility (Ohmsett) which is located at the Naval Weapons Station Earle Waterfront in Leonardo, New Jersey (Graettinger, 2016).

Ocean Imaging's (OI) role is to assist in the achievement of the overall goal of providing control and validation for surface oil detection and characterization by spaceborne-, aerial- and Unmanned Aerial Vehicle (UAV)-mounted sensors as well as further the development of oil classification algorithms and methodologies necessary for future response and damage assessment. Furthermore, the study incorporates the first-time creation and use of not only large amounts of emulsified crude oil, but also "weathered" oil so that the characteristics of the oil detected by the remote sensing instruments mimic as closely as possible that of oil on the ocean's surface immediately following and several days following a real spill event. As part of the first phase of the project, OI collected aerial multispectral (MS), Thermal Infrared (TIR) imagery at multiple altitudes using their helicopter-mounted Tactical Response Airborne Classification System (TRACS) over the test tank resulting in horizontal spatial resolutions or ground sampling distances (GSD) of approximately 0.08-1.5 meters. Close-range TRACS and Ultraviolet imagery were also acquired at heights varying from just a few meters to 30.5 meters above the water's surface resulting in very focused, fine resolution UV data and TRACS data with GSDs of approximately 0.018-.028 meters.

Keeping in mind the overall objectives of Phase One, as well as the main goal of the project, the OI TRACS and UV camera data were processed and analyzed with specific intentions in mind:

1) Compare the TRACS data collected at GSDs equivalent or very close to that of the satellite sensor- and UAV-derived multispectral, hyperspectral, thermal infrared (TIR) and Synthetic Aperture Radar (SAR)

acquired as close in time to each other as was possible to determine the level of spatial detail necessary in order to generate operational oil characteristic information products at the scale of the Ohmsett tank slick.

2) Gather aerial multispectral, TIR and UV data at various spatial resolutions in an effort to characterize: oil thickness, oil-to-water ratios and the effects of environmental weathering to assess each sensors ability and limitations to effectively determine the oil's actionability as well as generate oil volume estimate maps.
3) Assess the utility of a UV camera to provide data which could help identify differentiating characteristics of emulsified oil and sheen and thus aid in the semi-automated oil-on-water classification process resulting in more accurate and timely information products depicting the actionability of the oil, along with a more accurate oil volume determination.

OHMSETT AERIAL AND TANK-LEVEL DATA COLLECTION

Installation and testing of Ocean Imaging TRACS imaging system on helicopter and Ohmsett crow's nest tower: In preparation for Ocean Imaging's (OI) Tactical Response Airborne Classification System (TRACS) data acquisitions over the Ohmsett test tank, a custom mount had to be fabricated for the Robinson R44 helicopter (R44) chartered for the tank overflights. A solid aluminum pole-mount system was engineered to hang the TRACS unit on the right side of the R44 providing an unobstructed view of the area below the helicopter ***(Figure 1)*****.** The TRACS housing was also modified and fortified to accommodate the pole mounting system. On July 6-8, 2016 M. Hess and J. Reed travelled to Princeton New Jersey to meet with personnel from Platinum Helicopters to finalize and test the new mounting hardware as well as perform pre-flight ground tests with the modified TRACS. Based on this test installation and operation, additional modifications were made to the pole mounting system to ensure the safety and stability of the TRACS unit at aircraft flight speeds of up to 80 knots.



Figure 1: Modified TRACS unit installed on R44 helicopter using side-attached, pole mounting system.

In addition to the modification of the helicopter-mounted TRACS, the Ohmsett-based TRACS also had to be altered to meet the requirements of this project. This TRACS unit was mounted on the top of the Ohmsett bridge crow's nest, a fixed platform approximately 30.5 feet above the tank's water level ***(***Figure 2***)***. A custom steel TRACS

platform was temporarily attached to the railing of the crow's nest to allow the TRACS unit to extend over the water and limit the view of the bridge in the TRACS imagery. Special software was installed on the TRACS acquisition computer which allows data collection while the bridge is moving over the oil slick at slow speed. This software also allowed the operator to create simple, real-time classifications of oil in the tank for improved decision making during the data acquisitions.



Figure 2: *TRACS installed on the Ohmsett bridge's crow's nest for near-surface level data acquisition.*

TRACS Ohmsett Data Acquisition July 17-23, 2016: Four OI personnel (M. Hess, J. Reed, J. Svejkovsky and J. White) flew into New Jersey on Sunday July 17 and began work at the Ohmsett facility on Monday July 18. Installation and testing of equipment began immediately as the first helicopter-mounted TRACS data acquisition took place that evening. *Table 1* lists the overflight dates and times as well as the data collection altitudes. Altitudes were initially chosen based on the desire to match as closely as possible the horizontal spatial resolution or ground sampling distance (GSD) of the time-coincident satellite data, primarily the synthetic aperture radar (SAR) data (Table 2). Following Monday's TRACS overflight, it was determined that the higher altitude collections resulted in data with spatial resolutions too coarse to be useful for the size of the oil slick in the tank and purposes of this project. Acquisition altitudes were subsequently lowered as the week progressed as is shown in Table 1. Ohmsett crow's nest-mounted TRACS data were also acquired on Tuesday, July 19 and Thursday, July 21. These low level TRACS acquisitions provided very high resolution TRACS imagery to fill in the vertical gap between the higher altitude platforms and ground-level sensors. Crow's nest TRACS data were not acquired on Monday, July 18 due to software malfunctions in the Ohmsett TRACS unit nor on Friday, July 22 based on the need to package the unit for shipping back to Ocean Imaging's Colorado office along with

the determination that the emulsification level and character of the oil on the tank's surface was not significantly different than the day prior. Crow's nest TRACS data collected on Tuesday and Thursday of that week were, however, acquired near simultaneously with the data acquired on the helicopter - in the case of the data collected on Thursday literally within a few seconds of the helicopter acquisition *(Figure 3)*. UAV data collections by Water Mapping, Inc. directly followed the TRACS acquisitions a few minutes later. *Figure 4* shows the RGB multispectral imagery for the four acquisition days. *Figures 5* **and** *6* show a progression of TRACS imagery at overflight altitudes ranging from 3,800 feet to 300 feet and their resulting GSDs. The TRACS image acquired from the bridge crow's nest at ~30.5 feet above the water level is also shown.

Table 1: *Helicopter- & crow's nest-mounted TRACS data acquisition dates, times & altitudes over tank 07/18 – 07/22*

Date	TRACS helicopter Data Acquisition Times	Acquisition Altitudes
Monday, 07/18/2016	6:32 PM – 6:43 PM EDT	1000, 2400 and 3800 feet
Tuesday, 07/19/2016	6:04 PM – 6:16 PM EDT	30.5, 500, 1000 and 2400 feet
Thursday, 07/21/2016	7:16 AM – 7:22 AM EDT	30.5, 300, 500 and 1000 feet
Friday, 07/22/2016	6:02 PM – 6:09 PM EDT	30.5, 300, 500 and 1000 feet



Figure 3: *Helicopter-mounted TRACS acquiring imagery over Ohmsett test tank on the morning of July 21, 2016*

Table 2: *Planned SAR and optical satellite sensors and corresponding GSDs compared to TRACS altitudes and GSDs (all GSDs listed in meters)*

Date	SAR Sensor & Corresponding GSD	TRACS Altitude & GSD
Monday, 07/18/2016	TERRASAR-X: 0.4m WorldView-3: 1.24m - 3.70m	1000 ft. (RGB: 0.25m, TIR: 0.40m) 2400 ft. (RGB: 0.58m, TIR: 0.95m) 3800 ft. (RGB: 0.95m, TIR: 1.50m)
Tuesday, 07/19/2016	RADARSAT-2: 1.0m WorldView-2: 1.84m – 2.08m	30.5 ft. (RGB: 0.018m, TIR: 0.028m) 500 ft. (RGB: 0.13m, TIR: 0.21m) 1000 ft. (RGB: 0.25m, TIR: 0.40m) 2400 ft. (RGB: 0.58m, TIR: 0.95m)
Thursday, 07/21/2016	TERRASAR-X: 0.4m WorldView-2: 1.84m – 2.08m	300 ft. (RGB: 0.08m, TIR: 0.11m) 500 ft. (RGB: 0.13m, TIR: 0.21m) 1000 ft. (RGB: 0.25m, TIR: 0.40m)
Friday, 07/22/2016	RADARSAT-2: 1.0m WorldView-3: 1.24m - 3.70m	30.5 ft. (RGB: 0.018m, TIR: 0.028m) 300 ft. (RGB: 0.08m, TIR: 0.11m) 500 ft. (RGB: 0.13m, TIR: 0.21m) 1000 ft. (RGB: 0.25m, TIR: 0.40m)

In addition to the TRACS data, experimental imagery was also collected from the tank's bridge and crow's nest using an ultraviolet (UV) camera fitted with special filters to image in the 325nm and 365nm wavelengths. The UV camera was provided at the expense of Ocean Imaging for the purpose of evaluating the operational potential of sensors imaging parts of the electromagnetic spectrum presently not included on most existing aerial systems, particularly for characterizing the oil/water composition of floating emulsions, improving the detection of thin oil sheens and to better understand the ability of UV sensors to detect the fluorescence of emulsified crude oil verses its reflectance. As stated above, this added capability to a multi-sensor system could aid in the semi-automated oil-on-water classification process resulting in more accurate and timely information products depicting the actionability of the oil, along with a more accurate oil volume determination.

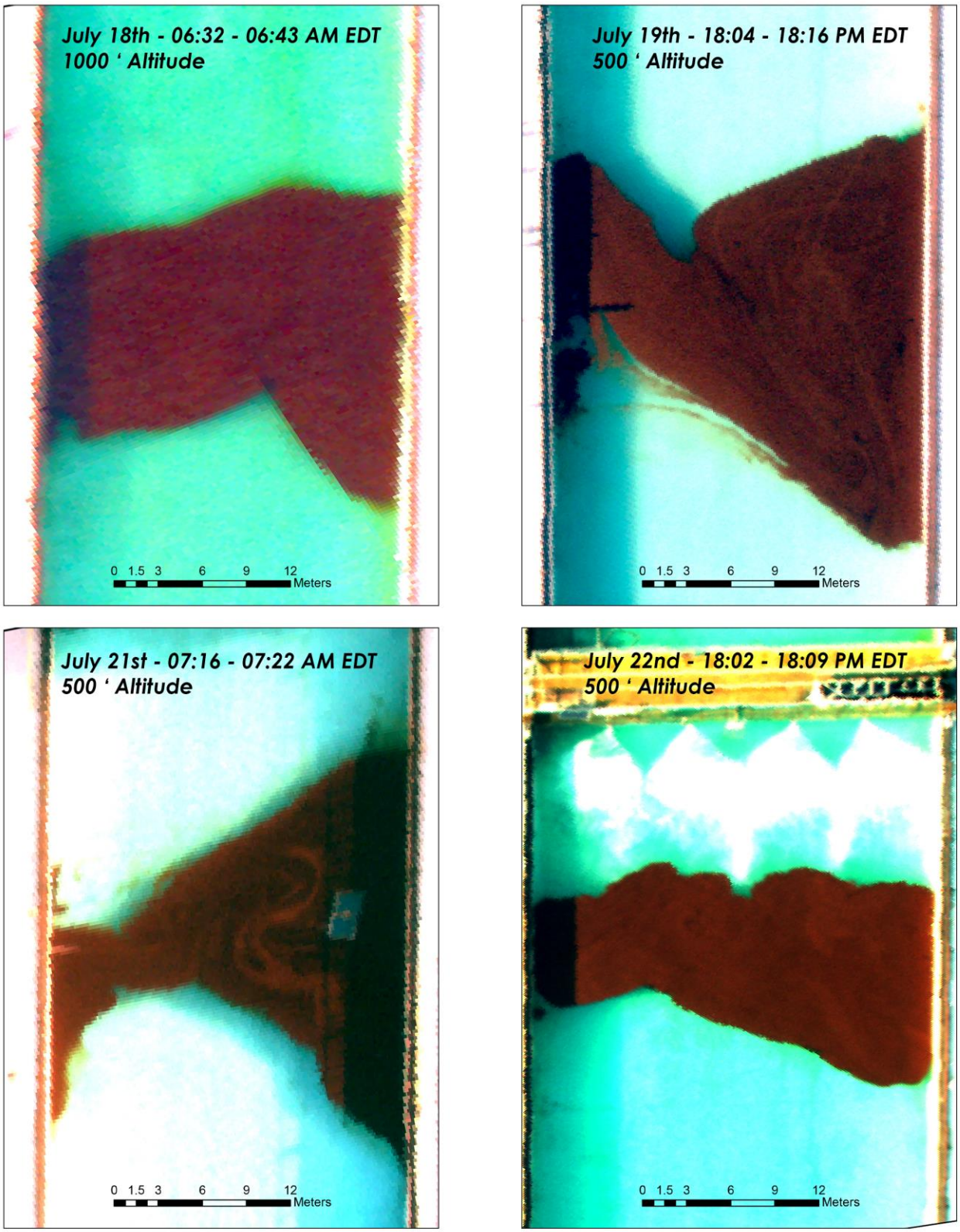

Figure 4: *The oil slick in the Ohmsett tank as imaged by the TRACS multispectral camera at altitudes of 1,000 feet* (07/18/16) and 500 feet (07/19/16, 07/21/16 and 07/22/16).

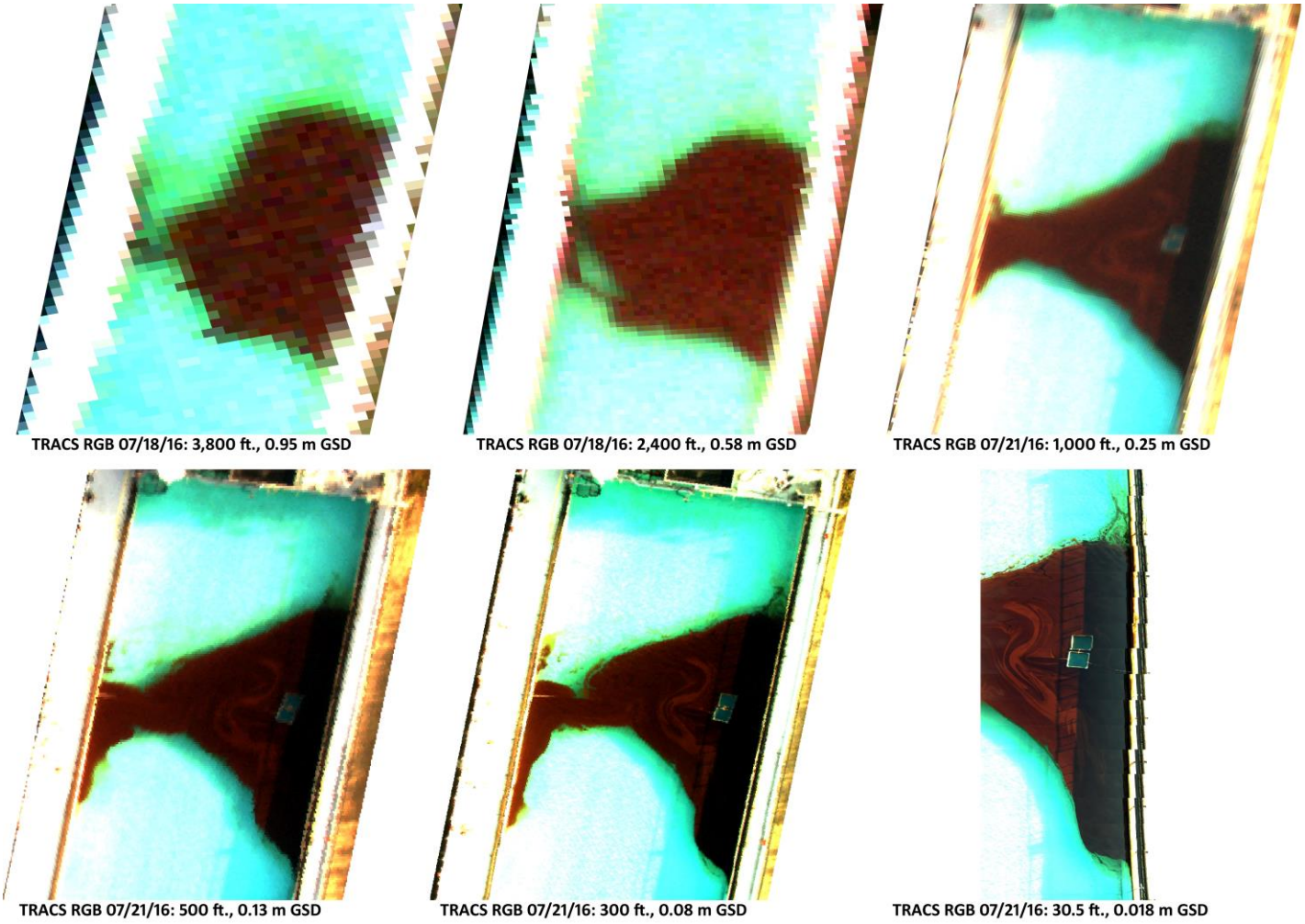

Figure 5: *TRACS RGB imagery examples at the various acquisition altitudes flown and the corresponding GSDs. Following the first tank overflight on 07/18/16, it was decided that the spatial resolutions (GSDs) resulting from flying at 2,400 ft. or higher were too coarse for any effective analysis of an oil slick of the scale provided at the Ohmsett tank. Subsequently, lower altitudes were flown on 07/19/16 – 07/22/16 to provide more detailed data. The 30.5 ft. imagery was acquired using the crow's nest-mounted TRACS unit on the tank's movable bridge and so only shows the eastern 2/3rds of the tank/oil. The two gray-blue squares near the east (right) side of the tank in the 07/21/16 imagery are PVC squares devoid of emulsified oil.*

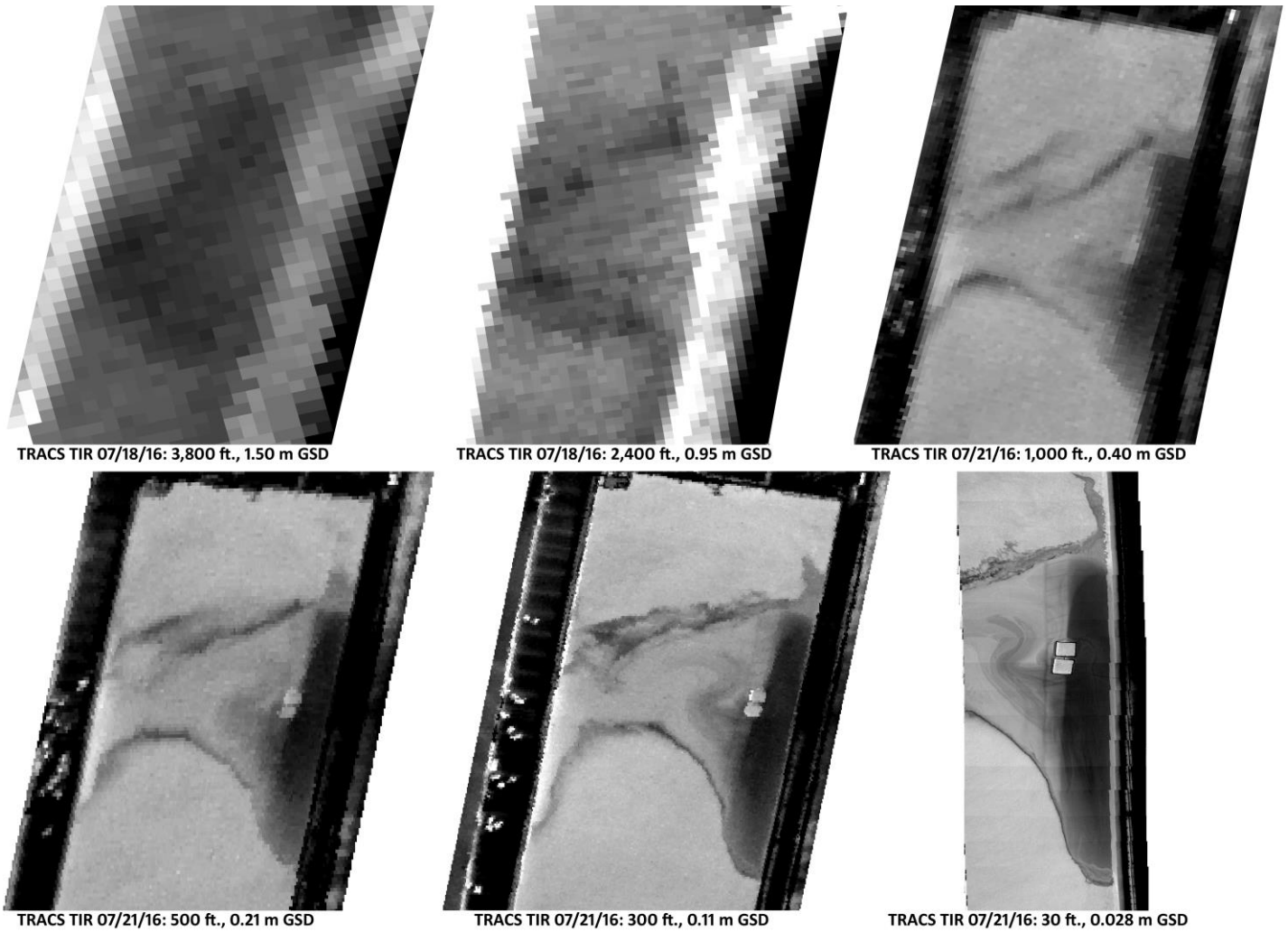

Figure 6: *TRACS TIR imagery examples at the various acquisition altitudes flown and the corresponding GSDs. Following the first tank overflight on 07/18/16, it was decided that the spatial resolutions (GSDs) resulting from flying at 2,400 ft. or higher were too coarse for any effective analysis of an oil slick of the scale provided at the Ohmsett tank. Subsequently, lower altitudes were flown on 07/19/16 – 07/22/16 to provide more detailed data. The 30.5 ft. imagery was acquired using the crow's nest-mounted TRACS unit on the tank's movable bridge and so only shows the eastern 2/3rds of the tank/oil. The two gray-blue squares near the east (right) side of the tank in the 07/21/16 imagery are PVC squares devoid of emulsified oil. In these images the cooler temperatures are the darker shades and the warmer temperatures are lighter. The temperature range of the water and oil in the tank as measured by the TRACS TIR sensor on 07/18/16 was 25.75 °C – 27.75°C and from 22.75°C – 26.5°C on 07/21/16. Dark (cool) areas near the east side of the tank are the result of water/oil cooling due to shadows cast from the tank wall and railing.*

Processing of TRACS and UV Data Acquired at Ohmsett Facility: Following the week at the Ohmsett facility OI staff began immediately offloading the acquired TRACS and UV data onto OI's network attached storage (NAS) drives for cataloging and preprocessing. The TRACS data were converted from their native format to GeoTIFF format for compatibility with ESRI's ArcGIS software and other GIS applications. Select scenes were then projected to a geographic WGS-1984 coordinate system and georeferenced to an ESRI base layer. Available photographs from the various cameras operating during the Ohmsett test were also downloaded and catalogued for later use as comparison information to the TRACS, and UV data, as well as the UAV and satellite data.

Tank-level In Situ Data: In situ data from the tank sampling which occurred throughout the week were obtained from project partners including NOAA, Abt Associates, Water Mapping, Inc, Ohmsett personnel and Dr. Gregg Swayze of the USGS. From these data various oil thickness, water:oil ratio, tank water temperature, oil and water spectroscopy along with other oil characteristics and corresponding photographs if available were extracted for the dates and times of the TRACS overflights as well as the bridge-level UV imaging work. Locations along the tank's edges and on the bridge where estimated for all the oil thickness, spectra and bulk oil samples based on the general site IDs provided, sampling time information and any time-stamped photography available which showed the in situ sampling in progress. Photographs were used to both corroborate and refine the sampling locations as they related to the TRACS data acquired on the same day. The photographs used for visual comparison of the oil to the UV imagery were all nearly time-synchronous to the UV data collection.

Using the ArcGIS software, in situ oil thickness samples, which were within approximately two hours of the TRACS overflight times, were plotted (as best as could be determined) over the corresponding TRACS imagery and used to aid in the oil classification process discussed below. *Table 3* lists the TRACS overflight times and the available in situ data used in OI's analyses and generation of the oil classification products. Note that the "slick descriptions" are non-standardized, subjective interpretations and do not follow any particular scale or terminology. Also, in all cases, the water:oil ratio numbers are more representative of the entire oil slick as opposed to a specific location along the tank or within the slick (Swayze, Guarino, personal communication October 26, 2016). It also should be noted that several of the in situ samples were replicates taken at the same location within minutes of each other, so for the purposes of this exercise were averaged to a single thickness value. The in situ samples on July 19 were taken in the shadow of the side of the tank and so were only loosely used when generating the final oil classes.

Table 3: *TRACS data acquisition times and the available in situ data available within two hours the aerial data collections. *In the case of the spectrally-derived percent water data, since samples on 07/19 and 07/22 were not within two hours of TRACS data collection, the sample taken closest to the overflight time was used. The percent water data were also not sampled at a specific point within oil slick, but meant to represent the water:oil ratio of the entire slick and thus do not correlate to a particular site ID.*

Date	TRACS Acq. Time (EDT)	Site ID	Sample Time (EDT)*	Sample Method	Slick Description	Thickness (um)	% Water in Oil Emulsion
07/18/16	18:32 - 18:43		14:52	bulk oil/lab	no description		79

07/18/16	18:32 - 18:43	6	18:51	dip plate	no description	398.69	
07/19/16	18:04 - 18:16		15:00	spectra	no description		70
07/19/16	18:04 - 18:16	22	17:52	dip plate	thick emulsion	574.83	
07/19/16	18:04 - 18:16	22	17:55	dip plate	thick emulsion	665.18	
07/19/16	18:04 - 18:16	22	18:40	dip plate	thick emulsion	374.80	
07/19/16	18:04 - 18:16	22	18:41	dip plate	thick emulsion	508.39	
07/19/16	18:04 - 18:16	7	18:42	dip plate	light emulsion	33.01	
07/19/16	18:04 - 18:16	7	18:49	sorb pad	thin emulsion	27.26	
07/19/16	18:04 - 18:16		19:00	bulk oil/lab	no description		82
07/21/16	7:16 - 7:22		7:00	spectra	no description		60
07/21/16	7:16 - 7:22	12	7:24	dip plate	thin emulsion	66.62	
07/21/16	7:16 - 7:22	12	7:25	dip plate	thin emulsion	70.70	
07/21/16	7:16 - 7:22	12	7:25	dip plate	thin emulsion	86.85	
07/21/16	7:16 - 7:22	23	7:28	dip plate	thick emulsion	1055.23	
07/21/16	7:16 - 7:22	23	7:29	dip plate	thick emulsion	1407.72	
07/21/16	7:16 - 7:22	23	7:31	dip plate	thick emulsion	1003.53	
07/21/16	7:16 - 7:22		8:00	bulk oil/lab	no description		74
07/21/16	7:16 - 7:22	13	8:31	dip plate	thick emulsion	898.29	
07/21/16	7:16 - 7:22	13	8:35	oil trap sampler	very thick	681.00	
07/21/16	7:16 - 7:22	13	8:35	dip plate	thick emulsion	912.39	
07/21/16	7:16 - 7:22	13	8:37	dip plate	thick emulsion	862.33	
07/21/16	7:16 - 7:22	14	8:46	dip plate	thin emulsion	30.24	

07/21/16	7:16 - 7:22	14	8:46	dip plate	thin emulsion	105.03	
07/21/16	7:16 - 7:22	14	8:46	dip plate	thin emulsion	36.78	
07/21/16	7:16 - 7:22	14	8:46	dip plate	thin emulsion	48.23	
07/21/16	7:16 - 7:22	14	8:46	sorb pad	no description	531.49	
07/21/16	7:16 - 7:22	14	8:46	sorb pad	no description	169.62	
07/21/16	7:16 - 7:22	14	8:46	oil trap sampler	very thick	322.00	
07/22/16	18:02 - 18:09		14:30	spectra	no description		80
07/22/16	18:02 - 18:09	52	15:20	oil trap sampler	very thick	25000.00	

DATA ANALYSIS

TRACS Ground Sampling Distance: As is noted above, the altitude of the TRACS overflights was lowered progressively throughout the study week due to the determination that any data flown at an altitude higher than 1,000 feet resulting in a spatial resolution or GSD of 0.4 meters or more was too coarse for the size of slick created in the Ohmsett tank. As can be seen if Figures 5 and 6 above, significant detail and information is lost, especially in the TIR data, if acquired at GSDs larger than 0.4 meters. This is most apparent in the centers and edges of the slicks imaged on July 18 and 19. The ability to distinguish variability within the core of the slicks using the multispectral data as well as to identify the thinner oil classes on the edges of the slicks using both the TIR and multispectral data diminishes quickly with increasing GSD. Even when using the data acquired at 1,000 feet (RGB GSD 0.25 m, TIR GSD 0.40 m), proven classification methods and algorithms could not effectively isolate as many distinct oil classes as was possible using the data acquired at the lower altitudes. While the size of this slick was obviously restricted to the limitations of the tank area and somewhat unrealistic in relation to an actual marine oil spill, this observation is pertinent in regards to how the scale of the spill and the desired level of detail in the oil volume or characteristic map will dictate the required GSD and hence the platform and sensor necessary to fulfill the needed information requirements.

TRACS – Satellite Data Comparison: The satellite data which were acquired during this phase of the project were primarily Digital Globe's WorldView-2, WorldView-3, RadarSat-2 and TerraSAR-X as listed in *Table 2* above, however the actual satellite data delivered on TRACS overflight days varied somewhat from the original plan. *Table 4* shows the satellite data acquired on TRACS collection days along with their acquisition times and resulting GSD of the data received.

Table 4: *Actual delivered SAR and optical satellite data and the acquisition times and GSDs compared to the TRACS data acquired on the same day*

Date	SAR Sensor, Acq. Time (EDT) & GSD	TRACS Acq. Time (EDT)	TRACS Altitude & GSD
Monday 07/18/2016	TERRASAR-X: 18:43:30, ~0.64 m	18:32 – 18:43	1000 ft. (RGB: 0.25m, TIR: 0.40m) 2400 ft. (RGB: 0.58m, TIR: 0.95m) 3800 ft. (RGB: 0.95m, TIR: 1.50m)
Tuesday 07/19/2016	RADARSAT-2: 18:41:00, ~ 1.0 m WorldView-2: 11:53:00, ~0.47 m pan-sharpened RGB	18:04 – 18:16	30.5 ft. (RGB: 0.018m, TIR: 0.028m) 500 ft. (RGB: 0.13m, TIR: 0.21m) 1000 ft. (RGB: 0.25m, TIR: 0.40m) 2400 ft. (RGB: 0.58m, TIR: 0.95m)
Thursday 07/21/2016	TERRASAR-X: 07:13:59, ~0.78 m	07:16 – 07:22	300 ft. (RGB: 0.08m, TIR: 0.11m) 500 ft. (RGB: 0.13m, TIR: 0.21m) 1000 ft. (RGB: 0.25m, TIR: 0.40m)
Friday 07/22/2016	RADARSAT-2: 18:53:27, ~0.67 m x 0.51 m WorldView-3: 12:01:00, ~0.33 m pan-sharpened RGB	18:02 – 18:09	30.5 ft. (RGB: 0.018m, TIR: 0.028m) 300 ft. (RGB: 0.08m, TIR: 0.11m) 500 ft. (RGB: 0.13m, TIR: 0.21m) 1000 ft. (RGB: 0.25m, TIR: 0.40m)

Unfortunately, since to-date, only the 3-banded (RGB), pan-sharpened (as opposed to the full multispectral) WorldView data have been made available to OI and the fact that both WorldView-2 and WorldView-3 datasets were either of poor quality due to sun glint and/or too far in time from the TRACS overflights, OI was unable to perform any comparison analyses between the optical satellite data and the TRACS data. Not having the full eight bands of WorldView-2 data and full 16 bands of WorldView-3 data at the native resolution of the sensors prohibits any true multispectral analysis and hence oil characteristic classification generation. *Figure 7 and Figure 8* show the WorldView imagery along with the TRACS imagery for general comparison; the glint bands along wave crests were caused by the wave generator's being active during the satellite overpass.

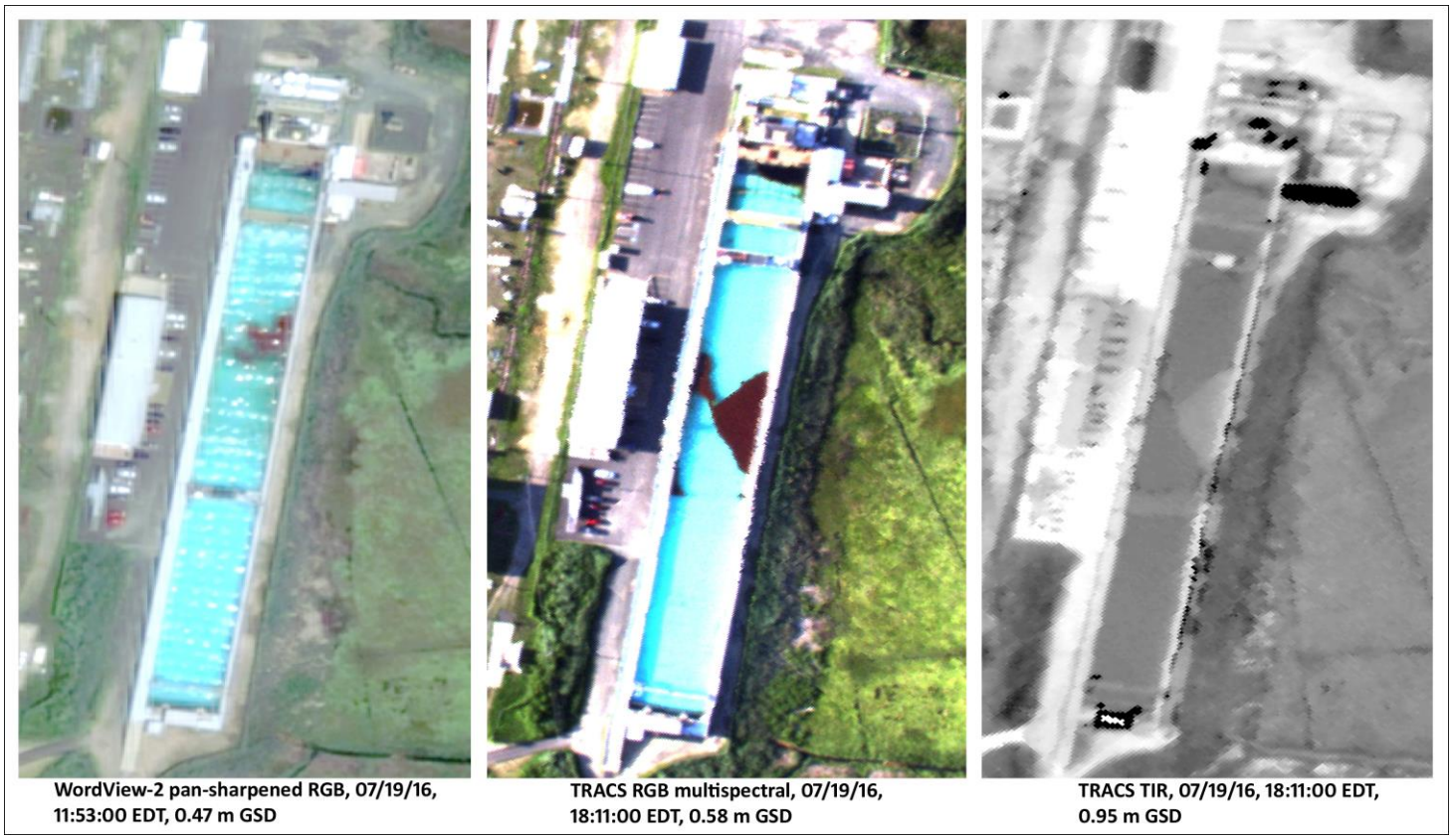

Figure 7: *WorldView-2 pan-sharpened RGB imagery compared to TRACS RGB multispectral imagery acquired approximately six hours apart. The TRACS data shown were flown at an altitude of 2,400 feet to match the GSD of the WorldView imagery as closely as possible (0.47 m WV vs. 0.58m/0.95m TRACS). Note the coarse spatial resolution of all three datasets in comparison to the size of the oil target. Also, note the significant sun glint contamination in the WorldView-2 imagery: the glint bands along wave crests were caused by the wave generator's being active during the satellite overpass.*

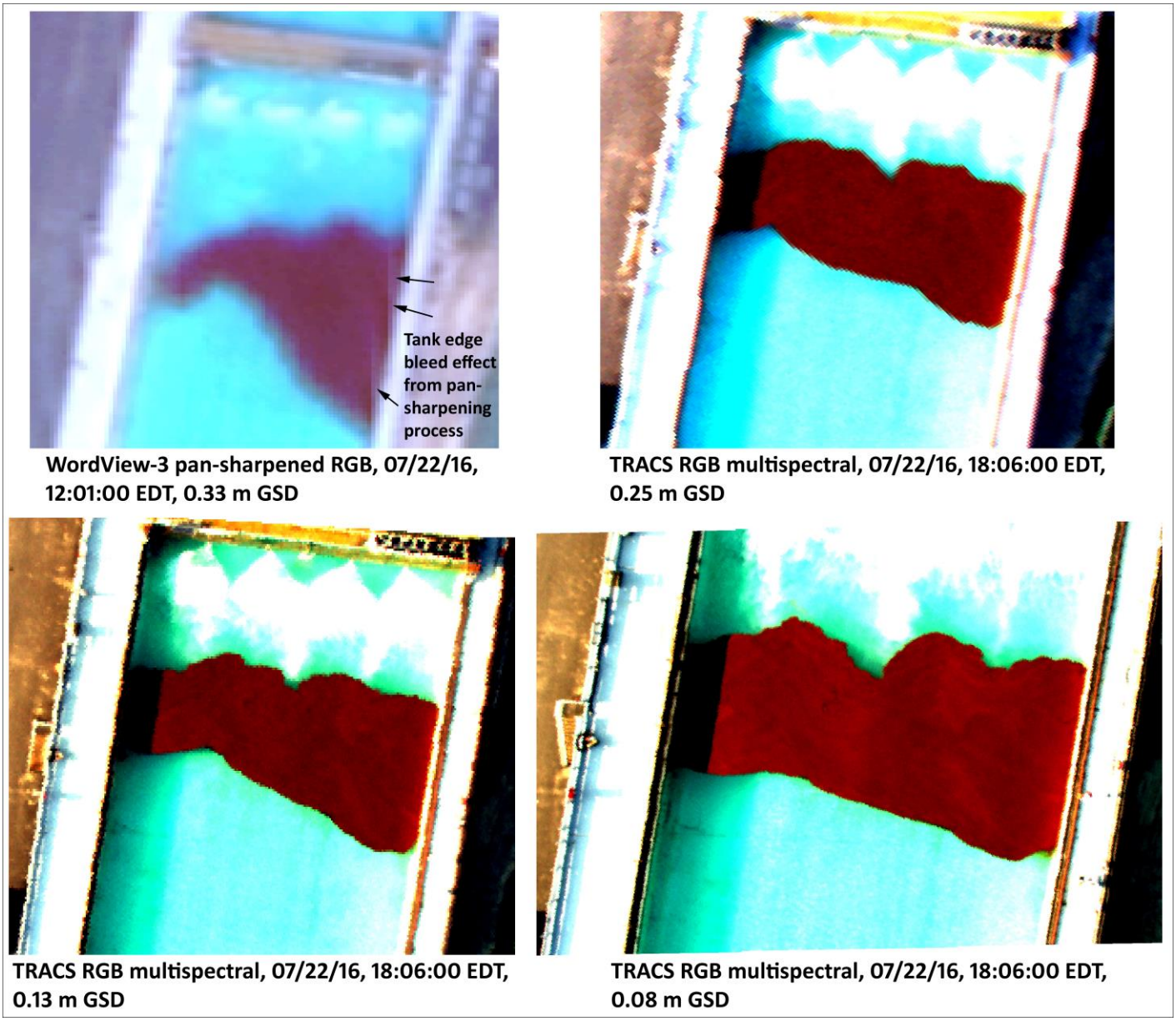

Figure 8: *WorldView-3 pan-sharpened RGB imagery compared to TRACS RGB multispectral imagery acquired approximately six hours apart. Note the white 'bleeding' effect of the tank's east wall into the oil part of the imagery as well as the coarse, blended transition on the oil slick's outer edges due to the pan-sharpening process.*

After initial visual assessment was performed on the SAR data from July 18, 19, 21 and 22, it was determined that a useful analytical comparison between the TRACS data and the SAR imagery was also not possible due to the SAR's poor spatial resolution, excessive background noise, and significant smoothing/interpolation along with the inability to confidently discriminate between oil and non-oil pixels within the SAR data. *Figure 9* shows the July 18 TerraSAR-X imagery in comparison the TRACS RGB and TIR data. Even after stretching the SAR data histogram to its full extent, the poor spatial resolution and lack of signal information in the tank area (DNs=0) made it impossible to analyze the TerraSAR-X scene. *Figure 10* shows possibly the best SAR data from July 21, however,

given the significant heterogeneity of pixel values within the tank region, the actual area and shape of the oil emulsion feature in the tank cannot be objectively determined. Working "backwards", i.e. knowing the actual oil feature location from the near-time-coincident TRACS imagery, some speculation could be made about potentially higher backscatter returns over that portion of the tank in the SAR data. The same SAR digital number values were also randomly distributed throughout the tank's entire area, however, making objective identification of the oil area using SAR data alone impossible. Any raster image classification algorithm whether unsupervised or supervised would therefore be unable to separate the data into distinct clusters, let alone classes unless only those pixels determined to be oil by use of another data type were used in the classification process. This fact by itself leads to the determination that an analytical comparison between the two data types would be more of a forced exercise and ultimately prove ineffectual in the context of this study. This is not to conclude that SAR data are not suitable for the characterization of oil into type and/or thickness classes, but merely that in this situation the data that were collected were unsuitable for analysis of oil at the scale and conditions which existed at the Ohmsett facility. It must also be noted that the Ohmsett tank's water surface almost always contains a very thin sheen layer due to oil's escaping from the boom or PVS pipe-enclosed areas and older, residual oil accumulations along the tank's edges bleeding off sheen throughout the tank. Since SAR backscatter is known to be depressed by even very thin sheens, it is likely that none of the tank areas provided a true "clean water" target during the tests, except perhaps the small areas in the immediate vicinity of the firehose sprayers that enhance vertical mixing and hence suppress formation of the sheen layer. It is expected that data acquired of the Taylor Energy leak will yield more promising results.

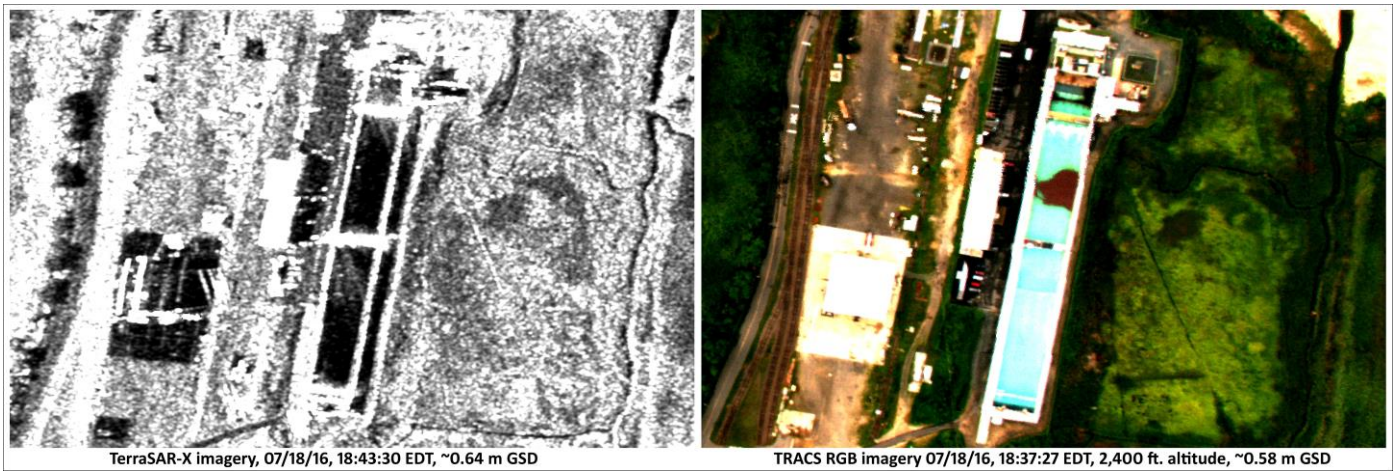

Figure 9: *TerraSAR-X imagery acquired at 18:43:30 EDT on 07/18/16 at ~0.64 m GSD next to TRACS RGB imagery acquired on the same day at 18:37:27 EDT with a GSD of 0.58 m. Dark area in water area of tank have DNs=0 and so no further information is available within this region of the image.*

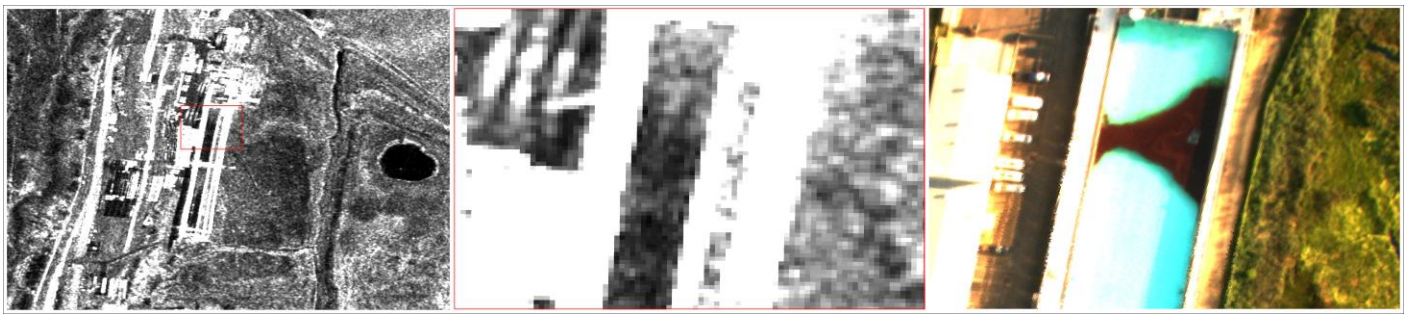

Figure 10: *TerraSAR-X imagery acquired at 07:13:59 EDT on 07/21/16 at a GSD of ~0.78 m (left), the area of the tank where the oil slick existed at that time (center) next to TRACS RGB imagery acquired on the same day at 07:21:56 EDT with a GSD of 0.25 m (right).*

UV Data Analysis: Visual assessment of the UV imagery in comparison to simultaneously taken was performed to assess ability to differentiate between different types of oil and oil thicknesses using this part of the electromagnetic spectrum. As seen in *Figure 11*, the UV data showed a high reflectance signal from the emulsified oil compared to the unemulsified 'fresh' oil. The presence of sheens was previously reported to increase reflectance in the UV range (Grüner et al., 1991). In our imagery, thin emulsified oil and oil sheen did indeed appear bright in the UV compared to surrounding water and thick, unemulsified oil. These observations indicate that data from the UV part of the spectrum do hold promise to help classifiers make the distinction between fresh crude and emulsified oil as well as possibly aid in the positive identification of oil sheen. From an operational oil spill response perspective, however, the overall results of these tests were inconclusive. Bright reflectance in the UV was also seen from sun glint on the water due to sun angle and/or waves and manmade objects such as the PVC squares. In some cases, the reflectance of dark, fresh oil did not show a significant difference in the UV when compared to surrounding water. It was also observed that the red band of the TRACS multispectral camera showed thicker-than-sheen oil reflectance characteristics similar to the UV data, which could therefore make the UV data of limited value as an additional differentiating band in an oil classification system. UV data have also been touted as a means to both isolate thin oil sheens as well as exclude false positive signal such as floating biological material. While this may hold true in some cases, sun glint from small ocean waves and/or strong reflectance from any floating object (biological or not) could easily be confused as thin sheens and therefore mislead an oil classification algorithm/system. Furthermore, we did not experience the expected petroleum product fluorescence in the UV versus non-petroleum targets which would make the UV camera a valuable tool to isolate oil from false positives. This may have been due to the lack of a strong enough energy source (i.e. normal solar input), but assessment of this capability remains inconclusive at this time. Unfortunately, integration of the UV camera for flights over the Taylor Energy site will not take place since the testing of the UV system at Ohmsett was not supported in the project budget and so was self-funded by OI. No funding exists to support UV camera integration for the Taylor overflights.

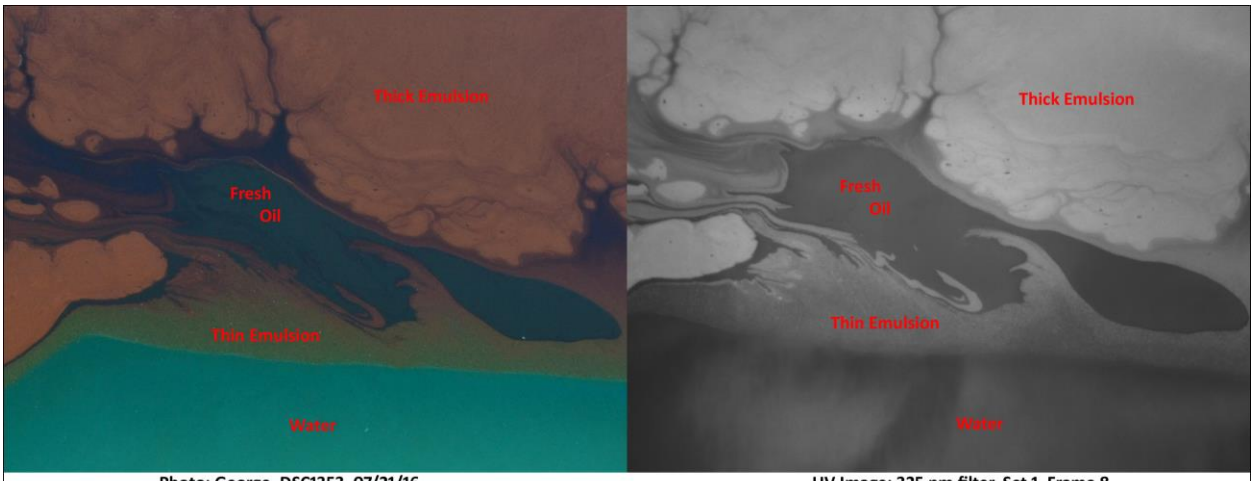

Photo: George_DSC1353 07/21/16 | UV Image: 325 nm filter, Set 1, Frame 8

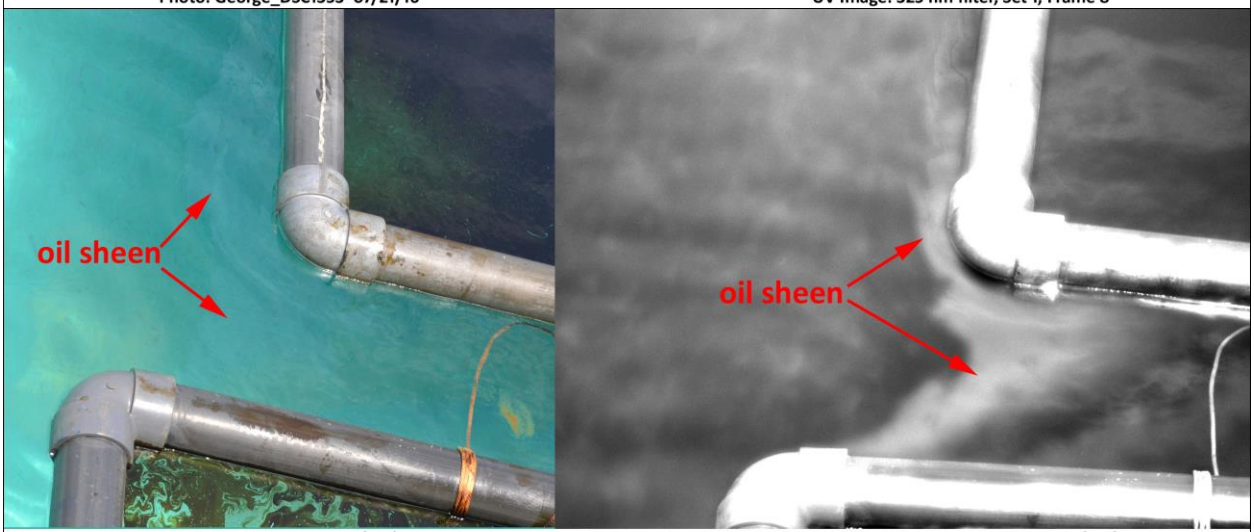

Photo: George_DSC0049 07/22/16 | UV Image: 325 nm filter, Set 7 Frame 004 07/22/16

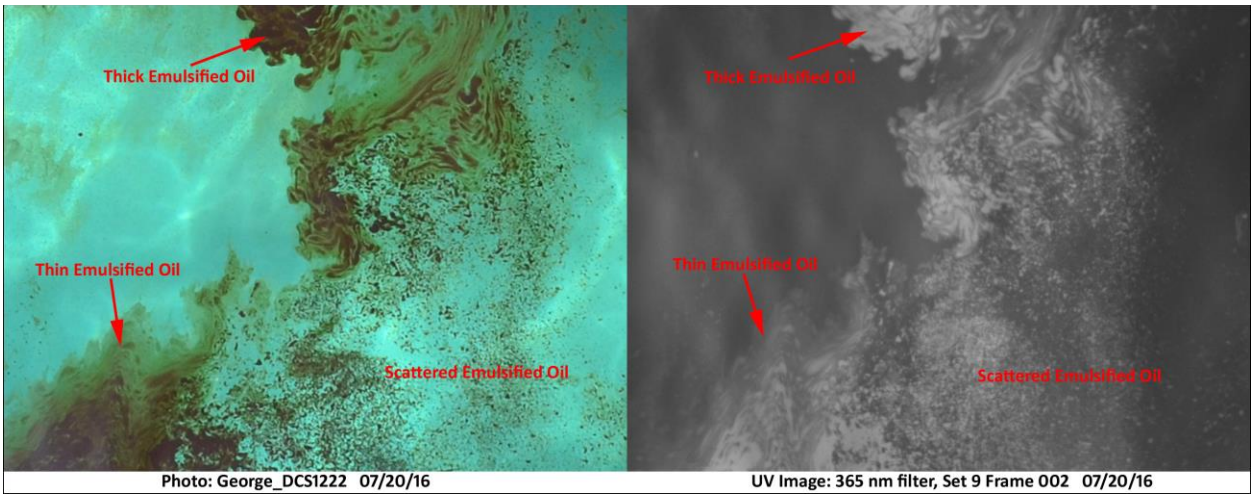

Figure 11: *Photographs taken simultaneously with UV data captures at close range over both emulsified and fresh oil in the Ohmsett tank 07/20/16 – 07/22/16. Several different oil types/states can be positively identified in the UV data; however further study must be done to confirm the usefulness of UV in a multi-sensor oil mapping system.*

TRACS – Aerial and UAV Data Comparison: A brief examination of TRACS imagery was performed compared to Water Mapping's UAV FLIR TIR data. Only rudimentary visual comparison could be done due to the time difference between to the two data collections as well as the fact that the FLIR camera only outputs uncalibrated 8-bit data (255 shades) and the TRACS TIR camera is a calibrated, 12-bit system providing 4, 096 shades (i.e. 16x greater thermal fidelity). Even though the TRACS and FLIR data were acquired only 10 minutes apart, the oil movement in the tank was very dynamic and so direct, precise comparison of TIR features observable in the different datasets was not possible. Initial observations reveal that the FLIR sensor operating on a low flying UAV can distinguish differences in the thermal emissivity of different thicknesses of oil, however, at what range or altitude the FLIR imagery would start losing both thermal and spatial definition to the point at which thickness differentiation would not be possible is unknown. Since the FLIR instrument is not calibrated, using these data in an automated or semi-automated classification process would not be possible. A skilled analyst would be required to assign the thickness classes to the end-user product. As is seen in *Figure 12*, in the case of the July 21 data, the emissivity temperature of the thicker emulsified oil was very close, if not the same as the surrounding water in both the FLIR and TRACS data and so a separate instrument/dataset would be required to help positively identify the thicker oil.



Figure 12: *TIR data from Water Mapping's UAV-mounted FLIR camera acquired at 07:26:00 EDT on 07/21/16 (left) shown with the TRACS TIR data acquired at altitudes of 30 (center) and 300 feet (right) acquire on the same day at 07:16 EDT.*

Oil Characterization Analysis and Classification: One of the stated goals of this project is to evaluate and compare surface oil thickness measurement methods from the different platforms and instruments. While OI has done much work on the identification and classification of the thickness of fresh, crude oil using its Digital Multispectral Camera (DMSC) system (Svejkovsky and Muskat; 2006, Svejkovsky and Muskat, 2008; Svejkovsky and Muskat, 2009; Svejkovsky and Muskat, 2012 and Svejkovsky, et al. 2016) and some limited study on the classification of oil emulsion thicknesses (Svejkovsky and Muskat, 2012), it was determined that, based on advanced analysis of data obtained at Ohmsett in October, 2011 and another Ohmsett visit in December, 2011 funded by ExxonMobil as part of a separate (dispersant-testing) project, as well as further analysis of data from DWH and Santa Barbara oil seeps, any emulsion quantification algorithm should provide a measure of actual oil content per unit of surface area, rather than an estimation of the emulsion layer's "thickness". OI believes that a reliable estimate of the actual oil volume within the emulsion is of the most relevance to recovery and other response operations rather than an estimate of a "thickness" which does not reflect the actual water:oil content ratio. Our work confirmed that, unlike in the case of unemulsified oil films that tend to have both their upper and lower boundaries well defined, the absolute thickness of emulsions, especially older, weathered emulsions, is not so clearly defined. Often the lower (i.e. submerged) boundary consists of a sponge-like texture, with water and air pockets interspersed between vertical strands of oil (Svejkovsky and Muskat, 2012). Since this recent Ohmsett exercise was the first documented creation of a large size, weathered oil emulsion slick, this presented a unique opportunity to see and document this phenomenon ***(Figure 13).*** The water:oil ratio also is a critical factor when determining the volume of oil of a spill or oil target area. Therefore, one of our main objectives was to build on OI's previous work and resulting methodologies to establish a consistently accurate algorithm to generate volume-pre-area analyses as opposed to thickness maps. For these reasons, while we did generate classifications of oil thickness derived from the TRACS multispectral and TIR data along with the available in situ thickness and water content data (Appendix A), the more relevant information product is the same classification with the classes defined as volume per unit area (Appendix B).

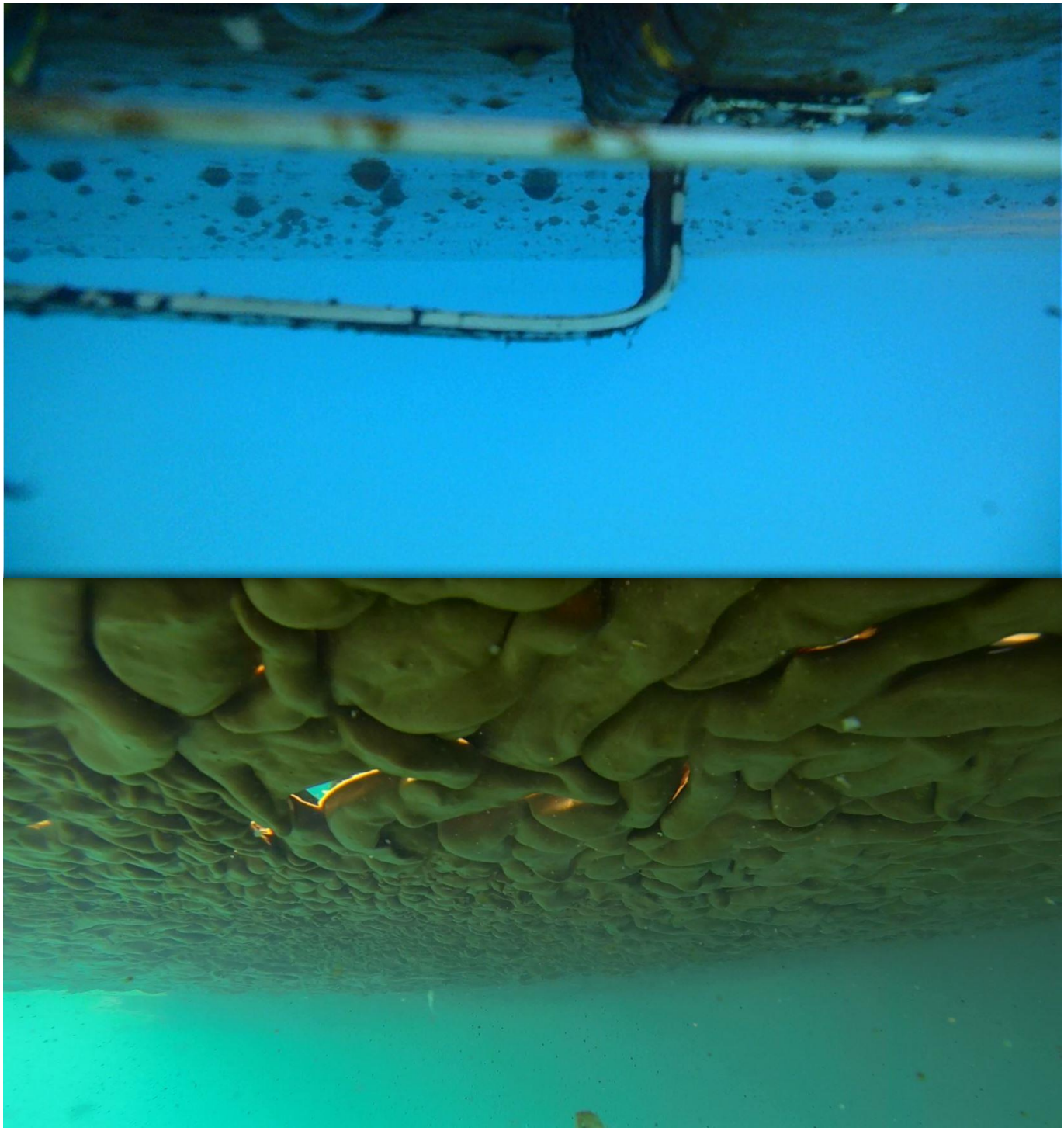

Figure 13: *Still shots from a GoPro video camera attached to the WaterMapping Oil Spill Sampler 2 (WM-OSS2) oil thickness mapping unit while recording the submerged side of the emulsified oil in one of the thinner oil areas of the tank on 07/21/16 (top) and the Ohmsett GoPro camera attached to a pole submerged beneath the thicker floating oil on 07/22/16. Note the large, downward extending 'bubbles' in the top photo and significant heterogeneity of the oil's lower boundary in both photos indicating a non-uniform overall thickness.*

Unlike the DMSC system used for OI's previous BSEE-funded Ohmsett research and during the DWH incident, TRACS is a system designed more with the responder and oil recovery/clean up in mind. TRACS-derived information products concentrate on showing the end user where the actionable oil (recoverable by mechanical skimming, dispersible with chemical dispersants or burnable) is located as opposed to non-actionable sheen or clean water. While previous algorithms developed using the DMSC system were not directly applicable to the creation of oil volume maps from this exercise due to the high water content (up to 84% on some days) and very thick and highly weathered oil in the tank (between 100 um and 1,400 um for most measurements and up to 60,000 um by some in situ measurement accounts), we were able to create oil thickness/volume classification maps using information from the red band of the multispectral camera combined with data from the TIR band ***(Figure 14)***.

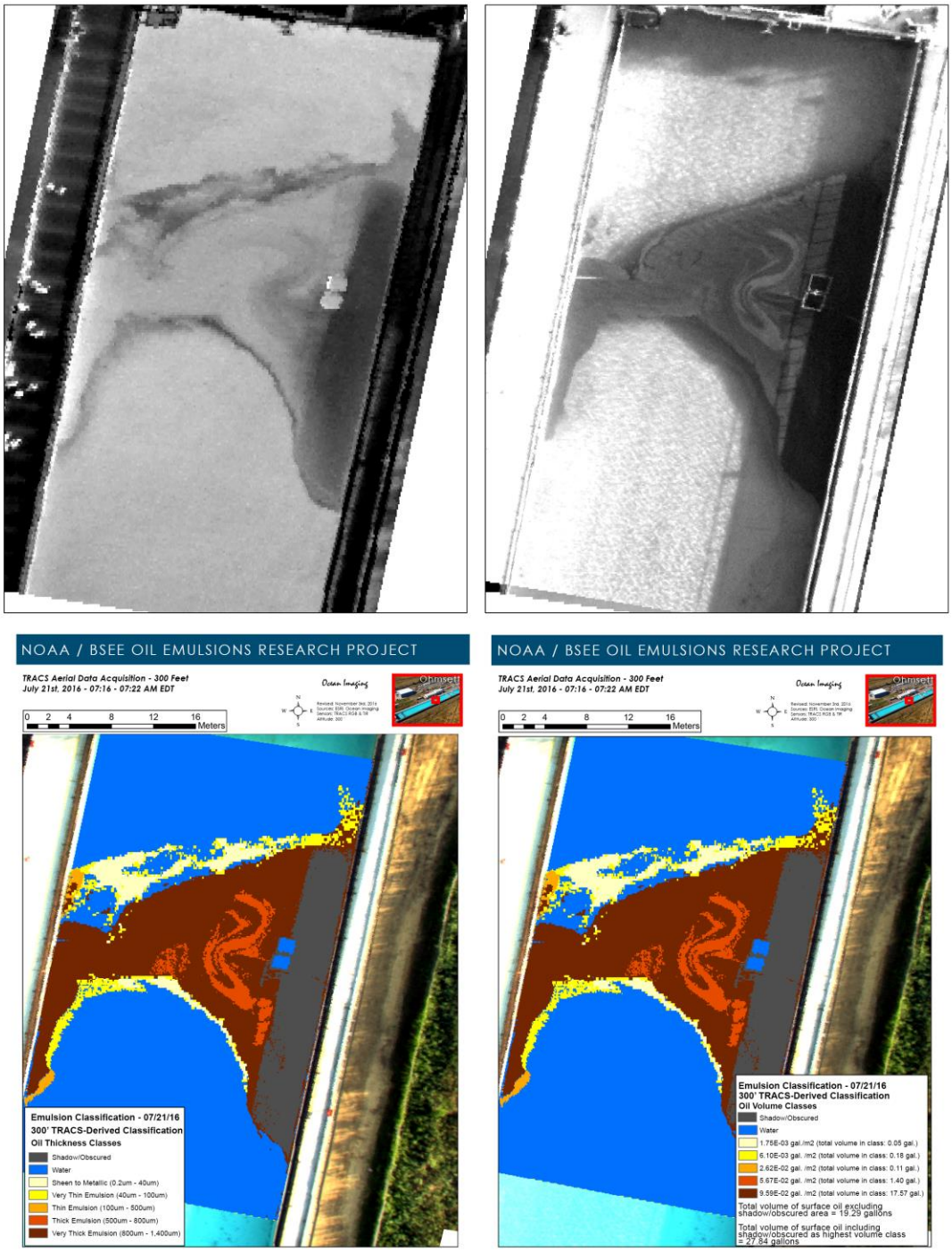

Figure 14: *TRACS TIR (top left) and multispectral red band (top right) data acquired on 07/21/16 at 07:16 am EDT at an altitude of 300 feet resulting in an overall GSD of 0.11 m was used to create the emulsified oil thickness classification (bottom right). Thermal cut-off values, adjusted from OI's original algorithm for crude oil based on the 2011-2012 work at Ohmsett with oil emulsions were combined with the reflectance values from the red band of the TRACS multispectral camera to create this seven-class product. From these data and an average water:oil ratio of 67% on this day, an oil-volume-per-area analysis was then generated (bottom right). Larger versions of the two classification analyses are in Appendix A and B.*

Oil thickness and volume analyses were created using the 500 and 1,000-foot altitude TRACS data acquired on July 19 and the 30, 300 and 1000-foot altitude TRACS data acquired on July 21. The oil classification maps shown in Appendices A and B were generated using the ESRI ArcGIS application. It should be stressed that both the oil thickness classifications and the volume analyses derived from them relied almost exclusively on the in situ measurements data which were limited in number and spatial coverage. Given the few in situ data points, we were unable to utilize supervised classification methods. Therefore, the red and TIR bands were run through a 100-class unsupervised (ISODATA clustering) classification with the ESRI software, and them merged down by an expert analyst to the six classes which best correlated with the tank-side sampling data as well as known relationships between thermal signal cut-off points and oil emulsions. From OI's 2011-2012 work it was determined that during the day the thermal contrast between the 60% emulsions and surrounding water is considerably smaller (approximately a factor of 10) for a given film thickness than pure crude oil. This is logical in that the water-containing oil emulsion absorbs and re-emits less solar heating than pure crude. The relationship is consistent with smaller oil/water content ratios (i.e. the 20% emulsion samples had IR emittance closer to pure oil) and is an important aspect considered in any emulsion-oriented classification methodology (Svejkovsky and Muskat, 2012). The average water content based on two different measurement methods of the oil in the tank at the time of TRACS data acquisition was 76% on July 19 and 67% on July 21. The classifications and the corresponding volume maps were quantified accordingly using these values.

Originally it was planned to correlate the in situ data with the TRACS image data by simple regression to generate an equation (albeit specific to this exercise) which could be universally applied to quantitatively define all of the oil classes. However, the insufficient number of time-coincident in situ data points along with the fact that no thickness measurements were taken within the thickest, center area of the oil slick, only allowed us to create estimated thickness range classes based on the location and timing of the available measurements. *Figure 15* and *Figure 16* show the approximate locations of the sampling sites listed in Table 3 above overlaid on the TRACS RGB imagery for the corresponding day and time. We found that the oil in the tank changed position and shape extremely fast. Knowing this and, given the few samples available, tank-side-only measurements, and imprecise locations of in situ thickness measurements, only approximate correlations could be made comparing the in situ data to the TRACS image data. This resulted in estimated oil thickness classes with relatively wide ranges. For the volume maps, the mean thickness of each class range was used in the volume computation.

NOAA / BSEE OIL EMULSIONS RESEARCH PROJECT

TRACS aerial data acquisition - 500 Feet
July 19th, 2016 - 18:04 - 18:16 PM EDT

Ocean Imaging

Revised: October 31st, 2016
Sources: ESRI, Ocean Imaging
Sensors: TRACS RGB & TIR
Altitude: 500 '
GSD: RGB: 0.13m, TIR: 0.21m



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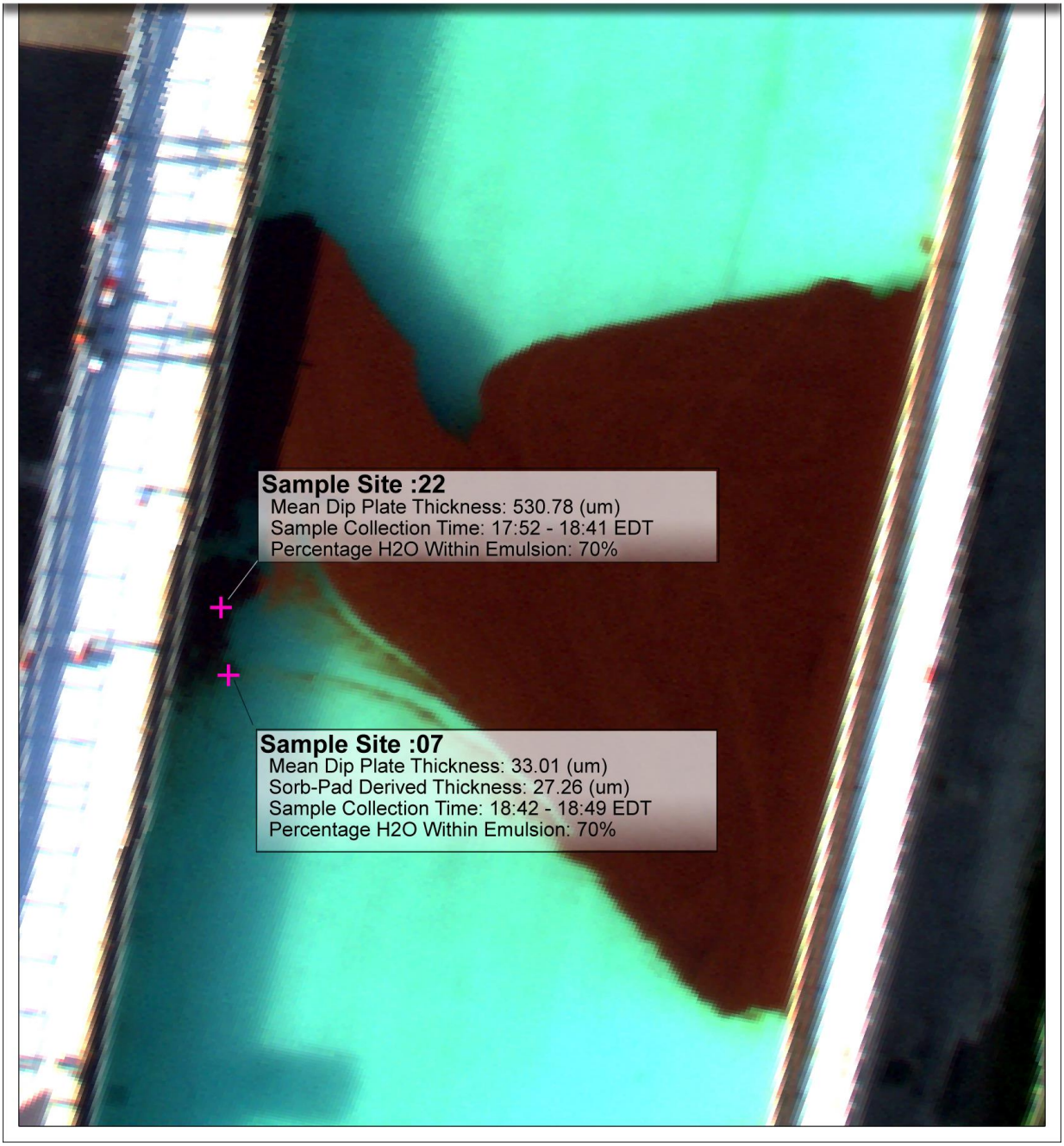

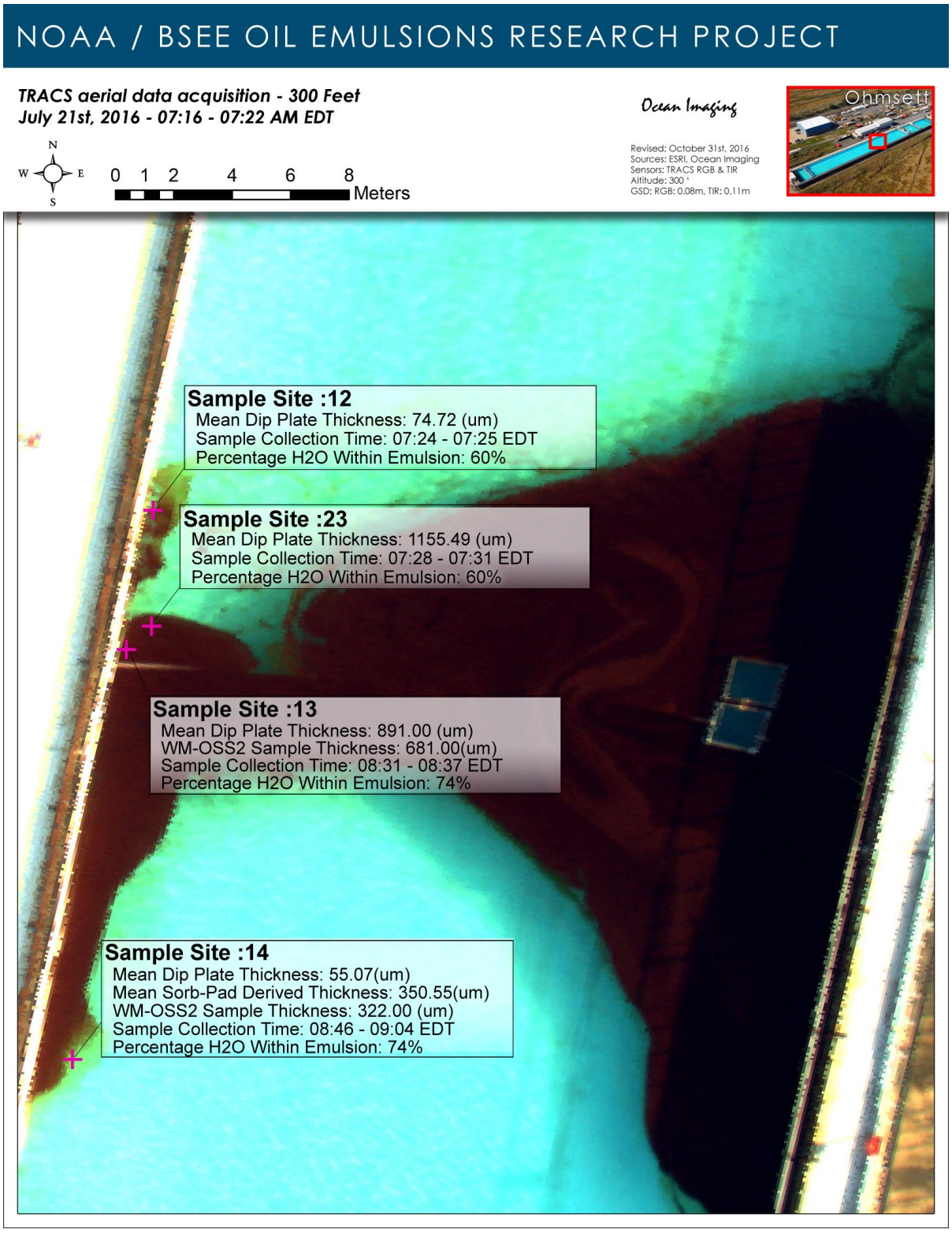

Figures 15 and 16: *Locations of in situ oil thickness sample data on July 19th and 20th overlaid on the corresponding TRACS multispectral image. Only oil thickness measurements taken within two hours of the TRACS data acquisition time were used to create the TRACS-derived oil thickness and volume maps shown in Appendix A below.*

The amount of oil in initially released into the Ohmsett tank on July 14 was 400 gallons as per the Ohmsett Daily Surface Oil Logs. Based on laboratory weathering tests and the chemical composition of the HOOPS oil used for this study, the estimate of oil that should have been remaining on the water's surface seven days later, on July 21st is estimated to be between 250 – 345 gallons (Guarino, Forth, personal communication, November 1, 2016). Computations of the total volume of oil remaining in the tank on July 19 and 21 using the TRACS data to derive total area were between 19.31-19.41 gallons and 22.83-27.84 gallons for each day respectively (amount varies depending on spatial resolution of TRACS data used to compute oil area in tank – see Appendix B for analyses). Even though the TRACS-derived volume quantifications are estimates, the difference by an order of magnitude from the expected amounts does require further examination. Determination of the water:oil ratios by lab analysis of the bulk oil samples and spectral reflectance analyses were within less than 10% of each other on both days and so are considered within the accuracy requirements for this analysis. Given that the estimated error in the computation of oiled area from the TRACS imagery for each day is approximately +/- 5%, the significant difference between total oil volume computed from the TRACS-derived analyses and the estimations by Guarino and Forth can only be due to errors in the in situ sample data. Rough calculations conclude that the thickest (and most abundant) oil would have to have been between approximately 12,000-14,000 um thick in order to result in total residual surface volume amounts between 250 – 345 gallons on July 19-21. This indicates that the in situ measurements used to quantify the classifications were taken either too close to the edge of the tank and not in the thickest oil and/or the methodology was simply inappropriate for the thick, emulsified oil created during this exercise creating significant error. The lower photo in Figure 13 provides one visual example of how the thickest oil was often quite thicker than the "thick emulsion" values shown in Table 3, and used for the oil classifications. Thickness samples taken by Greg Swayze of the USGS using the Vertical Emulsion Thickness Sampler (VETS) and the Water Mapping WM-OSS2 device resulted in a median thickness of the visually thickest oil on July 22 of 42,500 um. This is higher than the target thickness range noted above for July 19 and 21, however the oil slick was noticeably thicker in appearance on the 22nd and so these measuring devices may be better tools when working with oil of such thickness and emulsification levels – and the use of these measurements to calibrate the oil volume analyses would have certainly resulted in closer-to-expected residual volume determinations.

Spatial resolution or ground sampling distance of the TRACS data was also important in determining the volume of the oil on the water's surface. For the oil slick the size of that in the Ohmsett tank, TRACS data flown at altitudes higher than 500 feet (GSDs greater than 0.21 m) resulted "pixel mixing" of the reflected oil signal. This both limited our ability to classify all the surface oil's different thickness categories. For example, in the July 19 and July 21 classifications the algorithms and analysts could only effectively differentiate four oil thickness/volume classes using the data acquired at 1,000 feet compared to the five oil classes isolated using the finer resolution 300-foot data. In the case of the July 21 volume determinations, this resulted in an 18% loss in total volume when using the 1000-foot data compared to the higher resolution 300-foot TRACS data.

DISCUSSION

From an incident response/oil recovery perspective the TRACS-derived analyses of the Ohmsett tank oil (either thickness or volume) exemplify a very effective set of digital information products accurately identifying the actionable oil, easily ingestible by any Common Operating Picture platform such as NOAA's Environmental Response Application (ERMA). OI has already run tests with the ERMA support staff to demonstrate the seamless integration of OI-derived oil information products into their system via OI's server. Also, from the standpoint of Natural Resource Damage Assessment, these products also depict the relative coverages of each type of oil from the sheen to "metallic" class up to the very thick oil emulsions – valuable information for the assessment of biological contamination. Differentiation between emulsified/weathered and fresh oil using remotely sensed data has already been demonstrated by OI as part of work done for the DWH response and the NOAA Oil on Water working group efforts (Svejkovsky, et. al., 2012, Svejkovsky, et.al., 2016).

Calculation of precise thickness and volume per area quantities from any of the remotely sensed data products acquired for this phase of the project, however, will require additional work. First and foremost, as discussed above, knowing thicknesses alone will not serve the purpose of quantifying the amount of oil on the water's surface. Without knowing the water content of the oil to within 10%-20%of the actual percentage, accurate determinations of oil volume cannot be computed. Spatial resolution also is a significant determinant when generating oil volume analyses. Too coarse data will result in pixel blending or averaging, thus reducing the accuracy of the volume estimations. While it has been determined that for oil spills on the scale of DWH or similar, data must have a spatial resolution of 10 meters or better (Svejkovsky, et al., 2016), when working at the small scale of 400 gallons of highly water-entrained, emulsified oil coverage in a constrained area, RS data must be at least 0.25 meters or better in order to spatially, thermally and spectrally resolve the different states and thicknesses of oil for any acceptable volume determinations.

Finally, for any future work to generate RS-derived oil thickness/volume information products, refinement of the in situ sampling methods is a key consideration, as well as the precise recording of the measurement location and timing with RS data acquisition. It appears that some sampling/measurement methods showed better accuracy for the sheen to thin oil thicknesses (i.e. dip plates and sorbent pads), yet other methods were much better suited for the measurement of the very thick oil emulsions (i.e. the USGS VETS and the Water Mapping WM-OSS2 devices). While the sampling tools/methods may not be improved for the work at the Taylor Energy site, the choice of which measurement tool to use based on oil thickness and estimated water content should be carefully considered. Field thickness and water content measurements should be precisely located and taken as close to the satellite or aerial data acquisition as possible. This all will better facilitate the use of the in situ data for the further development of oil volume algorithms and methodologies which could be implemented by the NOAA NESDIS team when working to create more universally applicable RS-derived oil spill response and assessment information products.

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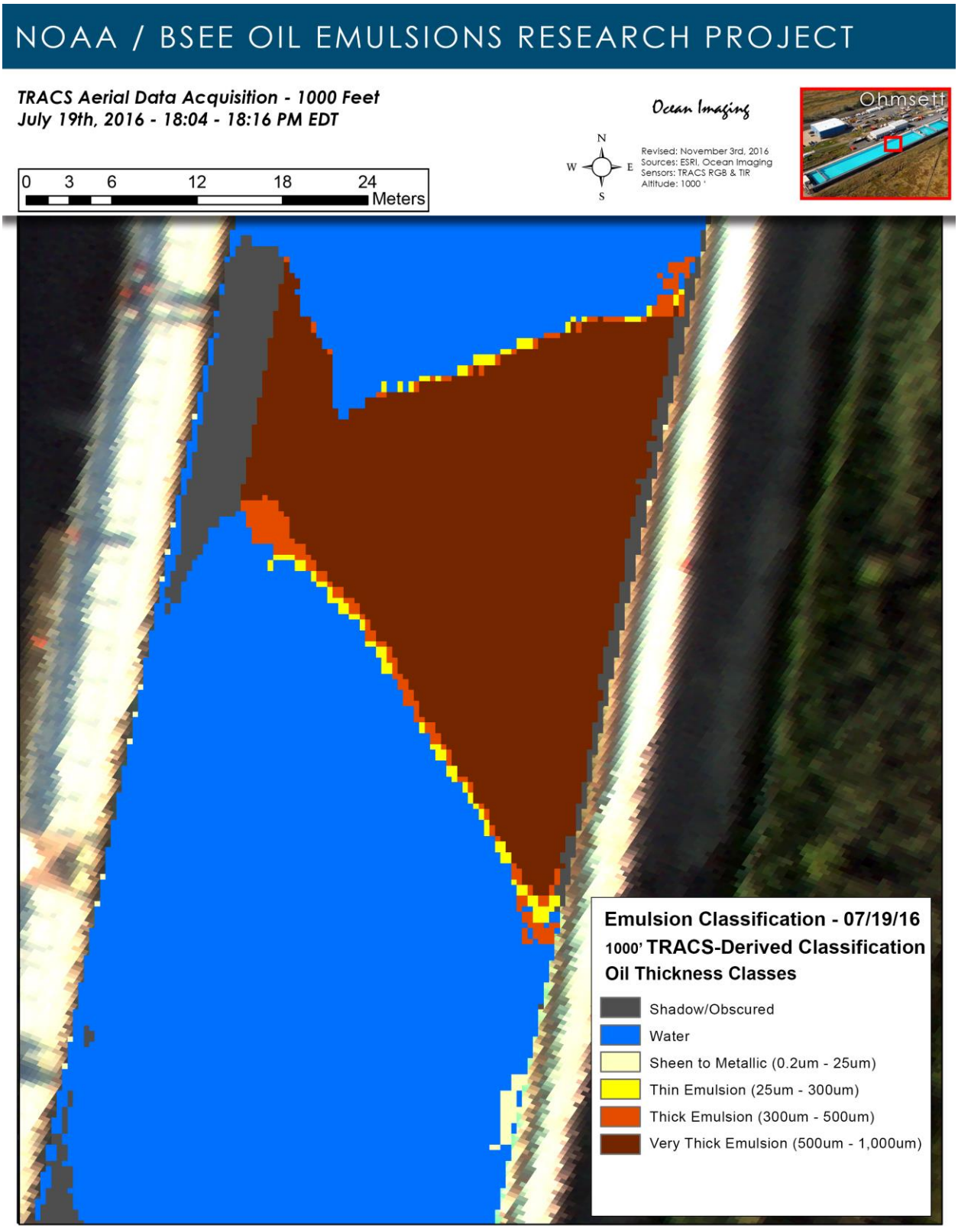
APPENDIX A – OIL THICKNESS ANALYSES



TRACS Aerial Data Acquisition - 500 Feet
July 19th, 2016 - 18:04 - 18:16 PM EDT

0 2.5 5 10 15 20 Meters

Ocean Imaging

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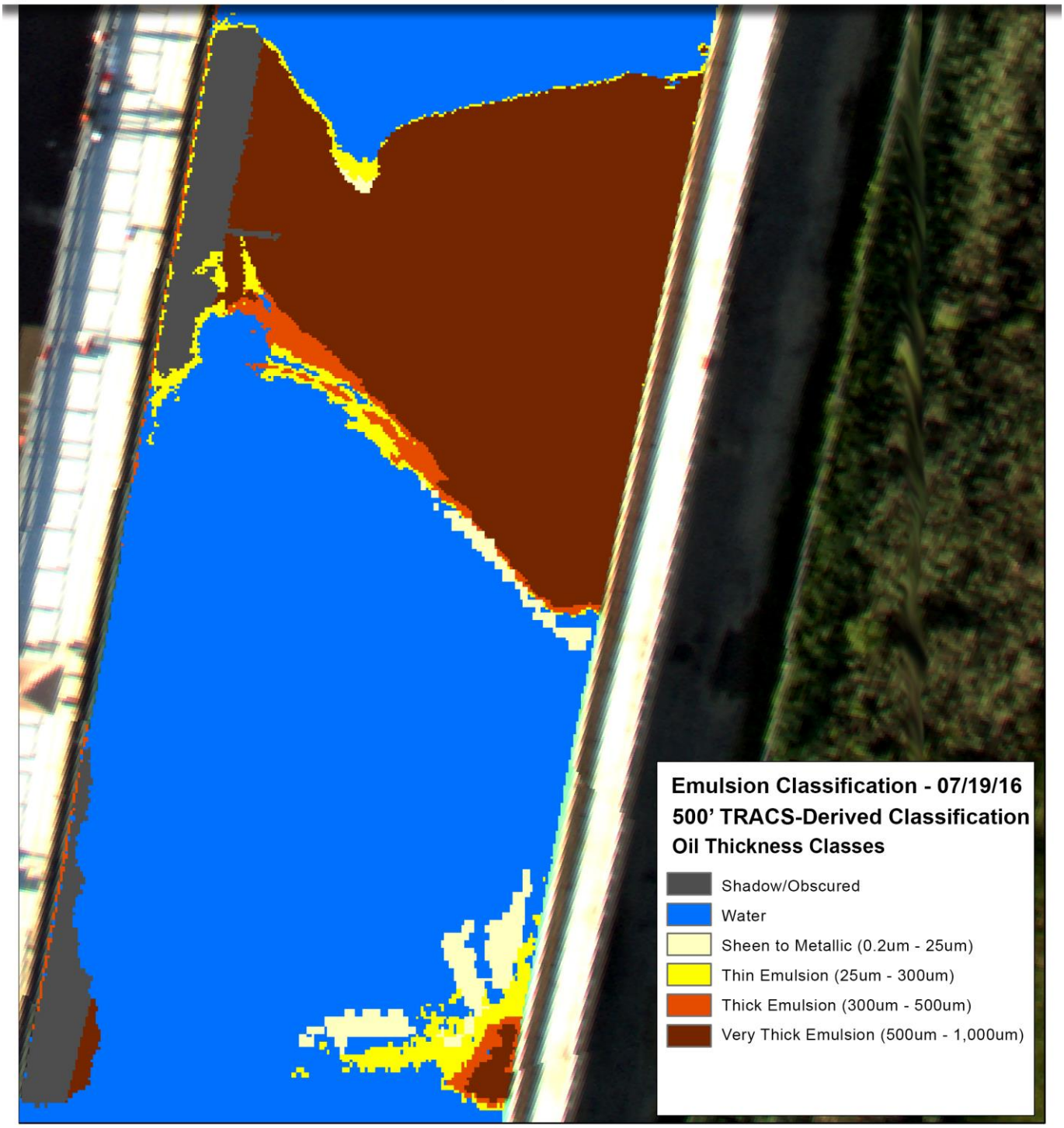
Revised: November 3rd, 2016
Sources: ESRI, Ocean Imaging
Sensors: TRACS RGB & TIR
Altitude: 500 '





NOAA / BSEE OIL EMULSIONS RESEARCH PROJECT

TRACS Aerial Data Acquisition - 1000 Feet
July 21st, 2016 - 07:16 - 07:22 AM EDT

Ocean Imaging

0 2 4 8 12 16 Meters

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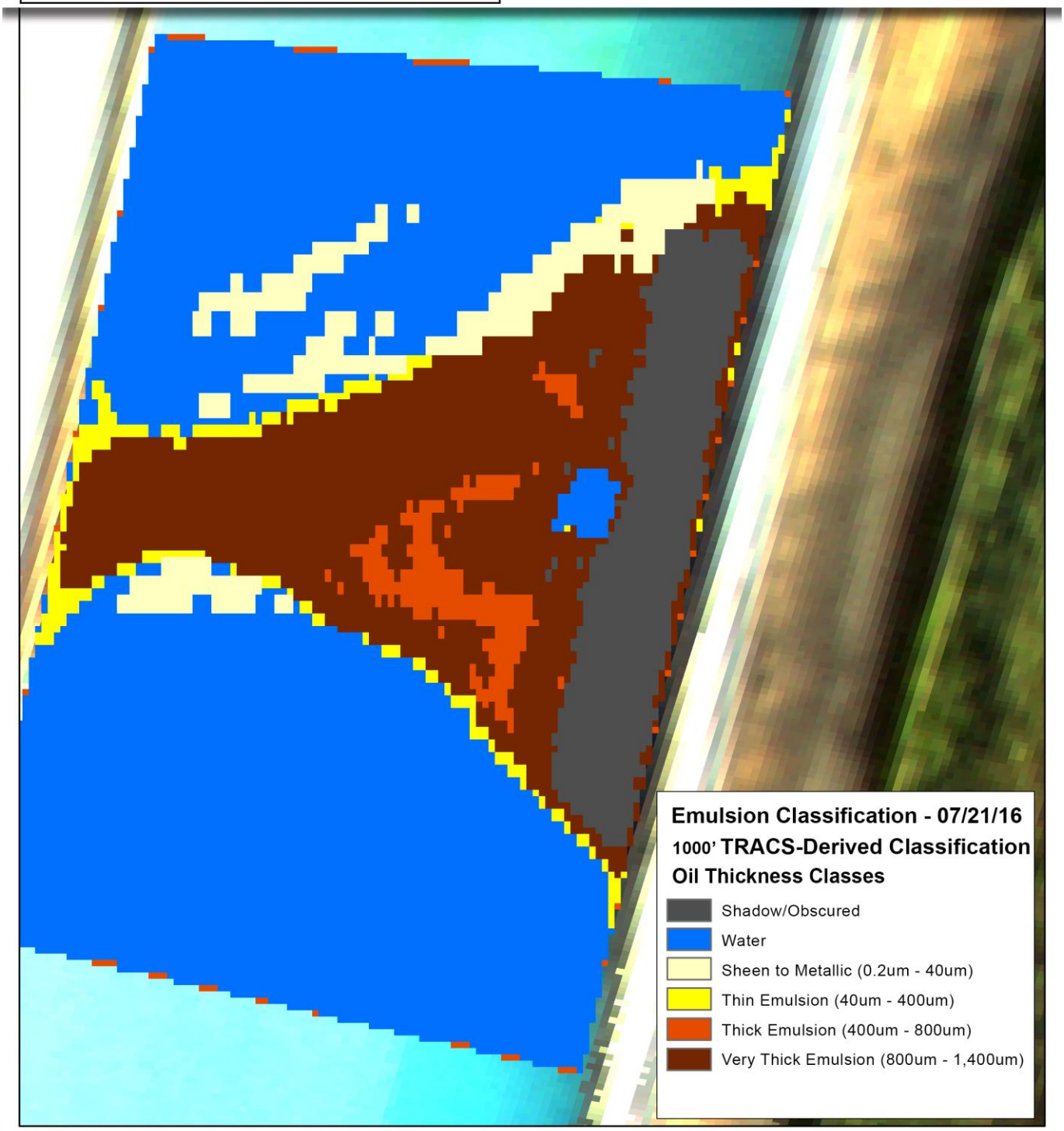
Revised: November 3rd, 2016
Sources: ESRI, Ocean Imaging
Sensors: TRACS RGB & TIR
Altitude: 1000 '





TRACS Aerial Data Acquisition - 300 Feet
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Ocean Imaging

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Revised: November 3rd, 2016
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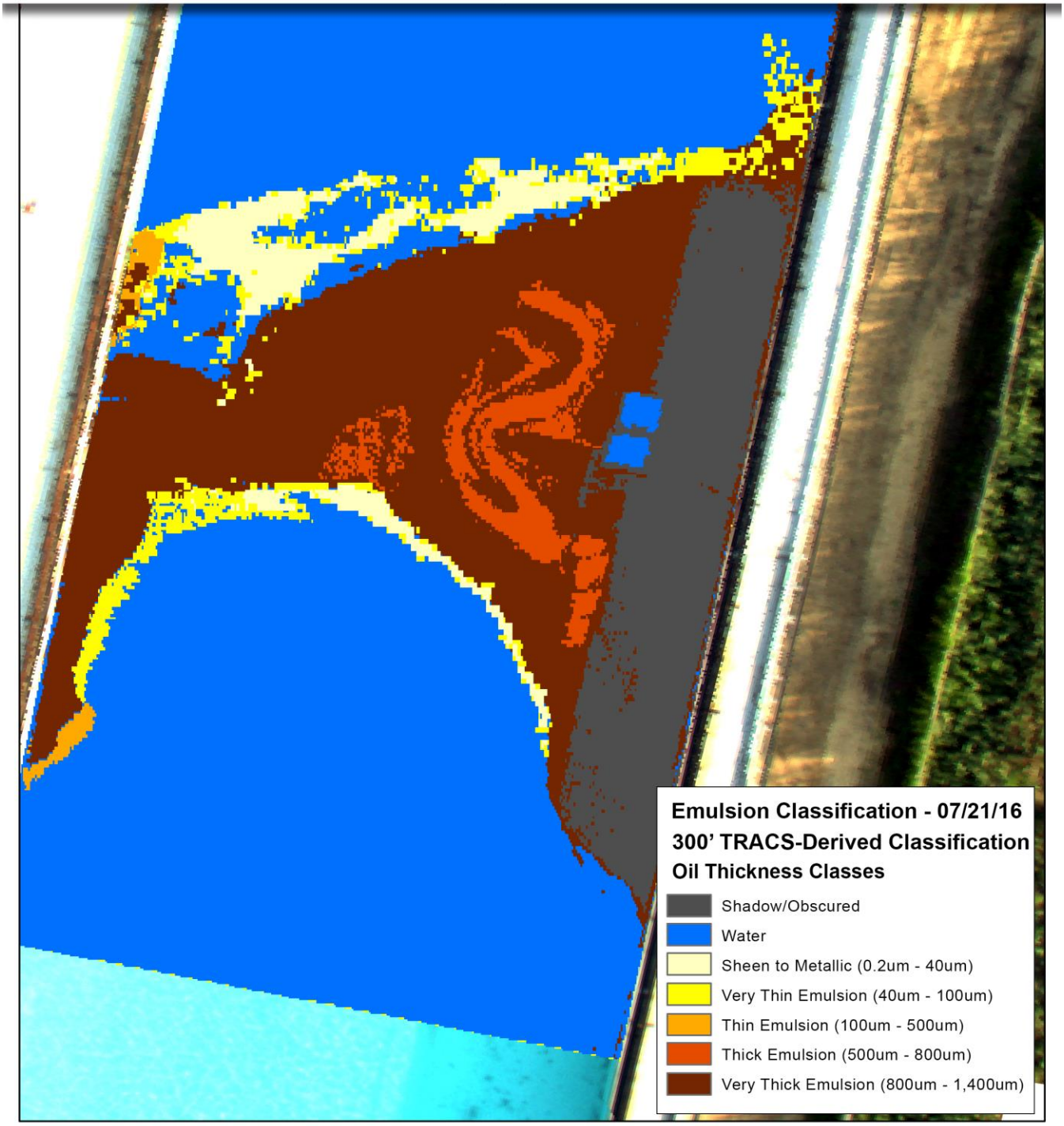
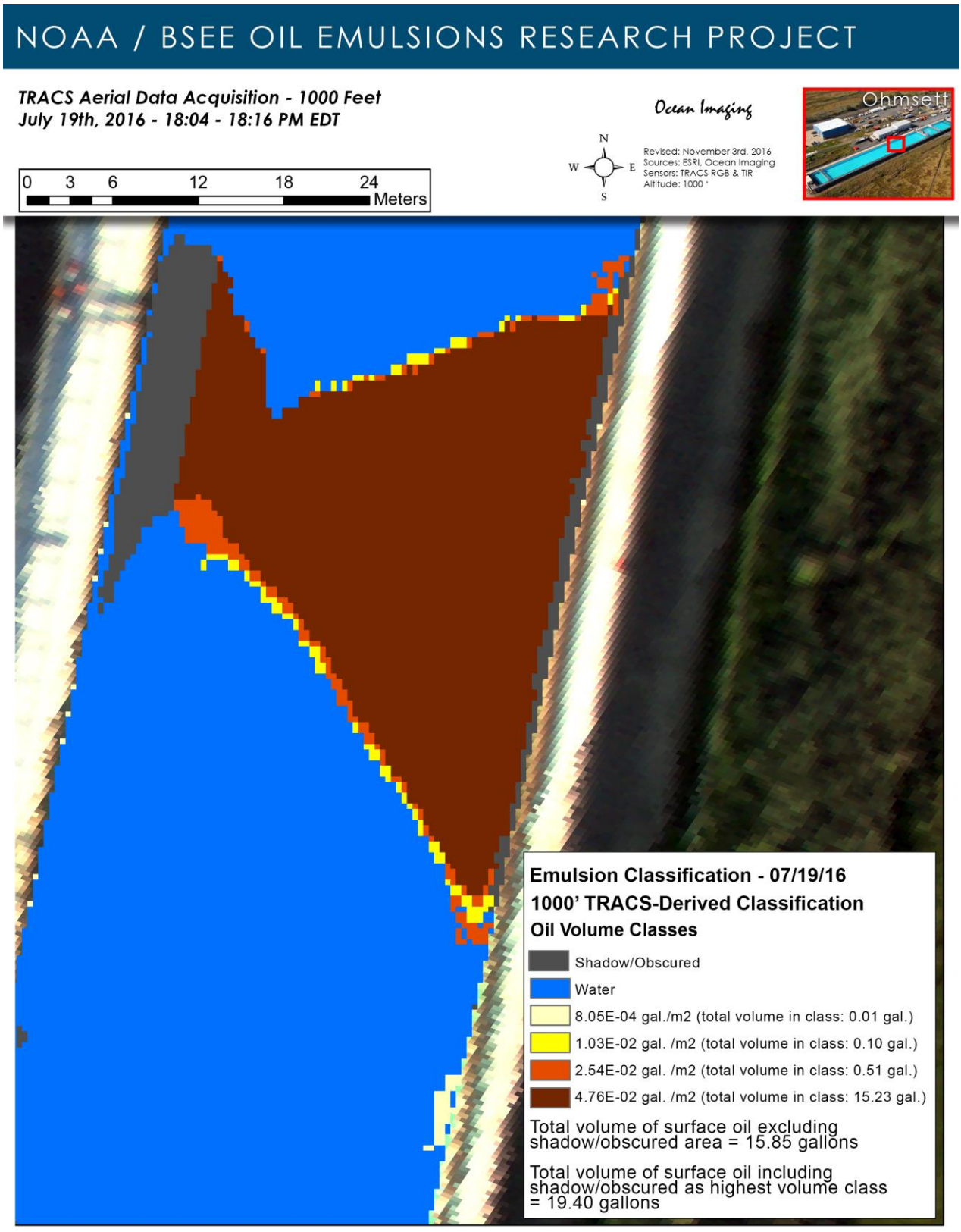
Sensors: TRACS RGB & TIR
Altitude: 300 '





APPENDIX B – OIL VOLUME PER AREA ANALYSES



NOAA / BSEE OIL EMULSIONS RESEARCH PROJECT

TRACS Aerial Data Acquisition - 500 Feet
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0 2.5 5 10 15 20 Meters

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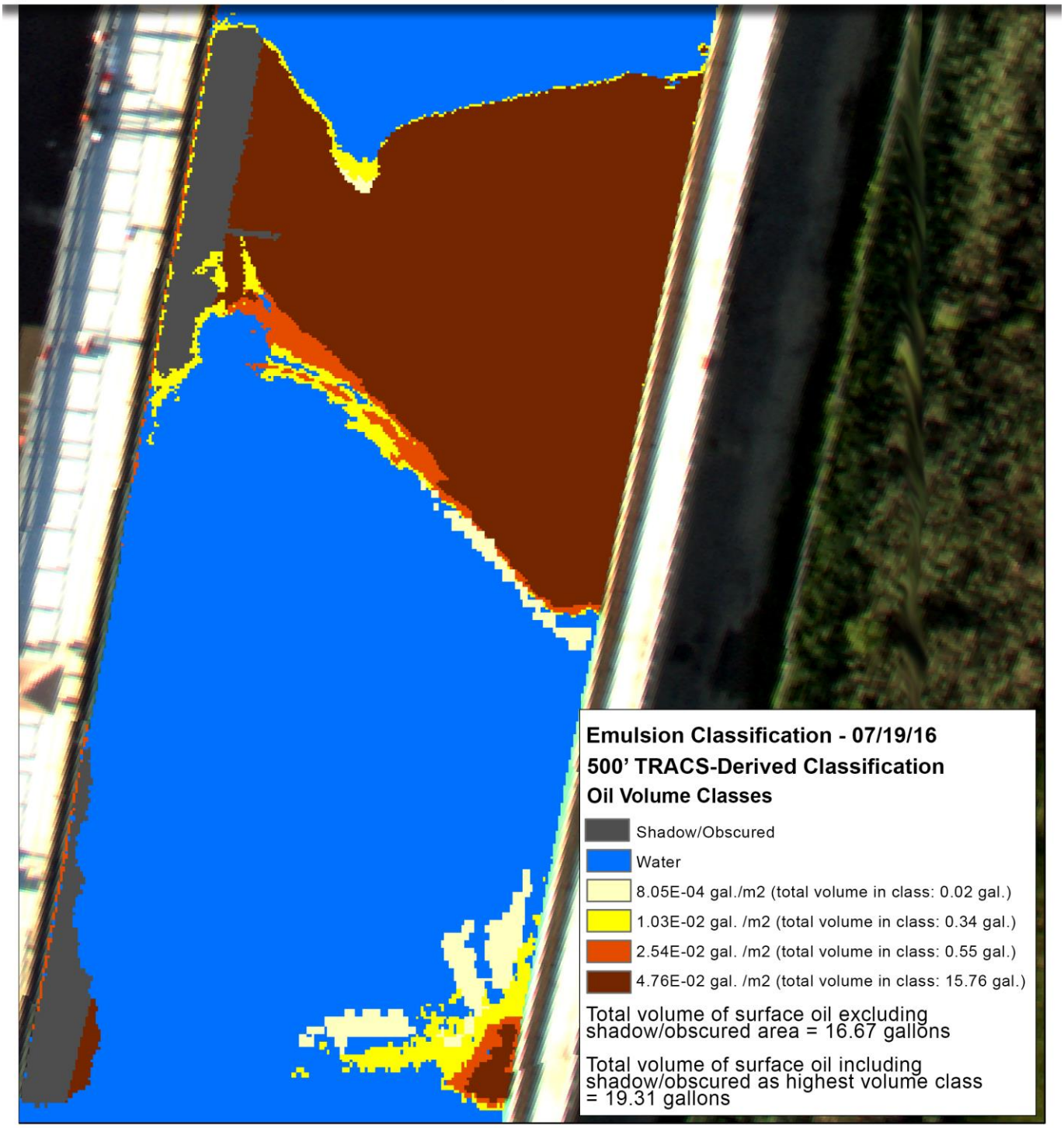
Revised: November 3rd, 2016
Sources: ESRI, Ocean Imaging
Sensors: TRACS RGB & TIR
Altitude: 500 '





NOAA / BSEE OIL EMULSIONS RESEARCH PROJECT

TRACS Aerial Data Acquisition - 1000 Feet
July 21st, 2016 - 07:16 - 07:22 AM EDT

Ocean Imaging

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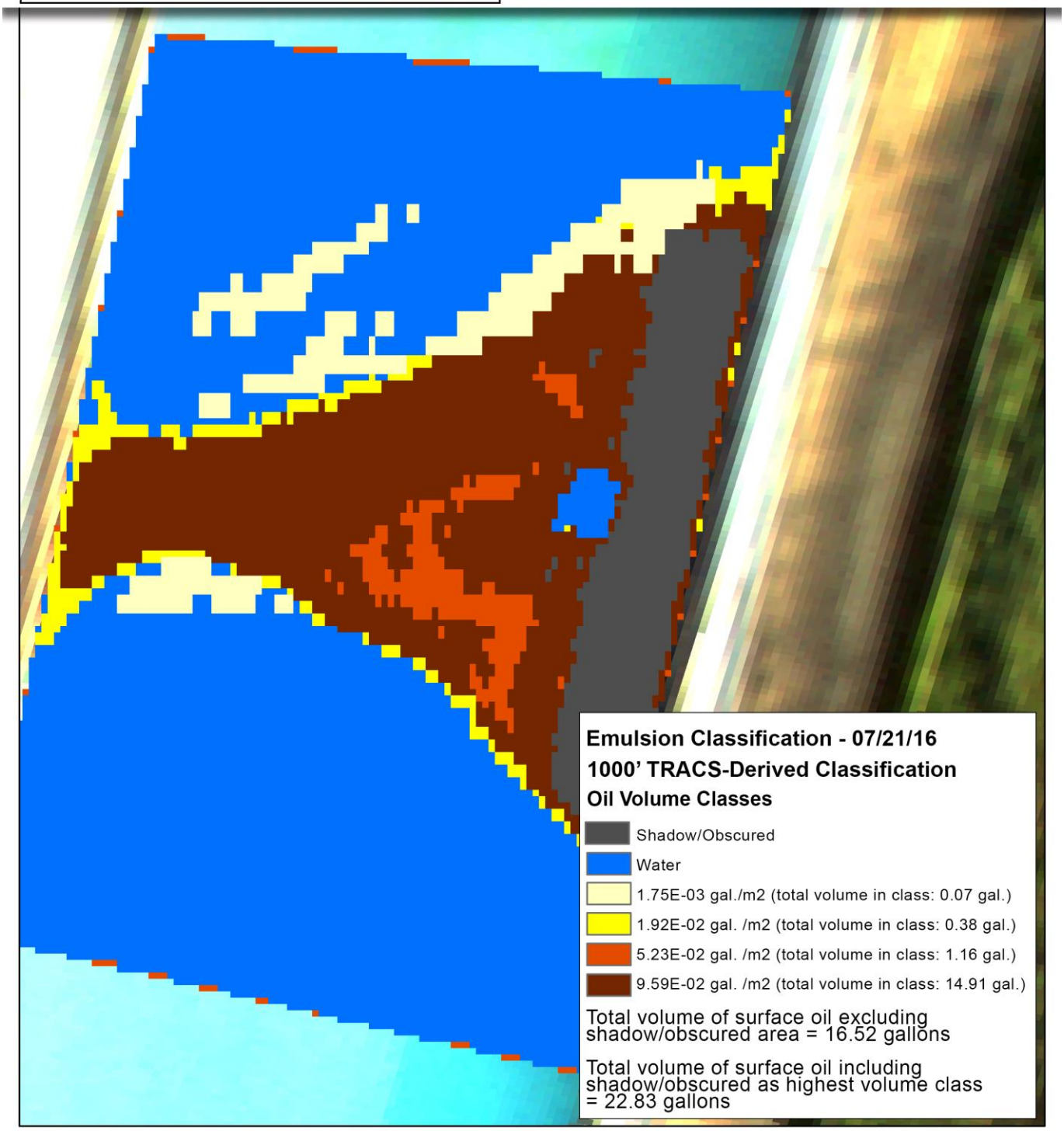
Revised: November 3rd, 2016
Sources: ESRI, Ocean Imaging
Sensors: TRACS RGB & TIR
Altitude: 1000 '





TRACS Aerial Data Acquisition - 300 Feet
July 21st, 2016 - 07:16 - 07:22 AM EDT

Ocean Imaging

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Revised: November 3rd, 2016
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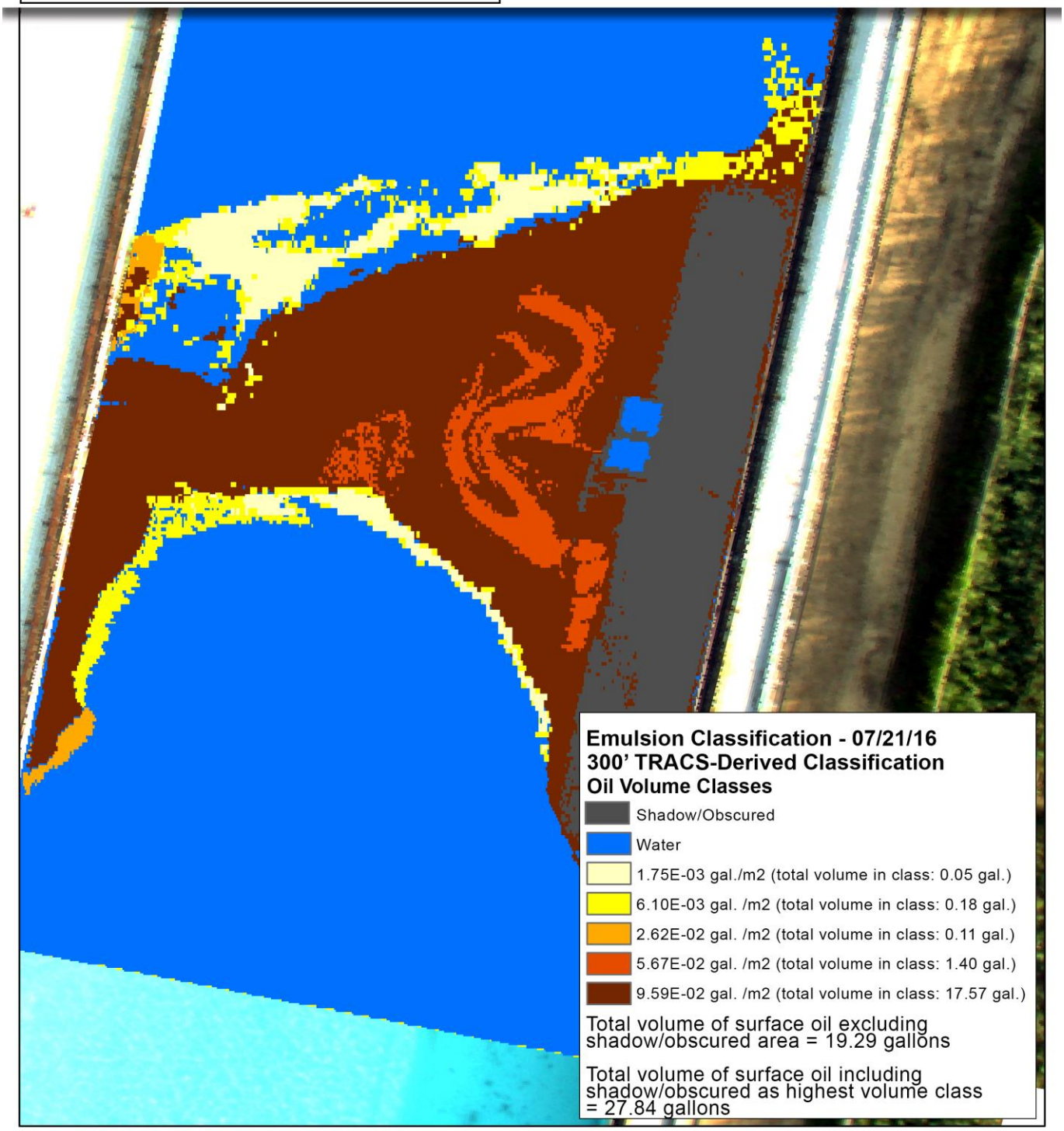

Attachment D. Fototerra Ohmsett Report

FOTOTERRA AERIAL SURVEY LLC
10435 PLADDAWA LN
RICHMOND, TX 77407

Houston, 3rd of August of 2016

Draft Report (Ohmsett Test)

Executive Summary

Fototerra is taking part of a series of tests coordinated by BSEE and NOAA called Deepwater Horizon (DWH) Lessons Learned Studies: Detection of Oil Thickness and Emulsion Mixtures using Remote Sensing Platforms. Aligned with BSEE and NOAA objectives to capture lessons-learned from DWH and advance the understanding for oil spill preparedness, a set of tests were carried out between the 10th and the 21st of July providing the options for controlled and open ocean synoptic data collection experiments from multiple sensors and platforms.

Fototerra was invited to participate in this event due its multisensors system Medusa on board Poseidon platform. Medusa system is composed by several sensors for oil detection, determination of the area of the spill, volume, type of oil and relative and absolute thickness. The platform includes real time data processing and communication system. Precise and quantitative information on the spill are crucial for an effective contingency action. The area of the spill, the thickness of the spill, the location of the source displacement of the spill and the type of the oil, are questions that arise frequently during an emergency situation and can be answered by Medusa.

Introduction

This set of tests is divided in 3 Phases: Phase 1 Controlled Experiment, Phase 2 Taylor Energy marine oil spill experiments and Phase 3 Operational Tools Algorithms and Training. Fototerra's tasks are:

"The findings and opinions expressed in this report are solely those of the authors and do not necessarily reflect the views and policies of the Bureau of Safety and Environmental Enforcement, nor does mention of the trade names or commercial products constitute endorsement or recommendation for use."

- Phase 1 part a – Disassembling from aircraft and setup LFS (laser fluorosensor) and MWR (microwave radiometer) on the testing tank at Ohmsett. Test and measure type of oil with LFS and thickness of the oil with MWR.
- Phase 1 part b – Reassembling and calibrating the sensors on the aircraft in order to perform the flight missions over the tank.
- Phase 2 – Flying over Taylor Energy Platform site in the Gulf of Mexico where the rig sank in 2004 in order to monitor the persistent leak.

This draft report aims to show chronology and the first results of Phase 1 (parts a and b).

Chronology and First Results

- **General Objective**

Characterize the detection of known oil thicknesses and oil-emulsions in a controlled environment, performing multiple tests and calibrations for thermal, optical, and microwave sensors at the National Oil Spill Response Research & Renewable Energy Test Facility (Ohmsett) located at the Naval Weapons Station Earle Waterfront in Leonardo, New Jersey -USA.

- **Specific Objective**

Fototerra's task is to test the sensors: LFS (Laser Fluorosensor) to identify the type of oil on the tank and the MWR (Micro Wave Radiometer) to measure the thickness of the oil.

PHASE 1 part a

Controlled Experiment

- **July 13th** – The aircraft arrived in New Jersey at Monmouth Executive Airport. On the same day, LFS and MWR sensors were disassembled and delivered to Ohmsett. At night, LFS sensor was assembled on the secondary bridge at the south part of the tank (figure 1).

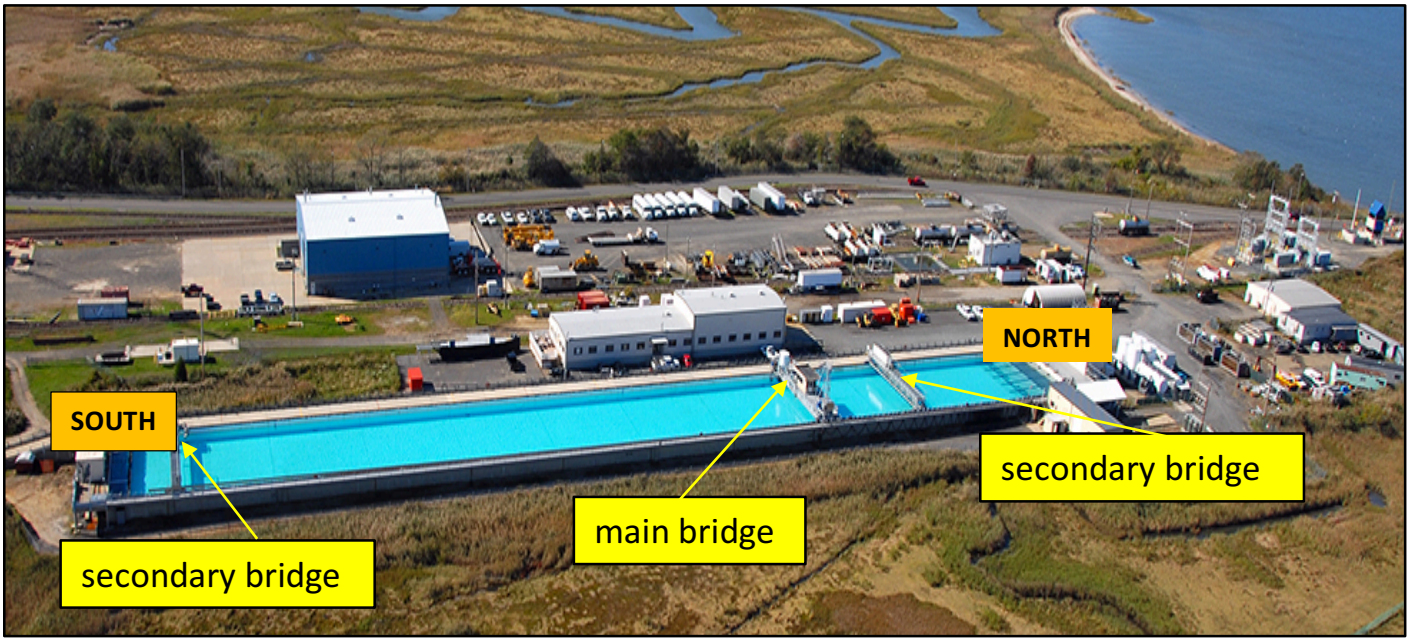

Figure 1 - Testing tank at Ohmsett facilities and main orientations

- **July 14th – LFS TEST** - at 7:30am Fototerra team started operation and calibration on LFS sensor and started to measure clear water for the reference data. This took 45 minutes.
- At 9:55am oil was placed in a contained section below the mirror mounted on the main bridge (figure 2).
- At 10:00am LFS was pointed at the mirror located by the main bridge and Fototerra operators started measurement of oil for about 20 minutes (figure 3).
  - Physical principle: Laser fluorosensor are active remote sensors based on sending pulsed laser light onto the water column and detecting the resulting laser-induced return signal.

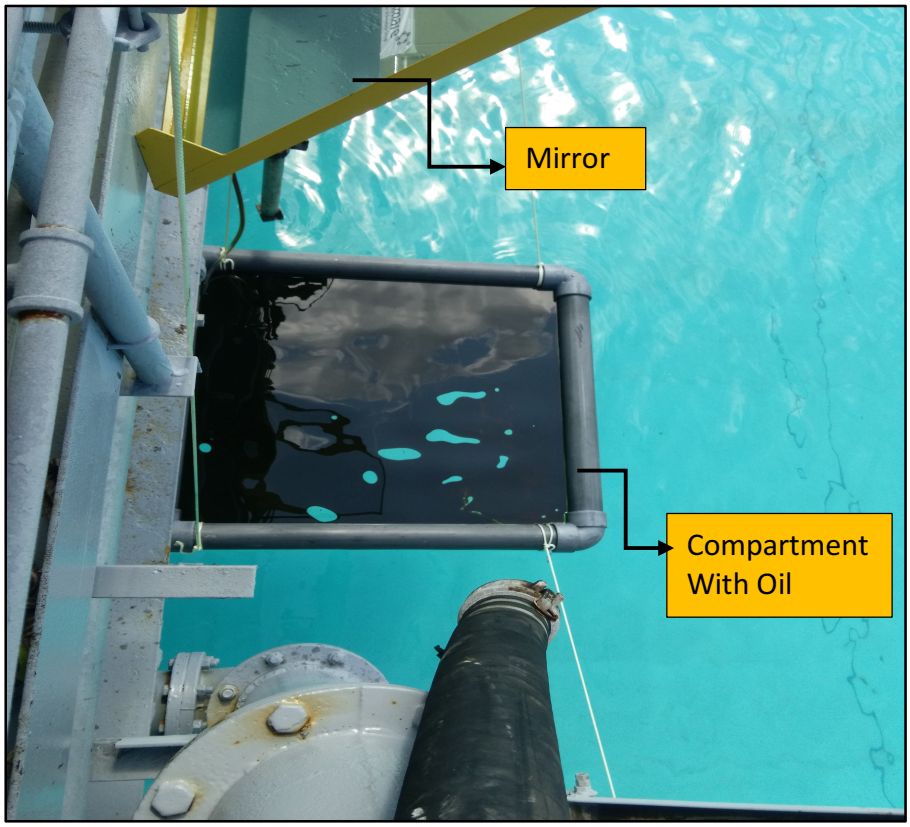

Figure 2 – Main bridge with Mirror and compartment with oil

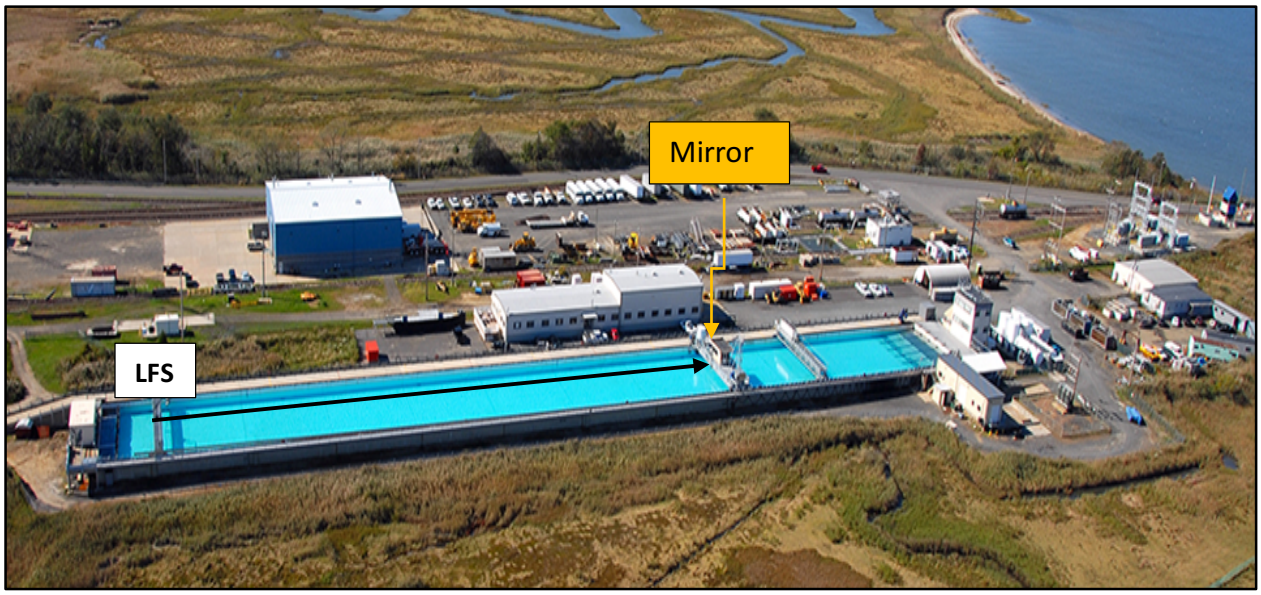

Figure 3 – LFS installed on secondary bridge South

- Data analysis of LFS is based on the contrast between the water and the oil on water surface. The characteristics of the water needs to be known. In a normal flight mission LFS measures clear water, then measures the oil and after measures clear water again. These 3 measurements are part of one single mission.
- During the tank test the LFS, installed in south secondary bridge, was pointed to the mirror in clear water in one mission, was pointed to the mirror that reflected the energy to the oil in the second mission, and again in water in a third mission.
- Figure 4a below shows the response of clear water that was measured for reference and the graphic beside the image is the response of laser in the different wavelengths.
- Figure 4b shows the response of the oil in the compartment.

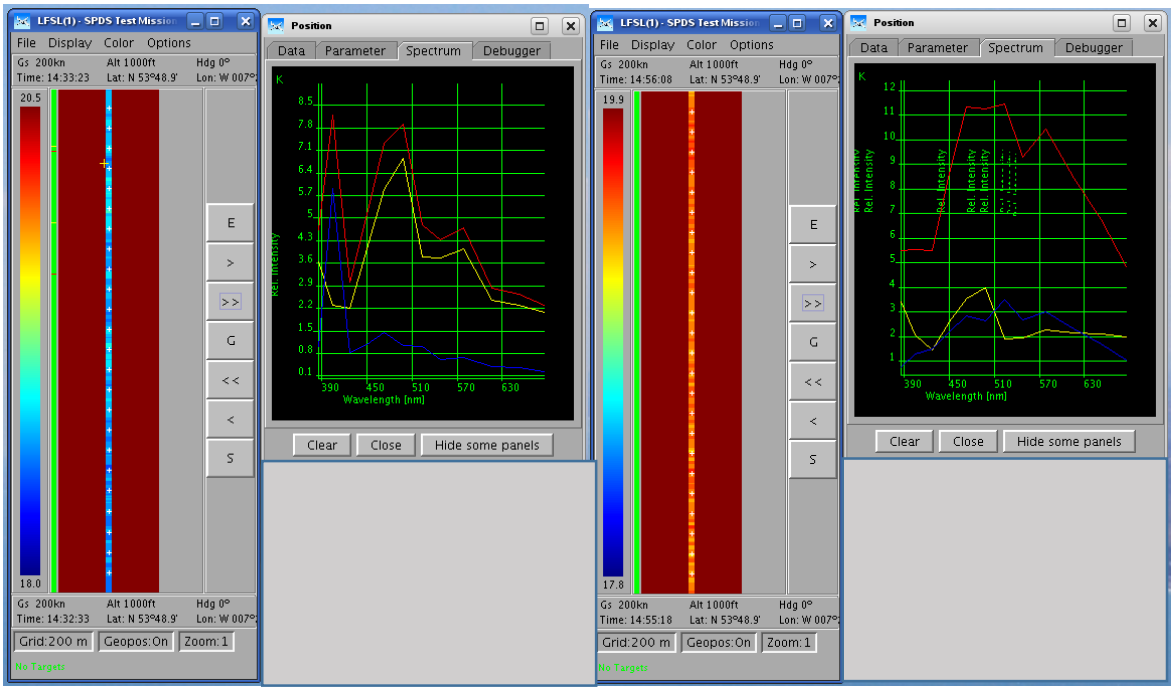

Figure 4a - LFS measurement in clear water

Figure 4b - LHS measurement on oil in compartment

- Sea water as well as crude oils and refined products contain a multitude of various organic molecular constituents. Marine organic matter can be divided into two major classes, namely particulate organic carbon (POC) and dissolved organic carbon (DOC). The colored fraction of DOC or CDOM (colored dissolved organic matter). CDOM consists mainly of humic and fulvic acids and is relevant in remote sensing because of the strong absorption in certain part of the spectrum.

- Chlorophyll a, which is enclosed in phytoplankton and their degradation products, is part of the POC fraction. Chlorophyll a shows a strong absorption of other region of the spectrum. Crude oils and refined products contain aromatics which show high absorption in other region of the spectrum.
- The comparison between figure 4a and 4b indicates what is mentioned above and the responses of both measures are different and spectral signatures are compatible to crude oil on figure 4b.
- In Ohmsett experiment measurements from the clear water have been taken before and after that the oil has been measured. As a consequence, the data of the clear water surface and the data from the oil were stored in different mission databases, and our IT team had to compilate all missions in one only mission data for further processing.
- The result after the processing is the one below in Picture 5:

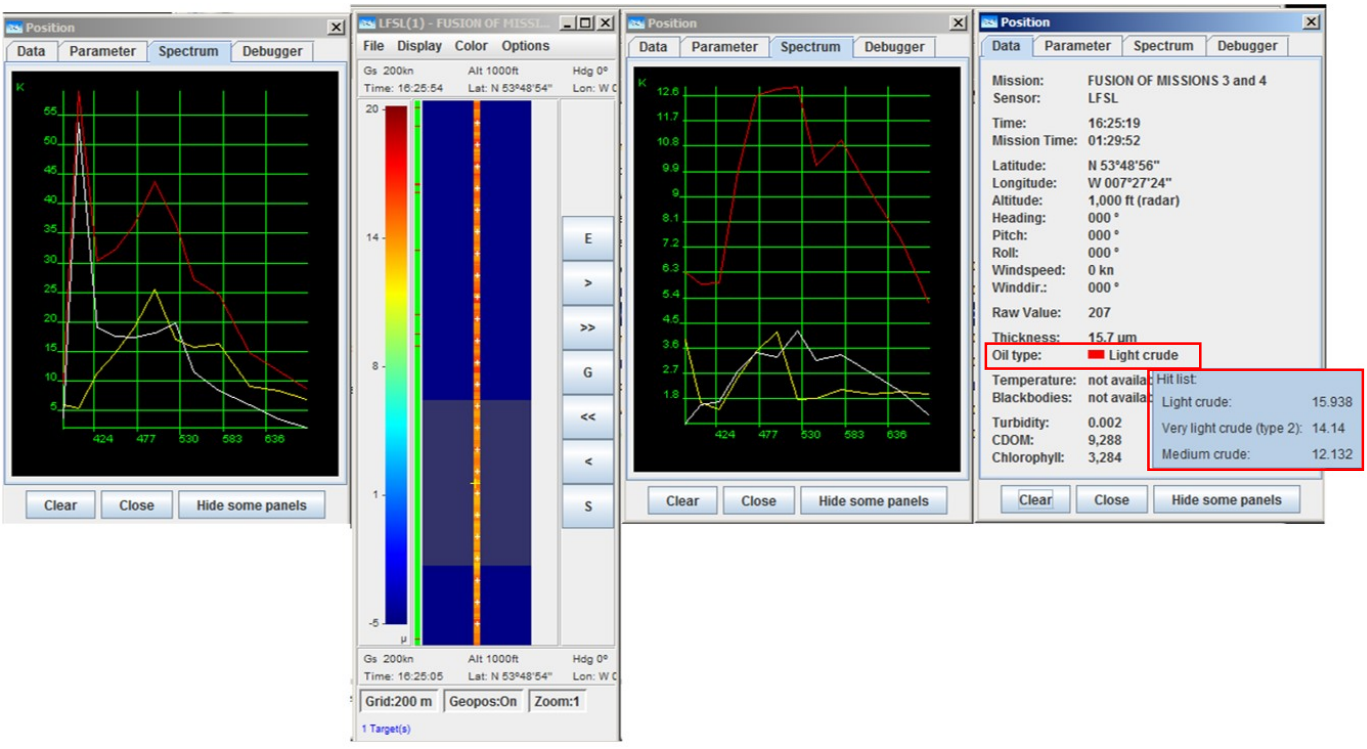

Figure 5 – After processing LFS data fusion of the missions

Analyzing the graphics generated by the processing in Fototerra the spectral signature of the oil (graphic on right side) is consistent with the signature of a **LIGHT CRUDE OIL** according to the API (American Petroleum Institute) classification.

July 15th – **MWR TEST** – MWR sensor was installed on the main bridge (Figure 6) at 9:25am Tank begun to be cleaned at 10:40am. At 10:47am MWR sensor measured clear water for reference (Figure 7).

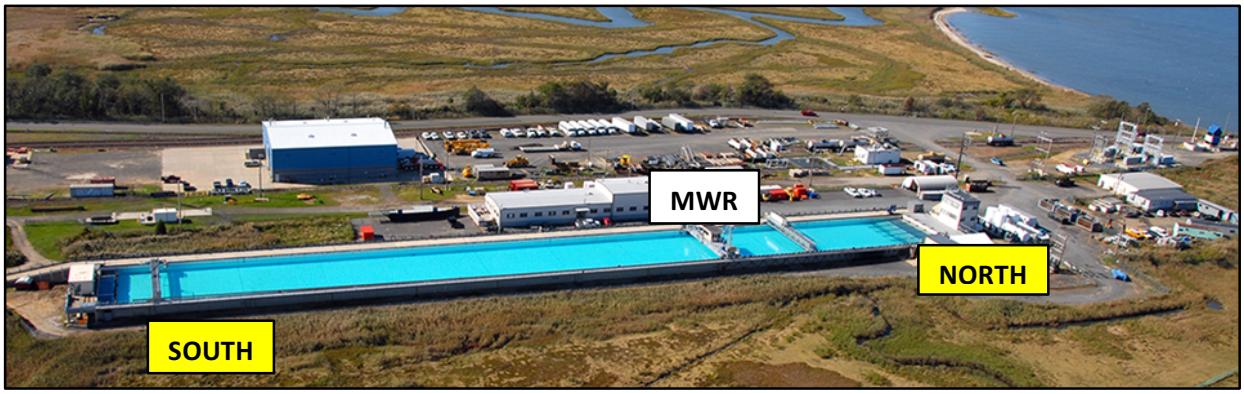

Figure 6 – MWR sensor installed in main bridge

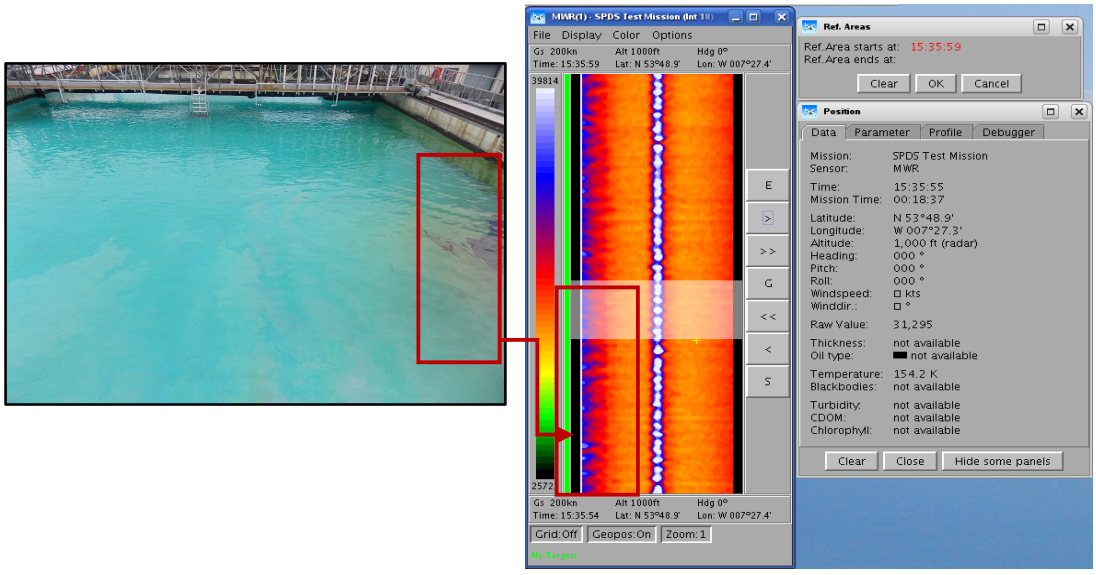

Figure 7 – MWR operation for clear water reference. OBS: some interference of oil in water by the borders of the pool while was being cleaned and was captured by MWR (red square).

At 10:57am measures with MWR started when main bridge approached the the oil released (Figure 8).

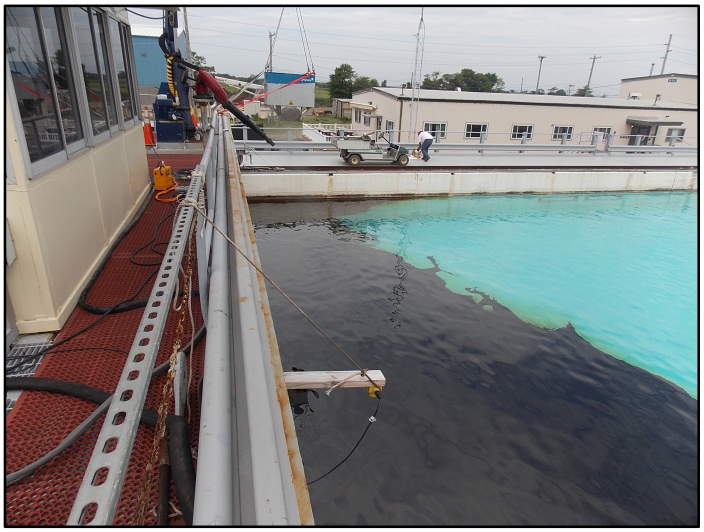

Figure 8 – Main Bridge approaching the oil and MWR starting to measure

- Physical principle: MWR System is a passive microwave sensor which can be used for near-range remote sensing of thick areas of oil spills. Microwave radiometry is based on remote measurements of the thermal microwave emission from the specific medium of interest.
- Unlike in the thermal IR range, oil spills appear as brighter objects in the microwave region relative to the oil-free sea surface. This is caused by the higher real and imaginary parts of the complex dielectric constant for water than for oil. The Fresnel relations thus result in a negative reflectance contrast and a positive emissivity contrast between oil and water in the microwave region.
- The first measure is the intensity (figure 9) that will be transformed in gray scale (figure 10). In the gray scale map, it is possible to know the thickness of the oil by clicking on any point of the map. The brighter area is the thicker part (figure10).
- Results during the tests have shown that **thickness varied between 0,1 mm and 2,5 mm**.

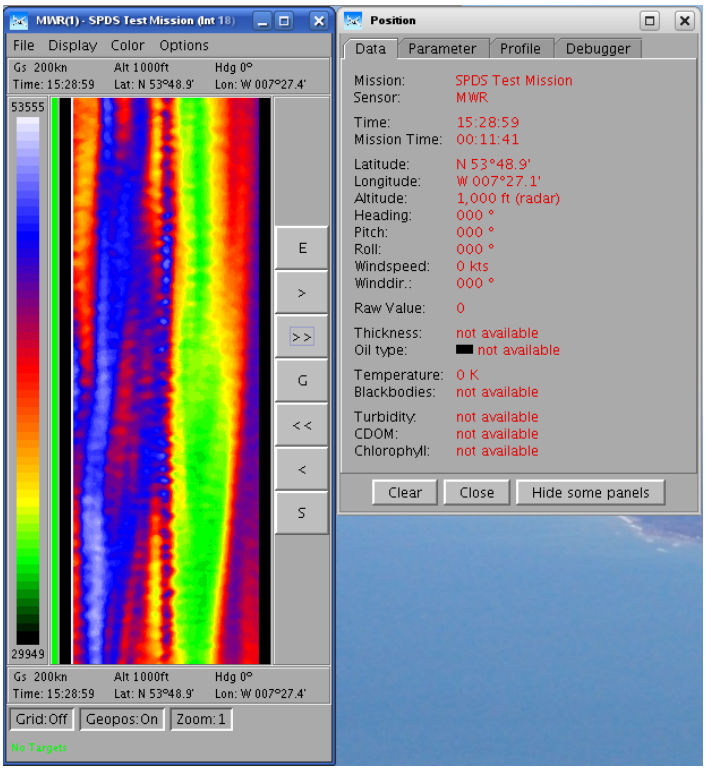

Figure 9 – MWR intensity measurement at 10:48 am

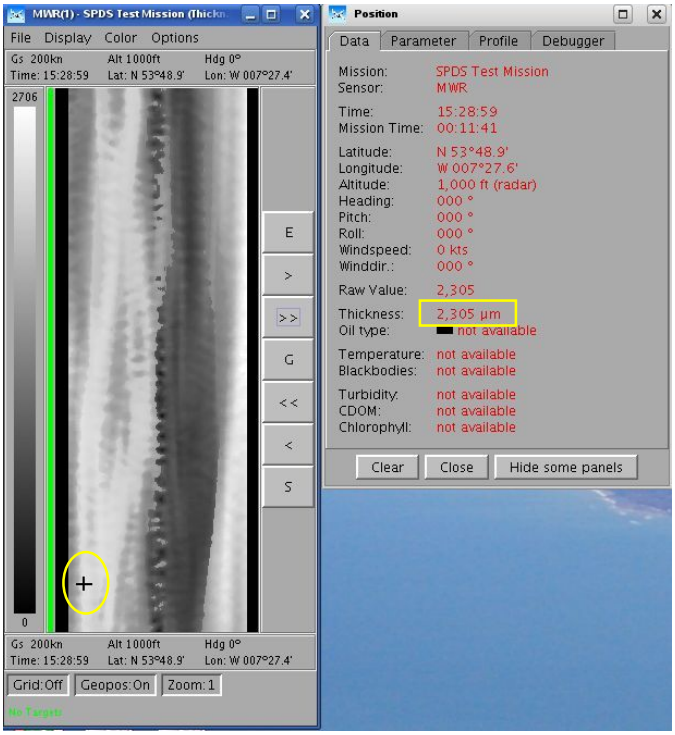

Figure 10 – Gray scale of the measure indicating thickness of 2,3 mm on brighter part

While the bridge was moving towards the oil released on the tank, data was captured. The next 6 screenshots are related to data measured during time of the test. The position of the cursor that is pointing to brighter or darker points and beside the indication of the oil thickness in this point.

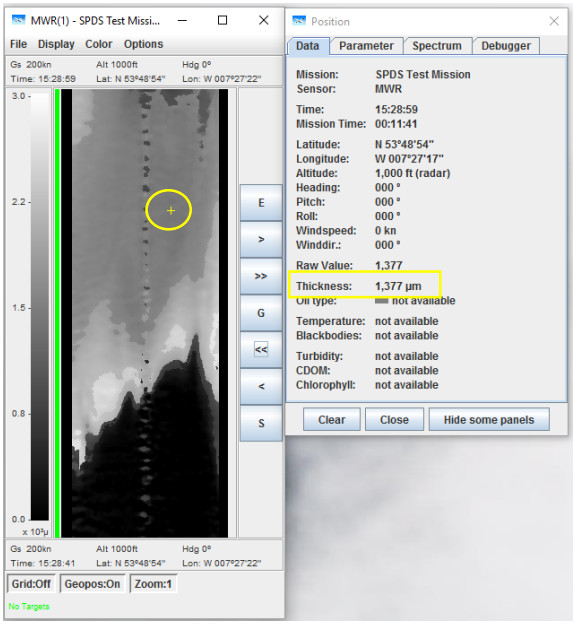

Figure 11 – In gray scale the cursor (yellow cross) is the point that indicates thickness of 1.3 mm.

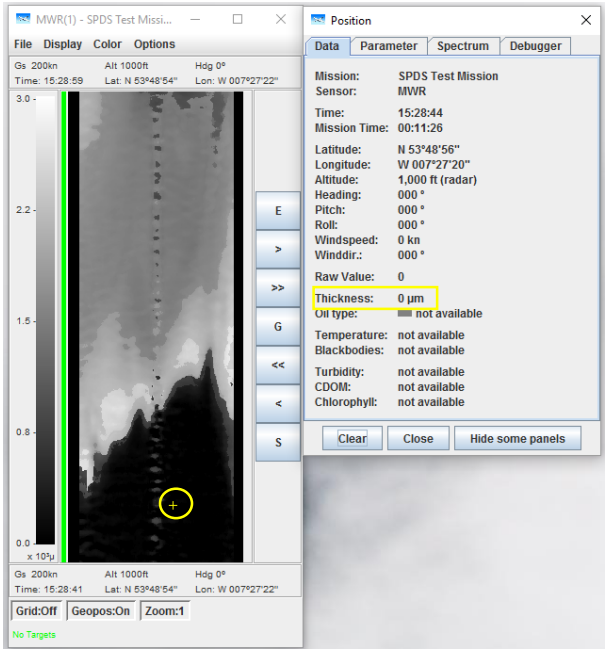

Figure 12 – In gray scale the cursor (yellow cross) is the point where thickness of 0 mm that means clear water.

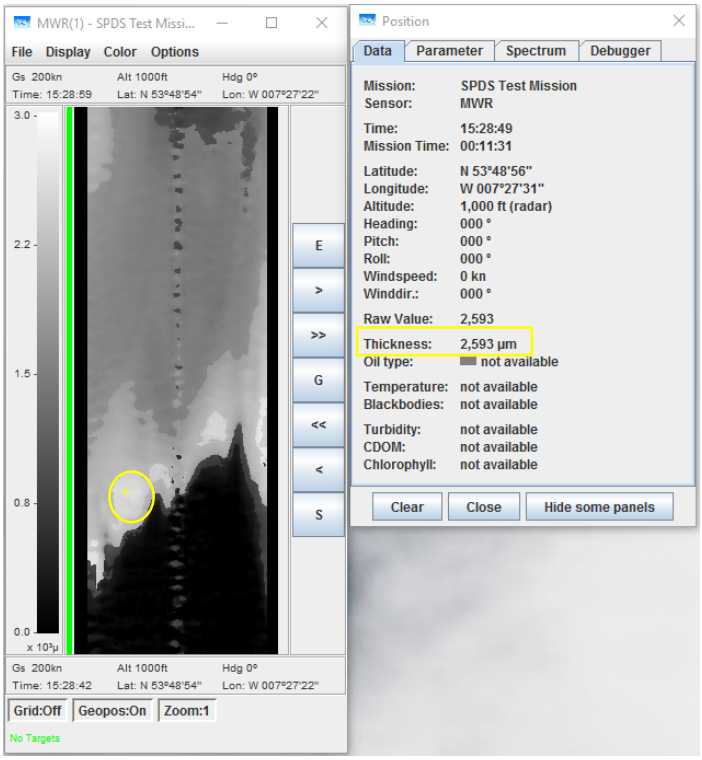

Figure 13 – In gray scale the cursor (yellow cross) is the point that indicates thickness of 2.59 mm.

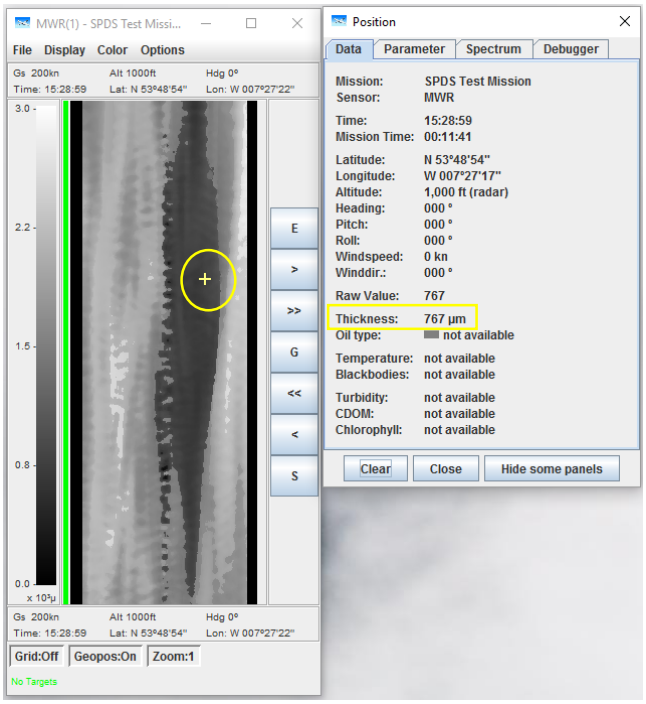

Figure 14 – In gray scale the cursor (yellow cross) is the point that indicates thickness of 0.767 mm.

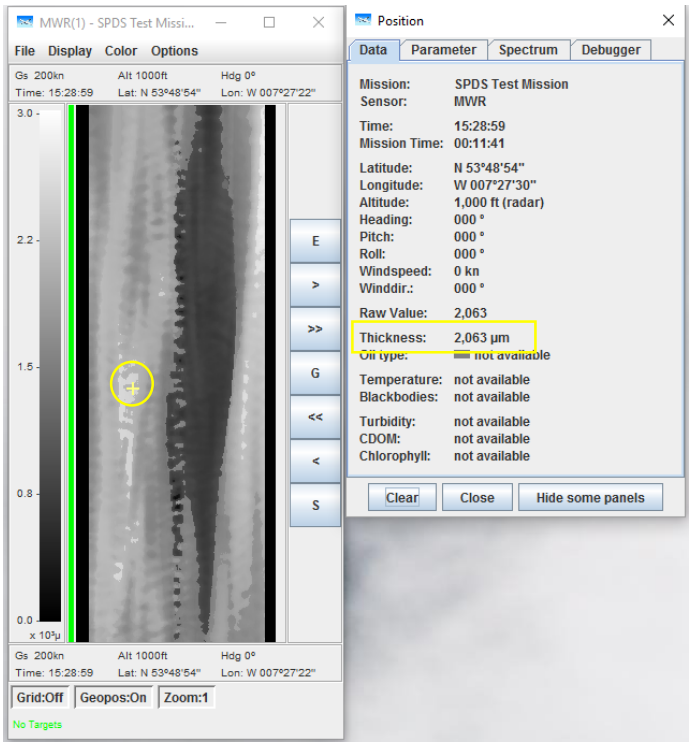

Figure 15 – In gray scale the cursor (yellow cross) is the point that indicates thickness of 2.063 mm.

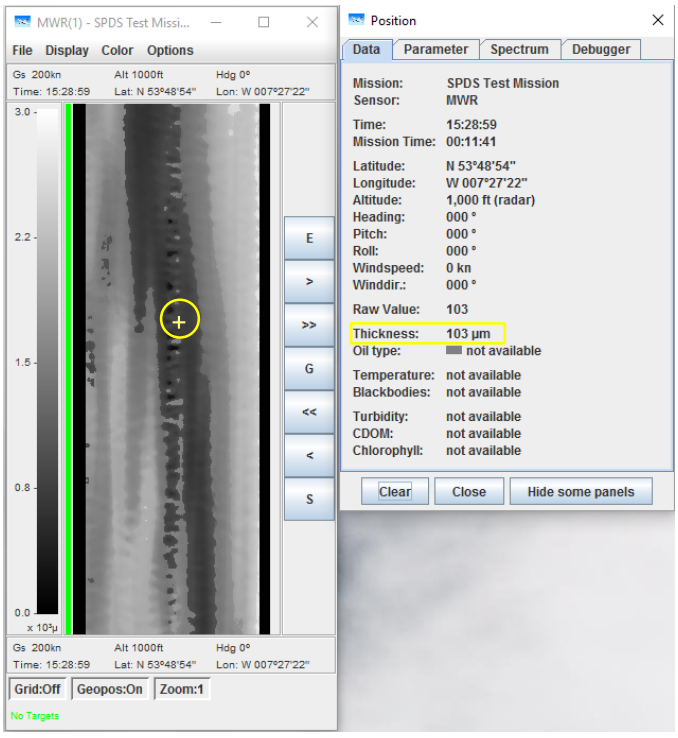

Figure 16 – In gray scale the cursor (yellow cross) is the point that indicates thickness of 0.103 mm.

PHASE 1 part b

Flying Test over the Tank – 1st Flight

- **July 18th** – The EMB-110 Poseidon equipped with MEDUSA system overflew the tank at a minimum safe altitude of 1000ft and at a minimum safe speed of 120 kts. Under this conditions the plane overflew the tank in about 3 sec.
    - The contained dimensions of the tank represented a constraint and a challenge for the sensor calibration and the data acquisition, however the system could still be able to acquire enough data to be processed and analyzed.

On the 18th of July at 6:45pm the aircraft overflew the tank three times, (see plan trajectory figure 17). The area was imaged with the following sensors: IR, UV, IRUV, MWR and VIS (Figure 18).

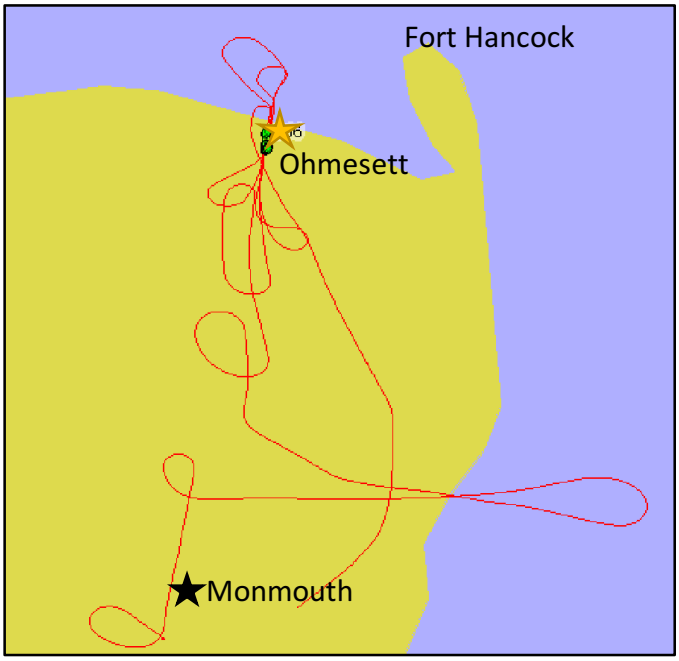

Figure 17 – Flight trajectory on the 18th of July

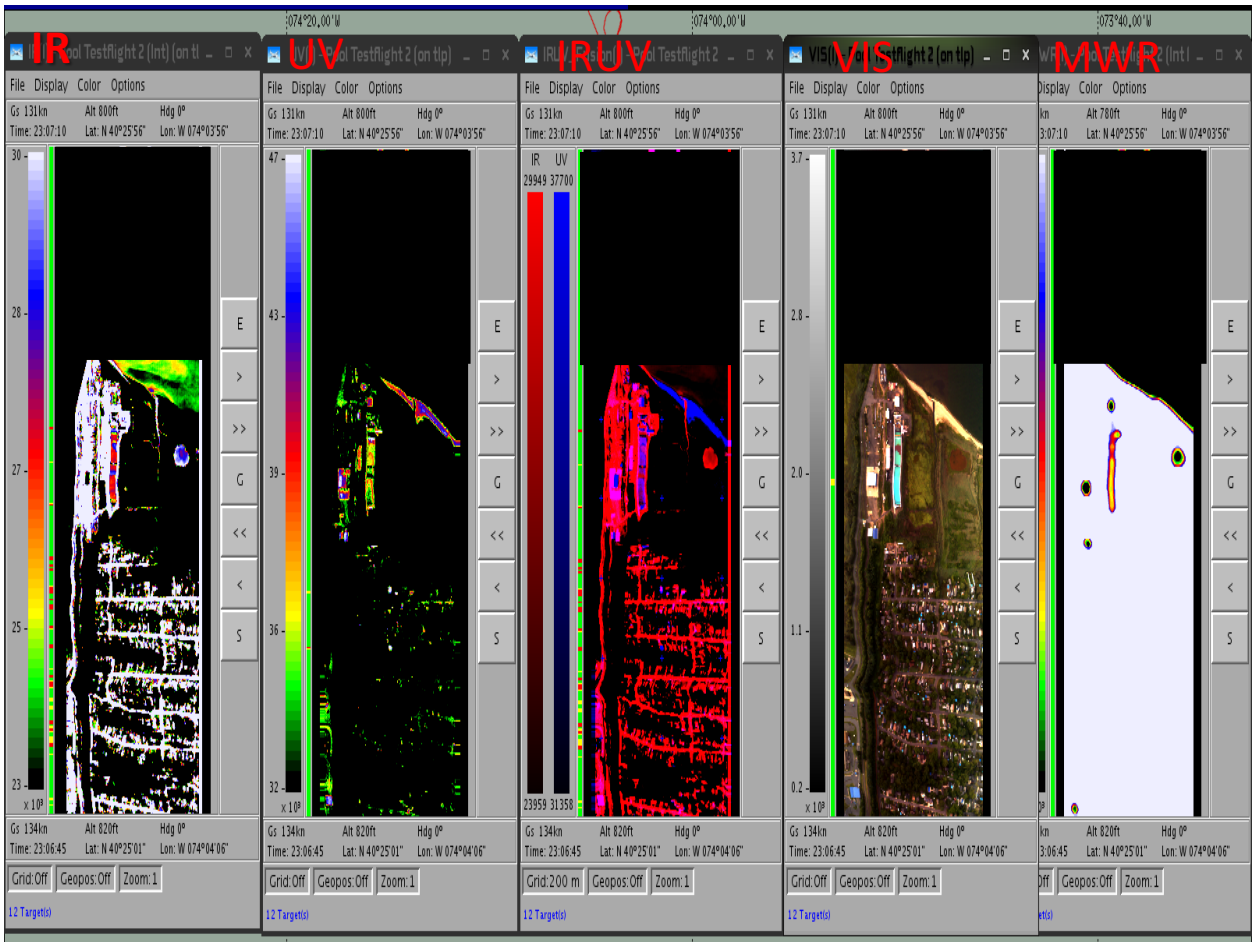

Figure 18 – Set of images captured on the flight of 18th of July

The images above were put side by side for comparison between sensors. Below we can find a zoom of each one Figures 20, 21 and 22. Figure 19 shows a photo taken from the plane on the same time as Poseidon platform was imaging the testing tank.



Figure 19 – Photo from testing tank at Ohmsett taken from the aircraft on 18th of July at 6:45pm

VIS Image – Visible Linner Scanner

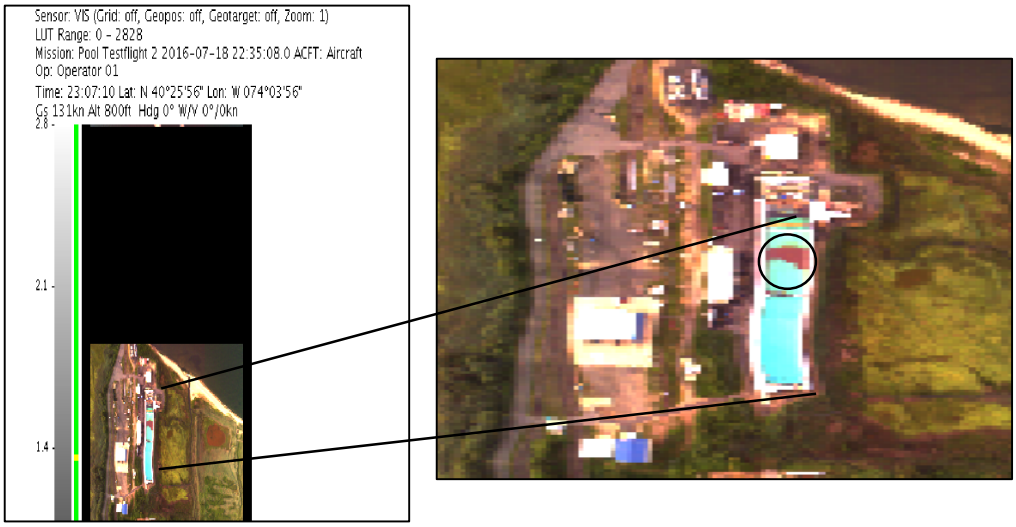

Figure 20 – VIS image from testing tank on the 18th of July flight

Visible Line Scanner have been established as auxiliary tool for various airborne remote sensing applications as for example airborne maritime surveillance.

VIS is a ruggedized, lightweight remote sensor for earth observation at visible wavelengths. In maritime surveillance, the system is used for the acquisition of highly-resolved georeferenced red/green/blue composite images. These images can be used for documentation.

The VIS Line Scanner consists of the power entry module, environmental and temperature controls of the sensor, camera module, and sensor processor.

IR Image

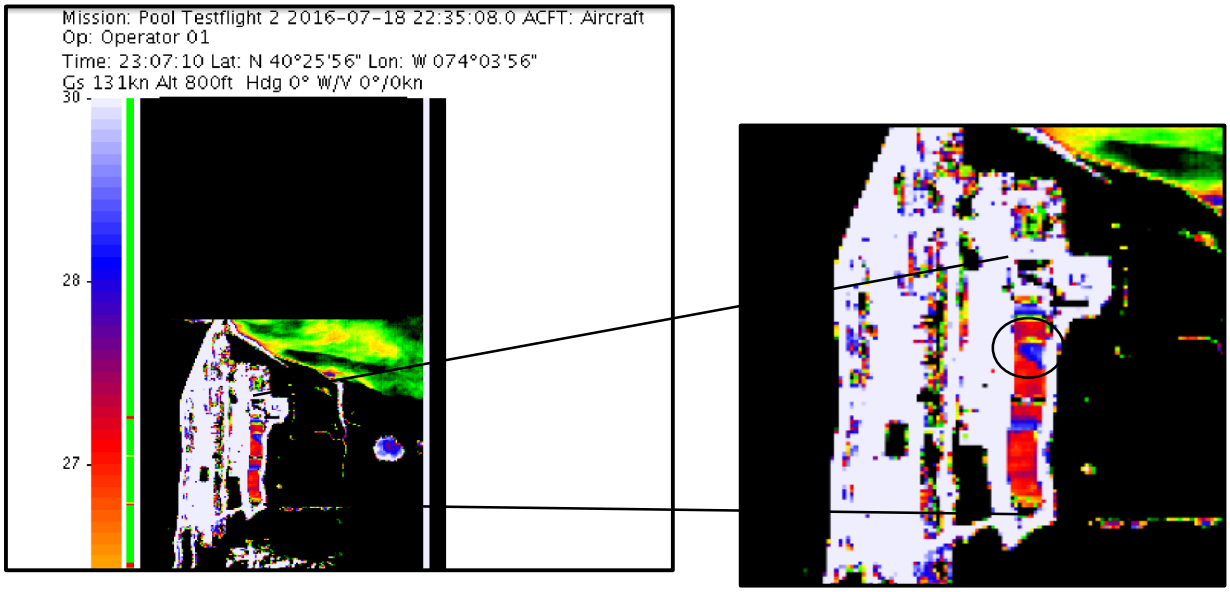

Figure 21 – IR image over the testing tank on 18th of July flight

R/UV Image

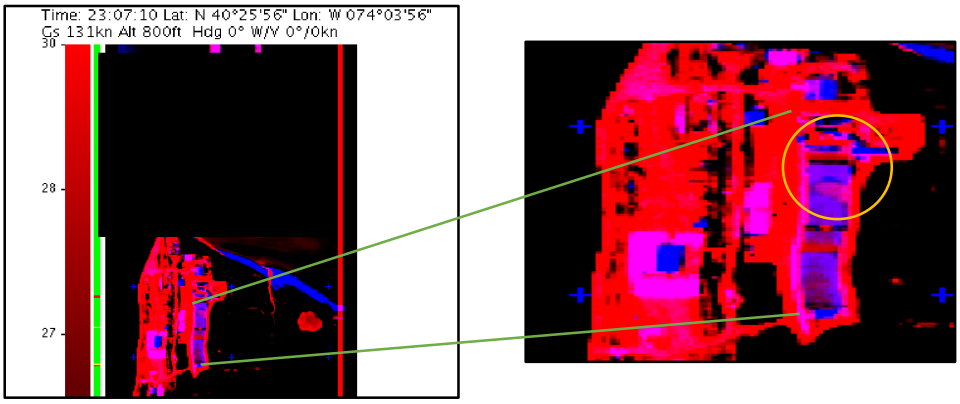

Figure 22 – IR/UV fusion image over the testing tank on the 18th of July flight

An IR/UV Line scanner is a passive bi-spectral sensor which is usually sensitive in the thermal infrared and the near ultraviolet. In the following both aspects, IR and UV remote sensing of marine oil spills, are

described. In principle, IR remote sensing of oil spills can be carried out in three spectral windows of low atmospheric absorption, namely in the near IR between 1 and 3 µm, the mid IR between 3 and 5 µm and the thermal IR between 5 and 8 µm.

The thermal IR characteristics of an oil spill are governed by environmental influences, specific properties of the involved oil and the spatial distribution of oil thickness. Thermal IR sensors can be operated at day and night time.

Flying Test over the Tank – 2nd Flight

July 19th – Aircraft departed from Monmouth Executive Airport at 2:45pm and overflew the testing tank at 3:00pm.

Figure 23 shows the flight trajectory on this flight since tak -off at Monmouth to Ohmesett. This flight plan is recorded on board Medusa System console.

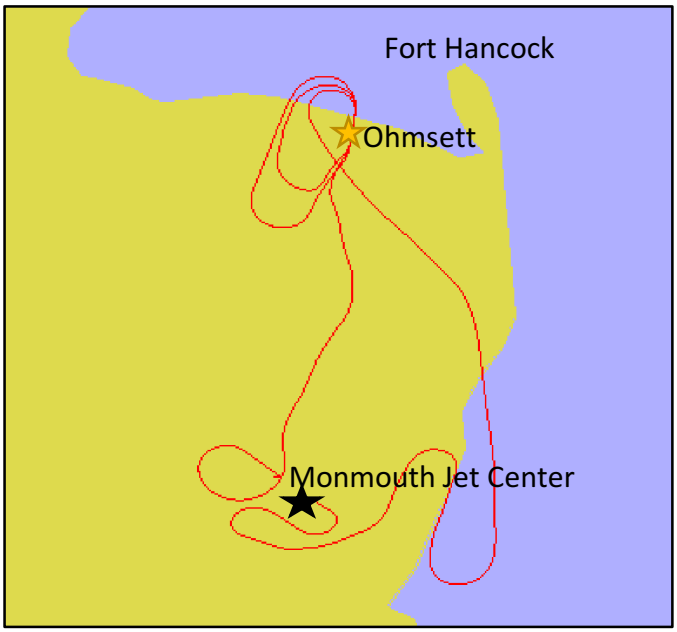

Figure 23 – 19th of July flight trajectory

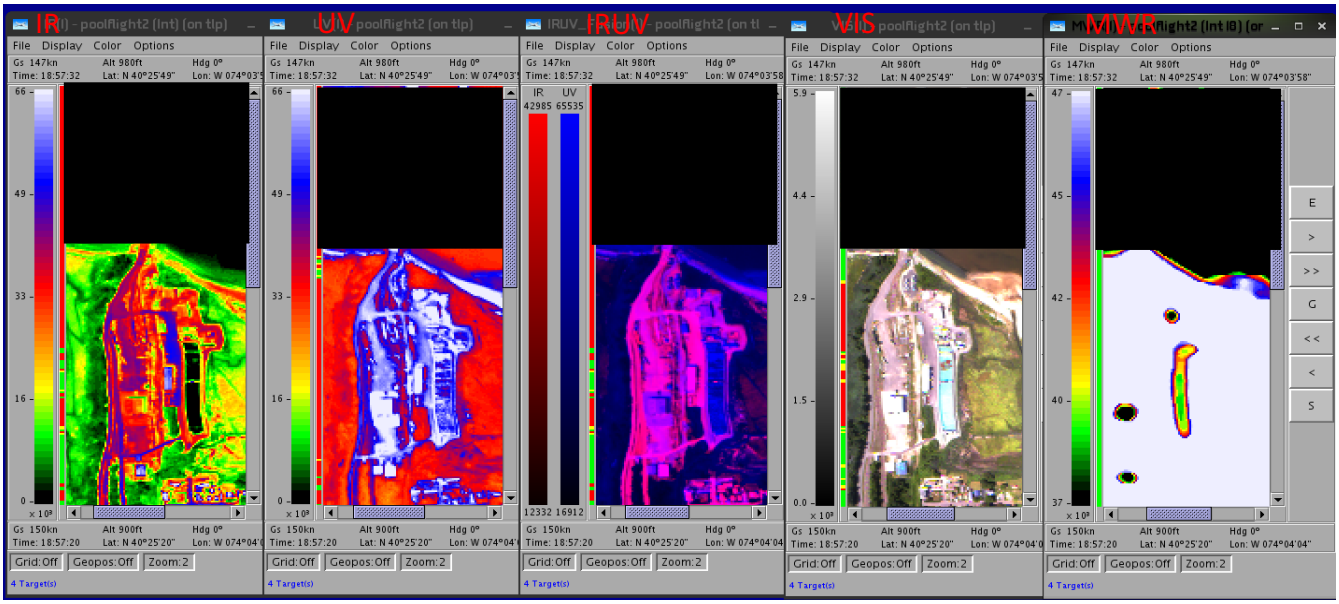

Figure 24 – Set of images during the 19th of July flight

Flying Test over the Tank – 3rd Flight

July 21st - morning flight – Aircraft/ Poseidon Platform with Medusa system departed from Monmouth Jet Center at 7:15am and overflew the testing tank at 7:35am.

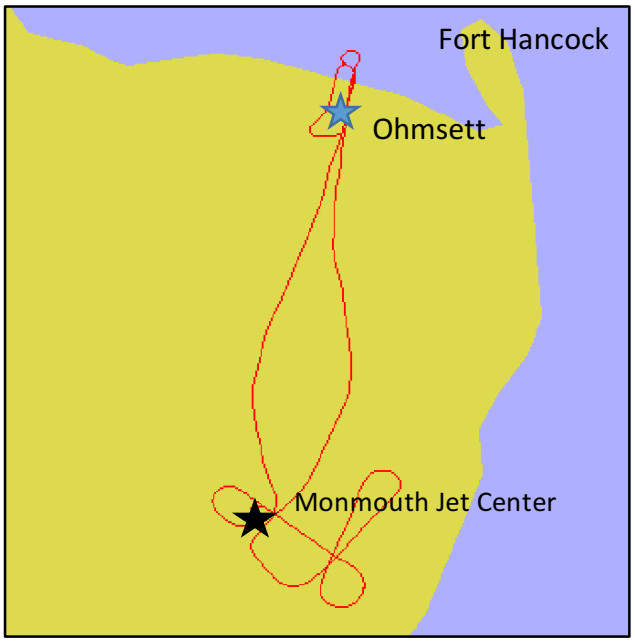

Figure 25 – Flight trajectory on 21th July by the morning

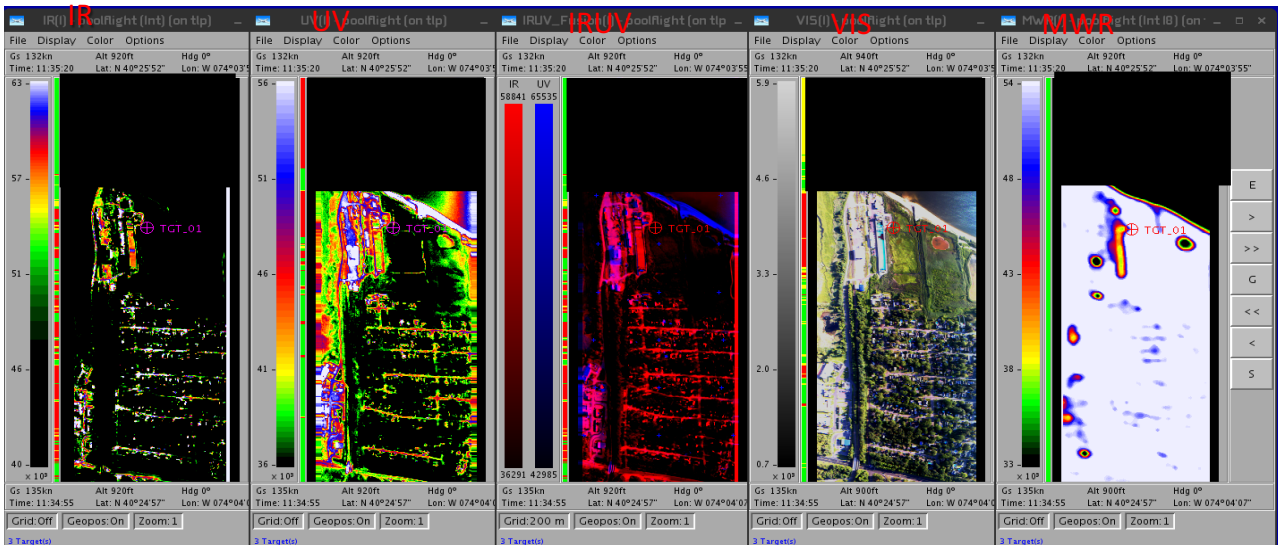

Figure 26 – Set of images over the testing on 21st July at 7:30am

VIS Image – Visible Linner Scanner

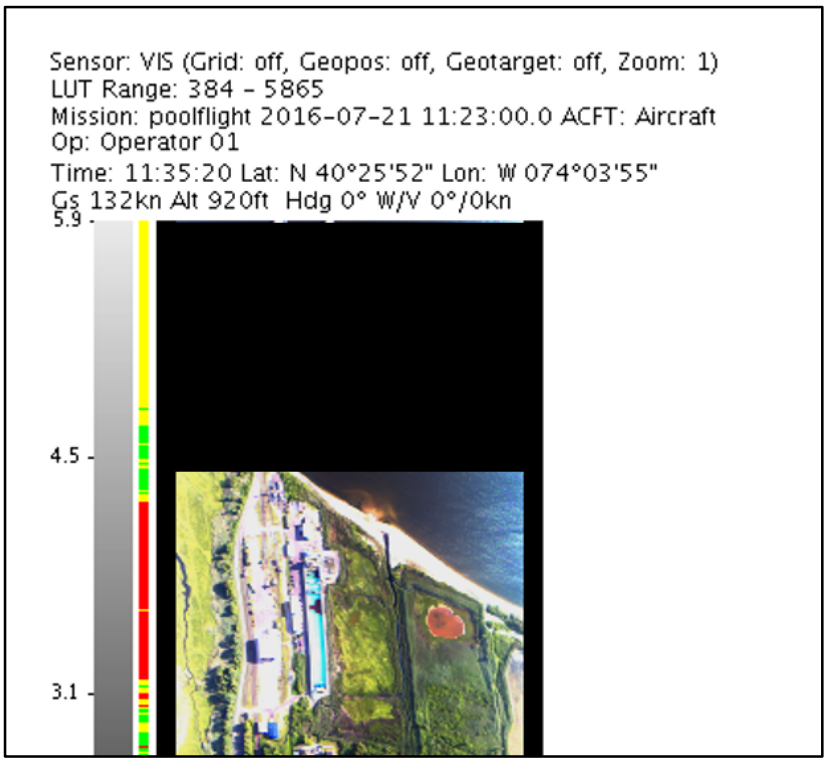

Figure 27 – Vis image from flight over the tank on the 21st of July 7:30am



Figure 28 – Zoom of Vis image from flight over the tank on the 21st of July 7:30am

IR image

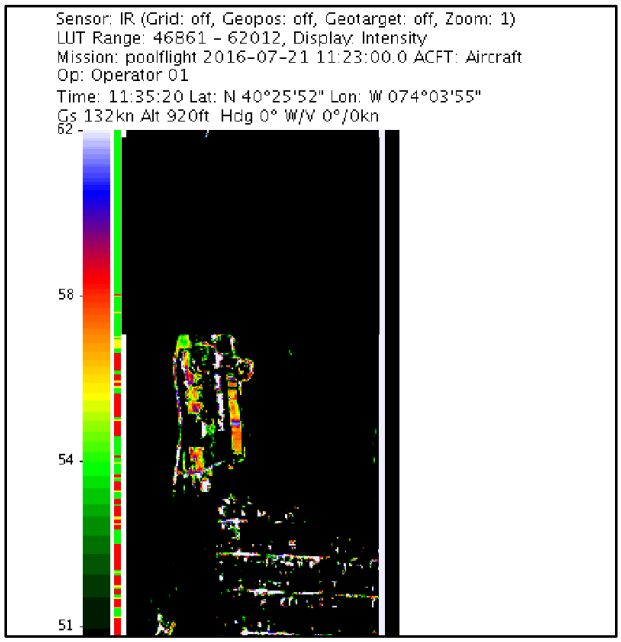

Figure 29 – IR image from flight over the tank on the 21st of July 7:30am

UV image

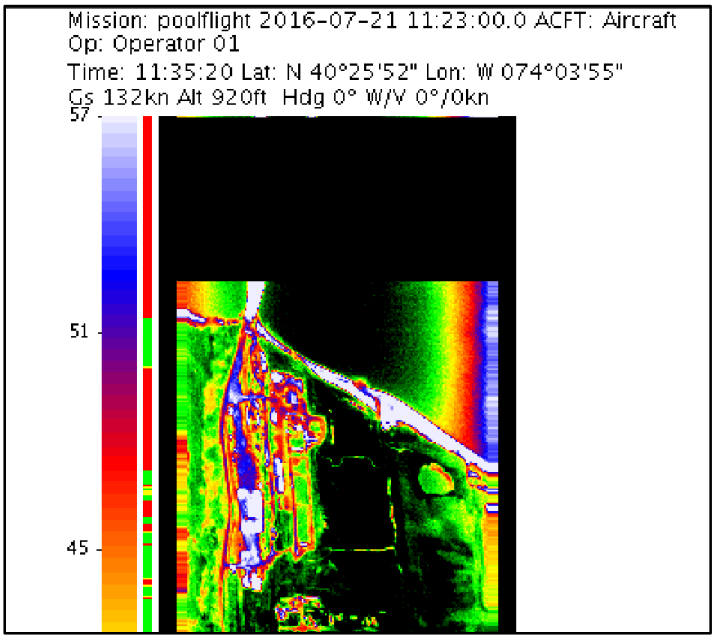

Figure 29 – UV image over the tank on flight 21st of July at 735am

IR/UV image

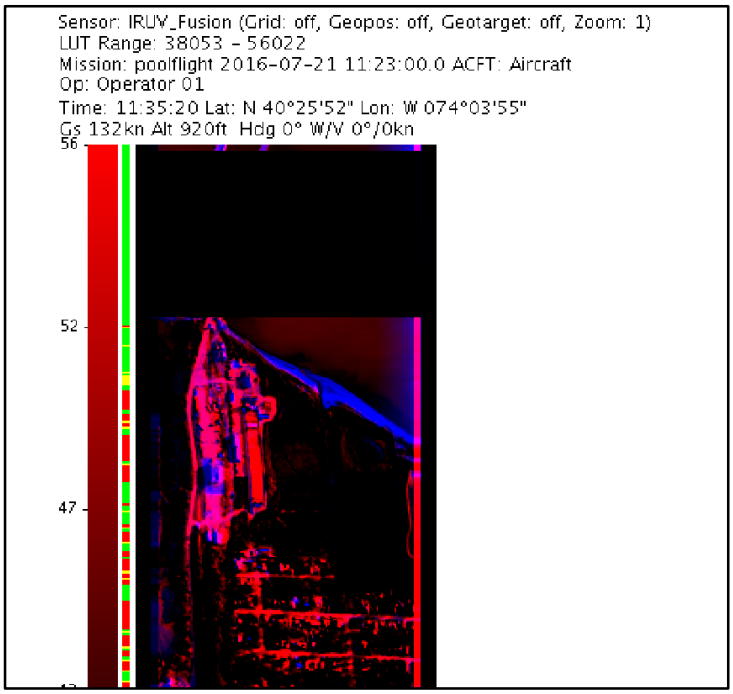

Figure 31 – IRUV image from flight of 21st of July 730am

MWR image

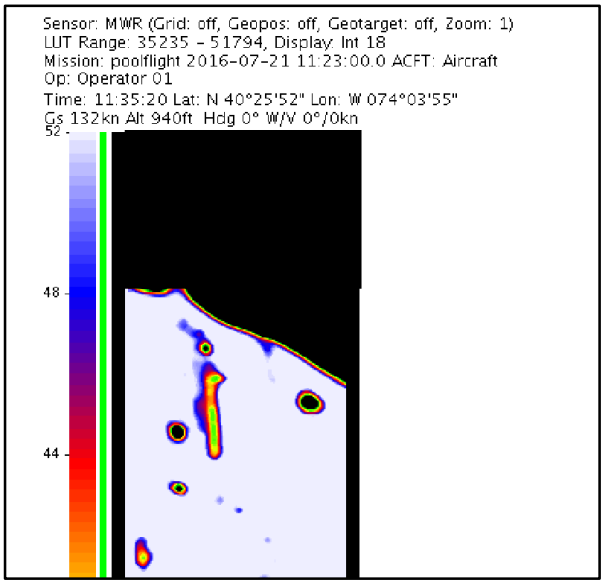

Figure 32 - MWR image from flight on 21st of July at 7:30am

Flying Test over the Tank – 4th Flight

July 21st - afternoon flight – Fototerra team received BSEE/NOAA/EPA/Coast Guard team (figure 33) at Monmouth Executive Airport to present the aircraft and Medusa system (figure 34). Poseidon platform departed from Monmouth Executive Airport at 2:45 pm and overflew the testing tank at 3 pm.



Figure 33 – BSEE/NOAA/EPA/Coast Guard team at Monmouth Jet Center



Figure 34 – BSEE/NOAA/EPA/Coast Guard team on site demonstration



Figure 35 – BSEE/NOAA/EPA/Coast Guard team on site demonstration

On the 21st of July at 3 pm Poseidon platform flew over the tank with the flight trajectory on Figure 36.

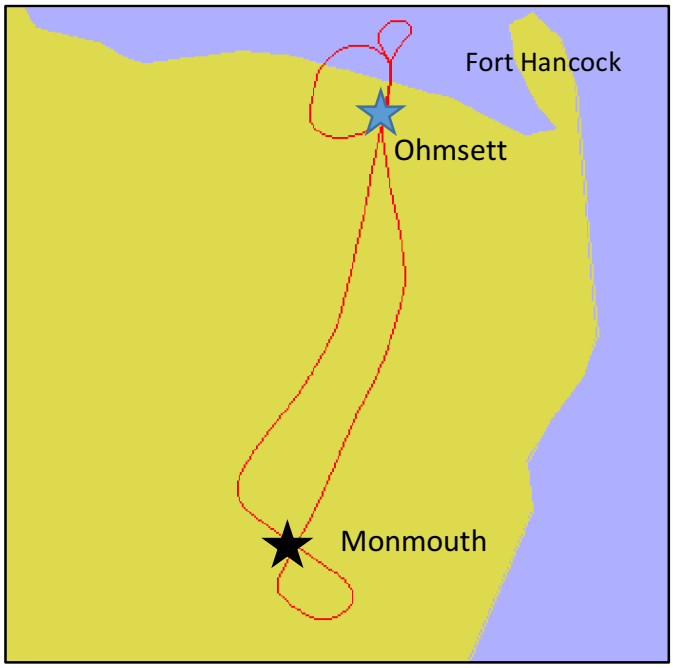

Figure 36 – Flight trajectory on the 21st of July in the afternoon

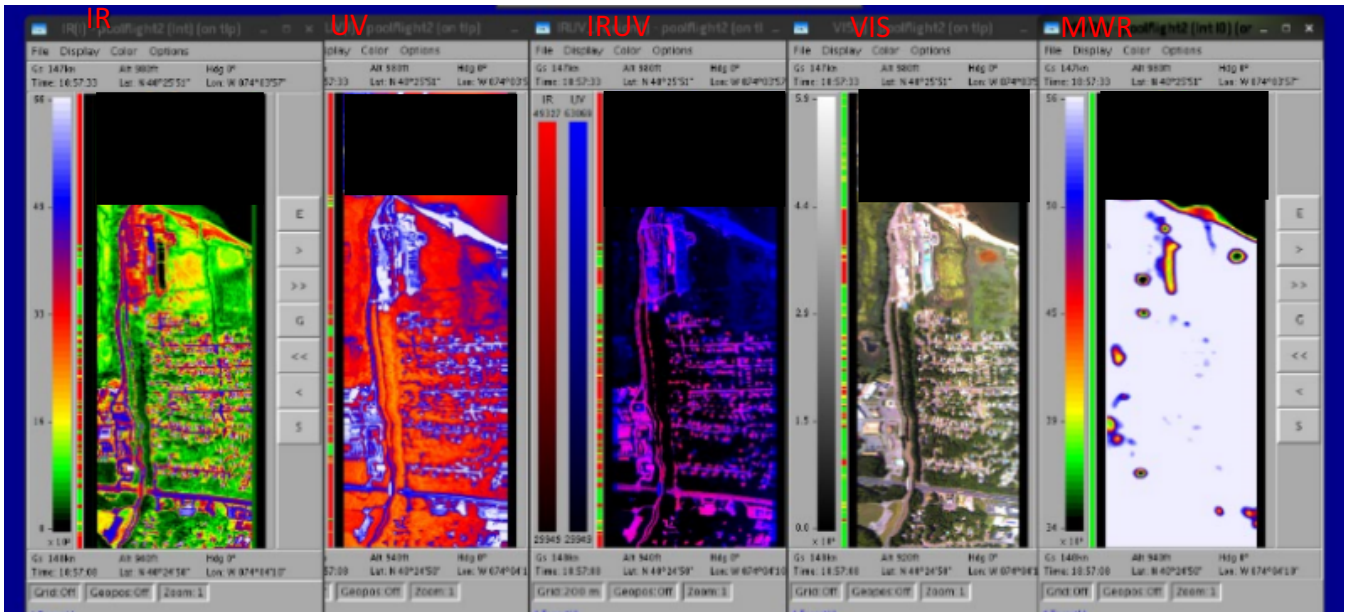

Figure 37 – set of images captured during afternoon flight over the tank

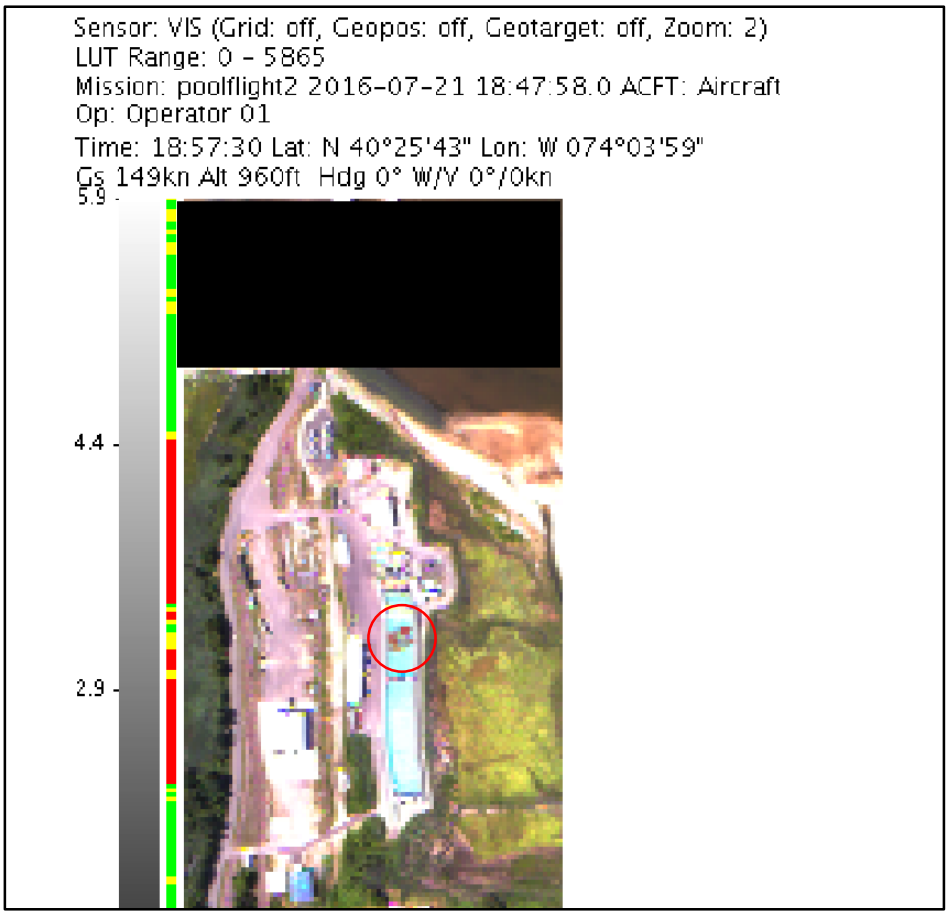

Figure 38 – VIS image in zoom on the 21st of July afternoon flight the oil on the tank is degradating

Defining Target tool

Medusa system has an interesting tool called *defining target*. Target can be defined by selecting it in an image that has a better definition, usually VIS. The target will be selected automatically in all the other images with the same coordinates.

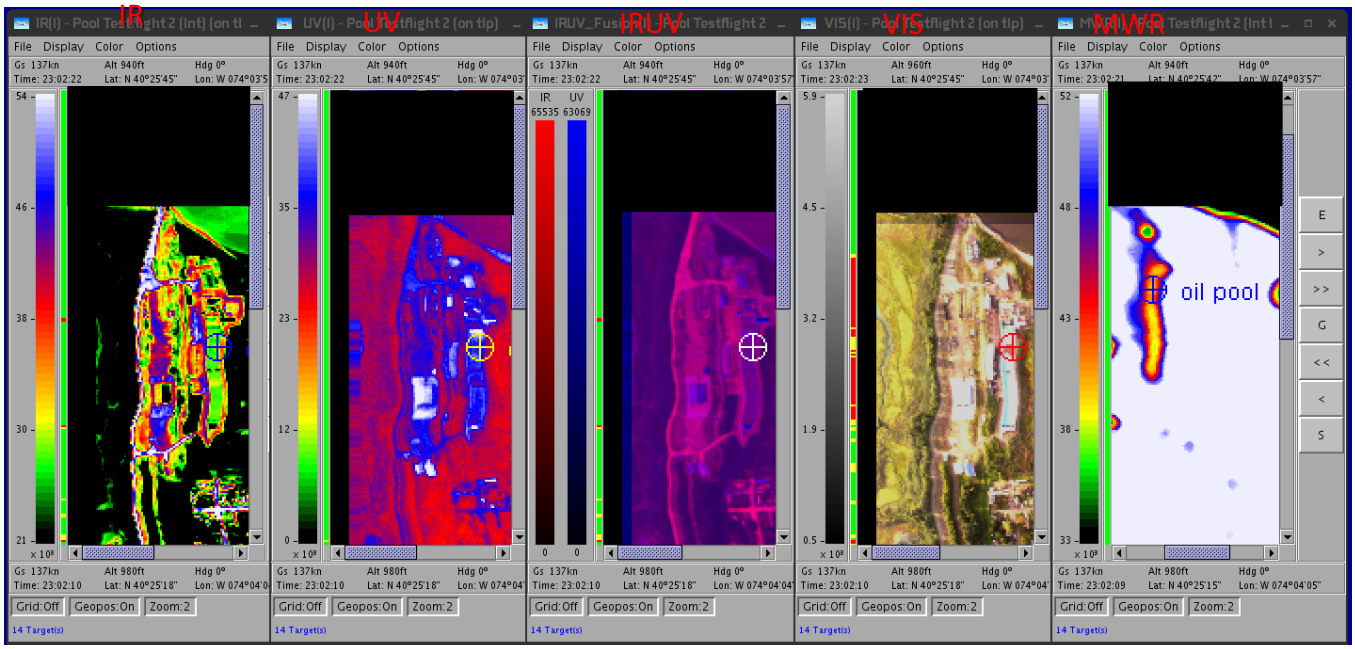

Figure 39 – Set of images over the tank and defining target tool

Conclusions

Between the 10th and the 21st of July tests were carried by BSEE and NOAA in order to understand oil behavior during its cycle of life using remote sensing tools and other ways of collecting data. This effort to enhance the ability to detect and measure oil spills offshore, have begun a study of multiple remote sensing systems at BSEE's Ohmsett facility. Fototerra was invited to take part of the project with its own airborne remote sensing platform Poseidon with Medusa system on board. Medusa system is an integrated multiple sensors system that can determine position, area of the spill, type of oil and thickness among other capabilities.

On the test at the Ohmsett tank, two sensors were installed, the LFS sensor to determine type of oil and the MWR sensor to determine the thickness of the oil. Both tests sensors responded appropriately with the expectations. The LFS determined clearly the classification of the oil and the MWR determined with precision the thickness of the oil.

Overflights, despite the challenging contained environment of the 200m by 20m test tank, provided very good results and the sensors from Medusa were imaging the area of the tank consistently.

In this draft report the first results are being shown as well basic physical principles of the sensors, the intention is to extend the results in the final report, adding the outcome from Phase 2 test – Flying over Taylor Platform, which is the perfect environment for Poseidon Platform/Medusa System shows all its potential.

Attachment E. USF Laboratory Report

Laboratory Analysis of Oil Slick Thickness

Final Report

Submitted to:

National Oceanic and Atmospheric Administration
Office of Response and Restoration
Attn: Lisa DiPinto and
George Graettinger

Submitted by:

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Jeffrey Morris, PhD
Jamie Holmes, MS

"The findings and opinions expressed in this report are solely those of the authors and do not necessarily reflect the views and policies of the Bureau of Safety and Environmental Enforcement, nor does mention of the trade names or commercial products constitute endorsement or recommendation for use."

January 17, 2018

1. Introduction and Objectives

The post-*Deepwater Horizon* (DWH) Oil on Water Group has focused on synoptic sampling to ground-truth advances in oil detection using remote sensing technology. Despite the inherent heterogeneity of oil slicks, characterizing slick thickness is an important aspect of on-the-ground data collection. Methods for measuring slick thickness are limited, and the accuracy and precision of the methods used are not well-established.

In this controlled laboratory study conducted at the University of South Florida in St. Petersburg, Abt Associates, together with collaborators from Water Mapping LLC and the National Oceanic and Atmospheric Administration, assessed three methods to measure oil slick thickness. We prepared oil slicks of known volumes that could be reasonably replicated, with the oil spread across a small measurement area. This allowed us to replicate slicks with a known average thickness. We then used three different methods to measure that average thickness, allowing us to determine the accuracy and precision of each measurement method.

The three different slick thickness measurement methods that we tested in this laboratory study included (1) the sorbent pad method, (2) the dip plate method, and (3) the Water Mapping sampler method. We report method performance parameters for these three methods using different oil types across a range of thicknesses. Ultimately, by understanding the performance of these methods across different thicknesses using different oil types, we can better interpret the data collected in the field.

2. Methods

2.1 Oil Types

We tested four different oil types during this study:

1. Fresh (unweathered) Canadian oil sands (a.k.a. tar sands) crude oil
2. Fresh (unweathered) West Texas intermediate crude oil
3. Field-collected weathered and emulsified slick oil from DWH (DWH Slick A)
4. Field-collected weathered and emulsified slick oil from MC20 (Taylor Energy oil spill site).

2.2 Preparing Oil Slicks

We prepared all replicate oil slicks in 9.5-L (2.5-gal) glass tanks divided into two 15 cm x 15 cm (6 in x 6 in) areas using a Plexiglass divider. To prepare the oil slicks, we filled each tank with seawater to an approximate height of 15 cm. We then carefully transferred a specific volume of oil (depending on the desired slick thickness – see Table 1) onto the surface of the water for each area (Figure 1). We estimated the volume of oil transferred by weighing the oil and converting to a volume using the oil's density. We determined the oil density for each oil sample using a pycnometer.

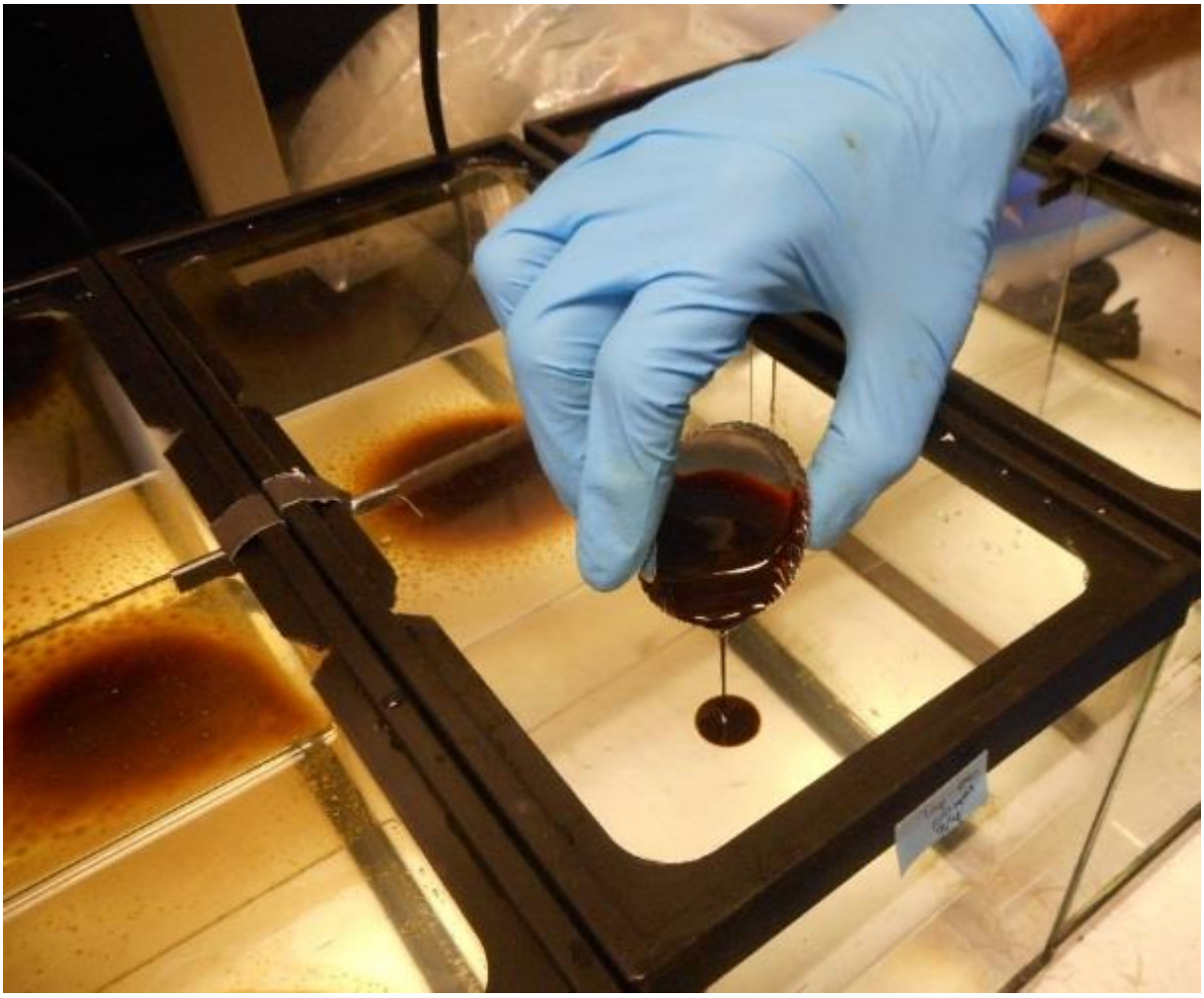
Table 1. Required oil volumes for different target slick thicknesses in a 15 x 15 cm tank (232 cm^2)

Target thickness (µm)	Oil volume/tank (mL)
10	0.2
50	1.2
100	2.2

Table 1. Required oil volumes for different target slick thicknesses in a 15 x 15 cm tank (232 cm^2)

Target thickness (µm)	Oil volume/tank (mL)
250	5.8
500	11.6
1,000	23.2
5,000	58.1

Figure 1. Preparation of sample tanks with different oil slick thicknesses.



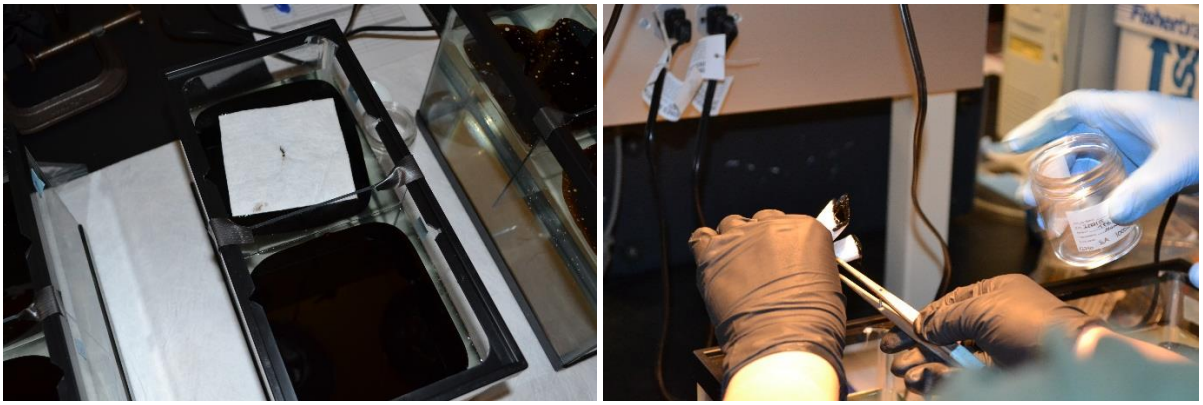
To determine the amount of oil transferred, we weighed the weigh boat before and after the transfer. For some of the thinnest sheens, we transferred a very small volume of oil using a pipette. We then measured the average weight per drop of oil from the pipette to estimate the volume of oil added per drop. Once the oil was transferred, we allowed the oil to spread across the test area before sampling. The time needed for the oil to spread varied depending on the viscosity of the oil and the volume of oil added to each test area. For the highly viscous DWH oil, we placed small heat lamps above each tank to warm the oil to help encourage spreading. If the oil did not fully spread across a tank area, we estimated the fraction of the area covered so that we could readjust the expected slick thickness in the tank.

2.3 Sorbent Pad Sampling

Daling and Leirvik (2002) described a method for measuring the slick thickness of floating oils using 3M T-151 sorbent pads. For this method, a sorbent pad of known size is placed onto the surface of the water, absorbing the floating oil from the area beneath the pad. The pad is then chemically analyzed for total petroleum hydrocarbons (TPHs) or another set of oil constituents to determine the mass of oil collected by the pad. The oil mass is then converted to oil volume using the bulk oil density and the TPH concentration (or other oil constituents). The thickness is then determined by dividing the oil volume by the size of the sorbent pad.

For this study, we used sorbent pads cut into 10 cm x 10 cm (4 in x 4 in) squares. We then rinsed the pads with methylene chloride, and let dry overnight in a fume hood to remove potential background contaminants from the pads. We deployed each pad onto the water (Figure 2) for 10 seconds. While longer deployment times may provide better measurements with this method, we chose to limit our deployment time to 10 seconds in this study to better replicate deployment conditions often faced in the field. All of the sorbent pad samples from this study were sent to ALS Environmental (Kelso, Washington) for TPH analysis using U.S. Environmental Protection Agency Method 8015.

Figure 2. Sorbent pad sampling.



2.4 Dip Plate Sampling

Svejkovsky and Muskat (2006) described the dip plate method of estimating oil thickness, where the slick thickness is measured using Plexiglass plates that are slowly lowered vertically through an oil slick, and the surrounding oil slick collects onto the plate. The slick thickness is then estimated by dividing the volume of oil collected on the dip plate by the surface area sampled. Svejkovsky and Muskat (2006) indicated that the plates collect slick oil both as they are lowered into the water and being raised, and thus the surface area sampled is equal to four times the plate surface area (where the surface area is the plate width times the depth the plate was deployed, and oil adheres to both sides of the plate as it is lowered and raised).

Svejkovsky and Muskat (2006) determined oil volume on the plate by collecting the oil off the plate and transferring it to a graduated cylinder. To improve method sensitivity as well as decrease sample processing time, we modified the method by measuring the weight of the oil collected and converting it to a volume using the oil density. For our modified method, we pre-weighed each dip plate in individual resealable plastic bags, and then reweighed the plate and its

respective plastic bag following sample collection to determine the weight of the oil sampled. In this study, we used 10-cm wide dip plates and dipped them to a depth of 4 cm or 8 cm (1.6 in or 3.1 in; Figure 3). In general, we dipped the plates vertically at a slow and deliberate speed. However, to simulate potential field conditions, we also evaluated additional parameters that could potentially effect the accuracy of the dip plate method, such as deployment speed and deployment angle.

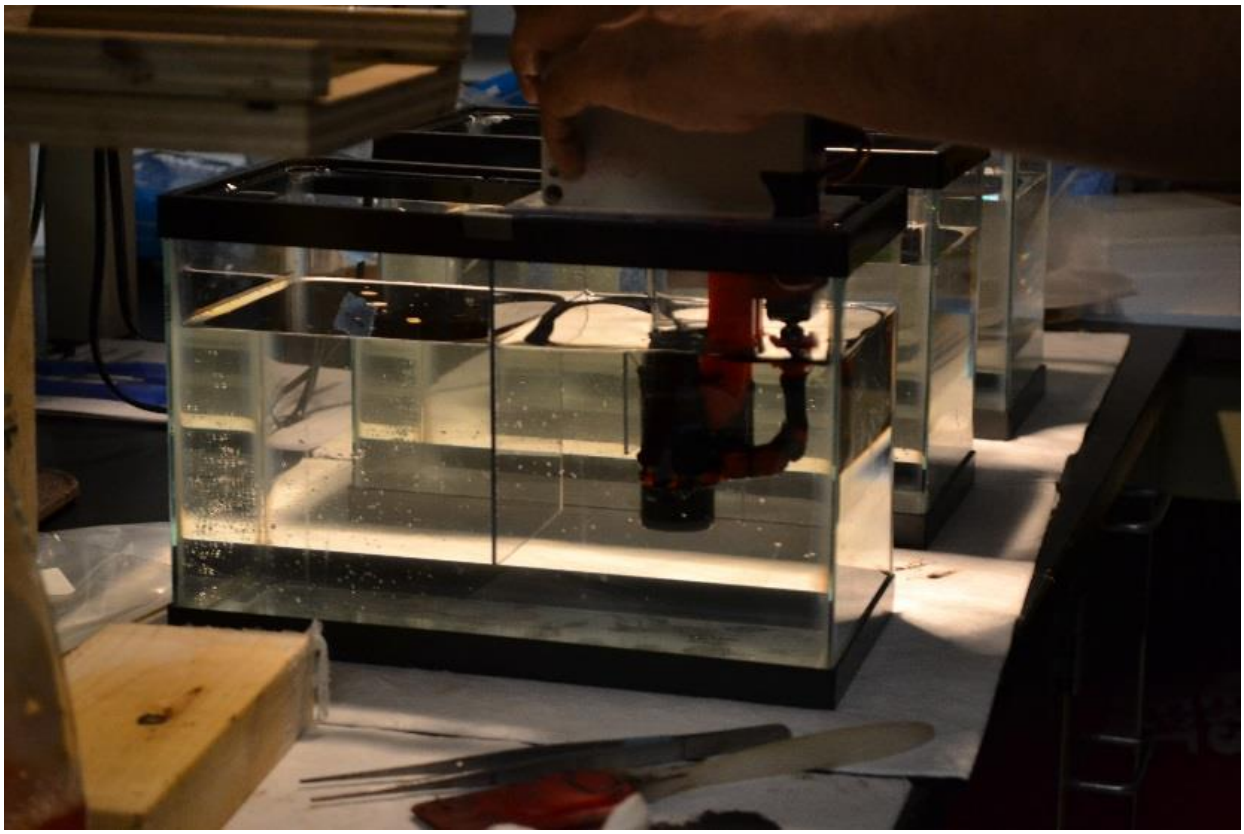
Figure 3. Typical deployment of a dip plate.



2.5 Water Mapping Sampler

Dr. Oscar Garcia of Water Mapping LLC developed a new method of measuring oil thickness, which we call the Water Mapping sampler. This sampler deploys a cylindrical plastic collection tube vertically into the water so that the tube intersects the water surface (Figure 4). Using a radio remote control, the sample tube is plugged to retain the slick oil captured within the tube. After the tube sits for several hours to ensure that all the oil in the tube floats to the water surface, the thickness of the layer of oil in the tube is measured using a high-definition photograph.

Figure 4. Water Mapping sampler deployed in sample tank.



Since some slick oil also adheres to the side of the tube, we also measured the slick thickness after adding a small amount of gasoline to the tube, which helped to solubilize the oil on the side of the tube, ensuring that it was also measured as part of the slick.

The oil thickness in the tube, which is intended to sample a cross-section of the slick, represents the sampled slick thickness. To calibrate the thickness measurement, we created a calibration curve by adding known volumes of oil to the tube and then measuring the thickness of the oil slick that formed. We estimated slick thickness by dividing the known oil volume by the surface area that the collection tube sampled.

3. Results and Discussion

3.1 Slick Formation

We used four different oils with a range of physicochemical properties to prepare our slicks (Table 2). Two of the four oils were fresh crude oils with lower densities and little to no water content. One of the fresh crude oils was an intermediate crude from Texas, and the other was a heavy crude from the Canadian tar sands; thus, the two fresh oils were very different. The two weathered oils were field-collected slick oils skimmed from the ocean surface. Both field-collected oils had higher densities than the fresh crude oils and were emulsified with water, although the DWH Slick A oil contained almost three times the water content as the MC20 oil.

Table 2. Bulk oil properties

Oil type	TPH (mg/kg)	% water	Density (g/mL)
Canadian oil sands crude	360,000	0.03	0.9231
West Texas intermediate crude	730,000	0.00	0.8974
DWH Slick A	337,000	56.70	0.9809
MC20	500,000	17.00	1.0043

The two fresh crude oils spread more quickly across the surface of the water compared to the two oil emulsions. In fact, the DWH Slick A oil required heat lamps for the oil to spread across the tank sample area. In addition, the Canadian oil sands crude created slicks that were visually more uniform than the slicks prepared with the other oils (Figure 5). We also found that the thicker slicks spread more quickly and also looked more uniform compared to the thinner slicks (Figure 6). Despite these differences, overall we successfully obtained slicks of different target thicknesses with all the oils.

Figure 5. Slick samples prepared with Canadian oil sands crude oil (upper left), West Texas intermediate crude oil (upper right), DWH Slick A oil (lower left), and MC20 oil (lower right). All photographs show 50-µm slicks except for the West Texas oil, which is a 100-µm slick.

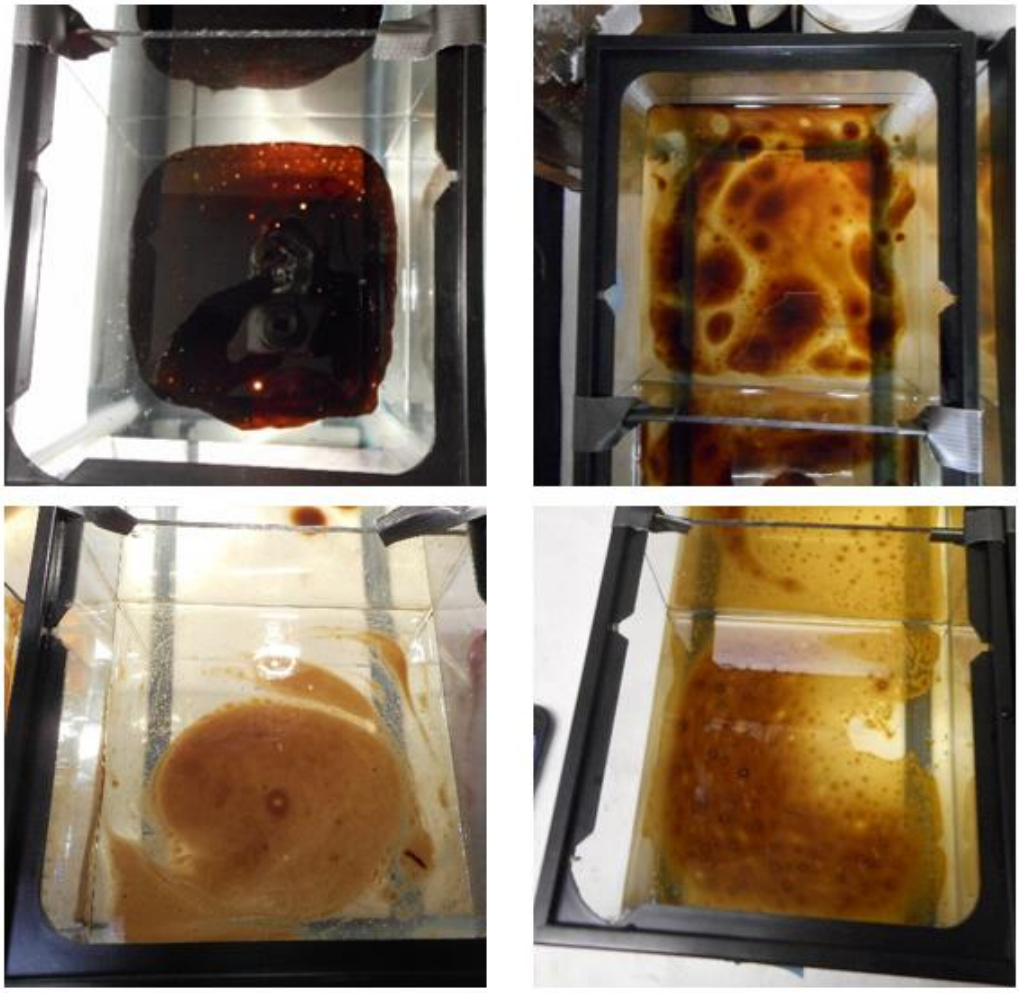
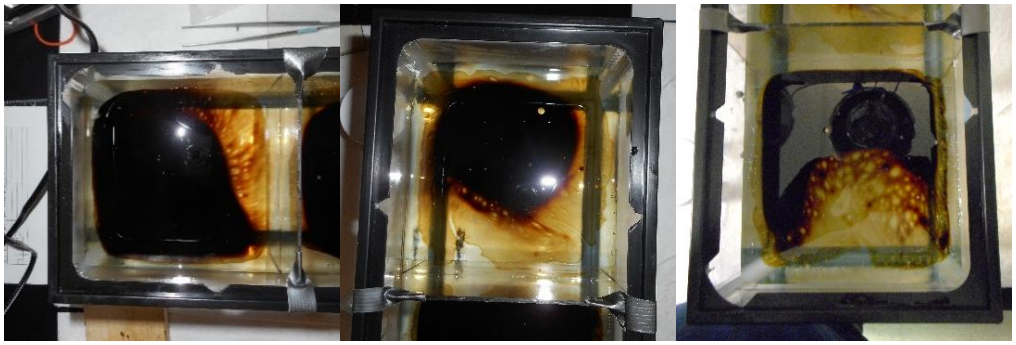


Figure 6. Slick samples of different thicknesses prepared with Canadian oil sands crude oil: 1,000 µm (A), 100 µm (B), 50 µm (C), and 10 µm (D).

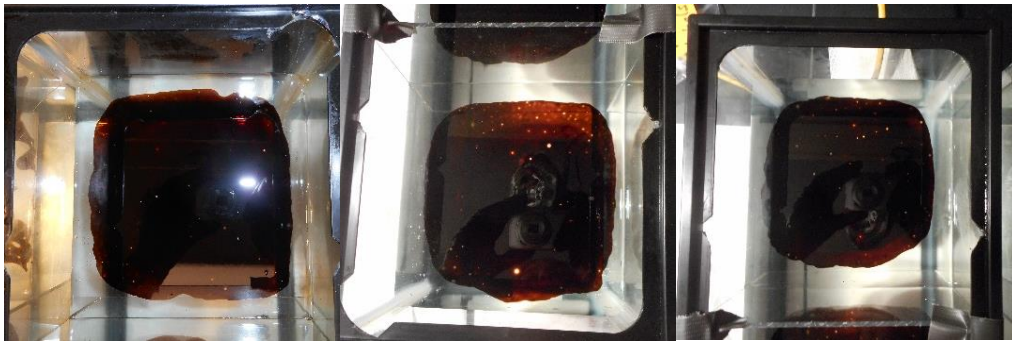
(A) 1,000 µm



(B) 100 µm



(C) 50 µm



(D) 10 µm

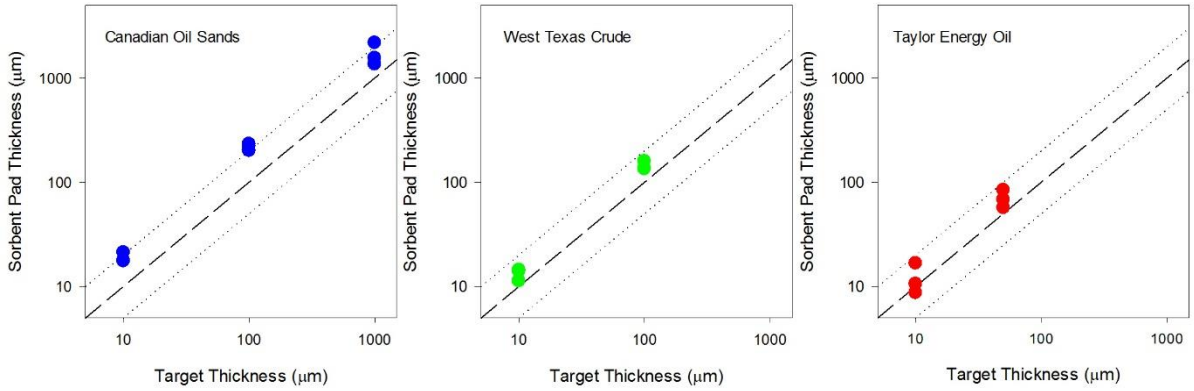


3.2 Sorbent Pad Measurements

Sorbent pads have been used by oil researchers to measure slick thickness for over three decades (Lichtenthaler and Daling, 1985; Daling and Leirvik, 2002). While these researchers claim this method is well-established, little available data exist that address this method's accuracy and precision. In this study, we evaluated the sorbent pad method using slicks ranging from 10 µm to 1,000 µm prepared with three different oils. The general working range described by Daling and Leirvik (2002) for sorbent pads is 1–5 µm up to 2,000–3,000 µm (2–3 mm).

For all three oils tested, the sorbent pad method overestimated slick thickness, based on the mass of oil available to absorb (Figure 7). The sorbent pad method assumes that the surface area sampled by the pad is limited to the area of the pad. If the pad not only collects the slick oil directly underneath the pad, but also wicks oils from the surrounding slick, the result would overestimate the slick thickness. We believe this is the likely cause of the overestimation we saw with this method. Other potential sources of error in the sorbent pad method could be incorrect bulk oil density and measured TPH concentration. However, we expect analytical errors to be more random across different oil types versus the bias in one direction that we observed in our data. Despite this bias, all measured thickness results fell within a two-fold difference from the target thickness.

Figure 7. Slick thickness measured by sorbent pad versus the expected target slick thickness. Dashed lines show 1:1 line and dotted lines show 2:1 and 1:2 lines.

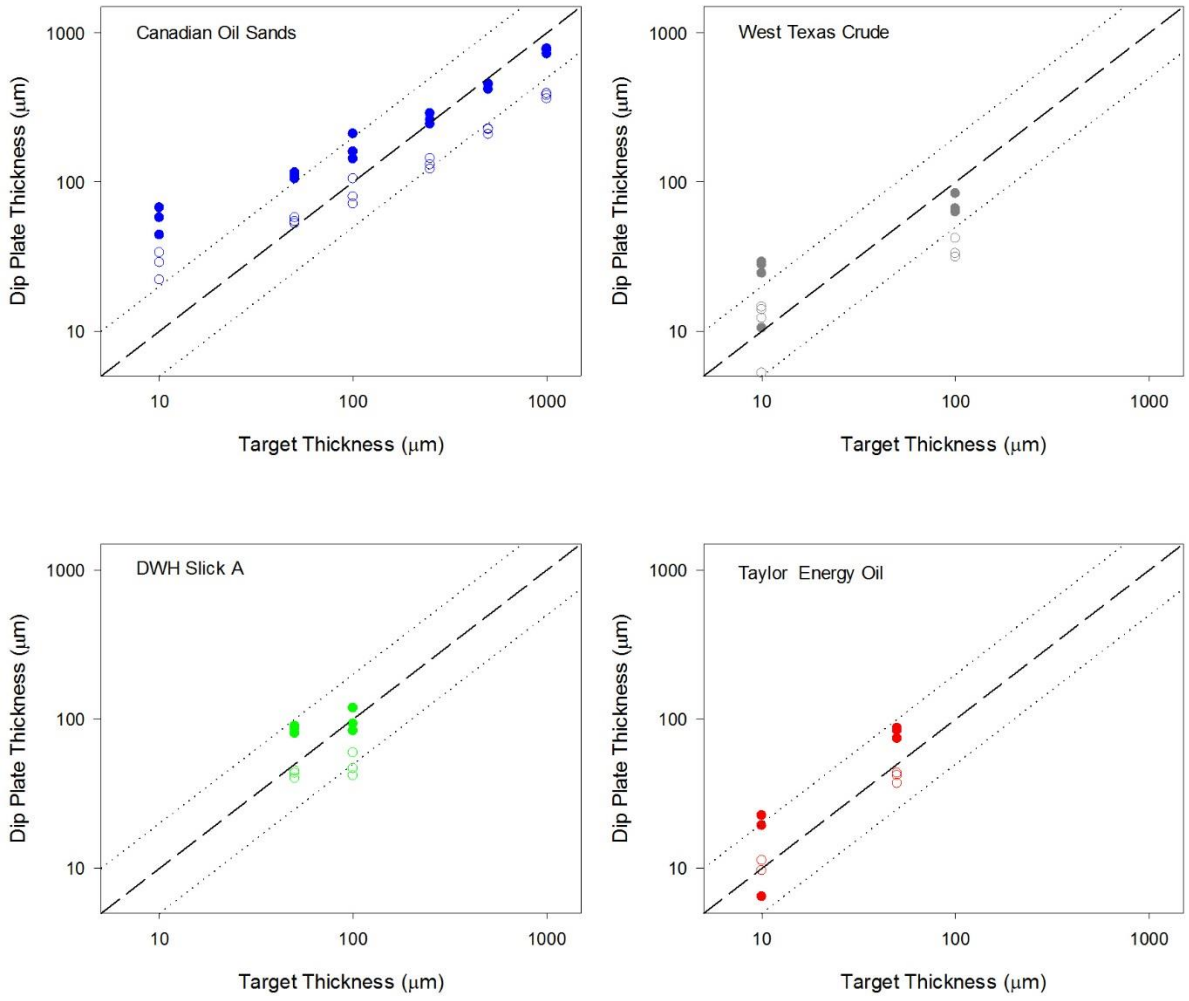


3.3 Dip Plate Measurements

When using the dip plate method to measure slick thickness, the biggest assumption one needs to make is the surface area sampled by the plate. As described previously, the slick oil generally adheres to the plate both as it is submerged into the water and as it is retrieved from the water, which means that the slick area sampled is equivalent to four times the surface area of the plate (Svejkovsky and Muskat, 2006).

In this study, we first calculated an average slick thickness assuming that the surface area exposed to oil was four times the dip plate area. We found that the resulting thickness measurements were generally accurate for slicks less than 100 µm, but were consistently low by a factor of two for thicker slicks (Figure 8). Since the results were consistently half of what we expected for these thicker slicks, we recalculated the thickness estimates assuming the sampled area is two times the exposed surface area of the plate rather than four times the exposed surface area of the plate, which produced measured thicknesses that better aligned with our target thicknesses. This suggests that for thicker slicks, the dip plate only collects slick oil when it is lowered into the water, and not when it is raised.

Figure 8. Slick thickness measured by dip plate versus the expected target slick thickness. 2X thickness means we assumed the surface area exposed to oil was 2 times the surface area of the exposed plate, and 4X thickness means we assumed the surface area exposed was 4 times the surface area of the exposed plate. Dashed lines show 1:1 line and dotted lines show 2:1 and 1:2 lines.



These results were consistent across multiple oils tested (Figure 8), which suggests that the dip plate method can be used across a diverse set of environments and oil types. We also found that for all oil types, the accuracy and precision of the dip plate measurements decreased for the 10-µm slicks, which we expect is due to the influence of water on the dip plate. In fact, we found

that a dip plate deployed in clean water will produce thickness estimates similar to those dipped in 10-µm slicks, suggesting that 10 µm is approaching the lower limit of the method. On the other end, our results indicate that the dip plate may start to underestimate thickness for slicks thicker than 1,000 µm.

While the dip plate method is effective at measuring moderately thick slicks, the method is complicated by the need to change the underlying calculations used to determine slick thickness from a 4X multiplier to a 2X multiplier around a thickness of 100 µm. Since the thickness of samples collected in the field are unknown, we suggest applying the following set of guidelines to determine which multiplier to apply:

> Calculate all sample measurements using the 4X multiplier. If the resulting 4X measurement is less than 50 µm, use the 4X result. If the measurement is greater than 100 µm, recalculate using the 2X multiplier to determine the measured thickness. If the calculated thickness is greater than 50 µm using a 4X multiplier and less than 100 µm using a 2X multiplier, it is unknown which multiplier will be more accurate.

Regardless, we generally found that the calculated thickness fell within a two-fold range of the target thickness regardless of whether a 2X or 4X multiplier was used. Ultimately, given the many other sources of uncertainty associated with measuring slick thickness in the environment, including the high heterogeneity of oil slicks in general, we feel this level of imprecision is acceptable.

3.4 Effect of Dip Plate Deployment Parameters on Thickness Measurement

Since it is not always possible to deploy the dip plates fully vertical at a slow speed while in the field, we assessed the effects of different deployment parameters on measurements. The deployment parameters we tested include (1) angled deployment; (2) a clean, degreased plate; (3) quick deployment; and (4) quick deployment with water removal. We found that a clean, decreased plate and an angled deployment generally increased the measured slick thickness, although the increase was minimal (Figure 9). Quick deployment resulted in the greatest increase in thickness measurement. However, there was no overestimate of thickness if we allowed the water to drip off the plate following a quick deployment. It is possible that the other deployment parameters, including the traditional deployment method, may have also benefited from this extra removal of water, but we only tested water removal on the quick deployment method.

3.5 Water Mapping Measurements

The Water Mapping sampler is a developing slick thickness measurement technique that continues to be refined. For this study, the plastic collection tube was mounted vertically in the sampler, and we used a robotic arm operated by remote control to plug the collection tube and capture the slick sample after deployment.

We originally assumed that the thickness of the oil layer in the tube was the same as the thickness of the sampled slick. However, this assumption resulted in a substantial overestimate of the slick thickness (Figure 10). Consequently, we created a calibration curve to define the relationship between the oil layer in the tube and the slick thickness sampled by the sampler by adding specific volumes of oil directly to each tube, and measuring the resultant oil layer in each tube (Figure 11).

Figure 9. Measured dip plate thickness using different deployment parameters.

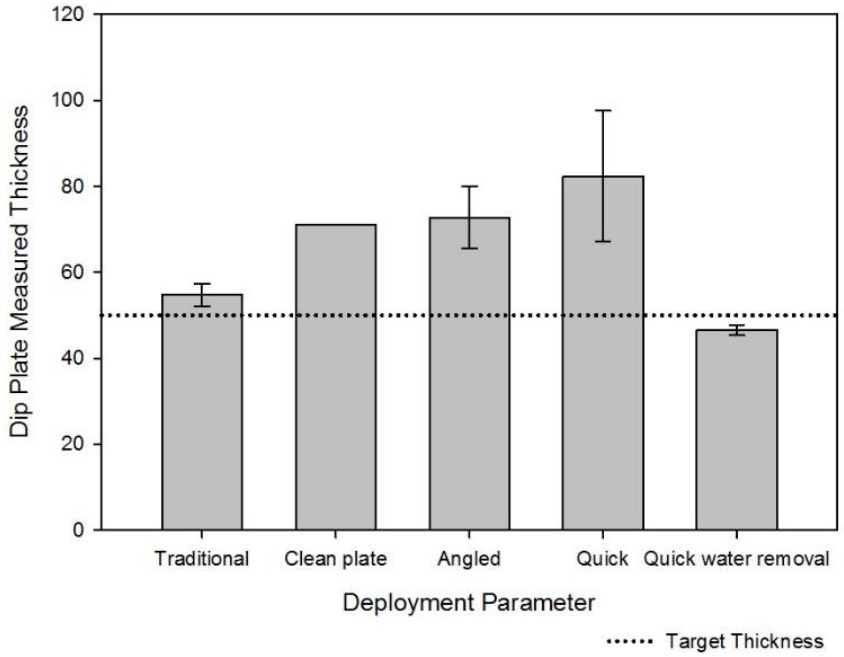


Figure 10. Measurements of slick thickness using the Water Mapping sampler calculated with and without a calibration curve and with and without the addition of gasoline to the sample tubes. Dashed lines show 1:1 line and dotted lines show 2:1 and 1:2 lines.

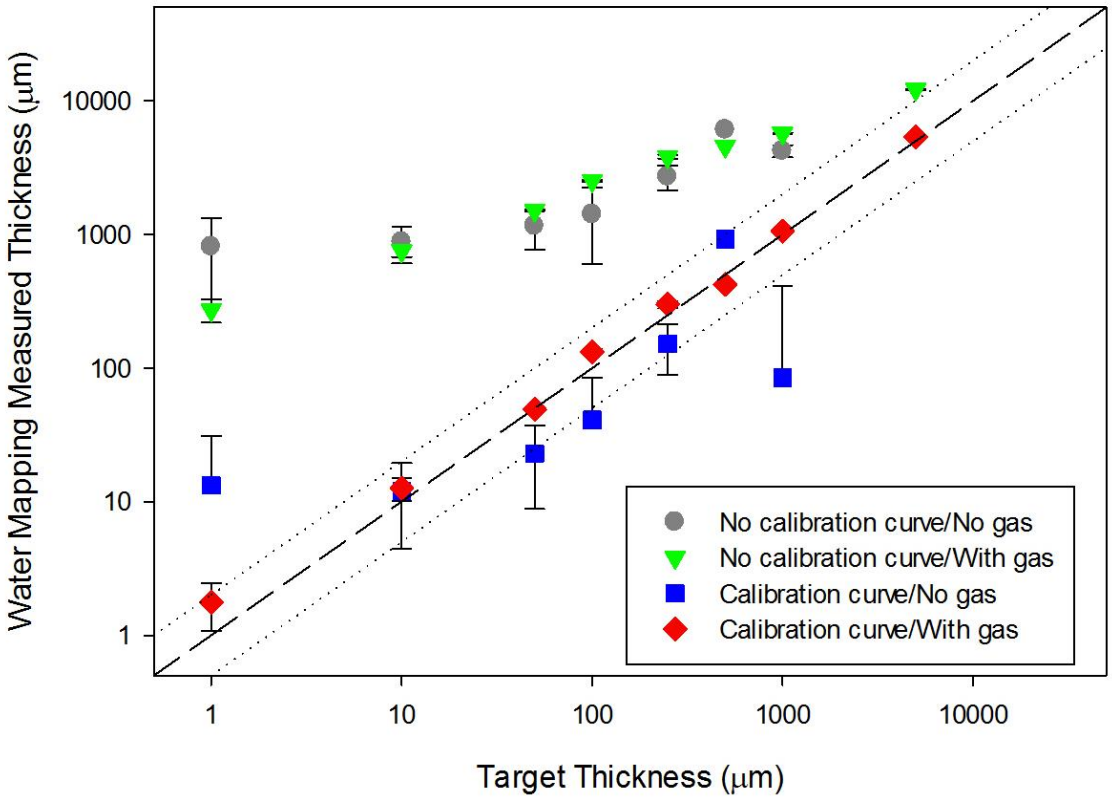
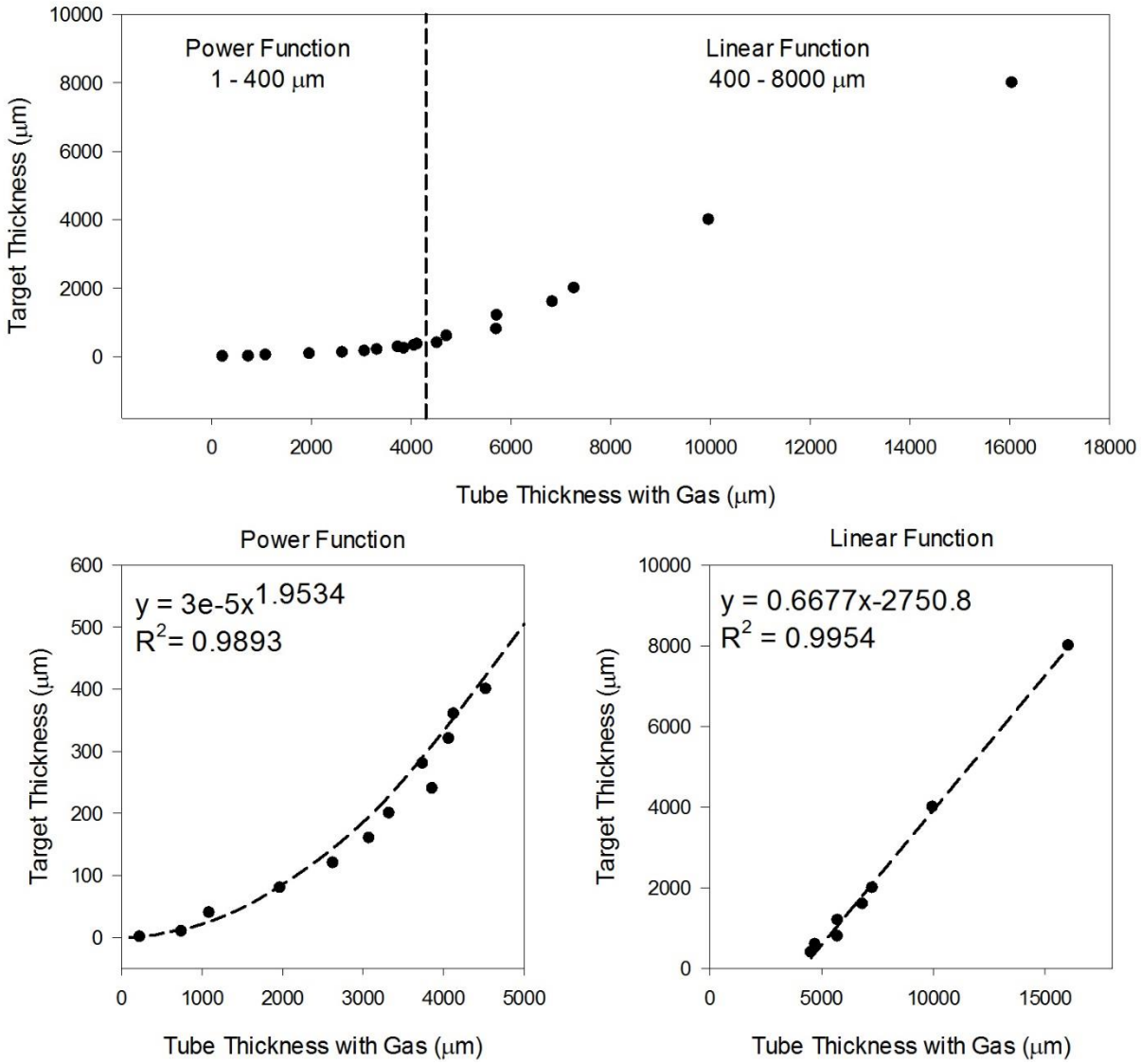


Figure 11. Water Mapping sampler calibration curve prepared using Canadian tar sands oil.



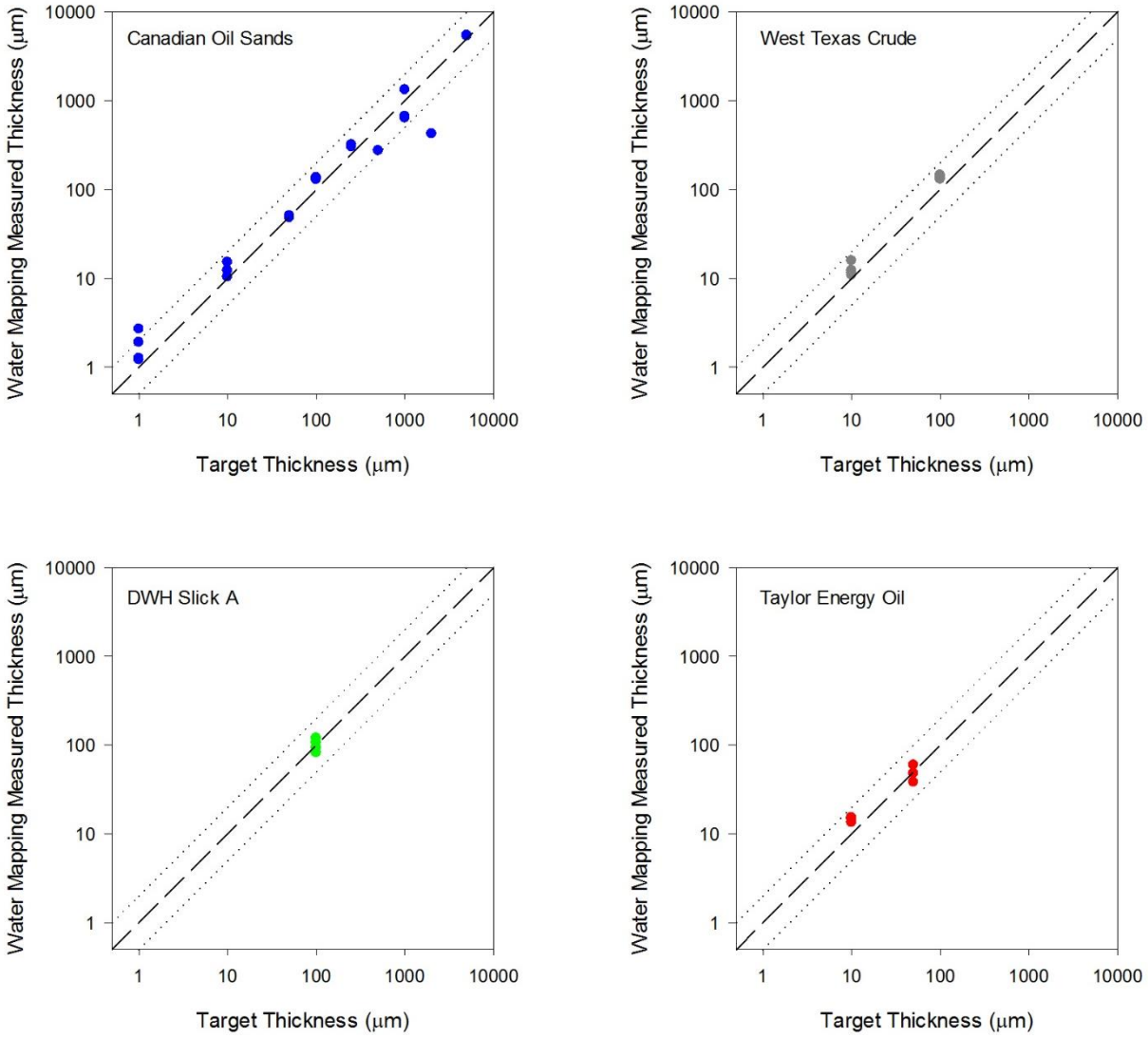
While the calibration curve substantially improved our estimation of slick thickness, the data were variable. We noticed that when the sampler collected a surface slick, slick oil would often adhere to the sides of the plastic tube. Despite allowing the tubes to sit for several hours, the oil would not always collect at the top of the water surface. To alleviate this problem, we added a solvent (i.e., gasoline) that solubilized the oil that adhered to the cylinder, allowing it to collect as a neat oil layer at the surface. We then allowed the gasoline to volatilize, leaving behind just the collected volume of oil that could be measured by a high-definition photograph. Ultimately, we found using a calibration curve and adding the gasoline to each sample greatly improved both the accuracy and precision of the method (Figure 10).

An interesting feature of the calibration curve is that at thinner slick thicknesses, the relationship between tube thickness and the target slick thickness is best described using a power function (Figure 11). However, for thicker slicks the relationship becomes linear. Therefore, we split the

curve and fit the data with two separate functions, one fit for slick thicknesses ranging from 1 to 400 µm and another fit for slick thicknesses ranging from 400 to 8,000 µm. We did not test slicks thicker than 8,000 µm.

Creating a calibration curve with each specific type of oil would be logistically challenging. However, given that the calibration is simply based on a volume of oil and not on specific oil characteristics, we felt a single calibration curve prepared from one oil type might apply to the measurement of other oil types. To test this, we used the calibration curve prepared with the Canadian tar sands oil to determine the thickness of slicks prepared with the other three oil types tested during this study. We successfully measured slick thickness for all four oil types using a single calibration curve (Figure 12).

Figure 12. Slick thickness measured by the Water Mapping technique versus the expected target slick thickness for four different oil types. All thicknesses were determined using a calibration curve prepared with Canadian oil sands oil. Dashed lines show 1:1 line and dotted lines show 2:1 and 1:2 lines.



3.6 Method Comparison

In field studies, we have found that the three methods often produce thickness measurements that differ by orders of magnitude at the same sampling location. Given the level of heterogeneity of the slicks in the field, it is difficult to determine if the differences represented real differences in the slicks sampled or are the result of inaccuracies in the methods used. This laboratory study suggests that each of the three methods yield similar results. The calibrated Water Mapping method is generally more accurate and precise than the other two methods (Figure 13). In addition, this method demonstrated the biggest working range, showing an ability to measure slicks ranging in thickness from around 1 µm up to 8,000 µm. However, this method suffers from slow mobilization/demobilization and time-consuming analysis, limiting the number of samples that can be collected in the field. In addition, this method provides only the measured thickness of a circle of oil slick less than 4 cm (1.6 in) in diameter; this area may not be representative of the thickness of the broader slick area.

The sorbent pad method was the least accurate of the three methods. The pads overestimated slick thickness across all oil types and volumes. Sorbent pads are also costly because they required digestion and analysis at a chemical laboratory, which limits the number of samples that can be collected for a project. In addition, the data from the sorbent pad analyses typically take several weeks to be delivered. While there seem to be many disadvantages with the sorbent pad method, it is the most well-established and commonly used method reported in the literature.

Finally, while the dip plate method was generally accurate for slicks of moderate thickness, the application to unknown slick thicknesses is complicated because of the apparent change in oil adherence that occurred when slicks were 100 µm or greater. In addition, the dip plates were limited to a narrower range of thicknesses, with decreased accuracy at the 10-µm thickness and the 1,000-µm thickness. However, dip plates are the easiest and least-expensive method to deploy, allowing considerably more measurements to be taken compared to the other two methods, and with a much faster turnaround time. Given the heterogeneity of oil slicks in the environment, the ability to collect numerous measurements with higher uncertainty can be more helpful for characterizing overall average slick thickness than collecting a small number of more accurate samples.

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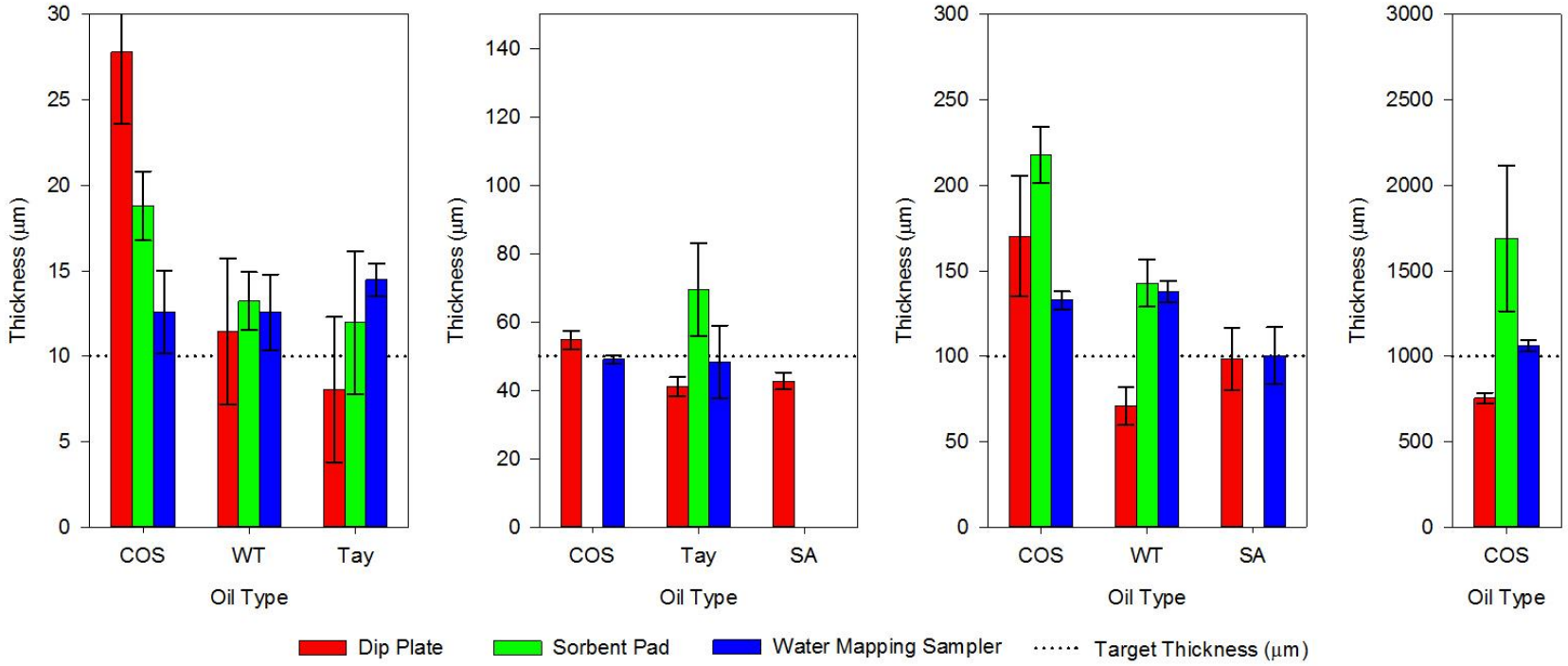
Svejkovsky, J. and J. Muskat. 2006. Real-Time Detection of Oil Slick Thickness Patterns with a Portable Multispectral Sensor. Minerals Management Service, Final Report for Project #0105CT39144.

Figure 13. Comparison of the three slick thickness measurement methods using different oils across a range of slick thicknesses.



COS = Canadian oil sands crude, WT = West Texas intermediate crude; Tay = MC20 (Taylor Energy) oil; SA = DWH Slick A.

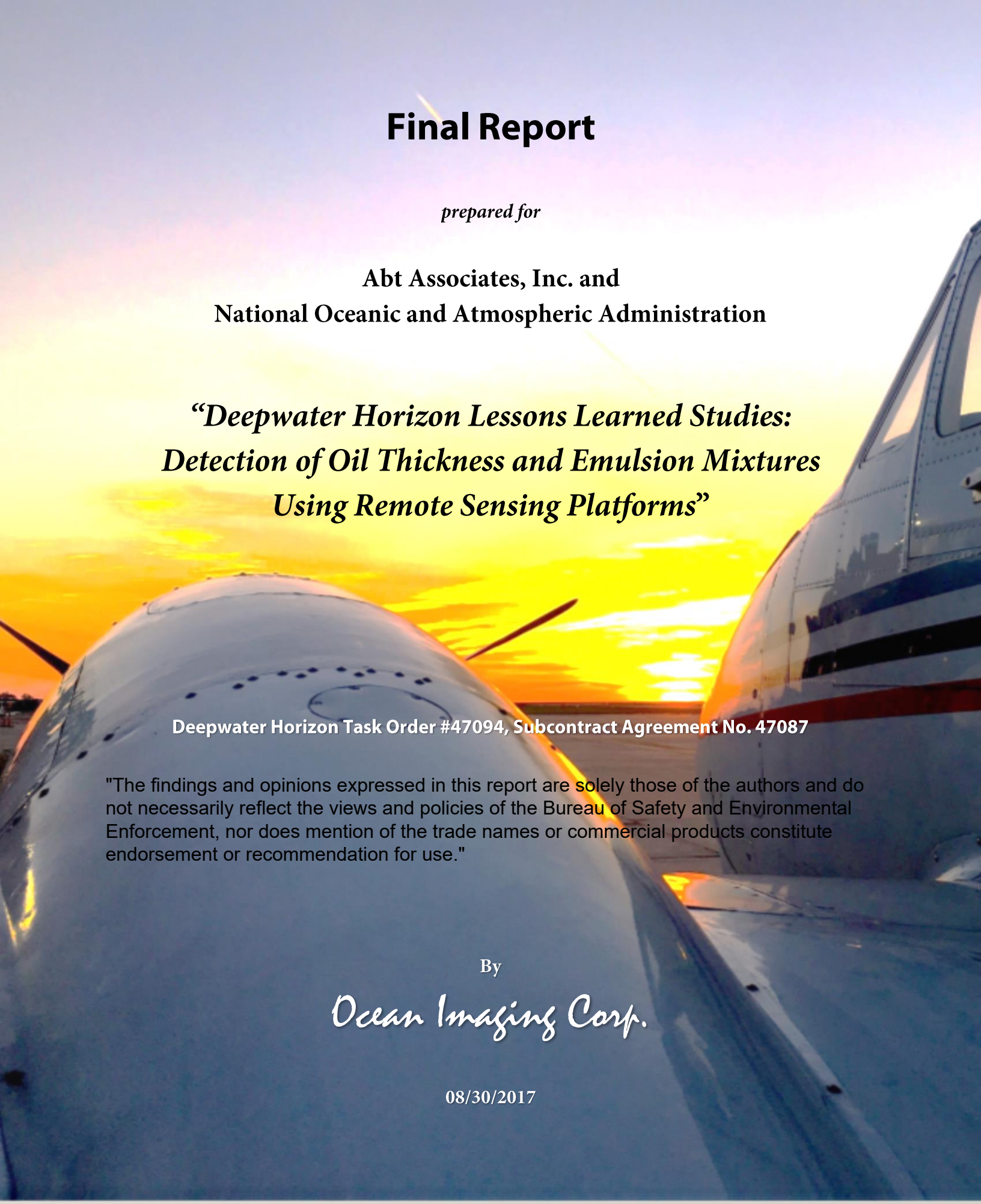
Attachment F. Ocean Imaging MC20 Report

Final Report

prepared for

Abt Associates, Inc. and
National Oceanic and Atmospheric Administration

"Deepwater Horizon Lessons Learned Studies: Detection of Oil Thickness and Emulsion Mixtures Using Remote Sensing Platforms"



Deepwater Horizon Task Order #47094, Subcontract Agreement No. 47087

"The findings and opinions expressed in this report are solely those of the authors and do not necessarily reflect the views and policies of the Bureau of Safety and Environmental Enforcement, nor does mention of the trade names or commercial products constitute endorsement or recommendation for use."

By

Ocean Imaging Corp.

08/30/2017

INTRODUCTION

The 2010 Deep Water Horizon (DWH) oil spill presented an unprecedented amount of remote sensing data used as part of the response effort as well as the post-spill National Resource Damage Assessment (NRDA) work. As stated in the original proposal for this project, significant progress has been realized, however, data collected and methods developed during DWH suffer from incomplete control and validation due to the operational timelines and Unified Command's (UC) requirements for operational decision making. During the DWH response remotely sensed data acquisition was almost exclusively performed without simultaneous in situ field data or any other form of quality/accuracy determination.

The stated goal of this project is to build upon lessons learned from DWH NRDA application of remote sensing (RS) to:

1) Evaluate remote sensing platforms and sensors for the detection and characterization of surface oil and emulsions
2) Coordinate simultaneous in situ water and oil collection and characterization for thickness and chemistry
3) Evaluate and compare surface oil thickness measurement methods.

These objectives all serve the overarching goal to validate and quantify the efforts put forward under the DWH NRDA Oil on Water workgroup and provide Bureau of Safety and Environmental Enforcement (BSEE) and National Oceanic and Atmospheric Administration (NOAA) the needed methodology and operational tools to assess future oil spills and the ability to monitor and measure more accurately the thickness of surface oil slicks in the marine environment. Phase One of this project was designed to characterize the detection of known oil thicknesses and oil-emulsions in a controlled environment, performing multiple tests and calibrations for thermal, optical, and microwave sensors at the National Oil Spill Response Research & Renewable Energy Test Facility (Ohmsett) located at the Naval Weapons Station Earle Waterfront in Leonardo, New Jersey (Graettinger, 2016).

Ocean Imaging's (OI) role is to assist in the achievement of the overall goal of providing control and validation for surface oil detection and characterization by spaceborne-, aerial- and Unmanned Aerial Vehicle (UAV)-mounted sensors as well as further the development of oil classification algorithms and methodologies necessary for future response and damage assessment. Furthermore, the study incorporated the first-time creation and use of not only large amounts of emulsified crude oil, but also "weathered" oil so that the characteristics of the oil detected by the remote sensing instruments mimic as closely as possible that of oil on the ocean's surface immediately following and several days following a real spill event. As part of the first phase of the project, OI collected aerial multispectral (MS), Thermal Infrared (TIR) imagery at multiple altitudes using their helicopter-mounted Tactical Response Airborne Classification System (TRACS) over the test tank resulting in horizontal spatial resolutions or ground sampling distances (GSD) of approximately 0.08-1.5 meters. Close-range TRACS and Ultraviolet imagery were also acquired at heights varying from just a few meters to 30.5 meters above the water's surface resulting in very focused, fine resolution UV data and TRACS data with GSDs of approximately 0.018-.028 meters. More details on the activities, analyses, results and conclusions reached as part of OI's

participation in Phase One of the project can be found in the document *OI Ohmsett-Taylor Phase 1 Report.pdf.*

Based on the data obtained, corresponding results and 'lessons learned' from Phase One, Phase Two focused on measuring the open water oil thicknesses and oil-emulsions at the damaged Taylor Energy well field surface oiling site performing multiple tests and calibrations for thermal, optical and microwave sensors. As was the case during Phase One, the second phase was also designed such that near-simultaneous data were acquired from platforms and sensors at the spaceborne, aerial and UAS level as well as collected from a vessel taking physical samples and in situ measurements. Similar to Phase One and keeping the overall project goals, the TRACS data were acquired, processed and analyzed with specific objectives:

1) Gather aerial multispectral and Thermal Infrared (TIR) TRACS data of the Taylor Oil Spill Site (TOSS) oil slick at spatial resolutions close to those of the near-simultaneous UAS and satellite data in an effort to characterize: oil thickness, oil-to-water ratios and the effects of environmental weathering to assess each sensors ability and limitations to effectively determine the oil's actionability as well as determine the level of spatial detail necessary in order to generate operational oil characteristic and volume information products suitable for delivery to a response vessel in real time as well as make available to a Common Operational Picture (COP) such as NOAA's Environmental Response Management Application (ERMA)

TAYLOR ENERGY SITE AERIAL DATA COLLECTION NOVEMBER 2016

Installation and testing of Ocean Imaging TRACS System on Aztec Piper Aircraft: In preparation for Ocean Imaging's (OI) November 2016 TRACS data acquisitions over the TOSS, a mount was fabricated to fit a Piper Aztec twin engine aircraft operated by Air America operating out of Daytona Beach, Florida. OI exhaustively investigated aircraft options for this field work. Air America aircraft charter was the only company at the time within a reasonable distance of the TOSS who operates a twin engine aircraft, has the capability to mount TRACS, has experience flying camera equipment, and was reasonably priced. The only other option found was a Sikorsky S-76 helicopter operating out of Venice, Louisiana at a cost of $15,000/day, compared to the $15,030 per week for Air America. Later in 2017, OI formed an agreement with Marine Spill Response Corporation (MSRC) to share the cost of a more expensive King Air aircraft operated by Dynamic Aviation operating out of Bridgewater Virginia. As is discussed in more detail below, this cooperative effort proved to be quite beneficial to the project. M. Hess and J. Reed travelled to the Flightline First Flight Base of Operations (FBO) at the Lakefront Airport in New Orleans, LA on 11/13/16, one day ahead of the scheduled TOSS overflights in order to install the TRACS on the Piper Aztec, configure the TRACS Inertial Measurement Unit (IMU) to the specifications of the aircraft and run ground tests on the system.

TOSS Data Acquisition November 14–16, 2016: The objectives of the November 2016 TOSS overflight trip were to carry out up to five TRACS overflights over the oil seep(s) emanating from the Taylor Energy site between11/14/16 and 11/17/16, acquiring TRACS data of the oil on the ocean's surface at altitudes of 1,000 and 6,000 feet. At the 1,000-foot altitude, the flight lines were sometimes offset from each other or minimized to focus on the areas of thicker oil as opposed to sheen extending into many potential flight lines. This was done to minimize flight time, leaving room and time for the other aircraft working on the project, but also because the 6,000-foot imagery provided the synoptic view of the slick with the 1,000 foot, high resolution imagery intended for the detailed analysis of the thicker oil patches. The five flight missions were, in fact, completed at the planned altitudes resulting in TRACS multispectral, Red-Green-Blue (RGB) and (TIR) data with average Ground Sampling Distances (GSD) of ~0.21 meters (RGB), ~0.34 meters (TIR) (1,000 foot) and ~1.29 meters (RGB), ~2.13 meters (TIR) (6,000 foot). *Table 1* shows the TRACS overflight dates, times, aircraft altitudes and corresponding GSDs along with the satellite data acquired near in time to the TRACS data collections. Following each flight, the data acquired were immediately, backed up and later used for the final analyses, generation of the oil characterization information products and comparison to the boat/in situ data as well as the data from the other platforms/sensors. *Appendix A.1* shows select RGB and TIR image mosaics of the TOSS oil slick acquired during the November 2016 aerial collections.

TAYLOR ENERGY SITE AERIAL DATA COLLECTION APRIL 2017

Installation and testing of Ocean Imaging TRACS System on King Air: Prior to the April 2017 aerial missions and field work, OI made arrangements with Marine Spill Response Corporation (MSRC) to share the cost of chartering a King Air aircraft operated by Dynamic Aviation. This partnership benefited this project in several ways. First, splitting the cost of the aircraft charter saved several thousand dollars in the budget compared to hiring Air America's Piper Aztec. It also allowed MSRC's remote sensing team to join OI's staff on the TOSS overflights providing training, opportunities for OI and MSRC to refine their spill response procedures, as well as create an opportunity for OI & MSRC to demonstrate our aircraft-to-boat communication system. For this series of overflights, the TRACS mounting plate had already been fabricated and installed in the aircraft prior to Dynamic Aviation bringing the aircraft to the New Orleans FBO. J. McCall, J. White and M. Hess all few into New Orleans on Sunday April 23rd with intentions of installing the air-to-boat communications antenna on the field sampling vessel that afternoon. Due to unforeseen issues with shipping the equipment, the OI staff ended up installing the communications equipment on the vessel the morning of Monday April 24th and then driving back up to the FBO to meet the King Air, install the TRACS and run ground tests. The installation of the antenna, boat-side computer, training of boat personnel on how to use the system, as well as testing of the boat-side antenna for the OI/MSRC communication system went smoothly. *Figure 1* shows photographs of the antenna on the stern of the vessel.



Figure 1: *OI/MSRC communication system antenna installed on the "Miss D" sampling vessel.*
On the afternoon of April 24th OI staff met with the Dynamic Aviation flight crew, successfully installed the TRACS, configured the TRACS Inertial Measurement Unit (IMU) to the specifications of the aircraft, ran ground-tests on the system and went over the flight plans for the next few days with the pilots.

TOSS Data Acquisition April 25-26, 2017: The objectives of the April 2017 TOSS overflight trip were to carry out up to four TRACS overflights over the oil seep(s) emanating from the Taylor Energy site between 04/25/17–04/28/17, acquiring TRACS data of the oil on the ocean's surface at altitudes of 1,000 and 6,000 feet. Two of the four planned flight missions were completed at the planned altitudes resulting in TRACS multispectral, Red-Green-Blue (RGB) and Thermal Infrared (TIR) data with average Ground Sampling Distances (GSD) of ~0.20 meters (RGB), ~0.31 meters (TIR) (1,000 foot) and ~1.33 meters (RGB), ~2.09 meters (TIR) (6,000 foot). Overflights on 04/27/17 and 04/28/17 did not take place due to poor weather and the subsequent cancellation of the vessel-based on-water sampling after 04/25/17. *Table 1* shows the TRACS overflight dates, times, aircraft altitudes and corresponding GSDs along with the satellite data acquired near in time to the TRACS data collections. *Appendix A.2* shows select RGB and TIR image mosaics of the TOSS oil slick acquired during the April 2017 aerial collections.

During the flight on 04/25/17, image mosaics were generated of the RGB and TIR TRACS imagery and transferred down to the sampling vessel within roughly 5-10 minutes of data acquisition via the MSRC/OI air-to-boat transmission system. On 04/26/17, since the field sampling trip was cancelled due to weather, yet the TRACS overflights did take place, in-flight image mosaics were generated and then sent down from the aircraft circling at 2,000 feet over the sampling vessel docked at the Port Eads facility. Additional discussion about the transmission of TRACS data from the aircraft to the boat team is below. Following each flight, the data acquired were immediately, backed up and later used for the final analyses, generation of the oil characterization information products and comparison to the boat/in situ data as well as the data from the other platforms/sensors.

Following each of the aerial missions on 04/25 and 04/26, the OI staff secured a room in the FBO and processed select flight lines ("Runs") from each day in order to create both geo-corrected image mosaics and oil thickness classifications. The imagery in GeoTIFF format and the oil thickness analyses in ESRI Shapefile format were then uploaded to OI's server facility in San Diego, California and made available for EMRA ingestion as Representational State Transfer (REST)-formatted map services. On both days, the data and resulting digital information products were available to ERMA within seven hours of data acquisition. This time gap could have been shortened significantly, however the available Internet connection at the FBO was extremely slow resulting in a substantial delay. Also, on the 26th, the flight time was extended in order to transfer the data down to the vessel in Port Eads. This delayed the generation of the data products and upload to the OI server. It is estimated that during a real oil spill incident, geo-corrected RGB and TIR image mosaics can be ready for ERMA ingestion within approximately 1–3 hours of aerial acquisition and oil characteristic analyses can be available for ERMA in 2–4 hours, depending on the size and location of the spill.

Date	TRACS Data Acquisition Times (UTC)	TRACS Altitudes & Corresponding GSDs	Satellite Sensor & Corresponding GSD	Satellite Data Acquisition Times (UTC)
Monday, 11/14/2016	16:41–17:04	1,000 ft. (RGB: 0.21m, TIR: 0.34m) 6,000 ft. (RGB: 1.29m, TIR: 2.13m)	ALOS PALSAR: 10.0m	21:33
Tuesday, 11/15/2016	13:00–13:42	1,000 ft. (RGB: 0.21m, TIR: 0.34m) 6,000 ft. (RGB: 1.29m, TIR: 2.13m)	RADARSAT-2: ~3.0m	17:56
Tuesday, 11/15/2016	13:00–13:42	1,000 ft. (RGB: 0.21m, TIR: 0.34m) 6,000 ft. (RGB: 1.29m, TIR: 2.13m)	UAVSAR: ~5.5m	12:23–14:25
Thursday, 11/16/2016	16:20–17:02	1,000 ft. (RGB: 0.21m, TIR: 0.34m) 6,000 ft. (RGB: 1.29m, TIR: 2.13m)		
Thursday, 11/17/2016	16:34–16:44	1,000 ft. (RGB: 0.21m, TIR: 0.34m)	UAVSAR: ~5.5m	15:10–17:47
Thursday, 11/17/2016	16:34–16:44	1,000 ft. (RGB: 0.21m, TIR: 0.34m)	EO-1 Aster: 30m	18:00
Thursday, 11/17/2016	22:28–22:50	1,000 ft. (RGB: 0.21m, TIR: 0.34m) 6,000 ft. (RGB: 1.29m, TIR: 2.13m)	UAVSAR: ~5.5m	21:58–23:47
Thursday, 11/17/2016	22:28–22:50	1,000 ft. (RGB: 0.21m, TIR: 0.34m) 6,000 ft. (RGB: 1.29m, TIR: 2.13m)	RADARSAT-2: ~3.0m	23:49
Tuesday, 04/25/2017	12:52–13:39	1,000 ft. (RGB: 0.20m, TIR: 0.31m) 6,000 ft. (RGB: 1.33m, TIR: 2.09m)	RADARSAT-2: ~3.0m	12:00
Tuesday, 04/25/2017	12:52–13:39	1,000 ft. (RGB: 0.20m, TIR: 0.31m) 6,000 ft. (RGB: 1.33m, TIR: 2.09m)	EO-1 Aster: 15m	16:49
Tuesday, 04/25/2017	12:52–13:39	1,000 ft. (RGB: 0.20m, TIR: 0.31m) 6,000 ft. (RGB: 1.33m, TIR: 2.09m)	WorldView-2: 1.84m–2.08m	17:02
Tuesday, 04/26/2017	14:01–14:15	1,000 ft. (RGB: 0.20m, TIR: 0.31m)	WorldView-2: 1.84m–2.08m	16:25

		6,000 ft. (RGB: 1.33m, TIR: 2.09m)		
Tuesday, 04/26/2017	14:01–14:15	1,000 ft. (RGB: 0.20m, TIR: 0.31m) 6,000 ft. (RGB: 1.33m, TIR: 2.09m)	TERRASAR-X: 8.5m	23:49

Table 1: *TRACS data acquisition dates, times & altitudes over TOSS November 2016 & April 2017 compared to the available SAR & optical satellite sensors & corresponding GSDs (GSDs listed in meters)*

REAL-TIME TRACS DATA TRANSER TO SAMPLING VESSEL APRIL 2017

As noted above, prior to the April TRACS overflights and field sampling trip at the TOSS, it was decided that the demonstration of the wireless, Multiple-Input, Multiple-Output (MIMO), 2.4 GHz-based air-to-ground communication system developed by MSRC and OI would not only widen the scope of the project, but enhance the overall goals of the TOSS data collection trip. Prior to this exercise MSRC had thoroughly tested and proved the capabilities of this system, yet never before had TRACS data showing oil on water been transmitted down to a vessel the size of the *Miss D* (44 feet in length) within a few minutes of acquisition. Several test data files ranging in size from a few kilobytes up to ~128 MB were transmitted to the *Miss D* on both 04/25 and 04/26. During the flight to the TOSS, two-way messaging communication was first established with the boat via a simple MS Windows-based application prior to arrival over the oiled areas. While the recording of communication statistics was not necessary for this demonstration, it was noted that connectivity was established between the aircraft and the boat at a distance of approximately ten miles and optimal data transfer performance occurred within a range of four to five miles. *Figure 2* shows the 10-mile connectivity range in reference to the area of oil imaged by the TRACS on 04/25, along with the on-water boat sampling track and the track of the OI/MSRC King Air. Following the acquisition of TRACS data, image mosaics of both the RGB and TIR imagery were created on board the aircraft while circling the boat. Once the mosaics were created and converted to GeoTIFF format for display on the boat, the person on the aircraft responsible for the data transfer contacted the person on the boat managing the communication computer and notified him via text that the data file transfer would begin. Most of the transfers took place at distances of 1.25 to 2 miles from the boat, however transfers were attempted and successful as far away as 4.5–5 miles. File transfers were quick and efficient with only one to two instances when the transfer did not fully complete. In these cases, the files were simply transferred again. On 04/25 the largest file sent was approximately 128 MB in size and was delivered to the boat in less than one minute. The RGB and TIR imagery of the oil slick imaged only moments earlier was then immediately available for review by the boat personnel. Following the first round of data transfers, OI and MSRC staff switched from the pre-installed, under-the-wing finlet antennas to an in-cabin phased array antenna attached to the inside of one of the cabin windows. The performance of this, much easier to install antenna proved to be equal to or better than the finlet antennas. The successful test of this new antenna technology has now cut hours off the time necessary to install and set up the communication system on the aircraft. On 04/26 weather prevented the *Miss D* and sampling crew from heading out to the TOSS. The TRACS team did, however, fly to the site and acquire data of the oil slick visible on that day. Following the collection of these data, the aircraft altered its course back to the FBO and circled round the *Miss D* docked at Port Eads. Once near Port Eads, the aircraft contacted the boat personnel to have someone turn on and make ready the receiving computer. Not only

was recently-acquired imagery of the TOSS slick transmitted down to the boat, TRACS data of the Port Eads facility was captured, mosaicked and immediately sent down to the moored boat. These data were transmitted from an aircraft altitude of 2,000 feet at close range (within a mile of the boat), not only demonstrating the capability to transmit TRACS data in real-time, but also that close-range, low altitude connections are well within the capabilities of the communication system. Overall, the demonstration of the aircraft-to-vessel data transfer system was considered a success and this equipment/communication package will now be part of all MSRC and OI aerial data collection missions.

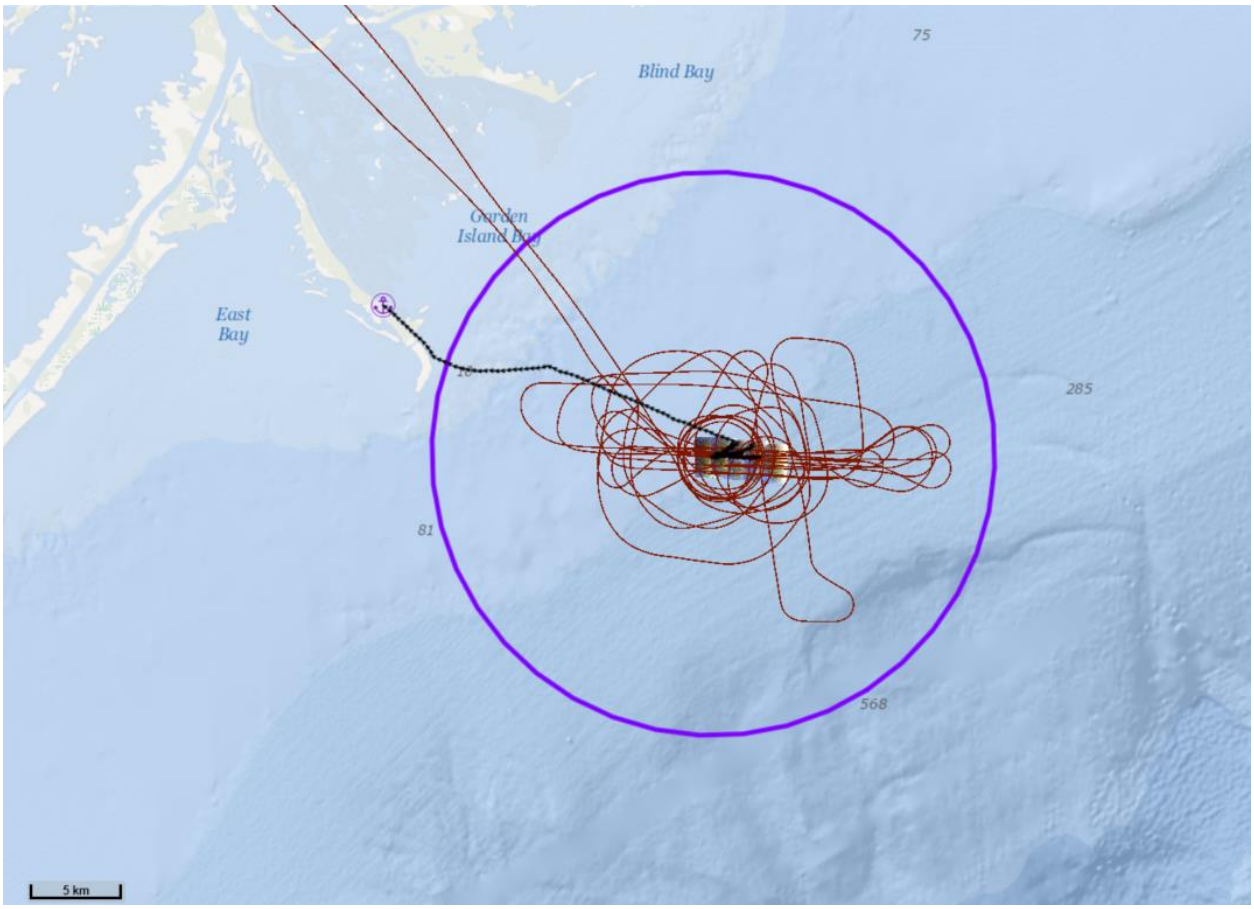


Figure 2. *The 10-mile range of the OI/MSRC communication system (purple circle) in relation to one of the TRACS imaging areas, the on-water sampling vessel track (black line) as well as the TRACS aircraft flight line (maroon line). Note the repeating flight track circles around the area where the sampling vessel was working. This shows the flight pattern while the data transfers were taking place roughly 1.25 to 2 miles from the boat.*

PROCESSING OF 2016 AND 2017 TRACS DATA AQCUIRED OVER TOSS

Image Processing and Geocorrected Image Mosaic Generation: Following each of the TOSS trips, OI staff began immediately offloading the acquired TRACS data onto OI's network attached storage (NAS) drives for cataloging and preprocessing. The TRACS data were converted from their native format to GeoTIFF format for compatibility with ESRI's ArcGIS software and other GIS applications. Select scenes were then projected to a geographic WGS-1984 coordinate system and georeferenced to an ESRI base layer. In a few cases from the April datasets when near-real-time processing speed was more important than absolute geospatial accuracy, the TRACS scenes initially used for the near-real time products were re-georeferenced to improve the overall accuracy of the final mosaics. The best data runs (flight lines or series of adjacent flight lines) for each day were then combined into image mosaics for both the RGB and TIR data scenes. The TIR mosaics were then georeferenced and re-projected to match the spatial coverage and resolution of the RGB mosaics. All of the RGB and TIR image files in GeoTIFF format were uploaded to the NOAA sFTP site and made available on OI's ArcGIS Server as REST services for ingestion by NOAA's ERMA Web Map Service (WMS). Available photographs from the various cameras operating during the TOSS acquisition times were also downloaded and catalogued for later use as comparison information to the TRACS data.

Oil Thickness and Volume-per-area Digital Information Product Generation: The oil classification maps shown in Appendices B.1 and B.2 were generated using the ESRI ArcGIS application. Both the oil thickness classifications and the resulting volume-per-area numbers relied on data gathered from the Ohmsett analyses performed as part of Phase One of this project as well as the on-water/in situ thickness measurements and bulk oil water sample data which were limited in number and temporal coverage. Due to boat logistics, weather and a number of other factors, the collection of oil thickness data simultaneously with the TRACS overflights was reportedly quite difficult. The lack of thick oil on the water also made the collection of bulk oil samples used to calculate the water:oil ratio problematic. As is illustrated in *Figure 3*, on some days the oil moved quite quickly. In the case of April 25th, two tracked oil features moved ~212 meters and ~328 meters in a period of eight minutes. Averaging the movement of the two features, this equates to oil movement of approximately 0.56 m/s. Knowing this, it is easy to understand the difficulty in obtaining multiple on-water oil thickness measurements at the same time as the TRACS overflights.

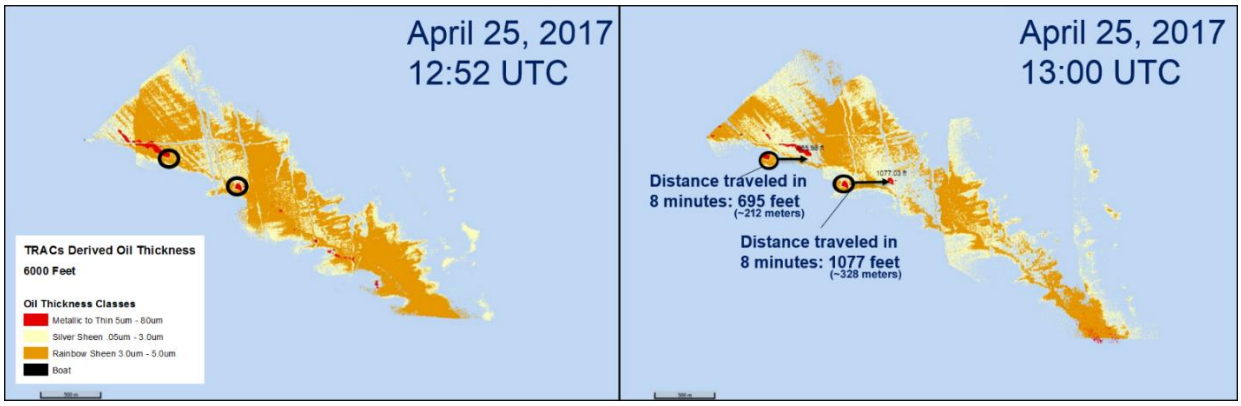


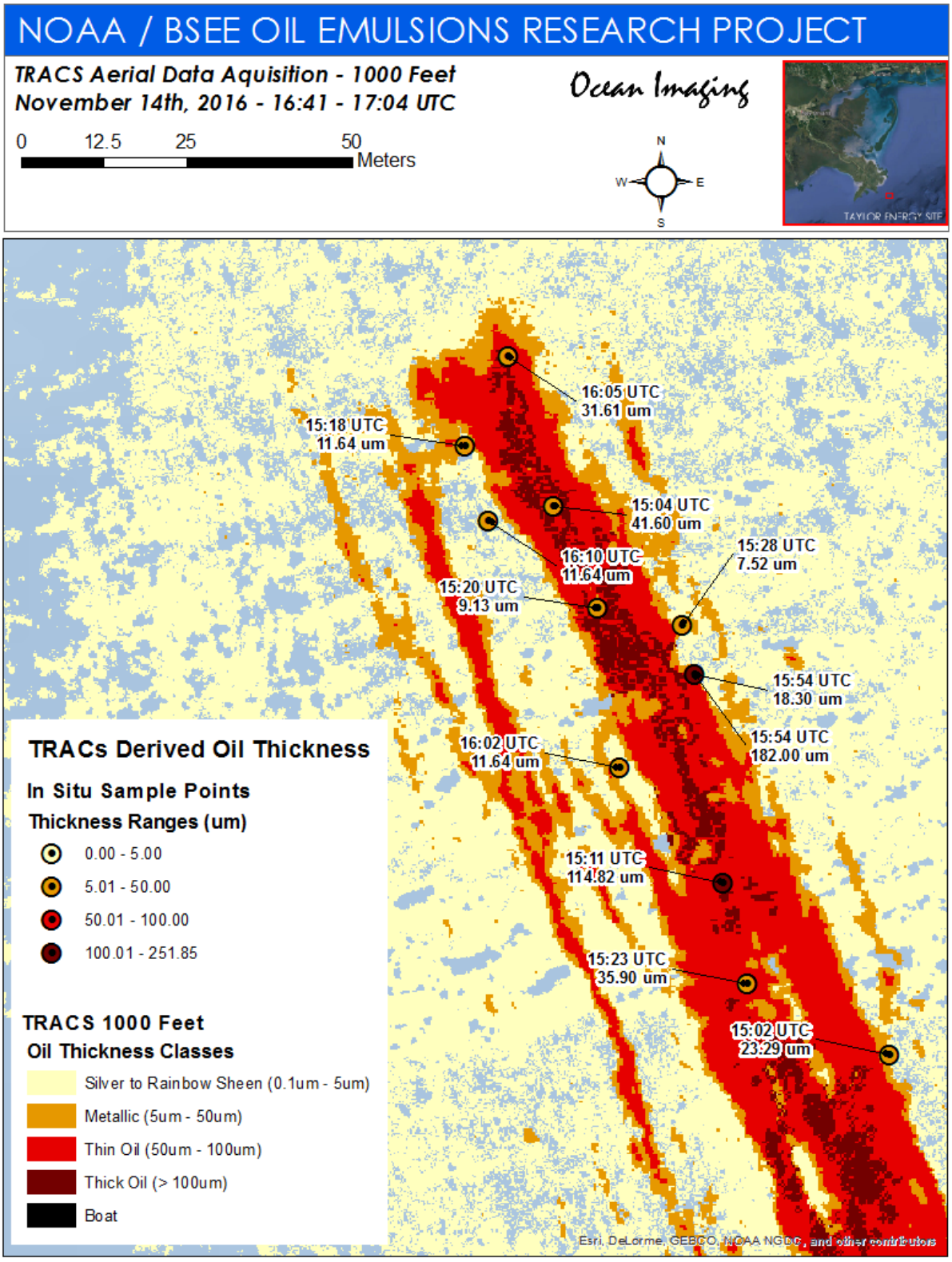
Figure 3: *Classifications of oil thickness over TOSS on 04/25/17. Two oil features were tracked over the eight-minute time period between the two TRACS data acquisitions illustrating the movement of the oil on the water.*

Given the few in situ data points, we were unable to utilize supervised classification methods to generate the oil thickness and volume-per-area thematic maps. Therefore, the RGB and TIR bands were run through a 100-class unsupervised (ISODATA clustering) classification with both the ESRI and ENVI image processing applications, and them merged down by an expert analyst to classes which best correlated with the Ohmsett results, known relationships between thermal signal cut-off points, oil reflectance properties and OI's previous work with oil emulsions. As was stated in prior reports, from OI's 2011–2012 work it was determined that during the day the thermal contrast between the 60% emulsions and surrounding water is considerably smaller (approximately a factor of 10) for a given film thickness than pure crude oil. This is logical in that the water-containing oil emulsion absorbs and re-emits less solar heating than pure crude. The relationship is consistent with smaller water:oil content ratios (i.e. the 20% emulsion samples had IR emittance closer to pure oil) and is an important aspect considered in any emulsion-oriented classification methodology (Svejkovsky and Muskat, 2012).

Following this logic, and mentioned in previous reports, any information product characterizing emulsified oil on water should provide a measure of actual oil volume per unit of surface area, rather than an estimation of the emulsion layer's "thickness". OI believes that a reliable estimate of the actual oil volume within the emulsion is of the most relevance to recovery and other response operations rather than an estimate of a "thickness" which does not reflect the actual water:oil content ratio. OI's work confirmed that, unlike in the case of unemulsified oil films that tend to have both their upper and lower boundaries well defined, the absolute thickness of emulsions, especially older, weathered emulsions, is not so clearly defined. Often the lower (i.e. submerged) boundary consists of a sponge-like texture, with water and air pockets interspersed between vertical strands of oil (Svejkovsky and Muskat, 2012, Phase One report, 2017). Therefore, the water:oil ratio also remained a critical factor when determining the volume of oil in the TOSS slicks imaged. For these reasons, while we did generate classifications of oil thickness derived from the TRACS multispectral and TIR data (*Appendices B.1 and B.2*), the more relevant information products are the same classifications with the classes defined as volume per unit area (*Appendices B.1 and B.2*). Unfortunately, the water percentages used to compute the oil volumes for the November classifications were from only two bulk oil samples taken during that field trip and only one bulk oil sample was available for use with the April 2017 classifications. Two bulk oil samples were collected on 11/15/16 yielding 17% water (83% oil) and 33% water (67% oil). On 04/25/17 one bulk oil sample was collected yielding 73% water (27% oil). For the November oil volume maps, an average of the two samples (25% water, 75% oil) was used to create the oil volume classes for the November TRACS-derived products and the single measurement taken on 04/25/17 was used to create the oil volume classes for the April TRACS-derived products. It should be emphasized that water:oil ratios from a single day in November were used for the volume calculations in all nine of the 2016 classifications. While it would have been much preferred to have multiple water:oil ratio values for each sampling day and within the different types of oil, this was not possible, and so the volume numbers derived from the TRACS classifications exist as rough estimates only, with no reliable means of assessing accuracy. All of the oil thickness and oil volume per unit area thematic maps were generated in ESRI Shapefile format and uploaded to the NOAA sFTP site and made available on OI's ArcGIS Server as REST services for ingestion by NOAA's ERMA Web Map Service (WMS).

DATA ANAYSIS

TRACS—On-Water Data Comparison: The on-water oil thickness and water:oil ratio data were not available to OI until after the TRACS-derived oil characterization products were generated. Therefore, the oil thickness and oil volume class ranges were determined solely on the information and methods described above. In order to assess the accuracy of the TRACS-derived products in relation to the temporally- and spatially-coincident on-water in situ data, the in situ data were first grouped by thickness into bins matching the TRACS oil thickness classification ranges for the matching day and/or time of the TRACS classification. Using ESRI's ArcGIS software, plots were generated displaying the in situ thickness samples taken within +/- two hours of the TRACS data acquisition time and binned into the TRACS thickness classes overlaid on to the TRACS-derived oil thickness analyses (*Figure 4*).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TRACS Aerial Data Aquisition - 1000 Feet
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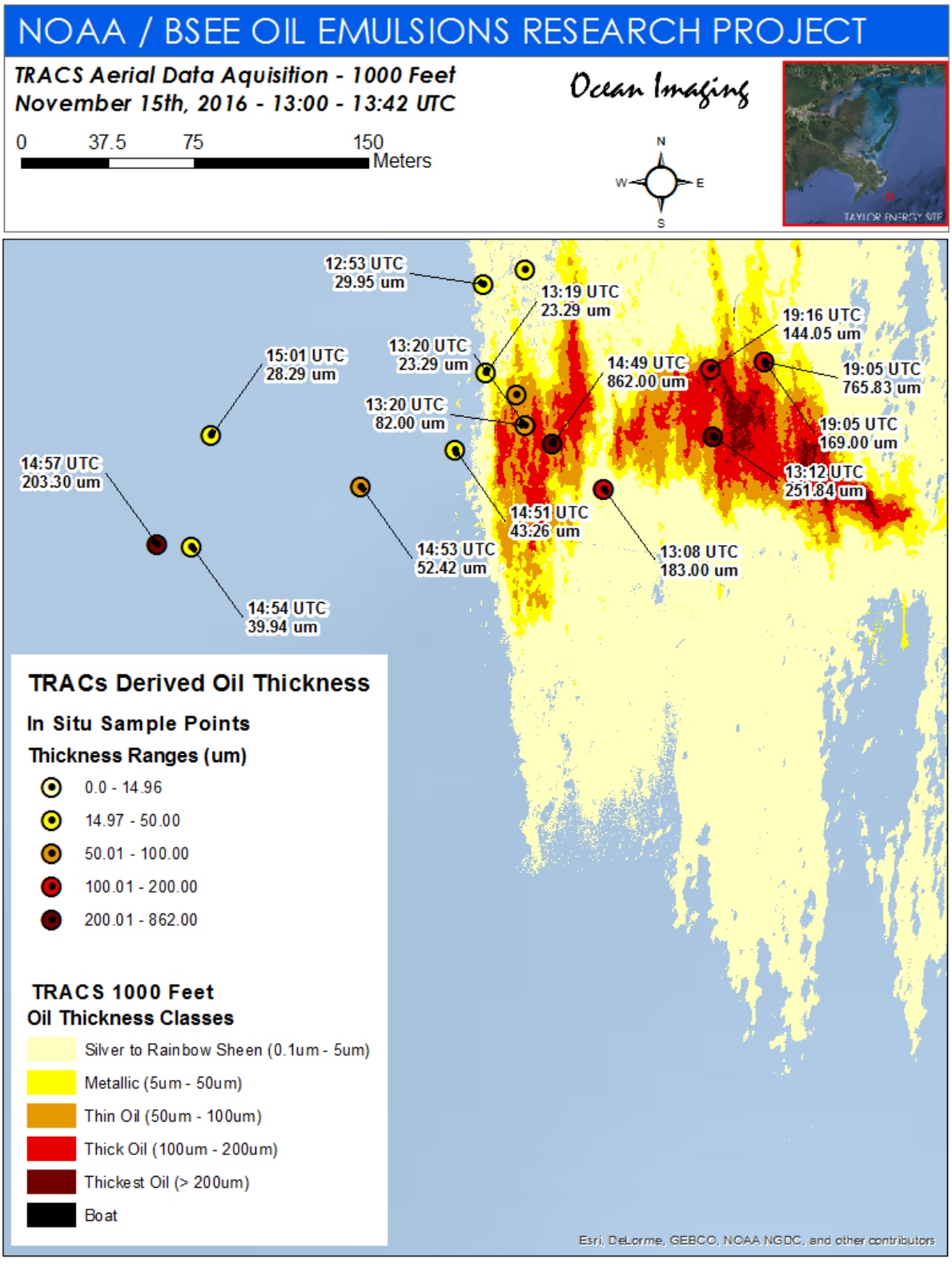
114.82 um
15:23 UTC
35.90 um
15:02 UTC
23:29 um
TRACs Derived Oil Thickness
In Situ Sample Points
Thickness Ranges (um)
0.00 - 5.00
5.01 - 50.00
50.01 - 100.00
100.01 - 251.85
TRACS 1000 Feet
Oil Thickness Classes
Silver to Rainbow Sheen (0.1um - 5um)
Metallic (5um - 50um)
Thin Oil (50um - 100um)
Thick Oil (> 100um)
Boat
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors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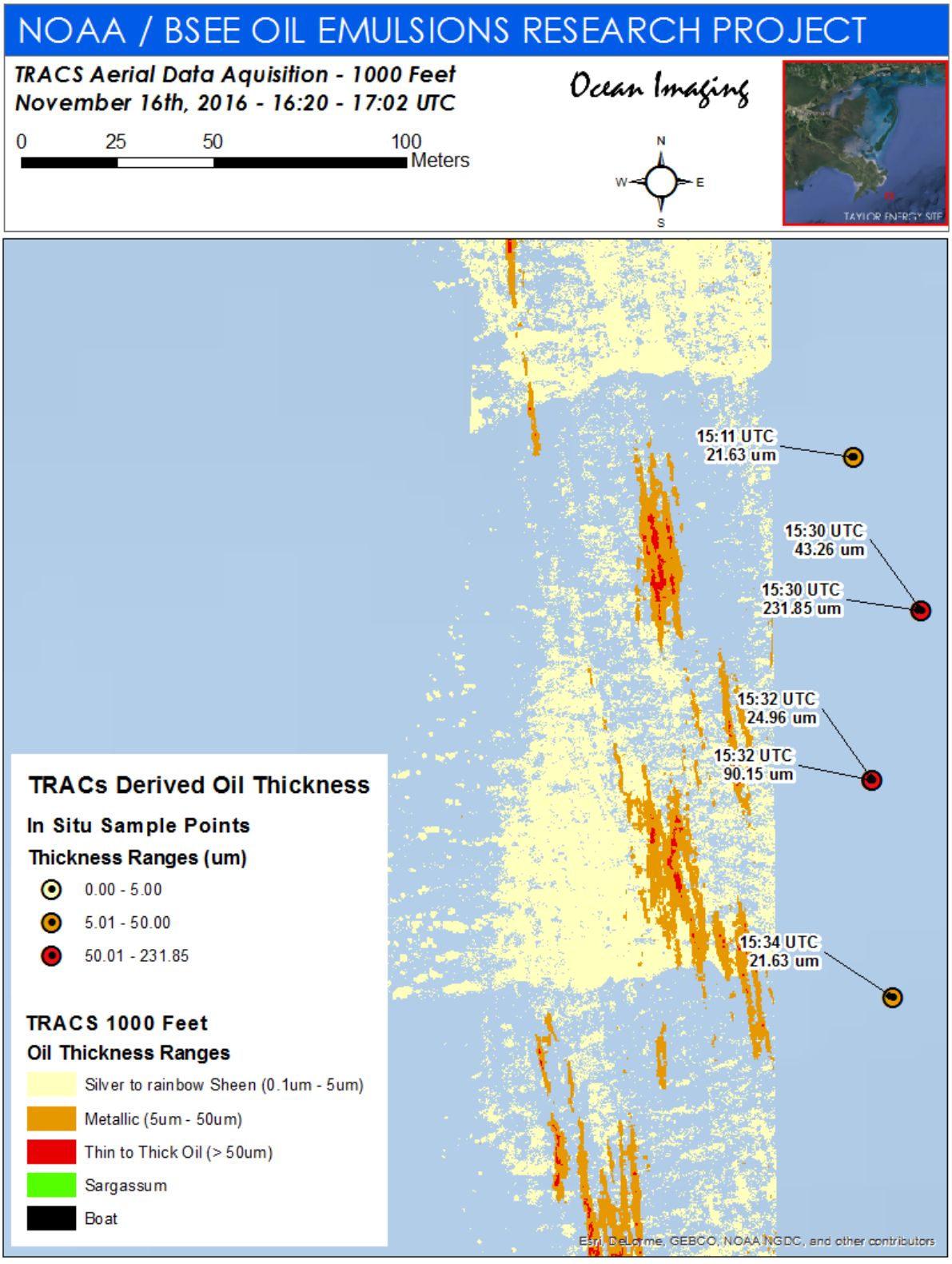
765.83 um
13:20 UTC
82.00 um
19:05 UTC
169.00 um
14:57 UTC
203.30 um
13:12 UTC
251.84 um
14:51 UTC
43.26 um
14:53 UTC
52.42 um
13:08 UTC
183.00 um
14:54 UTC
39.94 um
TRACs Derived Oil Thickness
In Situ Sample Points
Thickness Ranges (um)
0.0 - 14.96
14.97 - 50.00
50.01 - 100.00
100.01 - 200.00
200.01 - 862.00
TRACS 1000 Feet
Oil Thickness Classes
Silver to Rainbow Sheen (0.1um - 5um)
Metallic (5um - 50um)
Thin Oil (50um - 100um)
Thick Oil (100um - 200um)
Thickest Oil (> 200um)
Boat
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors


NOAA / BSEE OIL EMULSIONS RESEARCH PROJECT
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231.85 um
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24.96 um
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90.15 um
15:34 UTC
21.63 um
TRACs Derived Oil Thickness
In Situ Sample Points
Thickness Ranges (um)
0.00 - 5.00
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50.01 - 231.85
TRACS 1000 Feet
Oil Thickness Ranges
Silver to rainbow Sheen (0.1um - 5um)
Metallic (5um - 50um)
Thin to Thick Oil (> 50um)
Sargassum
Boat
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors

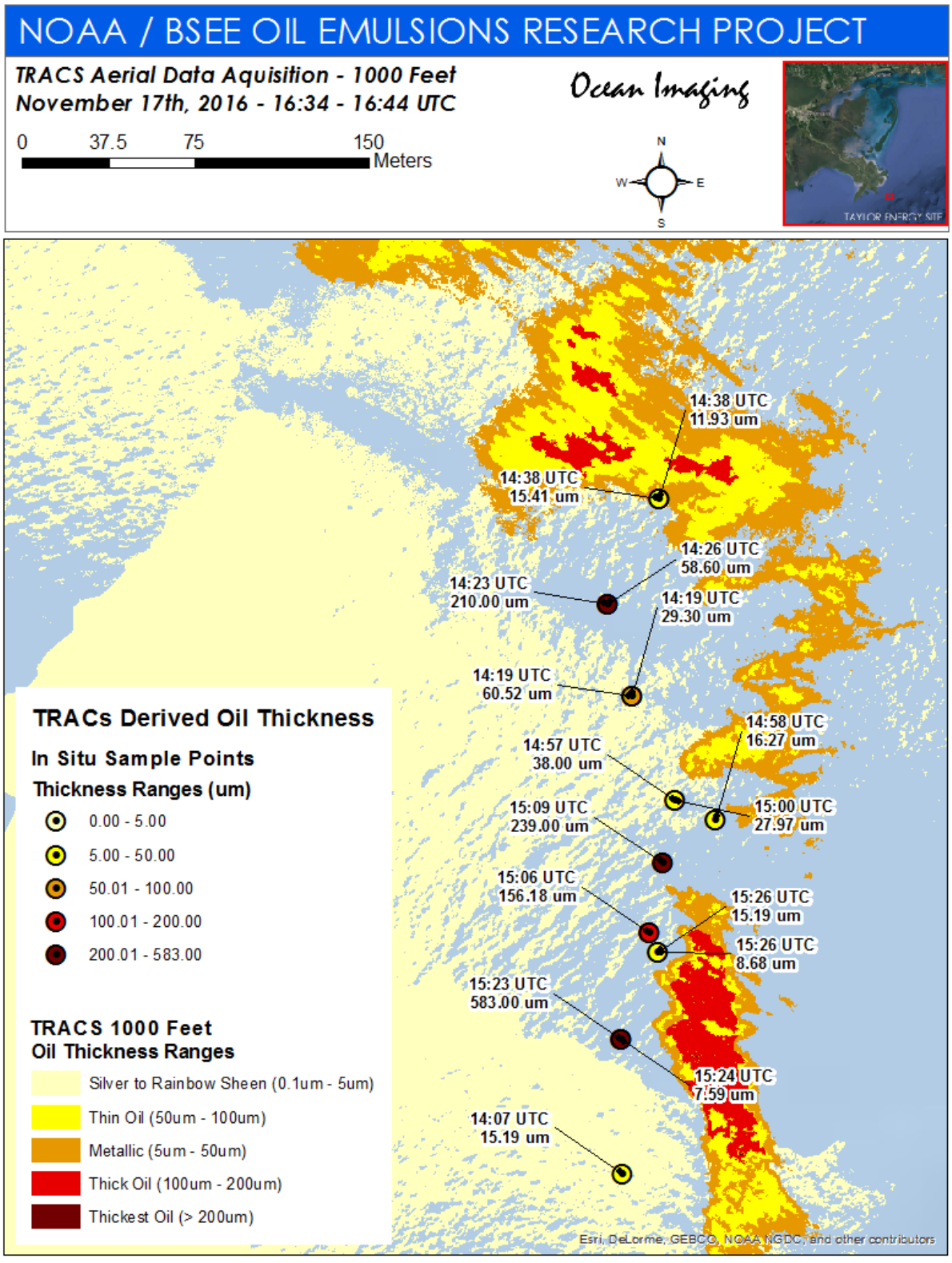


Figure 4: *On-water oil thickness measurements binned into the TRACS-derived oil thickness classes overlaid onto the TRACS oil thickness classification maps. 11/14/16, 11/15/16, 11/16/16 and 11/17/16 shown from top to bottom.*

The two-hour cutoff was chosen so that there were enough on-water data points to use in the accuracy assessment, yet not too far in time from the TRACS collections. We know from the two examples discussed above, that the oil can move at least ~0.5 m/s, so it is understood that the two hour time limit is quite long. However, any reduction in the time gap would have significantly reduced the number of available in situ thickness measurements. Using ERSI software, the distance was determined between each in situ thickness sample meeting the temporal cutoff criteria and the closest group of pixels of the same thickness class in the TRACS-derived map. In cases for which the in situ sample was of the same thickness class as the TRACS analysis, this distance would be zero and that sample would be considered a match between the two datasets. *Table 2* shows the number of matching classes when comparing binned the in situ thickness data to the TRACS-derived oil thickness classes at distances between 0 and 100 meters.

Date	Total # of On-Water Samples Taken Within 2 Hours of TRACS Data	Number of Matches Within 0 m	Number of Matches Within 0-10 m	Number of Matches Within 0-50 m	Number of Matches Within 0-100 m
11/14/16	13	7 (53.8%)	13 (100.0%)	13 (100.0%)	13 (100.0%)
11/15/16	19	6 (31.6%)	9 (47.4%)	13 (68.4%)	16 (84.2%)
11/16/16	9	0 (0.0%)	0 (0.0%)	4 (44.4%)	7 (77.8%)
11/17/16 AM	26	5 (19.2%)	11 (42.3%)	23 (88.5%)	25 (96.2%)
11/17/16 PM	6	4 (66.7%)	4 (66.7%)	4 (66.7%)	4 (66.7%)
04/25/16	12	2 (16.7%)	4 (33.3%)	5 (41.7%)	5 (41.7%)
Average %		31.3%	48.3%	68.3%	77.7%
Date	Total # of On-Water Samples Taken at Same Time as TRACS Data	Number of Matches Within 0 m	Number of Matches Within 0-10 m	Number of Matches Within 0-50 m	Number of Matches Within 0-100 m
11/15/16	8	5(62.5%)	6 (75.0%)	8 (100.0%)	8 (100.0%)
04/25/16	3	1 (33.3%)	2 (66.7%)	3 (100.0%)	3 (100.0%)
Average %		47.9%	70.8%	100.0%	100.0%

Table 2: *Number (percentage) of on-water to TRACS oil thickness class matches within distances of 0, 10, 50 and 100 meters from the in situ sampling location to the nearest TRACS-derived oil feature of the same class. The upper section shows on-water samples taken +/- two hours of the corresponding TRACS data acquisitions and the lower section shows those days for which there were on-water samples taken at the same time as the TRACS data (only 11/15/16 and 04/25/17 included simultaneous sampling.*

Average percent matches of the TRACS-derived oil thickness classes to the on-water sampled oil thickness of 68.3% within 50 meters and 77.5% within 100 meters seem reasonable given the approximate four hour window between sampling along with many other factors. The percentage match improves dramatically to 100% within 100 meters using only the in situ samples taken during the TRACS data collections (bottom section of Table 2). Considering the high variability of the on-water thickness samples (samples from the same location taken at the same time differed by up to 832 um), the wide ~four-hour time window necessary to obtain a decent sample size and the potential drift even within the short time of TRACS data collection, the TRACS-derived oil thickness classes correspond with the field data relatively well. It should also be noted that many of the on-water thickness measurements fell outside of the nearest TRACS oil thickness class/bin by only a few microns. If the TRACS class ranges are adjusted by only 15 microns based on the field measurements, the percentages of matching thicknesses would improve significantly. April 25th is a good example of this (see *Figure 5* for graphic). In effect, calibrating the TRACS-derived classification by slightly adjusting the class range categories increases the percent of TRACS to on-water

thickness correspondence to 75% within 10 meters and 83.3% within 50 meters. In the event of a real oil spill, the TRACS-derived oil thickness thematic maps would be well within the necessary margin of error to help responders locate actionable oil. Depending on the spatial and temporal correspondence between on-water measured thickness and the TRACS data, as well as the confidence in the on-water measurements, the TRACS-derived oil thickness analyses could be calibrated at a later date for purposes of assessing oil on water volumes and potential damage to natural resources.

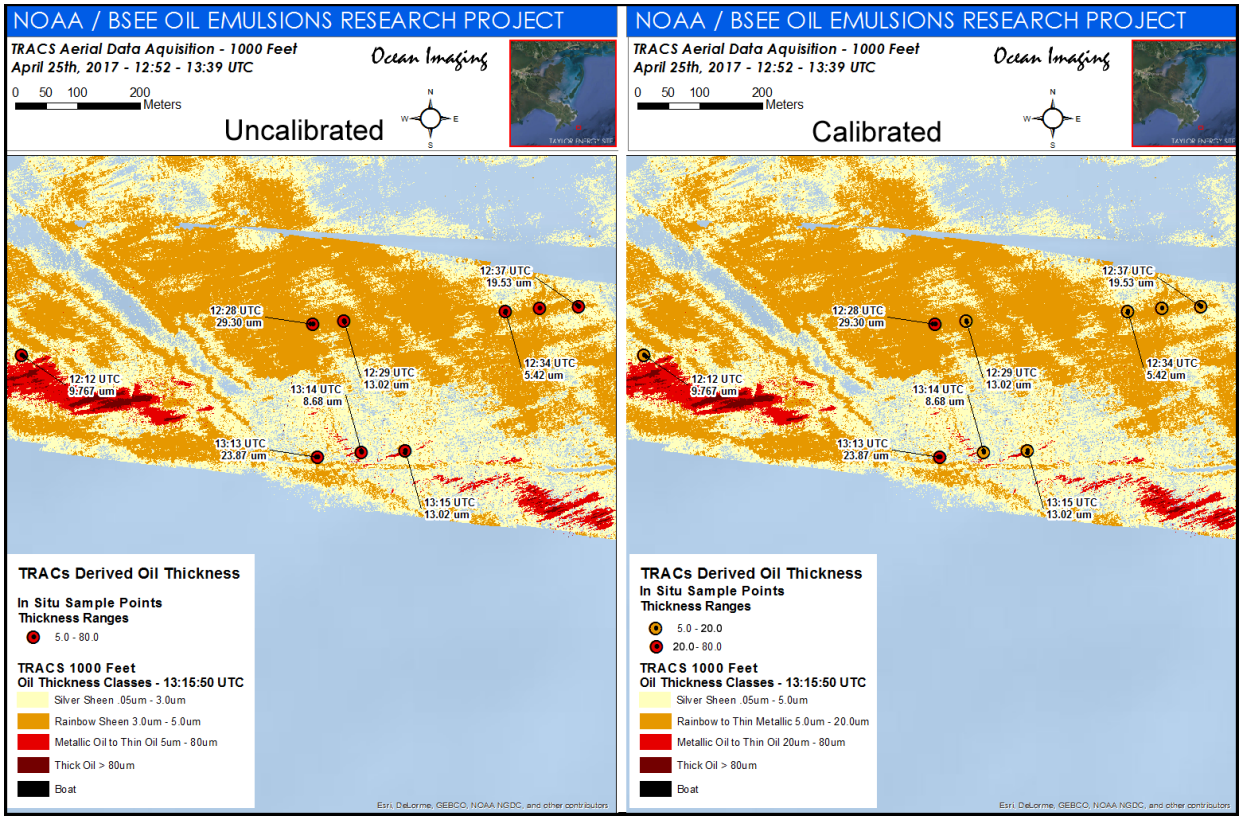


Figure 5: *Adjustment of the TRACS-derived oil thickness classes (right) based on the on-water thickness measurements. Original, uncalibrated classification is on the left.*

TRACS—RADARSAT Comparison: On November 15, 2016, November 17, 2016, and April 25, 2017 RADARSAT-2 (RS2) data were acquired for the project area of interest surrounding and including the TOSS. The RS2 data were collected at 17:56 UTC, 23:49 UTC and 12:00 UTC on 11/15/16, 11/17/16 and 04/25/17 respectively. The approximate time differences between the RS2 and TRACS data collections were 4.23 hours on 11/15/16, 0.98 hours on 11/17/16 and 0.87 hours on 04/25/17. The time differences of less than one hour between the TRACS and the RS2 data acquisitions on 11/17/16 and 04/25/17 warranted a comparison of a TRACS-derived oil thickness products to the oil characterization products derived from the RS2 data by Water Mapping, Inc. From the SAR data acquired on 11/15/16 and 04/25/17 Water Mapping generated their Texture-Classifying Neural Network Algorithm (TCNNA) and from the 11/17/16 data they produced their Oil Emulsion Detection Algorithm (OEDA) product which theoretically shows relative oil thickness. Since neither TCNNA nor OEDA produce quantitative thickness estimates, no quantitative comparison/analyses could be performed to the TRACS products.

Only a qualitative, visual comparison of the data products was possible. The TCNNA and OEDA oil characterization products are shown in *Figure 6* with the TRACS oil thickness analyses overlaid on top of the TCNNA/OEDA analyses. The most obvious difference between TRACS and SAR-derived products is that the SAR instrument detected and mapped a significantly larger area of oil than the TRACS. This is because the sensors used on the TRACS are not well suited to always be able to detect very thin sheens—the category that under the BONN Appearance Code would be characterized as silver sheen (Bonn Agreement, 2016). It is also because the OI flight crew was focused only on mapping the area around the TOSS and the location of the sampling vessel. Because of this, an area of presumably sheen is seen in the SAR products extending east of the TRACS oil in the 11/15/16 and 04/25/17 analyses and significantly farther north and to the northwest in the 11/17/16 product. In these cases, the larger footprint SAR data show a capability to better map the presence/absence of the entire slick, including the thinnest sheen. TRACS, however is more capable of mapping the areas of differing oil thickness (and volume-per-area if water content data are available). The TCNNA product only shows the existence of oil on the water's surface and the OEDA thickness product is very difficult to interpret for actual oil thickness and/or volume. The higher TRACS resolution capability is also better suited for mapping the fine heterogeneity of an oil slick to guide response efforts. As is discussed below in relation to the UAVSAR data, if time synchronicity can be achieved a TRACS-SAR fusion product would be the optimal response and oil on water documentation product for an actual spill incident.

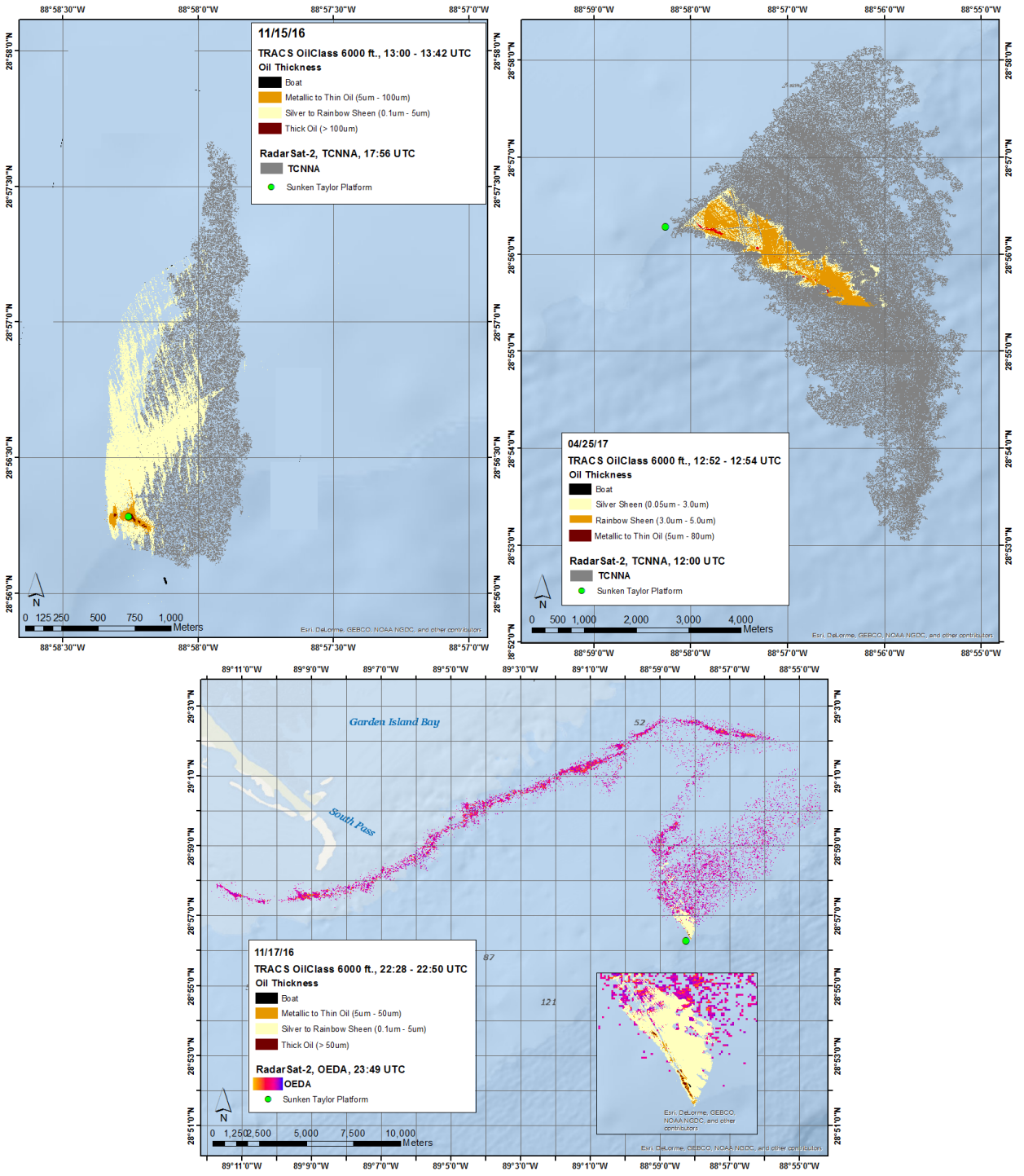


Figure 6: *TRACS-derived oil thickness classification analyses overlaid on top of Water Mapping's TCNNA or OEDA RADARSAT-2 analyses. Analyses from 11/15/16 are top left, 04/25/17 top right and 11/17/16 shown bottom center.*

TRACS—UAVSAR Comparison: On November 15, 2016 UAVSAR flew for several hours and acquired several datasets. From these data, NASA generated several classifications of relative oil thickness. The classification from the data acquired at 13:46 UTC was very close in time to the TRACS data acquired between 13:40:59–14:42:30 UTC used to generate one of OI's oil thickness classifications. This allowed for

the best temporal comparison of a TRACS-derived oil thickness products to a thickness product derived from a SAR instrument. Since the UAVSAR product only provides relative thickness estimates, no quantitative comparison/analyses could be performed. As was the case with the RS2 data products, only a qualitative, visual comparison of the data products was possible. The two data products are shown in *Figure 7*. As was also the case with the RS2 data, the most obvious difference between the two products is that the UAVSAR detected and mapped a significantly larger area of oil than the TRACS. Because of this, an area of sheen north and northeast of the main body of oil was missed by either the TRACS cameras and/or the flight crew. In this particular case, the higher altitude UAVSAR definitely showed a capability to better map the entire slick, including the thinnest sheen. The ability of the UAVSAR to detect and accurately map the oil thickness, however, leaves much to question. The thickness classifications (panels A & B in *Figure 7*) show a speckled rendering of thin to thick oil. This is typically not how oil naturally accumulates and distributes itself on the surface of the ocean. This is especially not the case for highly emulsified oil which in most cases will form into sinuous strands of thick mouse-like material (Svejkovsky, et.al. 2016). Furthermore, in the UAVSAR classification, much of the thicker oil is shown to be in the north side of the slick and along the southwest-to-northeast extensions of the slick which closely follows the convergence zone between the Mississippi River plume and the open ocean waters. It would be expected that such areas of thick oil would have been identified by the On Wings of Care spotter aircraft carrying trained NOAA observers, however was not. This lack of prominently thick oil to the north is confirmed by its absence in the NOAA overflight map for that day. These northern, thick oil patches also being on the river plume convergence zone, could have likely been biological material. Additionally, the UAVSAR analyses do not show areas of continuous thick oil in the southern part of the slick where the boat was sampling. TRACS data do show thicker oil as does the NOAA overflight map. Therefore, it is our conclusion that while the UAVSAR data do show some sort of variability in the radar reflectance signature within the oil slick, at this point the variability cannot confidently be attributed to areas of thicker or thinner oil. Based on that conclusion and the widely accepted belief that SAR data do accurately depict the presence/absence of oil on water, even down to the thinnest of sheens, the concept of a TRACS-UAVSAR fusion product is presented in panel D of *Figure 7*. Since the two data acquisitions were literally within a few minutes of each other, they can be used in combination to 'fill in the gaps' missed by the TRACS dataset. In this case the UAVSAR data are used to show the thinnest sheen class. If examined closely, a slight east-west mismatch between the UAVSAR data and the TRACS data is evident. A measurement of feature displacements between the two classifications results in offsets of approximately 100 to 130 meters. If using the center point time of the TRACS acquisition (13:41:44 UTC), the time difference between the two remotely sensed data sets is ~3.86 minutes. Given an average offset distance of 115 meters, that equates to an oil drift speed of ~0.50 m/s. Interestingly, that correlates quite well to the 0.56 m/s oil drift speed computed using the two TRACS classifications from 04/25/17 discussed above. This supports the premise that if the direction of movement was known, one or the other of the oil classifications could be shifted to match the other, thus creating a very accurate oil thickness map. Finally, as was the case for this project, if the UAVSAR can acquire a time series of datasets, these data could be used to compute the displacement of an oil slick over time with the TRACS data incorporated into the produce to identify where the thickest areas of oil are moving, thus lending these two remote sensing assets as valuable input to an oil transport forecasting model.

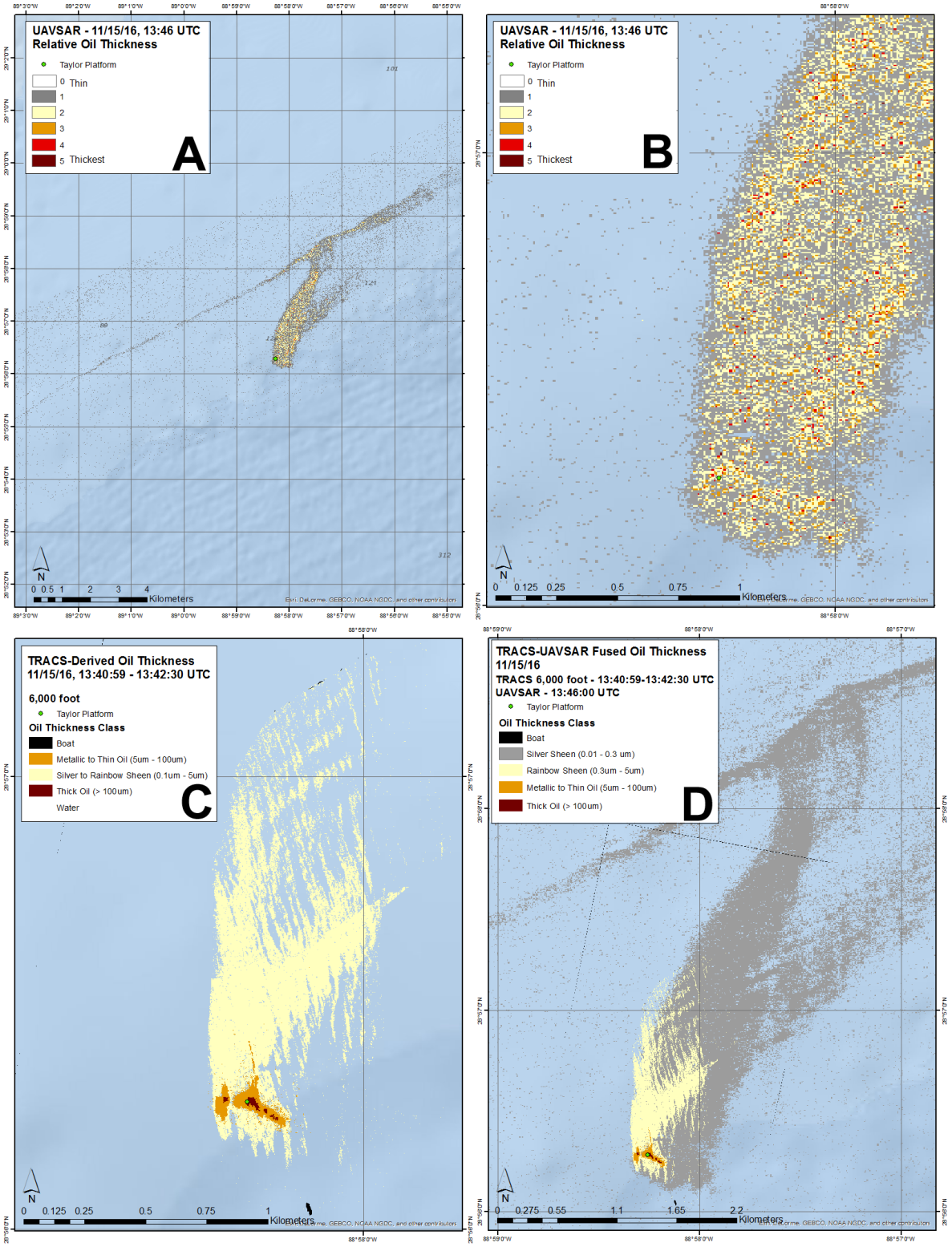


Figure 7: *A) full coverage view of the UAVSAR relative thickness classification B) UAVSAR classification rendered at the same scale and location as the TRACS-derived oil thickness classification C) TRACS-derived oil thickness classification D) TRACS-UAVSAR fused oil thickness product. The UAVSAR classes have been merged into a single silver sheen thickness class.*

TRACS—WorldView-2 and Aster Comparison: On April 25, 2017 both WorldView-2 (WV2) and Aster imagery were collected approximately four hours after the time of the TRACS overflight. While the time difference between the two satellite datasets and the TRACS data was too large for direct comparisons, the quality and coverage of the WV2 and Aster imagery warranted the creation of oil thickness and volume classification analyses from the data. As was the case with the TRACS data, given the few in situ data points, we were unable to utilize supervised classification methods to generate the oil thickness and volume-per-area thematic maps for either the WV2 or Aster-derived products. Therefore, all eight bands of the ~ 2-meter WV2 data and the three 15-meter bands provided for the Aster data were used in as input to a 100-class unsupervised (ISODATA clustering) classification with both the ESRI and ENVI image processing applications, and them merged down by an expert analyst to classes which best correlated with, known relationships between oil reflectance properties and previous work with oil emulsions performed during OI's work on the NOAA Oil on Water NRDA committee. When processing the WV2 data, band 6 (705-745 nm) and band 8 (860-900 nm) were used to extract information about the oil sheen classes and band 1 (400-450 nm) and band 2 (450-510) were used to help best extract the metallic, thin and thicker oil classes. The class thickness (and subsequent oil volume) ranges were assigned by examining 13 of the in situ thickness measurements taken within ~1 hour of the WV2 satellite overpass and 10 of the in situ thickness measurements taken within ~1 hour of the Aster satellite overpass. The on-water thickness measurements were plotted on top of the relative oil thickness analyses which then allowed for the assignment of oil thickness classes. It should be stressed again that the limited number of and only moderate level of confidence in the accuracy of the in situ data resulted in oil thickness/volume maps that should only be considered as loosely calibrated. Never-the-less, the large, synoptic coverage area and ability to extract sheen to thicker-than-sheen oil from these data sets makes these instruments well suited for use as 'tools' in the remote sensing oil spill response toolkit. The only drawback to these satellite assets is their susceptibility to cloud cover and sun glint contamination. *Figures 8 and 9* both show the enhanced imagery as well at the oil thickness/volume analyses derived from the WV2 and Aster data respectively.

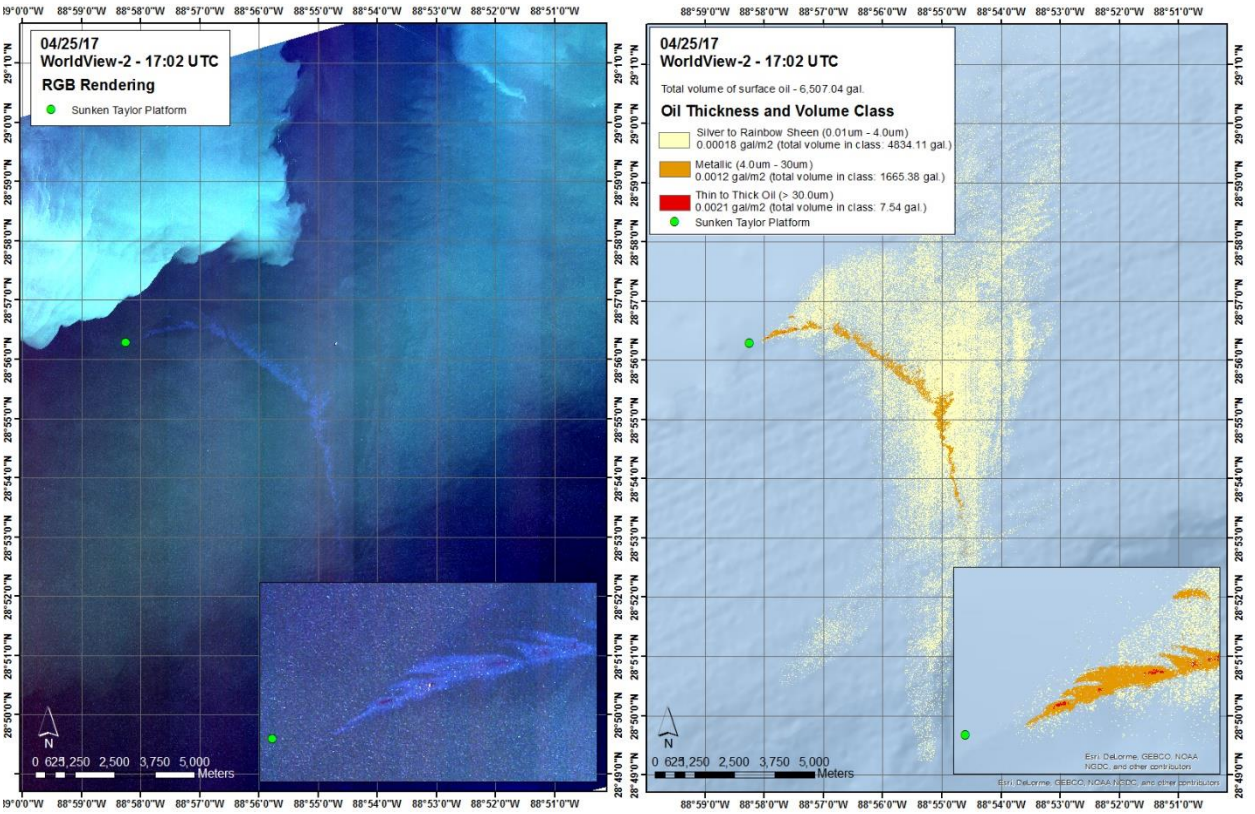


Figure 8: *WorldView-2 satellite image mosaic rendered using band 5 (630–690 nm), band 3 (510–580 nm) and band 2 (450–510 nm) (left). Image inset shows a zoomed in map scale of the oiled water near the TOSS which also shows the area of thickest oil on that day. The analysis on the right is an oil thickness and volume-per-area classification. The thickness value ranges and corresponding oil volumes were estimated using the on-water thickness and water:oil ratio data.*

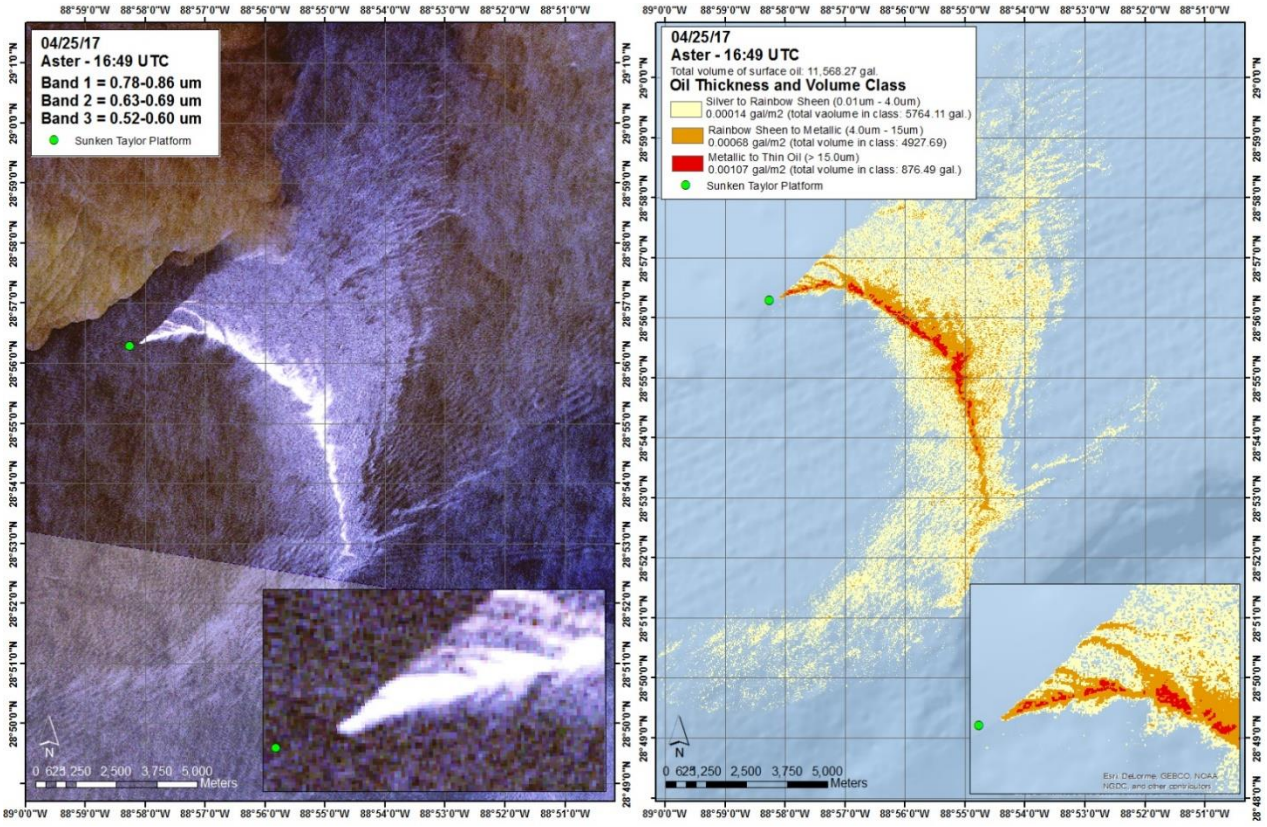


Figure 9: *Aster satellite image mosaic rendered using the 15-meter, three banded data provided by NOAA NESDIS. Image inset shows a zoomed in map scale of the oiled water near the TOSS. The analysis on the right is an oil thickness and volume-per-area classification. The thickness value ranges and corresponding oil volumes were estimated using the on-water thickness and water:oil ratio data.*

Using the single water:oil ratio number available for 04/25/17, oil volume classes and total oil volume numbers were computed from both the WV2 and Aster classifications. The WV2 analysis resulted in a total surface oil volume of 6,507 gallons and the Aster-derived analysis yielded a total surface oil volume of 11,568 gallons. These numbers are quite high when compared to the total surface volumes computed from the TRACS analyses which ranged from 161 to 530 gallons depending on time acquired and altitude of data acquisition. This large difference can be attributed to many possible factors. First and foremost, both the WV2 and Aster data showed areas of oil-covered water much larger than the TRACS data acquired four hours earlier. The total oiled area computed from the TRACS classifications ranged between 99,628 m^2 to 507,189 m^2, while the total area of oil-covered water computed from the WV2 and Aster data were 28,432,664 m^2 and 48,397,275 m^2 respectively. This large increase in coverage area is likely due to the four-hour difference between datasets and the obvious increase in surface oil during that time, as well as the ability of both WV2 and Aster to identify and map the thinner sheens. Depending on which satellite and TRACS data are used, the area of water covered by oil as derived from the satellite data ranges from 95 to 485 times that shown by the TRACS data, yet the volume of oil computed from the satellite data ranges from 12 to 71 times that computed from the TRACS data. The difference in these proportions is likely due to the fact that more of the sheen class was identified using the satellite data. Also, by

comparison the RS2 data from 04/25 acquired at 12:00 UTC showed a total oiled area of 15,864,615 m^2 which is just over half of the area computed from the WV2 data and one third of the oiled area computed from the Aster data.

DISCUSSION

As was determined in from the results of Phase One of this project, from an incident response/oil recovery perspective, the TRACS-derived analyses of the oil slick over the TOSS stand as very effective set of digital information products accurately identifying the actionable oil, easily ingestible by any Common Operating Picture platform such as NOAA's Environmental Response Application (ERMA). Not only was OI able to transmit usable information about actionable vs. non-actionable oil down to a small vessel within minutes of data acquisition, we were also able to demonstrate that quantitative, accurate, GIS-ready digital information products could be available for ingestion by ERMA within a few hours of data acquisition. With a bit of additional preparation in regards to Internet connectivity and available processing power, the time from TRACS data acquisition to ERMA availability can be decreased even further.

The comparison of the TRACS-derived oil thicknesses to the field-sampled thickness data showed that the TRACS characterization of the TOSS oil matched that of the in situ data quite well. Although there is some uncertainty in the level of confidence of the in situ thickness data due to high variability of some measurements in the same location and there were only three water:oil ratio samples to use for the oil volume computations, overall the remote sensing-derived thickness estimates were generally corroborated by the field data. The main limitation of the TRACS data was that the analyses did not always provide a full, synoptic map of the slicks—especially the areas of thin sheen. This issue can be overcome by both flying a larger area around the known spill area and acquiring more data (which would be common practice during an actual pill event anyway) as well as using available time-synchronous SAR and optical satellite data to fill in the areas of thin sheen that the TRACS system might miss. This would ensure a high-detail, accurate characterization of the oil type and thickness as well as a clear overall view of the entire slick. Further work is recommended on the best methods and operational procedures to both schedule aerial data acquisitions with satellite overpass times, fly at altitudes that both facilitate complete slick coverage, while matching the resolution of the satellite data, as well as fuse these data types in ways that preserve the detail and accuracy of the information they provide.

Recommendations for future work are similar to those discussed in the Phase One report. Methods to quickly and accurately measure the thickness and water content of the oil from a support vessel to be used as validation and calibration of the remote sensing data need to be improved. This is especially true if NOAA plans to develop oil thickness/volume algorithms for use in universally applicable, RS-based, semi-automated information product generation. Plans should also be considered to continue work on refining real-time air-to-boat and boat-to-boat communications capability and the specific data and/or information products transmitted between these response platforms.

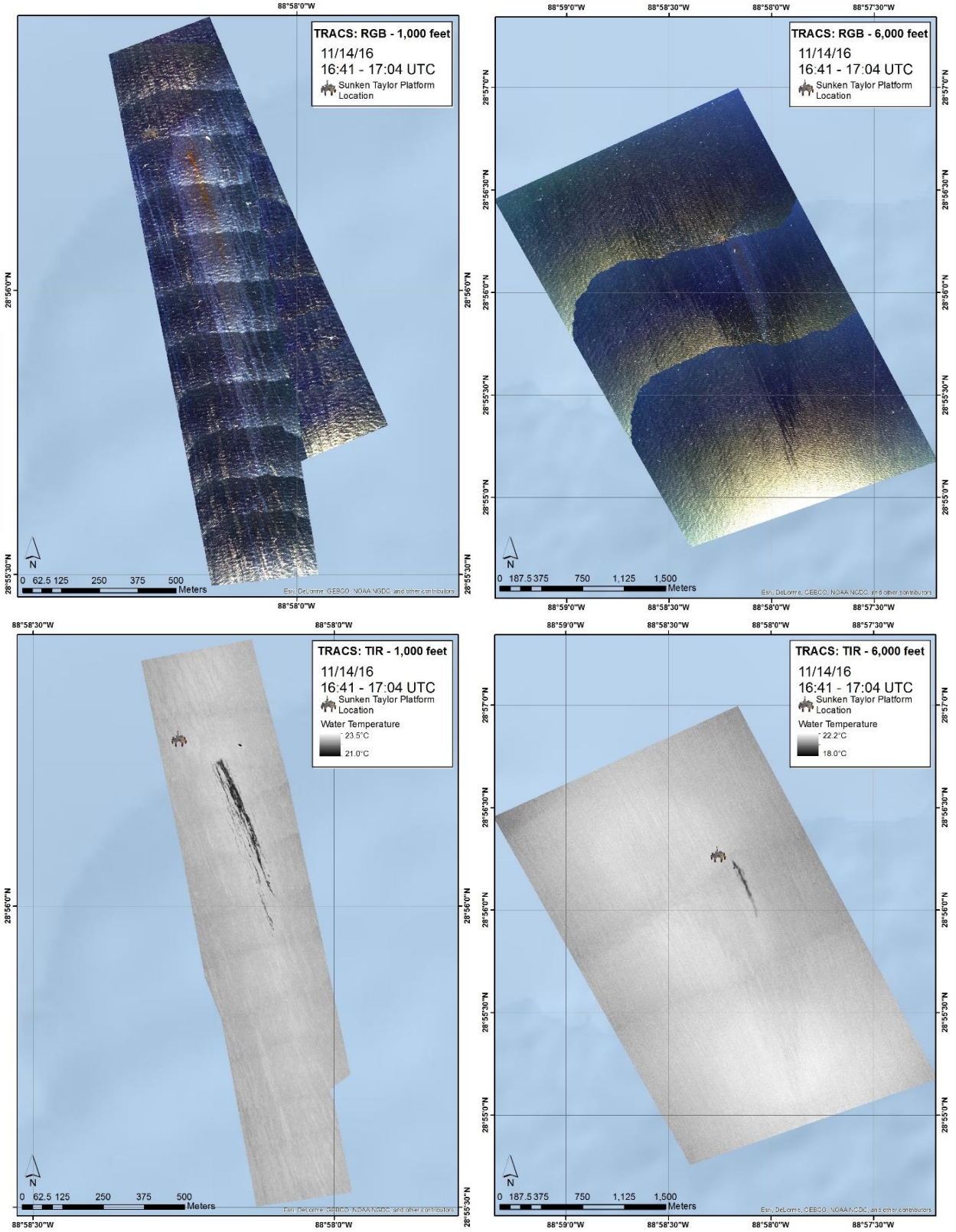
REFERENCES

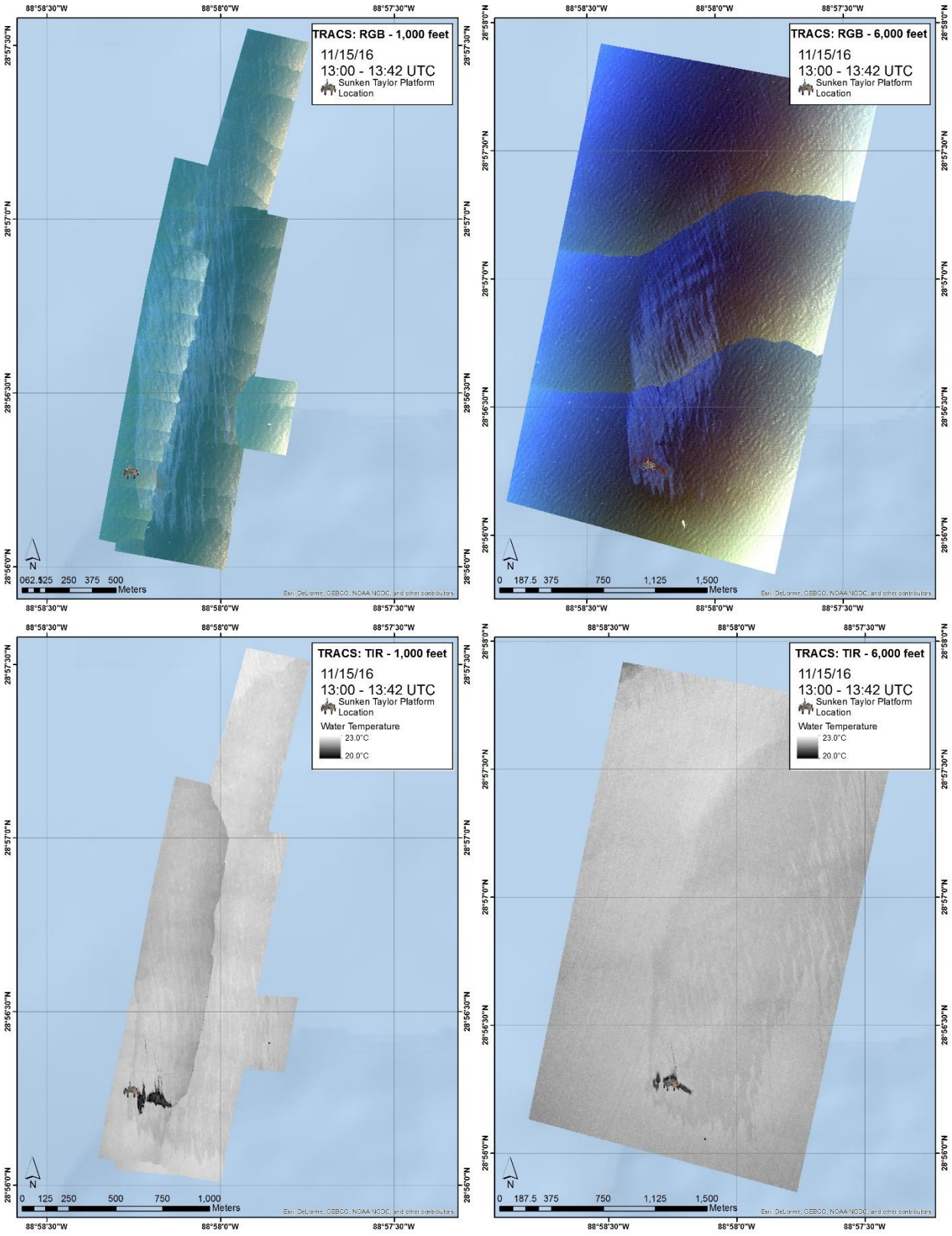
Svejkovsky, J., Muskat, J., *2012*. Open water multispectral aerial sensor oil spill thickness mapping in Arctic and high sediment load conditions. Final Report for Bureau of Safety and Environmental Enforcement Contract M10PC00068.

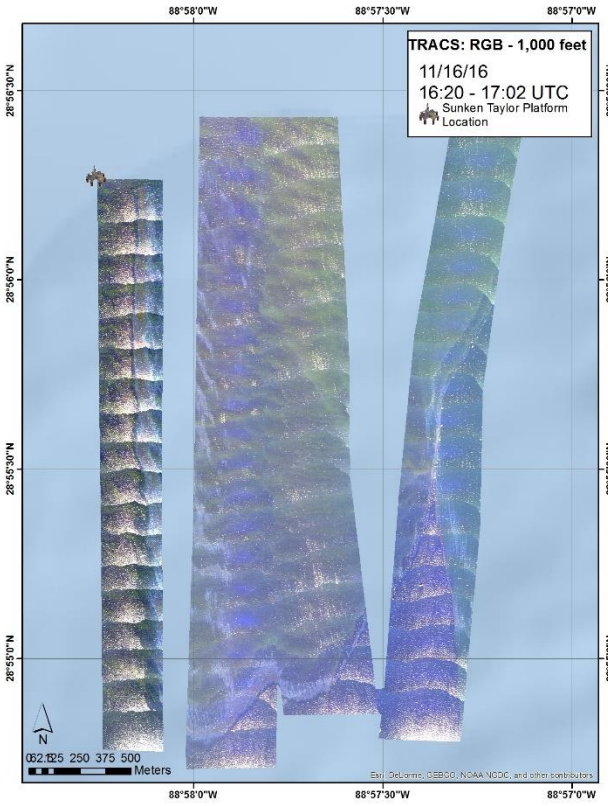
Svejkovsky, J., Hess, M., Muskat, J. Nedwed, T.J., McCall, J., Garcia O., *2016*. Characterization of surface oil thickness distribution patterns observed during the Deepwater Horizon (MC-252) oil spill with aerial and satellite remote sensing. Marine Pollution Bulletin.110 (2016), 162-176.

Bonn Agreement (2016). Aerial Surveillance Handbook. Version:14 September 2016. https://www.bonnagreement.org/site/assets/files/1081/aerial_operations_handbook.pdf

Appendix A.1—TRACS Imagery November 2016




TRACS: RGB - 1,000 feet
11/15/16
13:00 - 13:42 UTC
Sunken Taylor Platform Location
TRACS: RGB - 6,000 feet
11/15/16
13:00 - 13:42 UTC
Sunken Taylor Platform Location
TRACS: TIR - 1,000 feet
11/15/16
13:00 - 13:42 UTC
Sunken Taylor Platform Location
Water Temperature
23.0°C
20.0°C
TRACS: TIR - 6,000 feet
11/15/16
13:00 - 13:42 UTC
Sunken Taylor Platform Location
Water Temperature
23.0°C
20.0°C
88°58'30"W
88°58'0"W
88°57'30"W
28°57'30"N
28°57'0"N
28°56'30"N
28°56'0"N
N
0 125 250 500 750 1,000 Meters
0 187.5 375 750 1,125 1,500 Meters
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors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11/16/16
16:20 - 17:02 UTC
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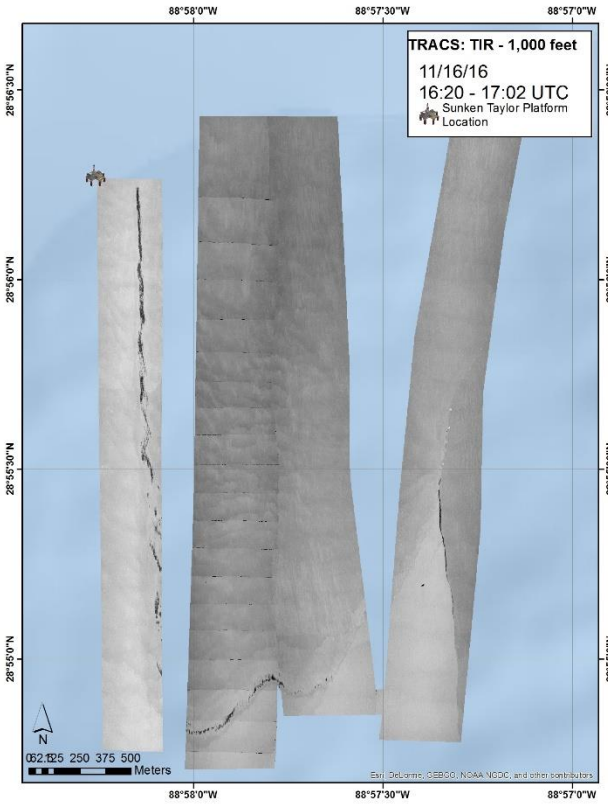
Meters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11/16/16
16:20 - 17:02 UTC
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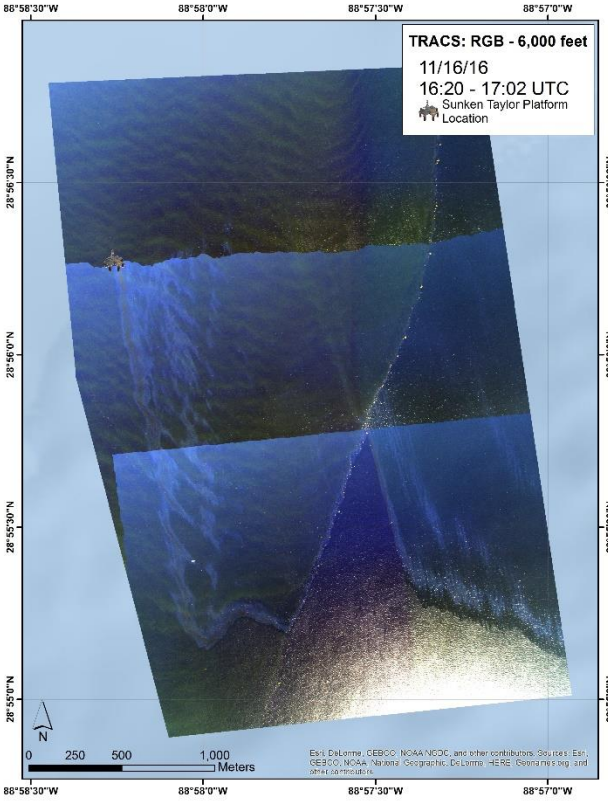
Meters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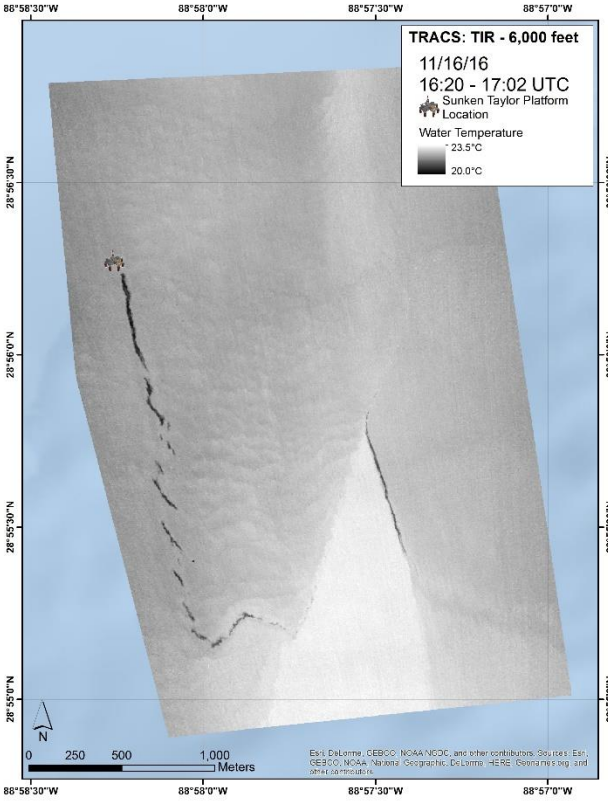
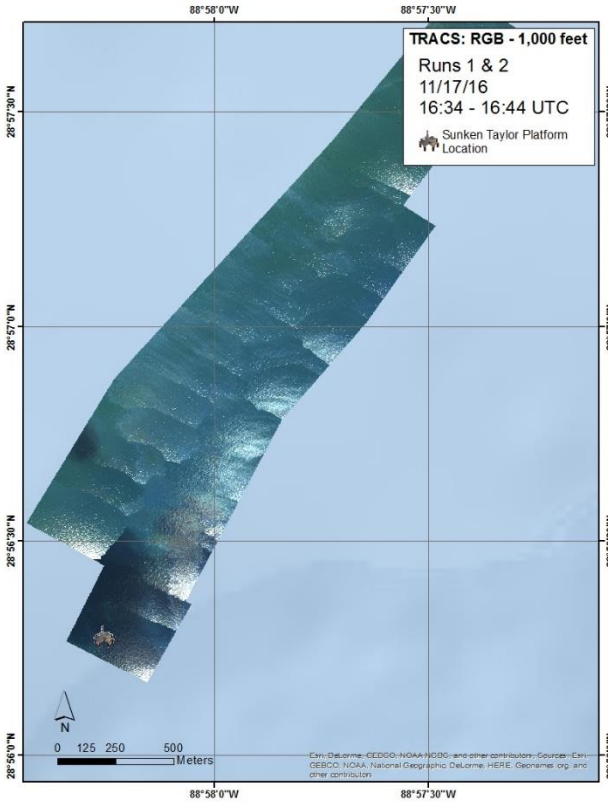
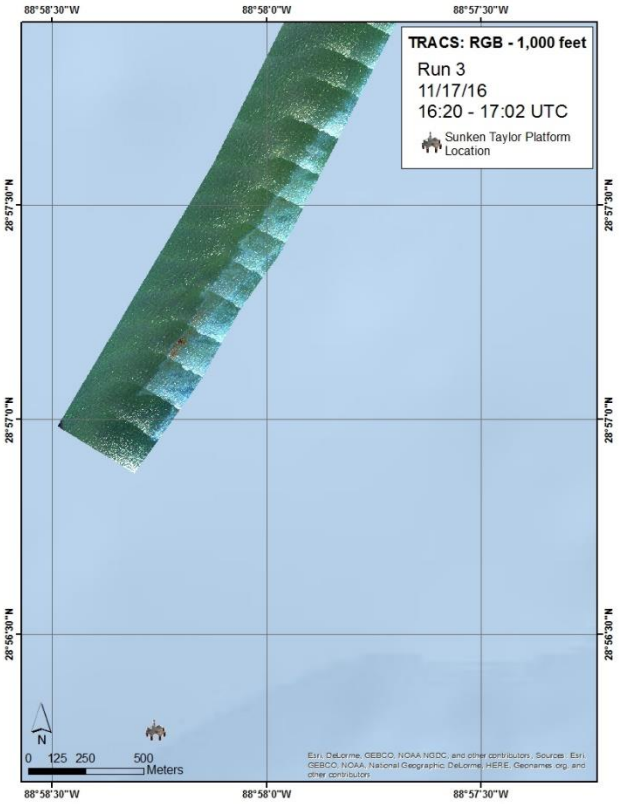
11/16/16
16:20 - 17:02 UTC
Sunken Taylor Platform Location
0 250 500 1,000
Meters


TRACS: TIR - 6,000 feet
11/16/16
16:20 - 17:02 UTC
Sunken Taylor Platform Location
Water Temperature
23.5°C
20.0°C
0 250 500 1,000
Meters


TRACS: RGB - 1,000 feet
Runs 1 & 2
11/17/16
16:34 - 16:44 UTC
Sunken Taylor Platform Location
88°58'0"W
88°57'30"W
28°57'30"N
28°57'0"N
28°56'30"N
28°56'0"N
N
0 125 250 500
Meters


TRACS: RGB - 1,000 feet
Run 3
11/17/16
16:20 - 17:02 UTC
Sunken Taylor Platform Location
88°58'30"W
88°58'0"W
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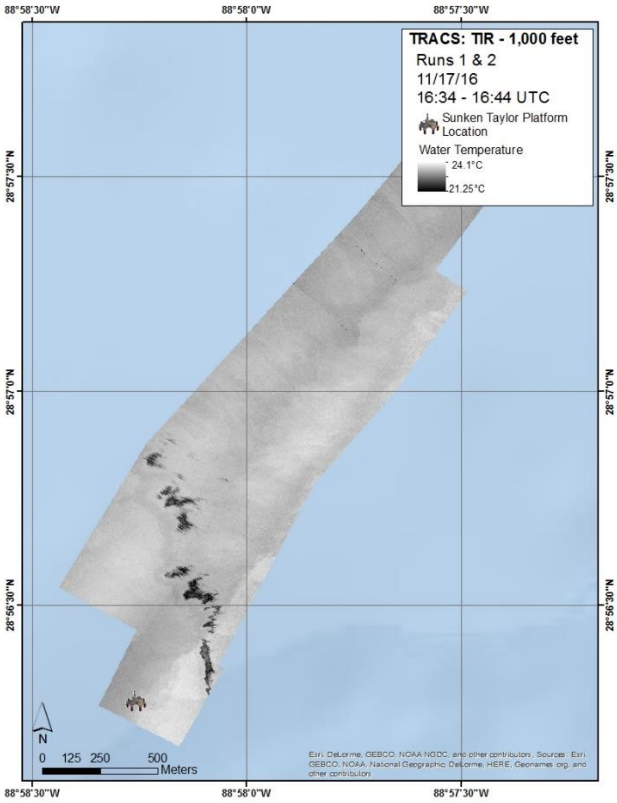
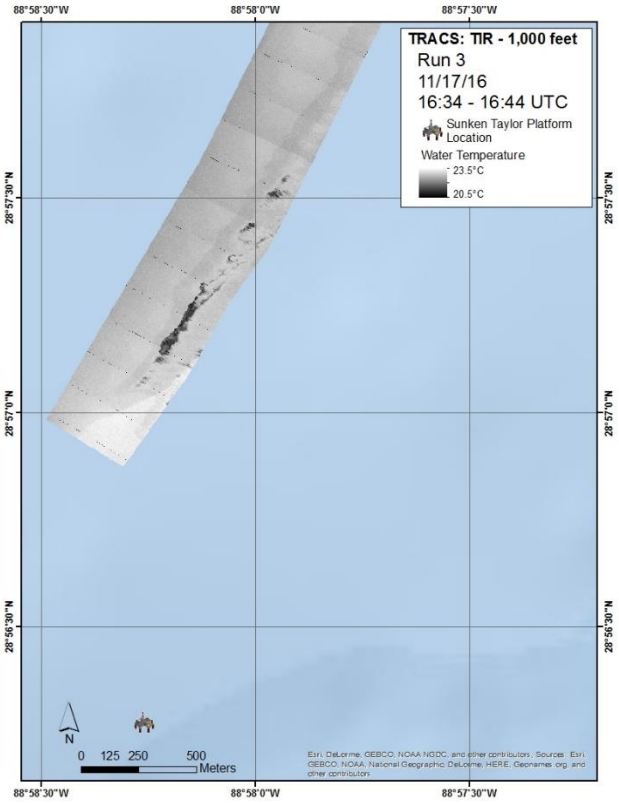
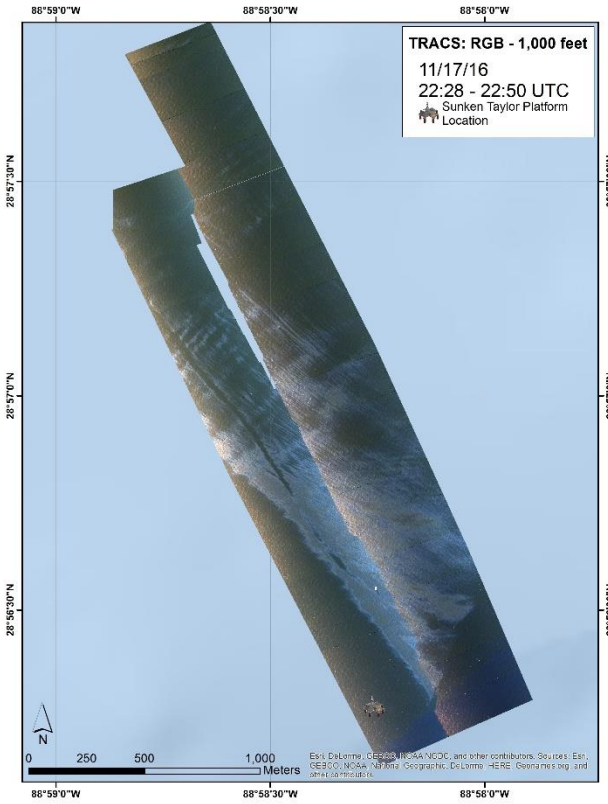
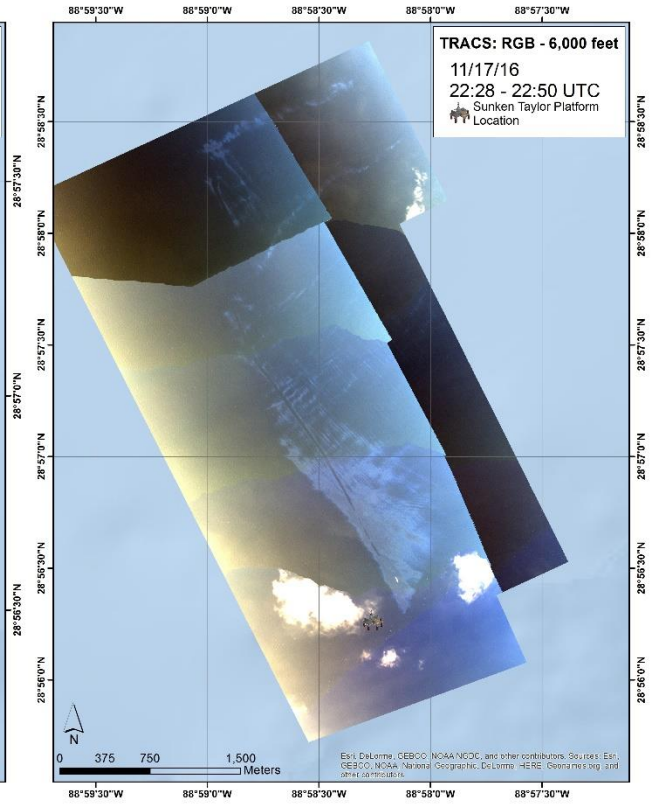
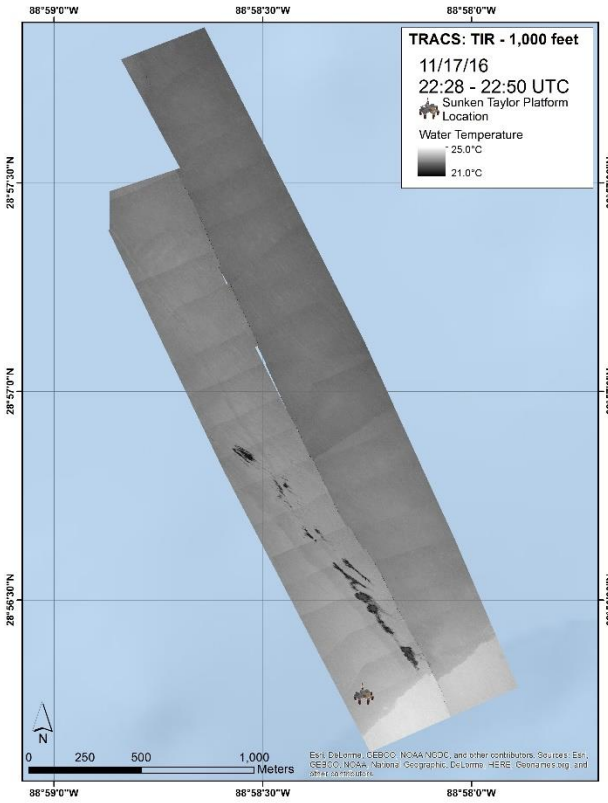
28°57'30"N
28°57'0"N
28°56'30"N
N
0 125 250 500
Meters

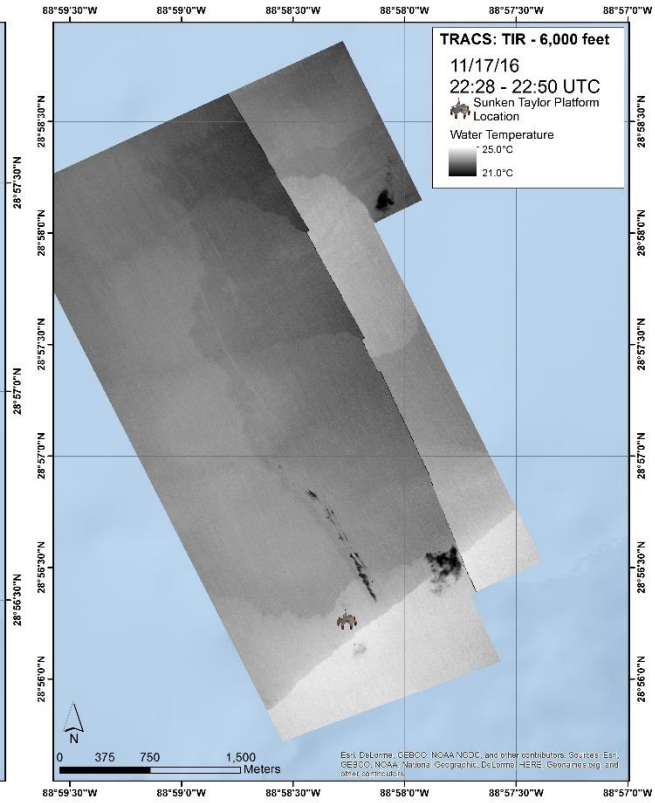

TRACS: TIR - 1,000 feet
Runs 1 & 2
11/17/16
16:34 - 16:44 UTC
Sunken Taylor Platform Location
Water Temperature
24.1°C
21.25°C
88°58'30"W
88°58'0"W
88°57'30"W
28°57'30"N
28°57'0"N
28°56'30"N
N
0 125 250 500
Meters


TRACS: TIR - 1,000 feet
Run 3
11/17/16
16:34 - 16:44 UTC
Sunken Taylor Platform Location
Water Temperature
23.5°C
20.5°C
88°58'30"W
88°58'0"W
88°57'30"W
28°57'30"N
28°57'0"N
28°56'30"N
N
0 125 250 500
Meters

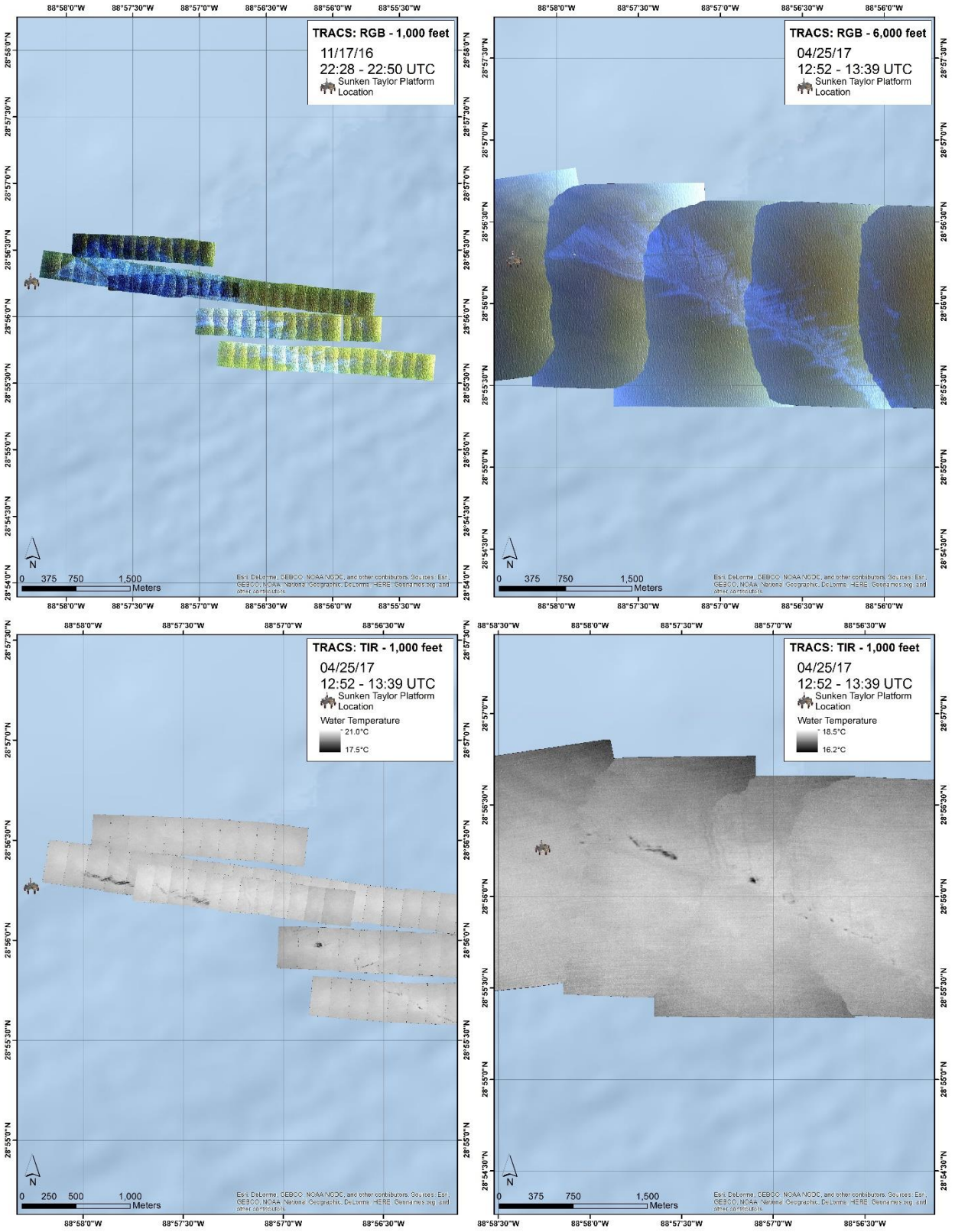

TRACS: RGB - 1,000 feet
11/17/16
22:28 - 22:50 UTC
Sunken Taylor Platform Location
0 250 500 1,000 Meters

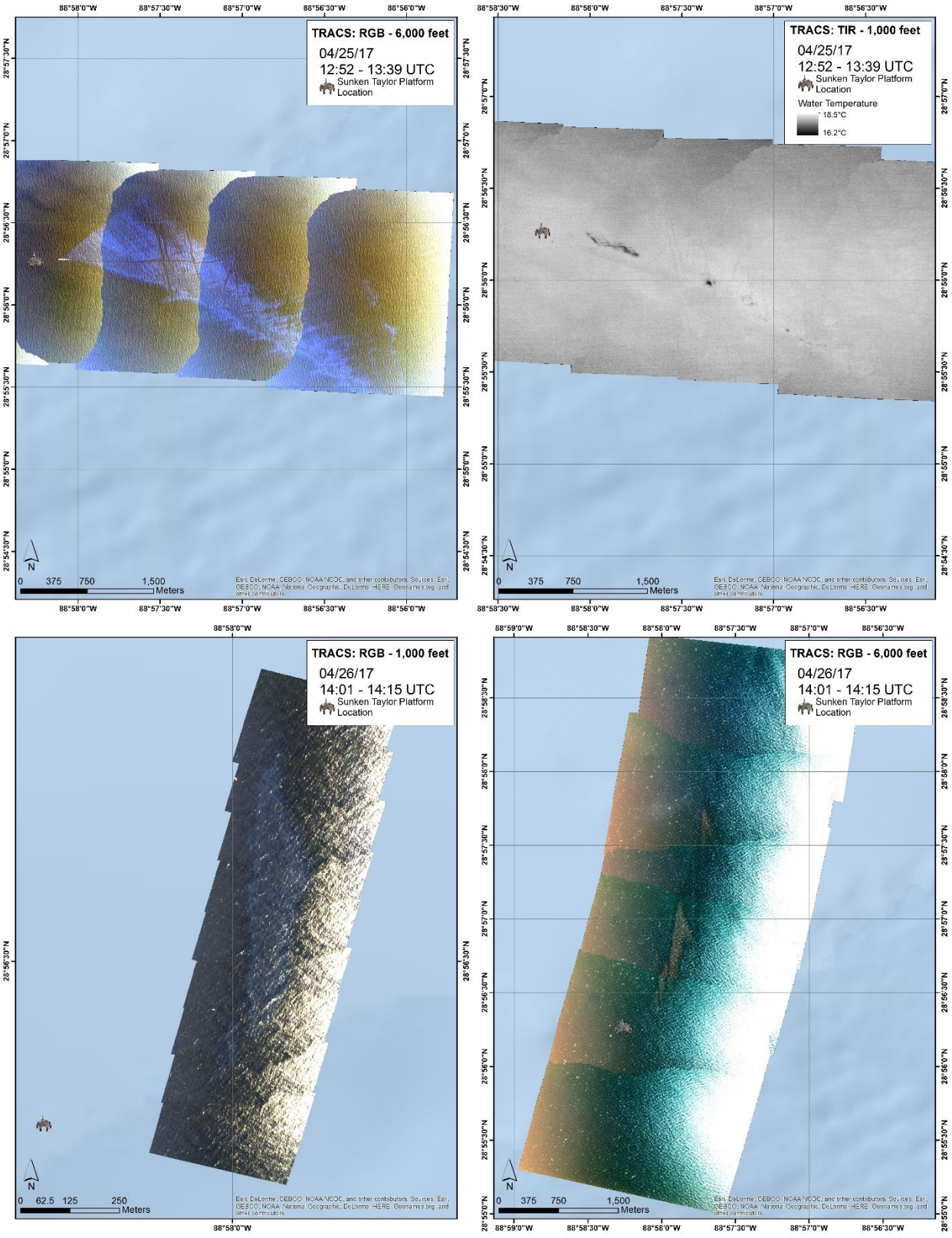

TRACS: RGB - 6,000 feet
11/17/16
22:28 - 22:50 UTC
Sunken Taylor Platform Location
0 375 750 1,500 Meters

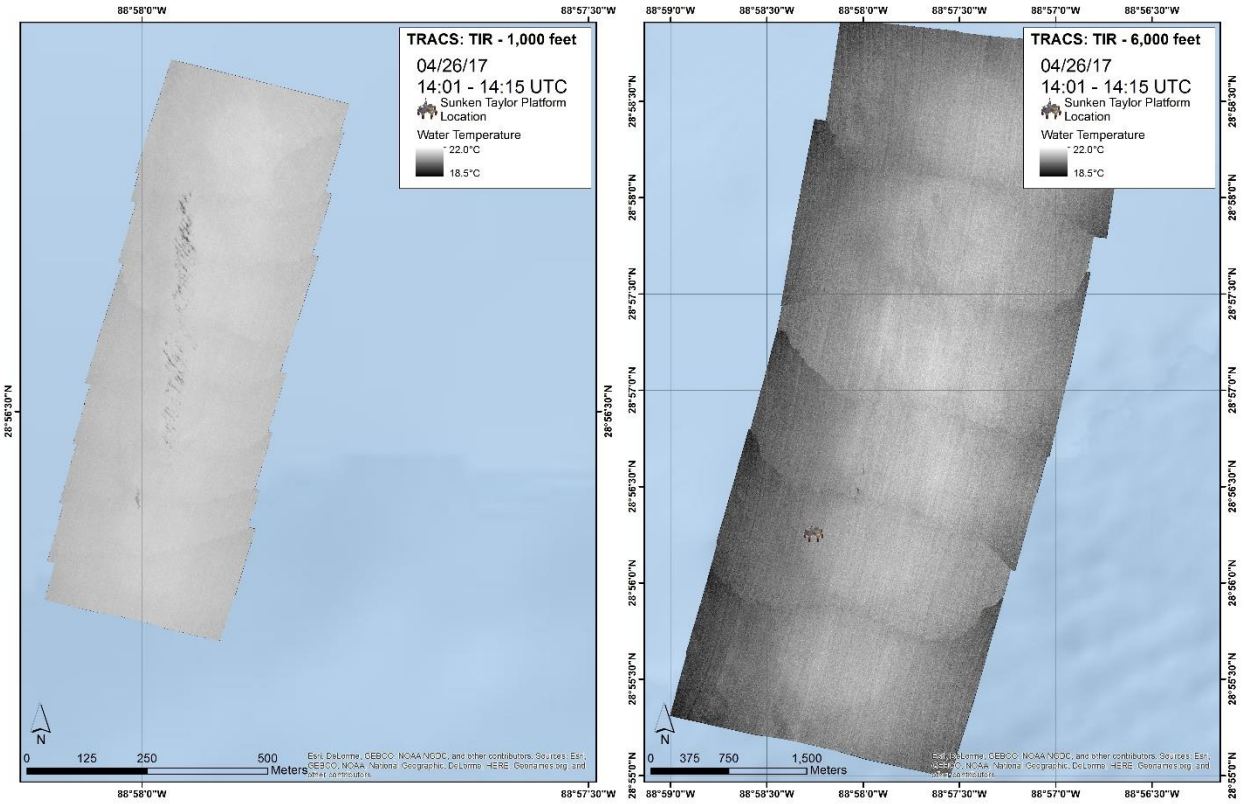

TRACS: TIR - 1,000 feet
11/17/16
22:28 - 22:50 UTC
Sunken Taylor Platform Location
Water Temperature
25.0°C
21.0°C
0 250 500 1,000 Meters


TRACS: TIR - 6,000 feet
11/17/16
22:28 - 22:50 UTC
Sunken Taylor Platform Location
Water Temperature
25.0°C
21.0°C
0 375 750 1,500 Meters

Appendix A.2—TRACS Imagery April 2017




TRACS: RGB - 6,000 feet
04/25/17
12:52 - 13:39 UTC
Sunken Taylor Platform Location
TRACS: TIR - 1,000 feet
04/25/17
12:52 - 13:39 UTC
Sunken Taylor Platform Location
Water Temperature
18.5°C
16.2°C
TRACS: RGB - 1,000 feet
04/26/17
14:01 - 14:15 UTC
Sunken Taylor Platform Location
TRACS: RGB - 6,000 feet
04/26/17
14:01 - 14:15 UTC
Sunken Taylor Platform Location
Meters


TRACS: TIR - 1,000 feet
04/26/17
14:01 - 14:15 UTC
Sunken Taylor Platform Location
Water Temperature
22.0°C
18.5°C
88°58'0"W
88°57'30"W
28°56'30"N
0 125 250 500 Meters
TRACS: TIR - 6,000 feet
04/26/17
14:01 - 14:15 UTC
Sunken Taylor Platform Location
Water Temperature
22.0°C
18.5°C
88°59'0"W
88°58'30"W
88°58'0"W
88°57'30"W
88°57'0"W
88°56'30"W
28°58'30"N
28°58'0"N
28°57'30"N
28°57'0"N
28°56'30"N
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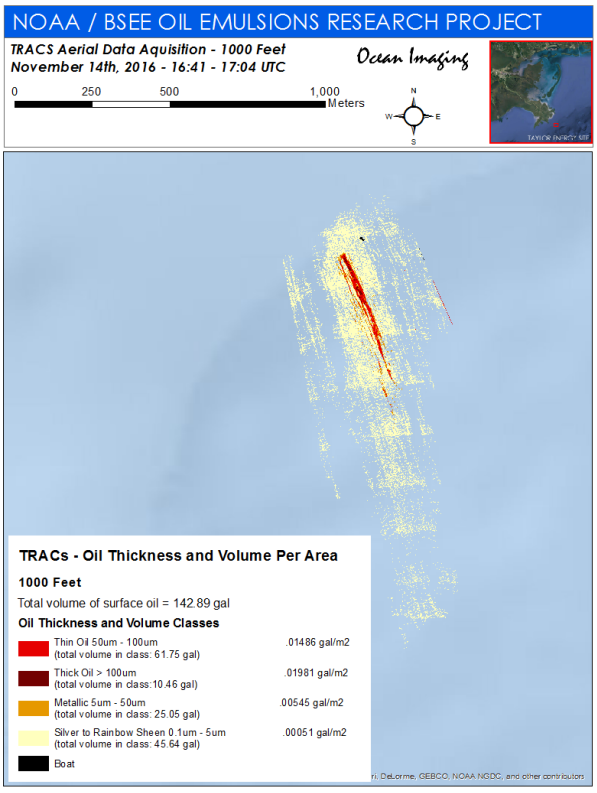
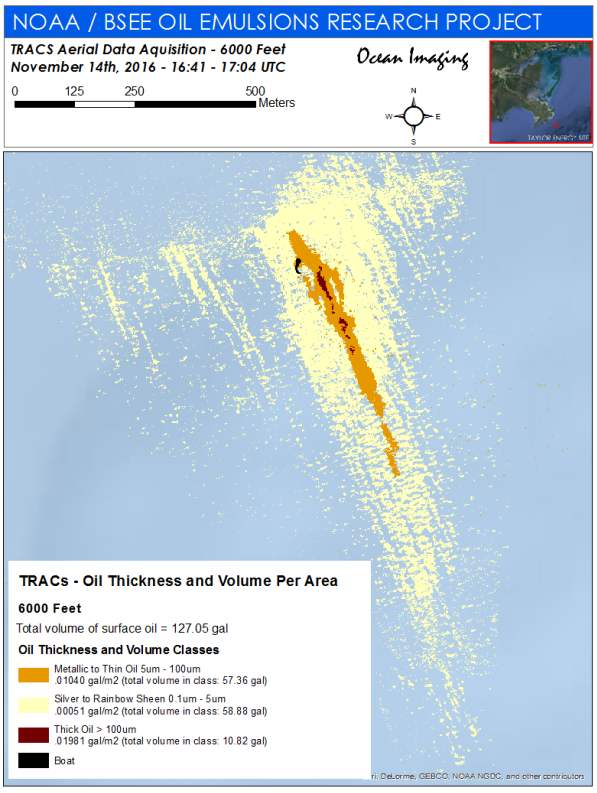
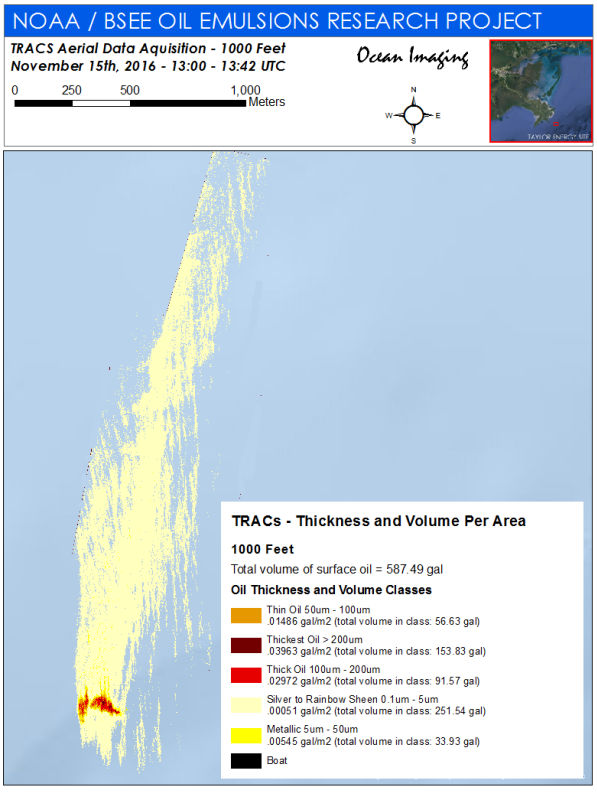
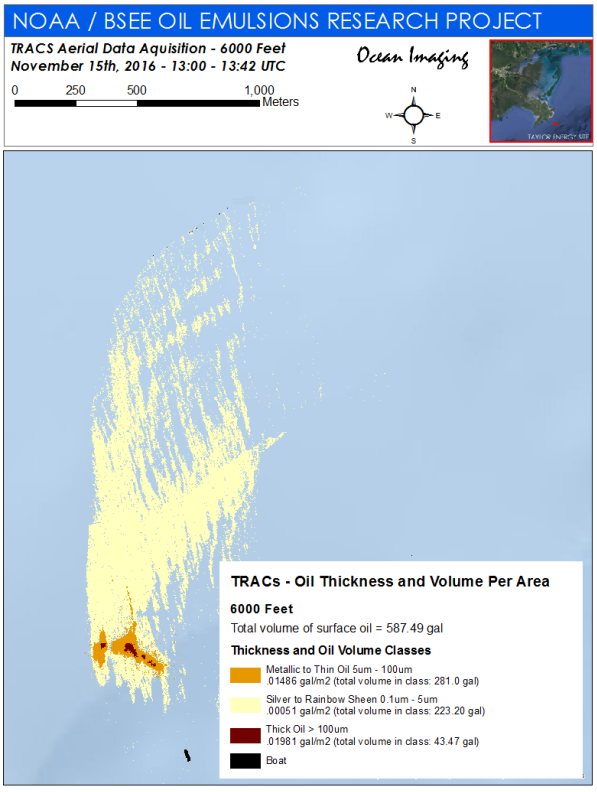
28°55'30"N
28°55'0"N
0 375 750 1,500 Meters

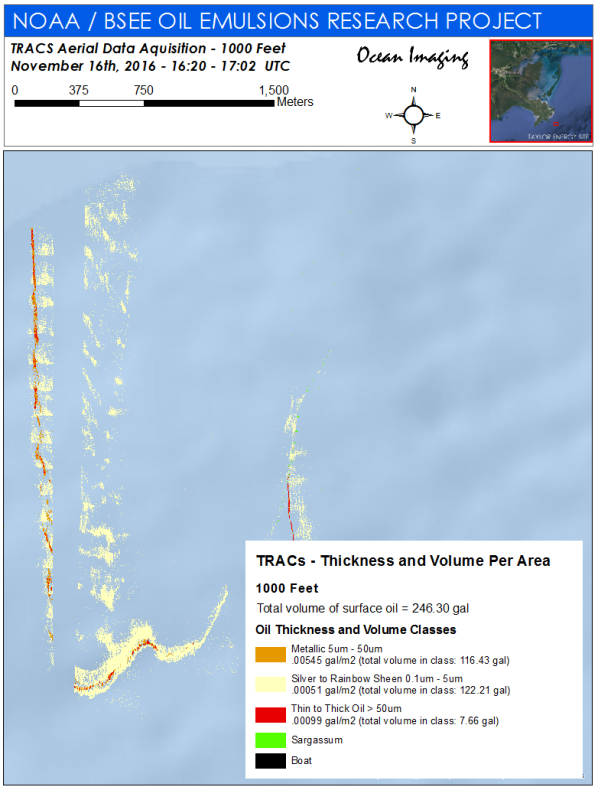
Appendix B.1—TRACS-Derived Oil Thickness and Oil Volume November 2016

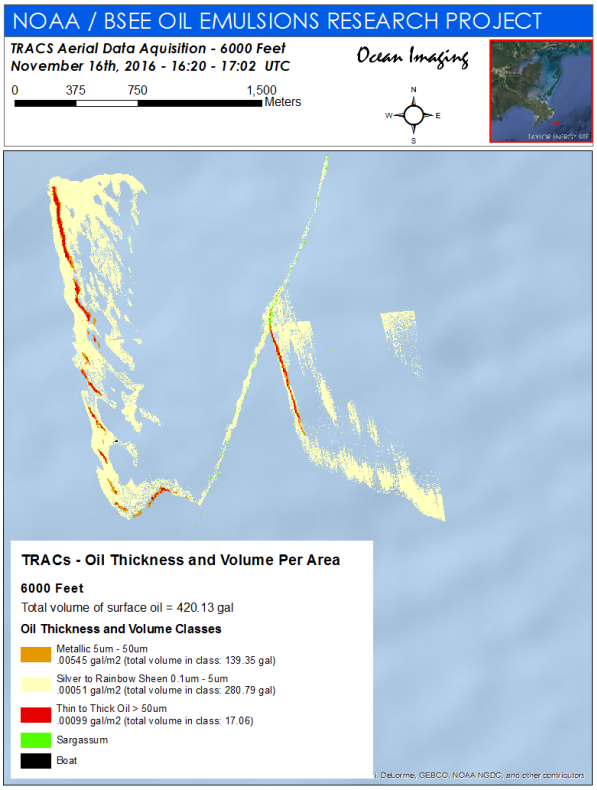


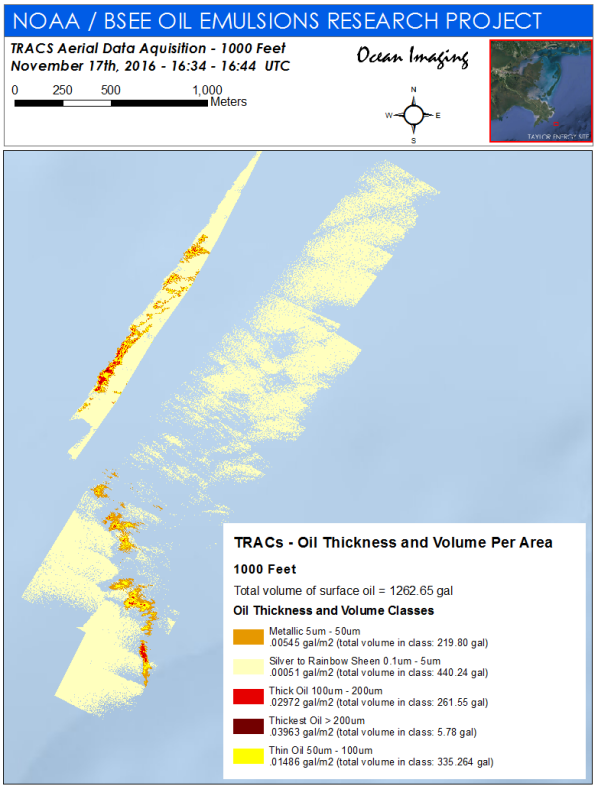


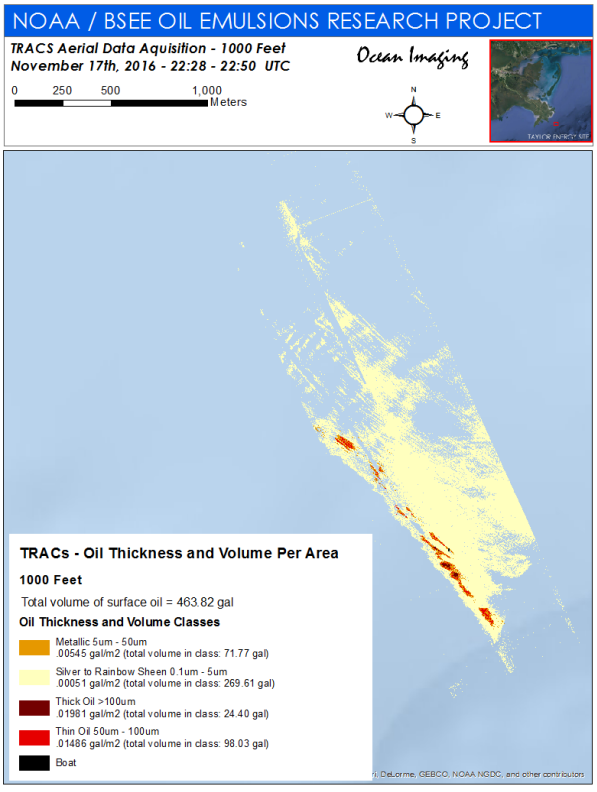


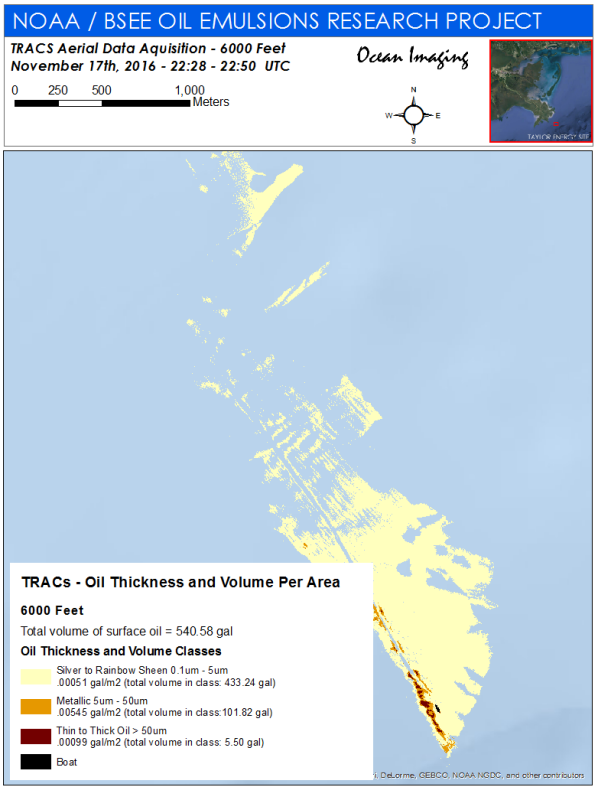



NOAA / BSEE OIL EMULSIONS RESEARCH PROJECT
TRACS Aerial Data Aquisition - 1000 Feet
November 16th, 2016 - 16:20 - 17:02 UTC
Ocean Imaging
0 375 750 1,500 Meters
TRACs - Thickness and Volume Per Area
1000 Feet
Total volume of surface oil = 246.30 gal
Oil Thickness and Volume Classes
Metallic 5um - 50um
.00545 gal/m2 (total volume in class: 116.43 gal)
Silver to Rainbow Sheen 0.1um - 5um
.00051 gal/m2 (total volume in class: 122.21 gal)
Thin to Thick Oil > 50um
.00099 gal/m2 (total volume in class: 7.66 gal)
Sargassum
Boat

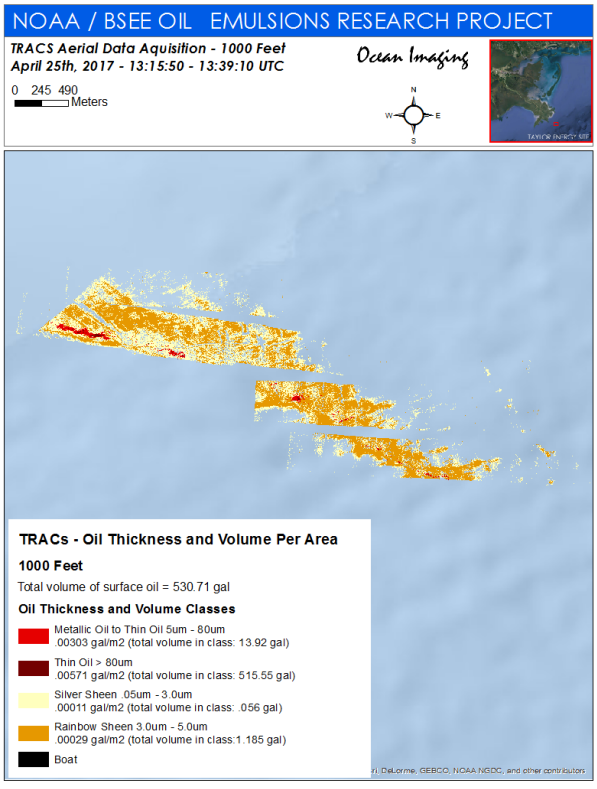

NOAA / BSEE OIL EMULSIONS RESEARCH PROJECT
TRACS Aerial Data Aquisition - 6000 Feet
November 16th, 2016 - 16:20 - 17:02 UTC
Ocean Imaging
0 375 750 1,500 Meters
TRACs - Oil Thickness and Volume Per Area
6000 Feet
Total volume of surface oil = 420.13 gal
Oil Thickness and Volume Classes
Metallic 5um - 50um
.00545 gal/m2 (total volume in class: 139.35 gal)
Silver to Rainbow Sheen 0.1um - 5um
.00051 gal/m2 (total volume in class: 280.79 gal)
Thin to Thick Oil > 50um
.00099 gal/m2 (total volume in class: 17.06)
Sargassum
Boat

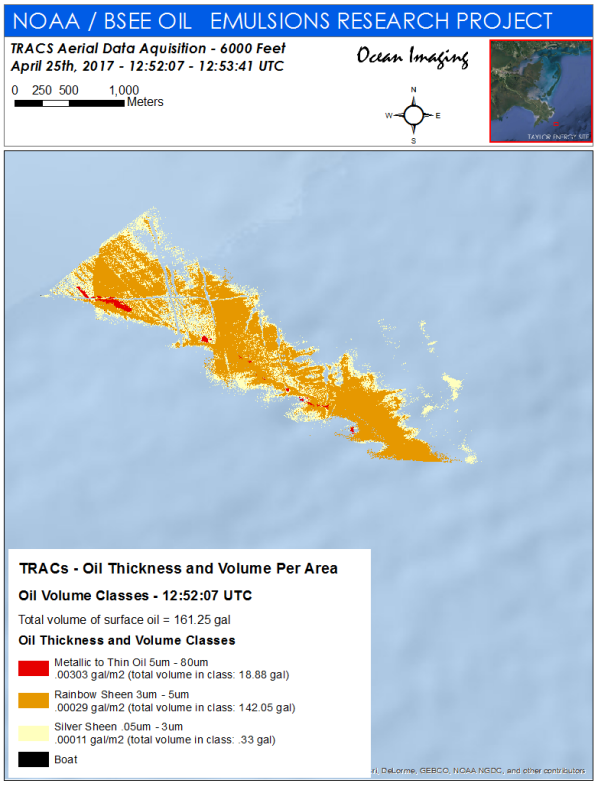

NOAA / BSEE OIL EMULSIONS RESEARCH PROJECT
TRACS Aerial Data Aquisition - 1000 Feet
November 17th, 2016 - 16:34 - 16:44 UTC
Ocean Imaging
0 250 500 1,000 Meters
TRACs - Oil Thickness and Volume Per Area
1000 Feet
Total volume of surface oil = 1262.65 gal
Oil Thickness and Volume Classes
Metallic 5um - 50um
.00545 gal/m2 (total volume in class: 219.80 gal)
Silver to Rainbow Sheen 0.1um - 5um
.00051 gal/m2 (total volume in class: 440.24 gal)
Thick Oil 100um - 200um
.02972 gal/m2 (total volume in class: 261.55 gal)
Thickest Oil > 200um
.03963 gal/m2 (total volume in class: 5.78 gal)
Thin Oil 50um - 100um
.01486 gal/m2 (total volume in class: 335.264 gal)

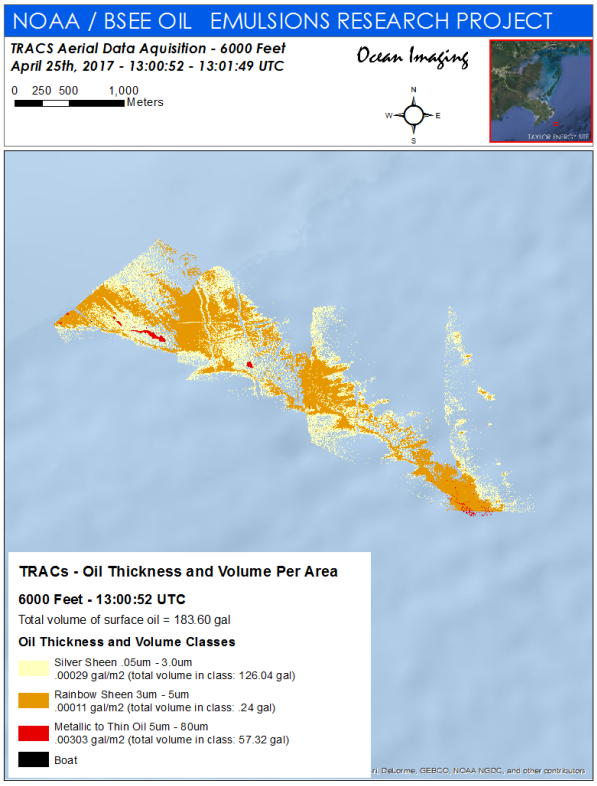

NOAA / BSEE OIL EMULSIONS RESEARCH PROJECT
TRACS Aerial Data Aquisition - 1000 Feet
November 17th, 2016 - 22:28 - 22:50 UTC
Ocean Imaging
0 250 500 1,000 Meters
TRACs - Oil Thickness and Volume Per Area
1000 Feet
Total volume of surface oil = 463.82 gal
Oil Thickness and Volume Classes
Metallic 5um - 50um
.00545 gal/m2 (total volume in class: 71.77 gal)
Silver to Rainbow Sheen 0.1um - 5um
.00051 gal/m2 (total volume in class: 269.61 gal)
Thick Oil >100um
.01981 gal/m2 (total volume in class: 24.40 gal)
Thin Oil 50um - 100um
.01486 gal/m2 (total volume in class: 98.03 gal)
Boat



Appendix B.2—TRACS-Derived Oil Thickness and Oil Volume April 2017






NOAA / BSEE OIL EMULSIONS RESEARCH PROJECT
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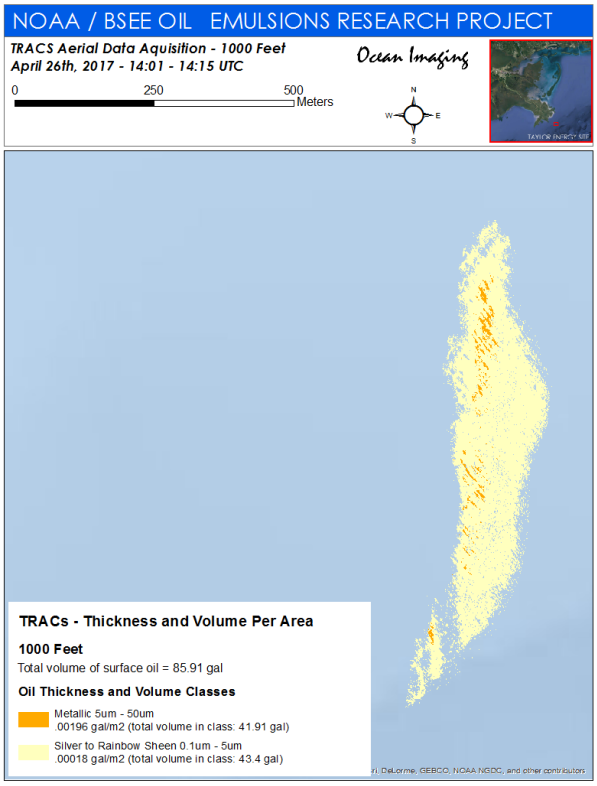
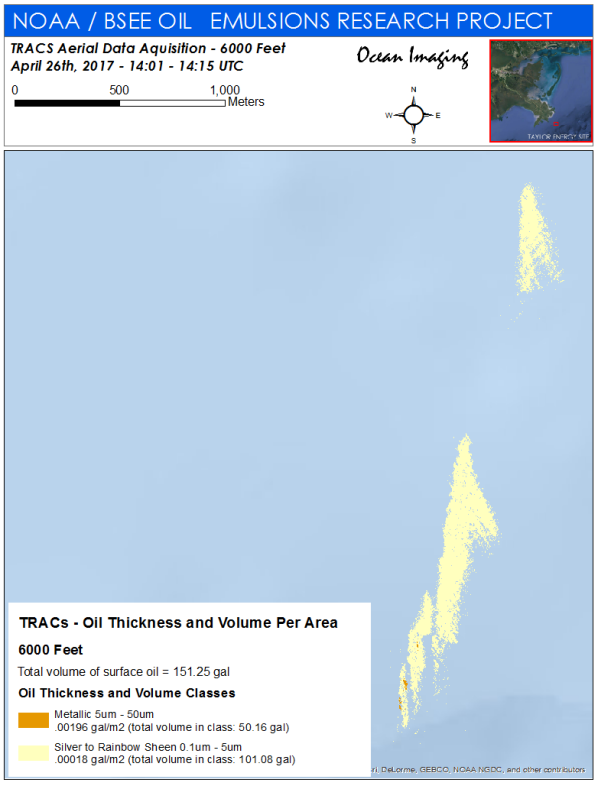
April 25th, 2017 - 13:00:52 - 13:01:49 UTC
0 250 500 1,000
Meters
Ocean Imaging
TRACs - Oil Thickness and Volume Per Area
6000 Feet - 13:00:52 UTC
Total volume of surface oil = 183.60 gal
Oil Thickness and Volume Classes
Silver Sheen .05um - 3.0um
.00029 gal/m2 (total volume in class: 126.04 gal)
Rainbow Sheen 3um - 5um
.00011 gal/m2 (total volume in class: .24 gal)
Metallic to Thin Oil 5um - 80um
.00303 gal/m2 (total volume in class: 57.32 gal)
Boat


NOAA / BSEE OIL EMULSIONS RESEARCH PROJECT
TRACS Aerial Data Aquisition - 1000 Feet
April 26th, 2017 - 14:01 - 14:15 UTC
0 250 500
Meters
Ocean Imaging
TRACs - Thickness and Volume Per Area
1000 Feet
Total volume of surface oil = 85.91 gal
Oil Thickness and Volume Classes
Metallic 5um - 50um
.00196 gal/m2 (total volume in class: 41.91 gal)
Silver to Rainbow Sheen 0.1um - 5um
.00018 gal/m2 (total volume in class: 43.4 gal)


NOAA / BSEE OIL EMULSIONS RESEARCH PROJECT
TRACS Aerial Data Aquisition - 6000 Feet
April 26th, 2017 - 14:01 - 14:15 UTC
0 500 1,000
Meters
Ocean Imaging
TRACs - Oil Thickness and Volume Per Area
6000 Feet
Total volume of surface oil = 151.25 gal
Oil Thickness and Volume Classes
Metallic 5um - 50um
.00196 gal/m2 (total volume in class: 50.16 gal)
Silver to Rainbow Sheen 0.1um - 5um
.00018 gal/m2 (total volume in class: 101.08 gal)

Attachment G. Water Mapping Phase 3 Report

Deepwater Horizon (DWH) Lessons Learned Studies: Detection of Oil Thickness and Emulsion Mixtures using Remote Sensing Platforms

PHASE 3

Algorithm and Tools development

By

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Executive Summary

This report contains a detailed description of the activities developed during the Phase 3 of the project: 'Deepwater Horizon (DWH) Lessons Learned Studies: Detection of Oil Thickness and Emulsion Mixtures using Remote Sensing Platforms (DWHLL)'. The purpose of Phase 3 of this project is the development and implementation of algorithms and tools specifically for NOAA National Environmental Satellite Data and Information Service (NESDIS) Satellite Analysis Branch (SAB) Oil Desk staff as well as for other interested researchers. These software tools will improve and refine NESDIS satellite-derived products for detection and reporting of oil spills.

The ultimate goal of this Phase 3 is twofold: Development and implementation of algorithms and tools for 1) Synthetic Aperture Radar (SAR) Satellites and 2) Optical Satellites. This Phase 3 report is organized into 4 sections as follows:

Section 1 summarizes the theoretical basis and methods for the utilization of satellites images for the detection of oil spills with examples of images taken by satellites during phase 2 of the DWHLL project.

Section 2 is a review of the algorithm design and implementation for the SAR imagery. Here we describe the complexity of the SAR imagery and how we have integrated a previously designed textural classifier algorithm (TCNNA) into the current workflow that SAB has implemented to analyze SAR imagery.

Section 3 is a review of the tools developed for the analysis of the Optical imagery. Here we show the development and utilization of a new classification tool specifically designed to be deployed in the NESDIS/SAB working environment.

Finally, Section 4 of this report includes the conclusions and summary of the current state of the algorithms designed and the proposed next-steps forward to fully integrate these tools for SAB and other partner use.

Appendix A is the technical description of the TCNNA algorithm implementation.

Appendix B is the code on IDL for the TCNNA algorithm

Appendix C is the routine for processing of the optical/visual imagery

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Section 1.

Detection of oil spills using satellite remote sensing.

1.1 Introduction

Remote sensing techniques for oil spill detection and characterization include optical, microwave, thermal, lidar, and radar sensors mounted on aircraft and satellite platforms (see reviews by Brekke and Solberg 2005; Fingas and Brown 2015; Garcia-Pineda et al. 2013a; Jha et al. 2008; Leifer et al. 2012). Synthetic Aperture Radar (SAR) satellite imagery has been used widely to detect the presence and absence of oil slicks, either by users manually delineating radar-dark areas, or using semi-automated data analysis schemes (i.e., Garcia-Pineda et al. 2009). Optical remote sensing provides useful, low-cost information on oil location and surface area coverage (Adamo et al. 2009; Hu et al. 2009; Hu et al. 2011a; Hu et al. 2003; Hu et al. 2011b; MacDonald et al. 1993). Photographs collected with digital cameras and Landsat images proved that visible radiance reflected off the ocean's surface provides valuable information on oil seeps and spills (MacDonald et al. 1993; MacDonald et al. 1996). Hu et al. (2003) demonstrated the use of medium-resolution (250-m) MODIS data for spill assessment in Lake Maracaibo, a large brackish tidal bay in Venezuela. Other studies have confirmed oil slick detection taking advantage of the sun glint in satellite images (Adamo et al. 2009; Chust and Sagarminaga 2007; Hu et al. 2009). Fig. 1-1 shows a RADARSAT2 (Fig 1-1A) and ASTER (Fig 1-1B) images, taken only few hours apart, and a WorldView2 (Fig 1-1C) image collected only few minutes after the ASTER snapshot over the area of the leaking platform located at the MC20 lease block of the Gulf of Mexico.

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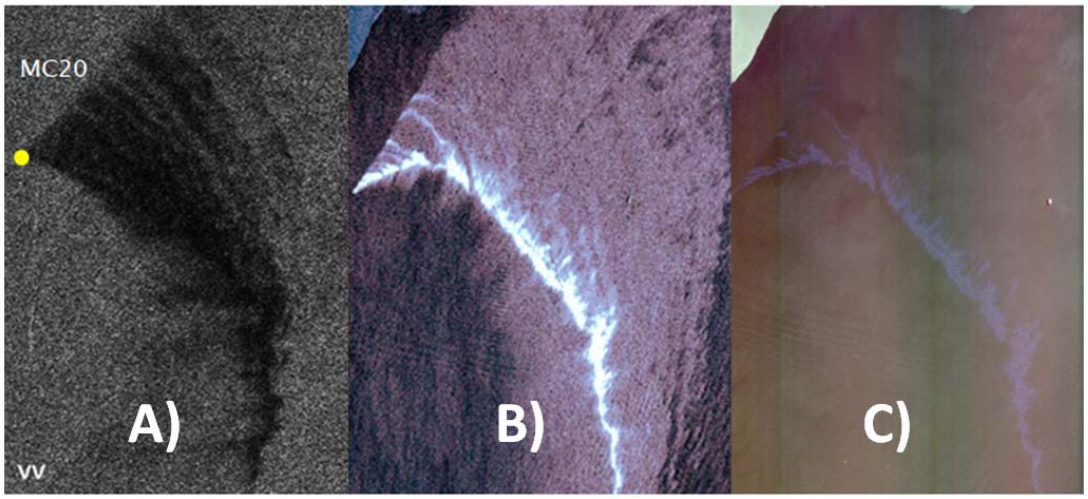

Figure 1-1. Satellite images collected by RADARSAT-2, ASTER, and Worldview-2 on April 25, 2017 over the MC20 oil spill area.

In Fig. 1-1A oil slicks are detected as the low backscatter from the ocean surface detected on the SAR satellite image. This low backscatter is shown as the dark area. In Fig. 1-1B and 1-1C, oil slicks can be clearly visualized under limited sun glint conditions. The close proximity of these acquisitions (the three images were obtained within a four-hour timeframe) allowed the observation a high correlation for the shape of the oil. Nevertheless, the viewing configurations and satellite capacities show a very different presentation of the detected oil. This showcases why it is important to understand the strengths and limitation of each of the available satellites for the detection of the oil spills. For example, Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and WorldView images are highly dependent on illumination conditions (including cloud free observations), sensor spatial resolution, sensor radiometric resolution, and the geometry between the viewing angles given by the relative position of the satellite with respect to the sun. This optical contrast method can be used for all collected imagery. This includes imagery collected from other satellites, such as Landsat 7/8 or Sentinel

2A. Fig 1-1 provides a comparison of the contrast difference of the oil from different sensors. It is reasonable to assume that oil did not change significantly in a period of four hours (the time between satellite images in Figure 1). This leads to the conclusion that oil appears differently in each of the images due to particular capabilities and specifications of each sensor. The bands and sensors used in Fig. 1-1 were Microwave from RADARSAT, and Visual/Multispectral from both ASTER and WorldView 2.

With synoptic and frequent observations, remote sensing serves a vital role in oil spill response, especially with recent technological advancements. SAR has proven to be the most applicable spaceborne sensor for detecting oil spills. It enables all-weather/all-day detection with medium-to high-resolution data. Due to its viscoelastic properties and its capacity to keep tension on the surface, the dampening effect of oil reduces the Bragg scattering in the oil covered regions, creating a distinct brightness contrast with surrounding water [Garcia-Pineda et al., 2009]. Passive optical remote sensing is another frequently used technique to complement SAR observations. In optical imagery, the same oil dampening effect enables a display of positive/negative contrast of oiled surfaces with water under proper sun glint conditions. This sun glint effect in optical remote sensing has been used to detect oil slicks on the ocean surface as shown in Figure 1-1.

However, even with the advanced satellite sensors from the multi-spectral ultra-high-resolution satellites (i.e. WorldView), oil slick detection (particularly for thick oil) still requires validation with in-situ observations to avoid misinterpretation with non-oil, false-positive features.

The reliability of satellites to detect oil spills depends on several factors: 1) the availability and frequency of observations to make sure that features are followed during its displacement, 2) the quality of the

data, which heavily depends on the technical capability of the satellite (spatial and radiometric resolutions), and 3) the weather and oceanographic conditions that would limit the detection of the oil.

1.2 Satellite remote sensing analysis.

Optical remote sensing, although being limited by cloud cover, can complement SAR observations for more synoptic and repeated measurements (Macdonald et al., 1993). For example, Hu et al. (2003 & 2009) used the 250-m resolution imagery collected by the Moderate Resolution Imaging Spectroradiometer (MODIS) to detect and quantify oil slicks from oil spills and natural seeps under condition with and without sun glint. More studies have also shown the possibility to estimate slick thickness (or surface oil volume) based on the spectral shapes and magnitudes of the oil slicks (Clark et al., 2010; Svejkovsky et al., 2012).

In addition to the sun glint illumination, the distinct optical properties of oil also create spatial contrast with water. Crude oil is characterized by the high absorption of blue wavelengths, which exponentially decays with increasing wavelengths. This results in the reflectance of the blue wavelengths decreasing as the amount of crude oil increases. When oil is emulsified, the mixture of water molecules enables strong scattering in red, near infrared (NIR) and shortwave infrared (SWIR) wavelengths. This optical detection of oil spills has been used efficiently in the marine environment [Garcia-Pineda 2013; Bulgarelli and Djavidnia, 2012; Clark et al., 2010; Hu et al., 2009; Leifer et al., 2012]. The differences observed in an oil slick when viewed from different directions are due to changes in solar and viewing geometry, not due to oil thickness or distribution. Radiative transfer modeling has been used to better understand the fundamental optics of oil-water interactions. According to Otremba 2004, sun glint is

important in facilitating oil detection (Otremba and Piskozub 2004). However, when sun glint is absent, thin oil slicks become harder to detect in optical images.

During large oil spills, the assessment of the spill's extent on satellite imagery should be confirmed and complemented using in-situ observations from responding operations. For example, records of flight paths, vessel tracks, aerial photography, dispersant applications, or sample collections logs, can be used to confirm that features observed in satellite imagery are oil slicks. Within reasonable space and time gaps, all the satellite and in-situ information available should be used to validate the detection of oil features in satellite images. This project has been limited to the identification of possible features and their thicknesses in satellite imagery (based on their pixel characteristics) and the available in situ thickness measurements but further analysis, including additional data is needed to correlate the observed features with in-situ observation records to estimate the actual volumes of surface oil.

The process of geo-referencing oil detection with concurrent observations is done by overlaying the spatial records (chronologically) with the polygons delineated as possible slicks. Then a temporal/spatial analysis is carried out to confirm that features observed correspond to oil or to other oil-like features (false positives). When a limited number of in-situ observations are available, meteorological and oceanographic records can be used to track the direction and speed of possible oil slicks in an attempt to correlate features that are separated in space and time.

Figure 1-2 shows a closer look at the image collected by WorldView on April 25th, 2017. In this figure, in-situ observations made by an Unmanned Aerial System (UAS) and direct measurements of oil thicknesses taken by the Water Mapping Oil Sampler (WM-OS) are overlain on the satellite image to

provide a better understanding of the pixel characteristics with their corresponding in situ measured oil thicknesses.

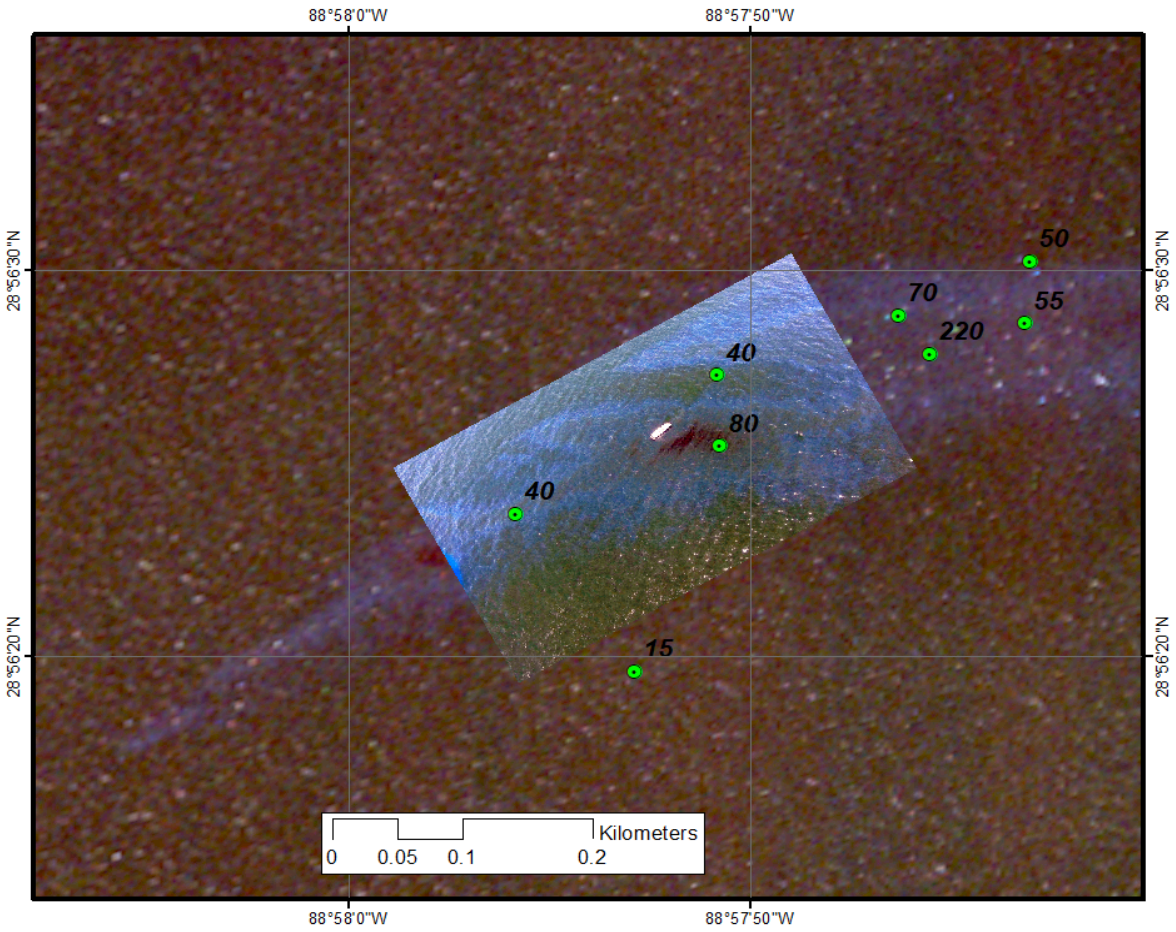

Figure 1-2. In-situ measurements and UAS observations taken at the same time as the satellite snapshot collected by WorldView2.

It is important to point out that the collection of the satellite snapshot takes less than one second, and the collection of the in-situ measurements can take several minutes to a few hours. An offset between some of the in-situ measurements and the signature features is expected during this process.

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The table below summarizes the list of currently available satellites and their main characteristics including the attributes of each satellite for using it for detection of oil spills. The capacity for each satellite listed in this table is driven primarily by its spatial resolution, and secondly by its radiometric resolution (including the number of collection bands).

	Satellite	Sensor Type	Spatial Resolution	Wavelength	Attributes
Visual Multispectral	Woldview-2/3	Optical	<1m	Multispectral	Data Sharing Agreement
	Worldview-1	Optical	~1m	Multispectral	Data Sharing Agreement
	Sentinel-2A/B	Optical	10m	Multispectral	Free Access Data
	Aster	Optical	15m	Multispectral	Free Access Data
	Landsat 7	Optical	30m	Visual	Free Access Data
	Landsat 8	Optical	30m	Visual	Free Access Data
	MODIS Terra/Aqua	Optical	250m	Multispectral	Free Access Data
	VIIRS	Optical	375m	Multispectral	Free Access Data
SAR Microwave	Radarsat-2	SAR	1-30m	C-Band	Full Polarimetric
	TerraSAR-X	SAR	1-30m	X-Band	Lowest Signal to noise ratio
	Sentinel-1A/B	SAR	5-40m	C-Band	Free access data
	COSMOSKY-MED	SAR	10-30m	X-Band	4 satellites constellation
	ALOS-2	SAR	5-40m	L-Band	Same as UAVSAR (Nasa)

Table 1. List of current satellites used for oil detection.

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Section 2.

Microwave Satellite Remote Sensing; Synthetic Aperture Radar (SAR) and algorithm implementation.

For oil spill monitoring, SAR has been widely used to detect the presence or absence of oil slicks. Although the details vary for each oil detection system, SAR oil detection algorithms generally have the same basic components [Brekke and Solberg, 2005]. These components are region selection, feature extraction, and spill classification. Semi-automated routines have been developed for this purpose that employ different image processing routines (i.e. neural networks, adaptive thresholding, fuzzy logic) (Garcia-Pineda et al. 2013). However, the data available for sea-truthing the results has sometimes limited opportunities for spill classification. For example, natural oil seeps reliably generate layers of floating oil that could be used to test the effectiveness of algorithms, but the low discharge rates do not produce thick layers of oil (Garcia-Pineda et al. 2009) see Figure 2-1.

Radar uses microwave radiation to detect the range, speed, and other characteristics of remote objects (Knott, Shaeffer et al. 2004). Similarly, active satellites such as SAR, will detect the interaction between different surface features. From the full range of microwave frequency bands, most SAR satellites use L, C, and X bands to image the surface of land and oceans. These frequencies have been chosen by satellite operators due to the number of applications and capability to detect different geophysical processes (Clemente and Yan 2000). SAR data collected during the Montara Spill (northern coast of western Australia) included images from RADARSAT-1 and ENVISAT (C-Band) and ALOS-1 (L-Band).

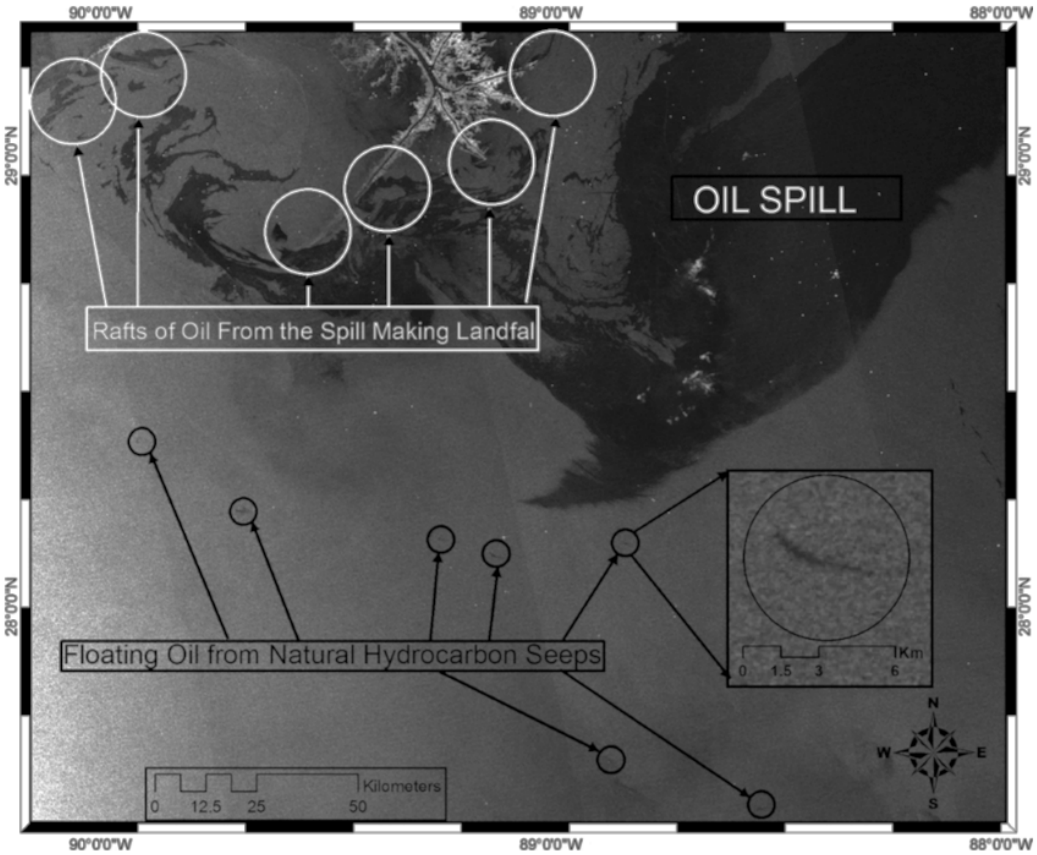

Figure 2-1 Envisat ASAR image from the BP spill in the Gulf of Mexico. Image Captured on May 2nd, 2010. Several oil slicks from natural hydrocarbon seepage (black circles) were imaged under ideal wind conditions, at the same time, rafts of oil (white circles) were separated from the much larger main spill that is centered around the BP well site.

For SAR ocean imaging, the energy backscattered and detected by the SAR satellite antenna, known as Radar Cross Section (RCS), depends on the sea surface roughness. This is a function of wind and sea surface type. Surface oil modulates the roughness of the surface, resulting in a backscatter signal that is lower than the surrounding oil-free water, thus making the oil slick in SAR imagery appear darker than water. The RCS will also depend on the satellite's imaging angle (incident angle). As the incident angle increases (with respect to nadir), less energy is reflected to the satellite's antenna (Holt 2004). This effect produces ocean SAR images with a gradient of brightness from one side of the image to the other.

The RCS will also be affected by the specific SAR system configuration, including its frequency, polarization, look-angle, sensor velocity, pulse repetition frequency and duration, chirp bandwidth, and pixel-sampling resolution. Additionally, the Bragg scattering will be dominated by three main components:

1. The geometry between the relative position of satellite and the surface imaged (e.g. directional spectra of waves and beam incidence angles).
2. The roughness of the surface (specifically if variations on the sea surface are within the microwave length range of few centimeters).
3. The dielectric properties of the surface's materials (Alpers & Espedal 2004).

Floating oil layers are also visible in optical images, especially under certain illumination conditions (Hu et al., 2003 & 2009) because of oil's different optical properties (absorption and scattering) in water and because the oil modulation of surface roughness can redistribute specular reflection of sunlight (sun glint).

Nearly all SAR applications of oil spill monitoring have relied on the spatial contrast to detect the presence/absence of surface oil slicks, based on the principles outlined above. Various segmentation techniques have been proposed. The Textural Classifier Neural Network Algorithm (TCNNA) employs a combination of edge detectors and texture statistical descriptors to detect floating oil. This algorithm produces an accurate pixel by pixel delineation of the oil slick boundaries regardless the local brightness and contrast in the SAR image (Garcia-Pineda, Zimmer et al. 2009; Garcia-Pineda, MacDonald et al. 2013).

It is important to point out that interpretation of floating oil in SAR imagery requires training and full understanding of the physics behind this process, as well as an understanding of the oceanographic and meteorological conditions that could lead to produce look anomalies in the SAR imagery.

2.1 TCNNA, Algorithm implementation at NESDIS/SAB

The purpose of this subsection is to provide an understanding of how spaceborne SAR systems can provide estimate of surface oil coverage at high resolution (100 m). More specifically, this section provides the scientific and engineering underpinning for the use of the SAR Operational Products System (SAROPS) to convert SAR measurement of Normalized Radar Cross Section (NRCS) into oil spills maps. These maps include an oil/no-oil estimate for each relevant pixel as well as an assessment of the confidence in the classification. SAROPS grew out of a joint effort between the National Oceanic and Atmospheric Administration (NOAA) and the Johns Hopkins University Applied Physics Laboratory (JHU/APL) to exploit available spaceborne SAR imagery for geophysical measurements.

SARs make high-resolution (1–1000 m) NRCS maps of the Earth's surface. Calibrated backscattered microwave radar returns from the ocean surface are strongly dependent ocean surface roughness. This roughness is increased with increasing wind speed and suppressed when the surface is covered with oil.

The physics underlying the measurement of marine wind speed by radar can be observed by a casual walk along a pond or lake. When no wind is present, the surface of the water is smooth, almost glass-like. Energy from a side-looking radar will largely be reflected away and the return to the sensor will be low. As the wind begins to blow, the surface roughens, and surface waves begin to develop. As the wind

blows more strongly, the amplitude of the water waves increases, further roughening the surface. As the surface roughness increases more energy is backscattered and the NRCS returns increase.

The first SAROPS product developed was retrieval of ocean surface wind speed. This estimate of wind speed, as will be described later, is an important input into the "Automated SAR Oil Spill Mapping Product (ASOSMP)." Surface roughness on the scale of the radar wavelength (5.3 cm) is responsible for most of the radar backscatter. The presence of wind roughens the surface at this wavelength. However, oil or other surfactants on the surface will increase the surface tension and suppress these small-scale waves.

The presence of oil on the surface can not be determined specifically from NRCS because both wind speed and direction as well as oil all contribute to this determination. Nonetheless, when oil is present on the surface, the resulting areas with reduced NRCS, are evident to human analysts. Figure 1-1 shows a Radarsat-1 SAR image from the Gulf of Mexico. The oil-covered areas are clearly visible from the changes in NRCS, the shape of the lower-NRCS areas, and the texture in and outside the spill areas. Neural network analysis (such as TCNNA) is applicable to this type of image classification challenge.

2.2. Results

The application of the TCNNA algorithm for oil masking represents the next extension of the SAROPS system. Automated daily outputs of the TCNNA/SAROPS system are being posted daily by NOAA NESDIS and can be reviewed at

https://www.star.nesdis.noaa.gov/sod/mecb/sar/AKDEMO_products/TCNNA_OIL/tcnna_daily.html?date=20180220

Appendix B of this report contains the procedure for the generation of the TCNNA training sets and the code on IDL for the program.

The following figures are examples of TCNNA data representation on the SAROPS website. First, for each of the SAR images, a world map with the SAR image footprint is provided as a guide for viewing the data coverage as shown on Figure 2-2



Figure 2-2: SAR image coverage shown in red.

The neural network diagram used is shown in Appendix A Figure 4. By way of example, we show the application of the neural network in the region showed Figure 2-3. The data were acquired by Sentinel-1A at 2014-10-15 15:10 UTC. The output of the TCNNA program is a measure of the likelihood of oil. Figure 2-3 shows the likelihood of oil in the TCNNA retrieval. An analyst can use this information to threshold the oil/no-oil classification. The TCNNA process also automatically applies a threshold of 5.00 as shown in Figure 2-4. Dark areas represent oil.

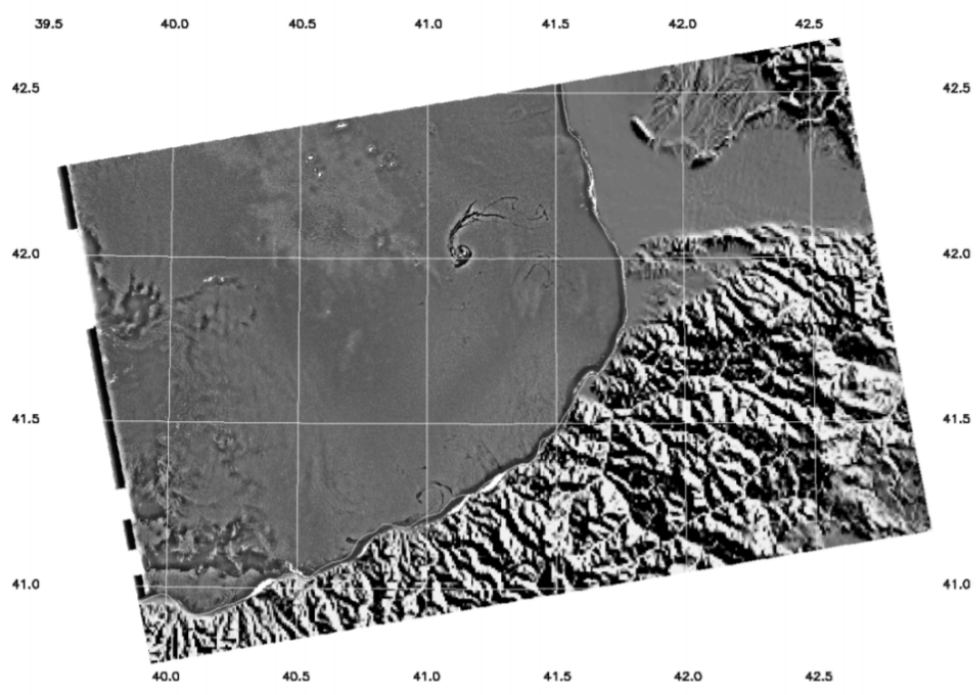

Figure 2-3: The likelihood of oil in the TCNNA retrieval.

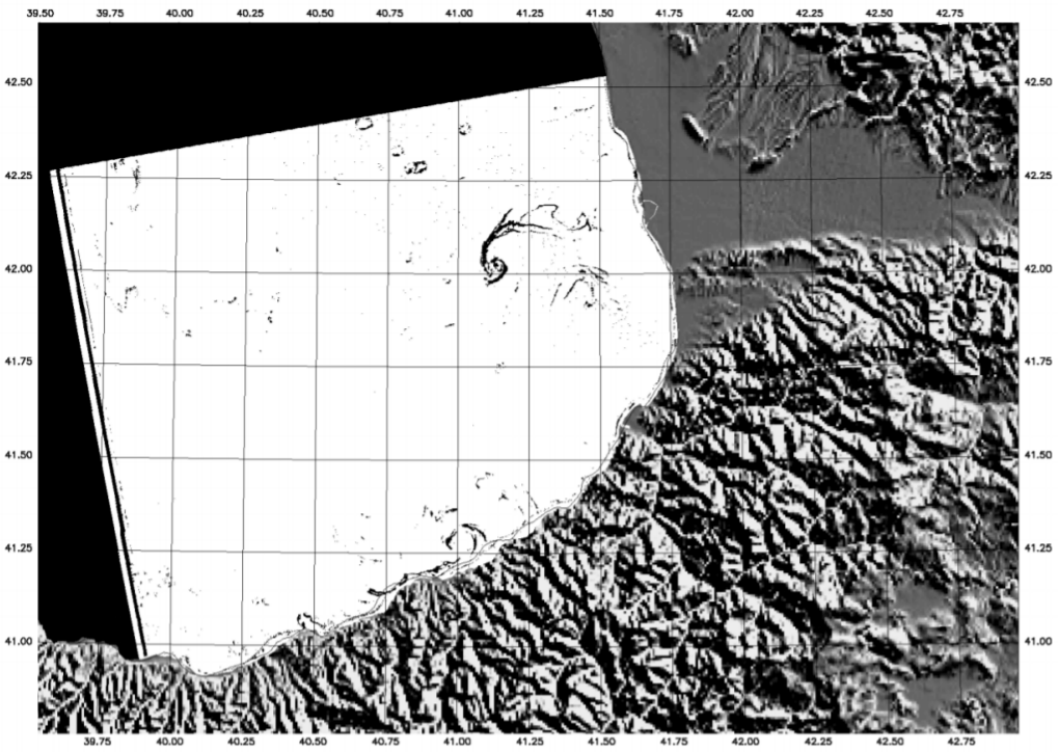

Figure 2-4 Oil/no-oil mask using threshold of 5.00

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Section 3.

Visual/Optical satellite analysis and algorithm implementation.

Optical satellite imagery is often obtained by NOAA NESDIS at no cost and routinely available through data sharing agreements with different satellite operators. This section outlines a procedure for the detection, delineation, and classification of visual/optical satellites like Landsat 7/8, Sentinel 2A, ASTER, MODIS (AQUA/TERRA), and WorldView 2/3. As illumination conditions, viewing angles, and cloud obstruction can alter the identification of oil and change its aspect regardless of satellite platform, we selected a classification method based on an image processing technique known as Maximum Likelihood Classification (MLC). This method has been selected not only because it's a proven image classification method, but also because NOAA NESDIS SAB currently uses the software and extension tools that can run these routines within their operational ArcGIS environment. We have developed an ArcGIS toolbox that includes a Graphic User Interface (GUI) that facilitates the operation of this algorithm. This section outlines the steps to operate this software. Here we show examples of the performance of this algorithm with examples of satellite images collected during Phase 2 of this project.

MLC is based on a probability density function, meaning the classifier estimates the probability that a specific pixel belongs to a class. Larger deviations from the center point will be allowed where a pixel is in a category with a low number of candidate pixels – lower deviations will be used where there is a high competition among candidate pixels. This procedure operates by the identification of areas within the oil slick that share common characteristics for oil type. We developed and customized a Graphic User Interface (GUI) that integrates several methods, algorithms and image processing routines; we called this GUI the 'Oil Supervised Classifier Algorithm Routine' (OSCAR). OSCAR was developed in Python using

multiple ArcGIS tools and functions contained within the Spatial Analyst and Geostatistical Analyst extensions in ArcMap. This tool has the advantage that it has been adapted to run transparently under the template that NOAA NESDIS SAB analysts use to generate their routine Marine Pollution Surveillance Reports (MPSR). The next section outlines the suggested steps to operate OSCAR. This method requires previous knowledge and training for the SAB analyst on the identification of floating oil in a satellite image. OSCAR has been developed with a user-friendly front-end that requires the user to follow 6 simple steps. This procedure runs quickly (~5 minutes) and the user can obtain a highly detailed classification of the oil including any thicker oil layer classes from an optical satellite image.

Section 4.

Conclusions.

Phase 3 of the DWH-LL project consisted of the development of algorithms and software tools that would allow NOAA NESDIS SAB to utilize satellite imagery more efficiently. In this section we discuss the current development and capabilities for each of the two satellite types (SAR and Optical) and we discuss the steps needed to fully test and integrate these tools into full operational use within current SAB workflows.

4.1 SAR TCNNA Software

The physics and science behind the TCNNA algorithm allowed us to develop a fully automated routine that is currently producing daily outputs from every single SAR image currently acquired by NOAA NESDIS. These TCNNA daily automated outputs can be reviewed at

https://www.star.nesdis.noaa.gov/sod/mecb/sar/AKDEMO_products/TCNNA_OIL/tcnna_calendar.html

Currently, the TCNNA software is in the 'testing and validation' stage. During the last interaction between Water Mapping personnel and NOAA NESDIS SAB analysts we demonstrated a prototype of a GUI to facilitate this testing and evaluation process. This GUI converts the outputs from the automated system into a shapefile that can be imported and used in the ArcMap interface that SAB uses on a daily basis.

Initial testing of the TCNNA outputs shows that the 'oil likelihood index' is the most important variable from the fully automated output; and a the development of a GUI where the SAB user could select specific oil index values and convert that classification into a shapefile would be extremely useful for consistently producing the daily oiling reports.

4.2 Optical Satellite Imagery Analysis Software

We have also developed an ArcMap-Compatible toolbox called 'WaterMapping.tbx' for optical imagery. This software was installed, demonstrated, and tested for the NOAA NESDIS SAB. This toolbox is a user-friendly interface that integrates multiple routines into a simple six step process. During our last interaction with SAB analysts, we identified a number of modifications and additional features that can be incorporated into this tool to make it fully operational and useful for SAB analysts.

There are limitations to the ability to in situ and remotely sensed, surface oil measurements and characterization. Absolute thickness and even more so for specific volume estimates are very difficult targets to meet. The measures evaluated in this multi-phase project examine only the surface extent and relative thickness of surface oil. Our understanding gained through these experiments give us significant insight into one substantial portion of released oil, but for a more complete understanding of an oil plume both the surface and sub-surface components

of the oil must be determined. Further studies on the full, three dimensional delineation of oil have been recommended and are currently proposed.

Regardless, these tools represent a significant step forward to deploy fast, user-friendly tools that will improve the consistency and speed of delivery of satellite analysis for emergency response and damage assessment.

This rapid and standardized product development and delivery is critically important to bring these remote sensing based decision support tools and products to our response community via a Common Operational Picture (COP) applications such as NOAA's Environmental Response Management Application (ERMA) and other desktop GIS systems. All of the data and product discussed in this report will be made available in Gulf of Mexico ERMA publicly upon final reporting and release by NOAA and BSEE.

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APPENDIX A: TCNNA ALGORITHM IMPLEMENTATION UNDER THE SAROPS SYSTEM

A.1 SAR Operational Products Systems (SAROPS)

NOAA NESDIS have worked for several years building an infrastructure of software modules that process SAR data into operational products, this system is known as SAR Operational Products Systems, which originally included the generation of operational products like: SAR Ice Masks, SAR Wind Speed Products, SAR Ocean Wave Spectra, and SAR Ship Detection Products. For the integration of a 'SAR Oil Mask' we needed to build the TCNNA as an ingestible module into the SAROPS system. Understanding the approach described here for classification of oil spill areas in SAR images should be considered in the context of SAROPS. The SAROPS system grew out of APL/NOAA SAR Wind Retrieval System (ANSWRS) and was primarily directed toward the processing of SAR imagery for wind speed retrieval. Figure 1 shows an overview of SARPOPS and the addition of the TCNNA/Oil Mask module (in Yellow).

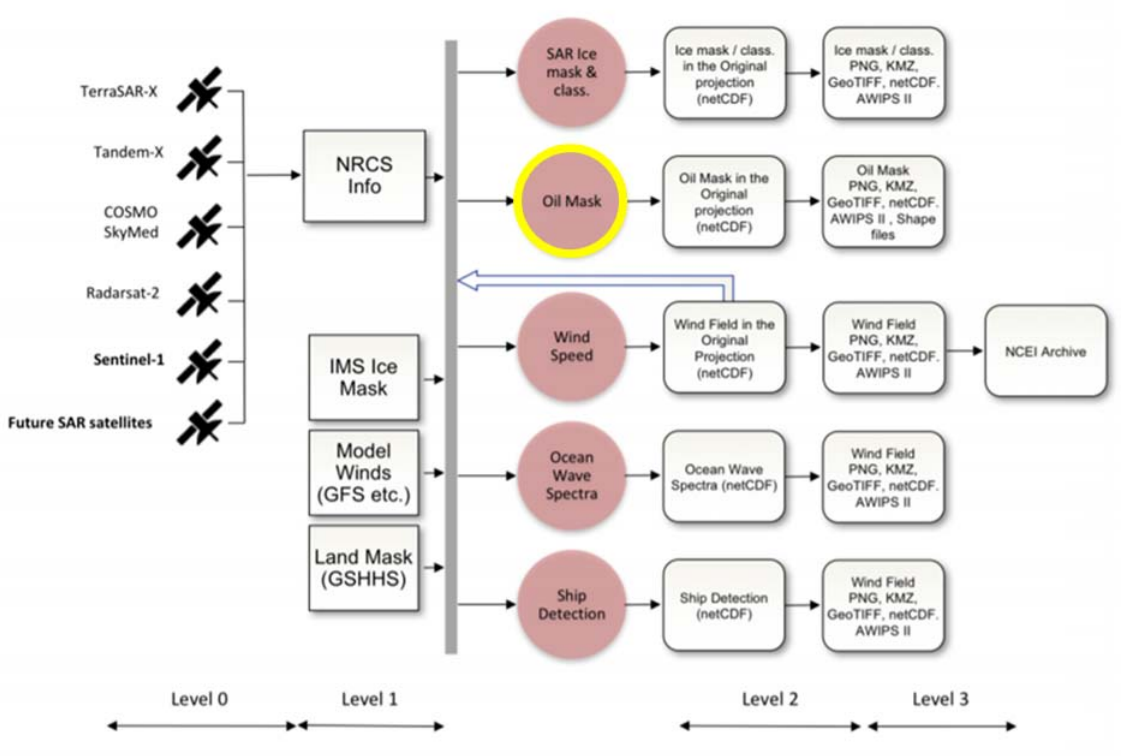

Figure 1: Overview of the SAROPS system

One of the key features of SAROPS system is the conversion of SAR imagery from a variety of sources into an internal standard format. We use here the Standard Input Output (SIO) developed by the Environmental Research Institute of Michigan (ERIM), now a part of General Dynamics. The NRCS and land mask data are flat binary files with a 20-byte header. The header data is listed in Table 1.

Table 2-1: Contents of SIO 20-byte header in image file.	
Data Type	**Information**
Four-byte signed long	−16678914, Magic number indicating SIO format
Four-byte signed long	Number of lines of data

Four-byte signed long	Number of pixels of data
Four-byte signed long	Pixel element data type, 3= floating point, 2= unsigned integer, 1= signed integer
Four-byte signed long	Bytes per element

The NRCS data is represented as floating-point values, while the land mask data is represented as signed two-byte integers. Positive values represent land pixels. Negative values represent water pixels. The absolute value of the land or water integers represents the number of pixels to the nearest land/water boundary. This land mask format will allow easy separation of land and water returns, while permitting users to decide how to treat SAR image data near the land/sea boundary. SAROPS can also produce an ice-mask SIO file using Interactive Multisensor Snow and Ice Mapping System (IMS) data (Helfrich et al., 2007). The data are stored a unsigned one-byte integers with the values: 0 for “no data,” 1 for “water,” 2 for “land,”, 3 for “sea ice”, 4 for “snow.”

The SIO ancillary data files are text files providing general information. Each line is formatted with the relevant value, a “%” character as a delimiter, and a description of the value.

At Level-1, we generally produce the land mask file, but the software will function without it. We can, as necessary, produce SIO files of the latitude, longitude, incident angle, and radar look angle. Typically, these are not produced because they can be computed from data contained in the ancillary data files.

The KMZ file shows the NRCS image displayed in Google Earth. We use this file validate the georeferencing of the NRCS image. The Climate-Forecast Level-2 netCDF file contains the NRCS, longitude, latitude, incident angle, radar look direction, land mask, ice mask arrays, oil mask, oil-mask

certainty. This file is sampled at the resolution specified in the processing (typically 100 m) in the same projection as the original data. This product is the only required output product. Since this is the only required product, we provide a detailed description.

There are three types of data (formatted as arrays) stored in the Level-2 netCDF file. The first type includes identically dimensioned arrays of NRCS, retrieved oil mask, retrieved oil mask certainty, retrieved wind speed, input model direction, input model speed, longitude, latitude, incident angle, radar look direction, the land and ice masks. All but the mask arrays are stored in a floating-point data type. The land mask data are stored as signed shorts, and the ice mask data are store an unsigned one-byte integers. For wind retrievals from cross-polarized data, there is an additional NRCS array for the cross-polarization channel and a second-order polynomial expression representing the noise-equivalent NRCS as a function of range pixels.

Secondly, there are arrays providing the polynomial relationships between image elements and line and longitude, latitude, incident angle, and radar look direction. In addition, we provide the polynomial relationships, which allow an inverse computation of either element or line from longitude and latitude.

A.1.1 Product Requirements

The output NetCDF-4 Level-2 file should contain oil mask and oil mask certainty sampled at 100 m or less, with a goal for geolocation accuracy of 100 m. The latency requirement is dependent upon the application, but for nominal oil spills, products will be delivered within six hours of the acquisition of the data. The latency includes the processing of raw SAR signal into calibrated imagery, the transmission of

such imagery to NOAA, then conversion of SAR imagery into Level-2 netCDF-4 oil mask files, and the posting of these products.

A.1.2 Instrument Characteristics

Although SAROPS is capable of processing data from a variety of spaceborne SAR systems, we focus on Radarsat-2 and Sentinel-1 imagery. The NRCS data needs to be nominally calibrated to 0.5 dB. In order to obtain 2 m/s accuracy, winds are input into the oil mask retrieval.

A.1.3 Textural Classifier Neural Network Algorithm (TCNNA) Approach

The NRCSs of the ocean surface at off-nadir incident angles between 20◦ – 50◦ depend on the roughness of the ocean surface near the radar wavelength. For C-band Radarsat-2 and Sentinel-1, this is about 5–6 cm. However, the presence of oil and other surfactants will reduce surface tension, smooth the surface and decrease the radar cross section. There is not a one-tone relationship between low-return NRCSs and the presence of oil. Low NRCSs can be caused by low wind speed. At very high-wind speeds, the presence of oil often decreases NRCSs relative to the wind caused NRCSs in a noticeable fashion. Although oil masking from SAR can be effective outside this wind regime, the optimum wind speed for oil masking in between 3–8 m/s (Garcia-Pineda et al., 2009, 2013). The phenomenology of oil imaging is illustrated in Figure 2 from Garcia-Pineda et al. (2013).

The structure of dark areas in a SAR image can often be identified by human analysts. The key to a neural network approach for oil feature recognition is to identify those parameters that human analysts use to identify oil-covered areas in SAR images, use those parameters to train a neural network, and give

these parameters weighted values. Once the input parameters are decided upon, neural networks are trained against samples. In this case, Sentinel-1 SAR imagery of oil spills in the black sea were collected and a human analyst was used to identify the oil covered areas in these images. The neural network was trained and then used to generate the weighting coefficients for the input data and the intermediate nodes to reproduce the oil spill area. The entire oil masking identification system was named the Textural Classifier Neural Network Algorithm (TCNNA).

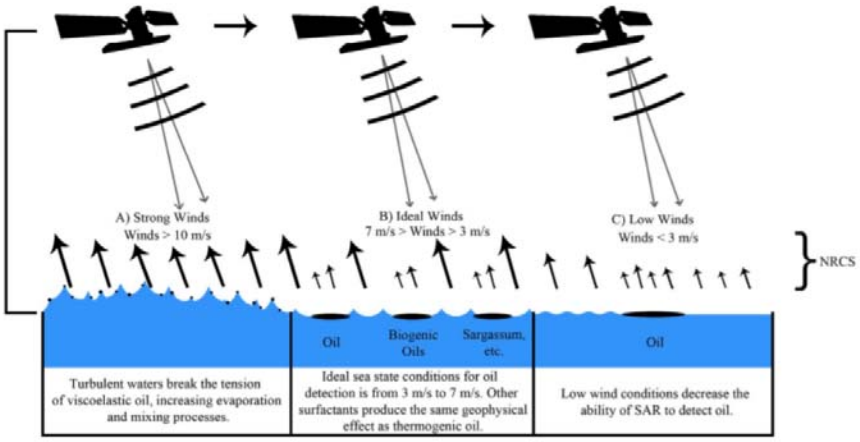

Figure 2: Phenomenology of SAR oil imaging.

There are three fundamental inputs into the neural network and neural network training: NRCS ($\sigma 0$), SAR-derived wind speed (u) and incident angle (θ). These additional derived parameters to extract the texture from the image are computed and used as the input for the neural network. The NRCS values and wind speeds help identify potential oil areas, while the incident angles helps deal with the variation of NRCSs as the range increases. The other parameters are various measures of the SAR image texture. Parameters were selected that resulted in a statistically significant improvement of the neural net training. The precise values that are used in the neural network are:

1. The NRCS at each two-dimensional index, σ 0 (i, j).
2. The incident angle in degrees at each index, θ(i, j).
3. The low-pass filtered output of the σ 0 (i, j) values clipped at a value of 0.1. The low pass filter is defined as at each index value i, j as

$$F_{\mathrm{lp1}}(i,j) = \Sigma_{\ell=-1}^{\ell=1}\Sigma_{m=-1}^{m=1}\sigma^{0}_{\mathrm{clipped}}(i+\ell, j+m)k(\ell,m)$$

where

$$k(\ell,m) = \begin{bmatrix} 0.1111 & 0.1111 & 0.1111 \\ 0.1111 & 0.1111 & 0.1111 \\ 0.11111 & 0.1111 & 0.1111 \end{bmatrix}$$

4. The high-pass filtered output of the σ 0 (i, j) values clipped at a value of 0.1. The high-pass filter is defined as at each index value i, j as

$$F_{\mathrm{hp1}}(i,j) = \Sigma_{\ell=-1}^{\ell=1}\Sigma_{m=-1}^{m=1}\sigma^{0}_{\mathrm{clipped}}(i+\ell, j+m)h(\ell,m)$$

where

$$h(\ell,m) = \begin{bmatrix} -1 & -1 & -1 \\ -1 & 1 & -1 \\ -1 & -1 & -1 \end{bmatrix}$$

5. The square root of NRCS (or image amplitude) at every index, p σ0(i, j).
6. The SAR-derived wind speed, u(i, j).
7. The square-root of SAR-derived wind speed, p u(i, j).
8. The high-pass filtered SAR wind speed, or

$$F_{\mathrm{lp2}}(i,j) = \sum_{\ell=-1}^{\ell=1}\sum_{m=-1}^{m=1} u_{(}i+\ell, j+m)k(\ell,m)$$

9. The high-pass filtered SAR wind speed or

$$F_{\mathrm{hp2}}(i,j) = \sum_{\ell=-1}^{\ell=1} \sum_{m=-1}^{m=1} u(i+\ell, j+m) h(\ell, m)$$

10. The low-pass filtered output of the p σ0(i, j) values. The low pass filter is defined as at each index value i, j as

$$F_{\mathrm{lp3}}(i,j) = \sum_{\ell=-1}^{\ell=1} \sum_{m=-1}^{m=1} \sqrt{\sigma^0(i+\ell, j+m)} k(\ell, m)$$

11. The high-pass filtered output of the p σ0(i, j) values. The high-pass filter is defined as at each index value i, j as

$$F_{\mathrm{hp3}}(i,j) = \sum_{\ell=-1}^{\ell=1} \sum_{m=-1}^{m=1} \sqrt{\sigma^0(i+\ell, j+m)} h(\ell, m)$$

12. A running 2400 m-wide average of the √ σ0 or

$$C_0(i,j) = \frac{\sum_{\ell=i-\Delta\ell}^{\ell=i+\Delta\ell} \sum_{m=j-\Delta m}^{m=j+\Delta m} \sqrt{\sigma^0(i+\ell, j+m)}}{(2\Delta\ell+1)(\Delta m+1)}$$

where
Δ` = (2400 m)/*ρi*
Δm = (2400 m)/*ρj*
(*ρi* is the image spatial sampling in the i-direction, *ρj* is the image spatial sampling in the j-direction.)

13. A running 600 m-wide average of the u or

$$C_1(i,j) = \frac{\sum_{\ell=i-\Delta\ell}^{\ell=i+\Delta\ell}\sum_{m=j-\Delta m}^{m=j+\Delta m} u(i+\ell, j+m)}{(2\Delta\ell+1)(\Delta m+1)}$$

where
Δ` = (600 m)/*ρi*
Δm = (600 m)/*ρj*
(*ρi* is the image spatial sampling in the i-direction, *ρj* is the image spatial sampling in the j-direction.)

14. A running 1200 m-wide average of the u or

$$C_2(i,j) = \frac{\sum_{\ell=i-\Delta\ell}^{\ell=i+\Delta\ell}\sum_{m=j-\Delta m}^{m=j+\Delta m} u(i+\ell, j+m)}{(2\Delta\ell+1)(\Delta m+1)}$$

where
Δ` = (1200 m)/*ρi*
Δm = (1200 m)/*ρj*
(*ρi* is the image spatial sampling in the i-direction, *ρj* is the image spatial sampling in the j-direction.)

15. A running 2400 m-wide average of the u or

$$C_3(i,j) = \frac{\sum_{\ell=i-\Delta\ell}^{\ell=i+\Delta\ell}\sum_{m=j-\Delta m}^{m=j+\Delta m} u(i+\ell, j+m)}{(2\Delta\ell+1)(\Delta m+1)}$$

where
Δ` = (2400 m)/*ρi*
Δm = (2400 m)/*ρj*
(*ρi* is the image spatial sampling in the i-direction, *ρj* is the image spatial sampling in the j-direction.)

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16. A running 1200 m-wide average of the high-passed filtered and clipped σ 0 image or Fhp1 or

$$C_4(i,j) = \frac{\sum_{\ell=i-\Delta\ell}^{\ell=i+\Delta\ell} \sum_{m=j-\Delta m}^{m=j+\Delta m} F_{\mathrm{hp1}}(i+\ell, j+m)}{(2\Delta\ell+1)(\Delta m+1)}$$

where
Δ` = (1200 m)/*ρi*
Δm = (1200 m)/*ρj*
(*ρi* is the image spatial sampling in the i-direction, *ρj* is the image spatial sampling in the j-direction.)

17. A running 600 m-wide average of the low-passed filtered and clipped σ 0 image or Flp1 or

$$C_5(i,j) = \frac{\sum_{\ell=i-\Delta\ell}^{\ell=i+\Delta\ell} \sum_{m=j-\Delta m}^{m=j+\Delta m} F_{\mathrm{lp1}}(i+\ell, j+m)}{(2\Delta\ell+1)(\Delta m+1)}$$

where
Δ` = (600 m)/*ρi*
Δm = (600 m)/*ρj*
(*ρi* is the image spatial sampling in the i-direction, *ρj* is the image spatial sampling in the j-direction.)

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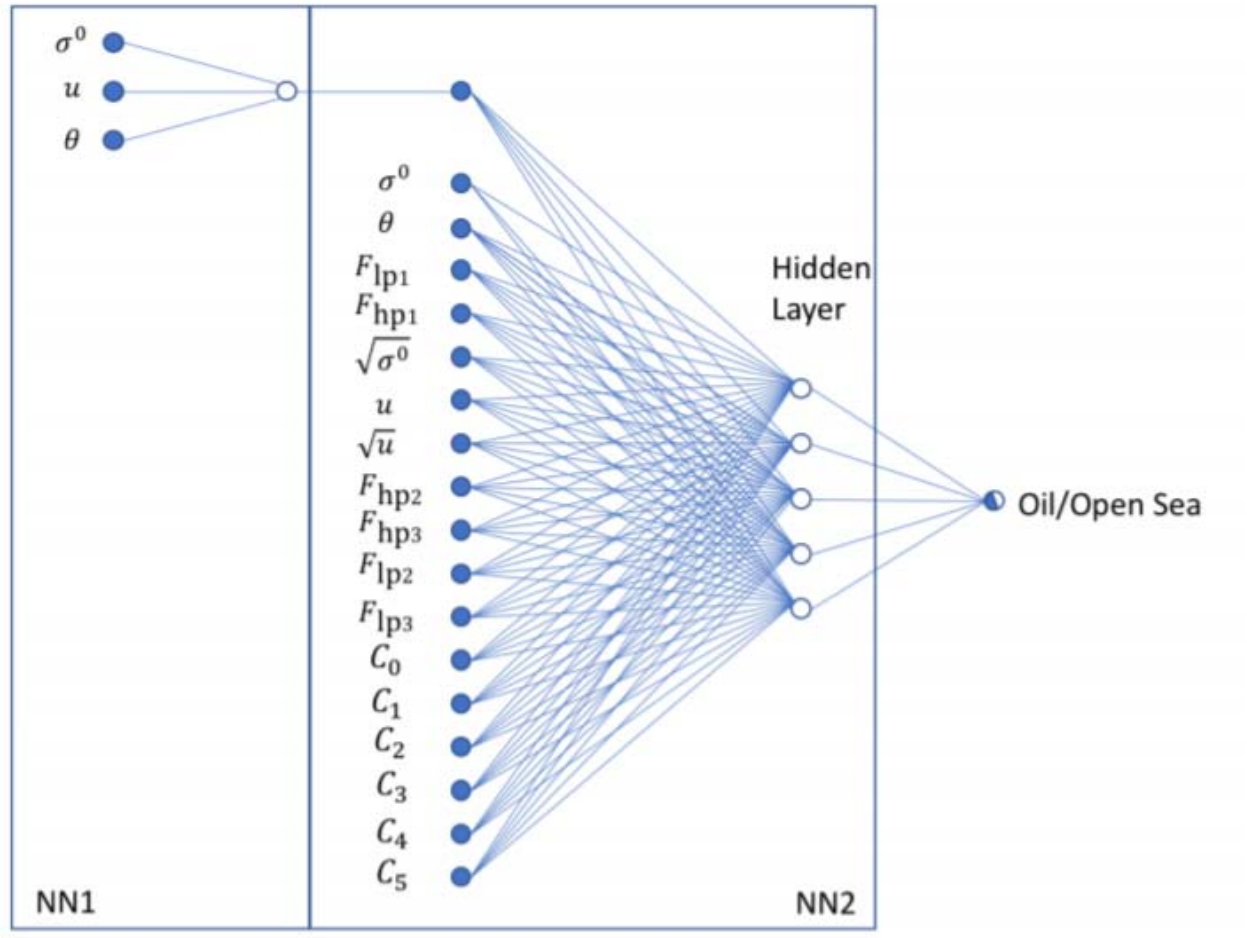

Figure 3: Neural Network Diagram. The first neural network classifies the pixels as candidates for the textural classification. The second neural network only runs on those pixels selected by the first neural network saving considerable processing time. The textural analysis is made in two neighborhood sizes.

A.2 The Neural Network training set procedure

The purpose of the algorithm is to map the surface waters covered by oil. Due to the transport and drifting processes (depending on the wind conditions), rafts of oil can separate from a much larger slick, producing irregular distribution of oil. Due to this effect, the 'oil' vs 'non-oil' classification needs to be done on a pixel-by-pixel basis, so that the overall goal of the algorithm is to segment the original SAR scene into a binary image with "oil pixel value" =1, or "non-oil pixel value" = 0. We chose to use a Neural Network (NN) approach as a classification method. In order to use this method, we needed to define a set of conditions for the NN.

A.2.1 Pixel Database and Input Layer Vector

In order to build a catalog of pixel conditions, all the images from our Sentinel and Radarsat dataset were ranked based on the wind conditions present at the time of the data collection. In total 114 SAR images were used to sample 'oil' and 'non-oil' pixels along the incidence angle, with wind speed ranging from 0 to 20 m/s (42 Images from Radarsat and 72 Images from Sentinel). For Radarsat we built a database of 59,107 classified pixels; and for Sentinel we built a database of 15,534 pixels. An example of the classification is shown in figure 2-5.

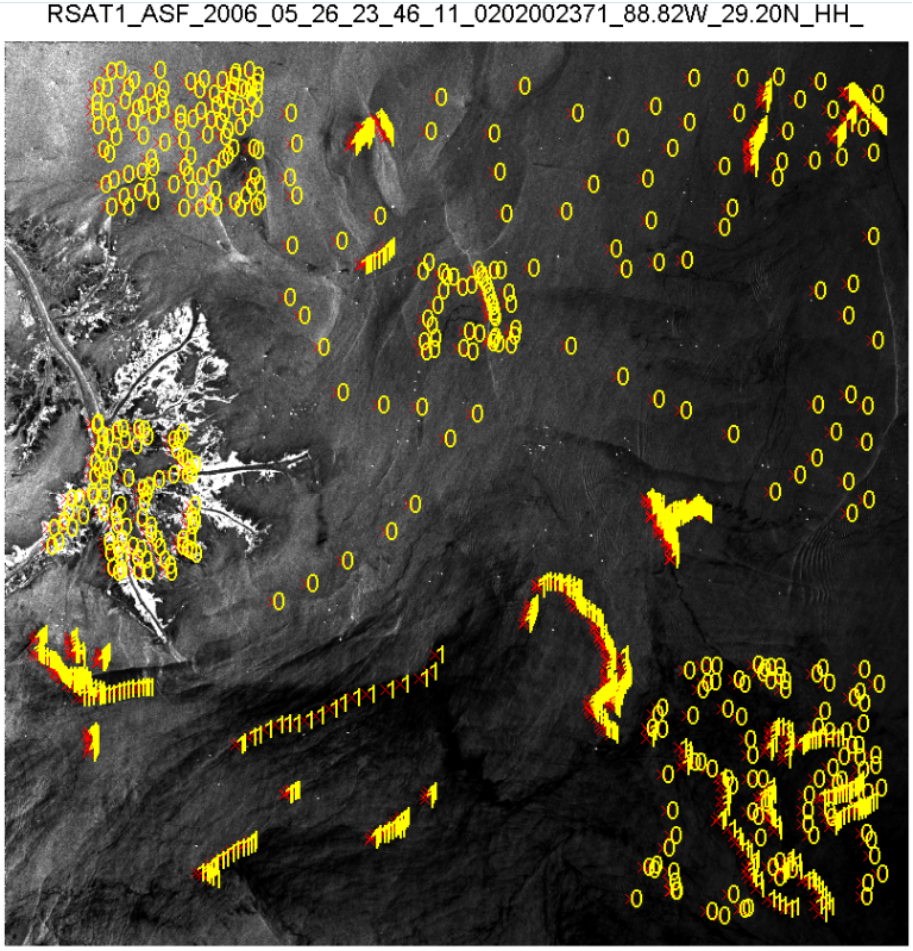

Figure 2-5. Classified samples of pixels with oil = 1, and with no-oil =0.

Sampled pixels were recorded with the X-Y location on the image. Then for each of the pixels sampled, we constructed an Input Layer Vector (ILV) of conditions. These conditions included:

a) Energy backscattered to the satellite (represented by the pixel value)

b) Radar incidence angle

c) SAR wind output calculated from CMOD5 algorithm

d) Textural statistics of the neighborhood around the pixel to classify

To limit the instrumental signature and increase the geophysical features, we use sampled SAR data along the incidence angle. To sample pixels from the image (and make them part of the pixel database), we systematically explored each image at a high magnification. For each image we selected between 800 and 1000 pixels, distributed more or less evenly over the whole image. When oil was present, we would pick several points within each oil slick and several non-slick points adjacent to the features. Locations were saved in a database containing the image name, pixel coordinates and classification as "oil" or "no oil" with corresponding values of "1" and "0". Consequently an ILV was constructed for each of the pixel locations selected in the training set, resulting, in a database of 74,641 vectors with 18 inputs and 1 target classification as "1" or "0". The neural net algorithm consisting of a pixel by pixel Feed-Forward Neural Network (FFNN) classification method was trained on this data set. This database was divided randomly in two parts, in order to have a pixel training dataset and a pixel validation dataset.

To optimize the processing time, we divided this operation into two main steps: 1) Mask classification, and 2) Textural classification. The main purpose of having these two steps is to filter out the areas of the image that are not required or suitable for analysis through a textural analysis, thus saving significant amount of processing time (Figure 3.3).

APPENDIX B: TCNNA IDL CODE

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CLASSIFICATION ROUTINE:

```
;-------------------------------------------------------
;+
; NAME: classification.pro'
; PURPOSE:'
;   This program generates the oil probability mask'
; CALLING SEQUENCE:'
;   classification, rows, cols, cmod5, IncAngle, sigma, lpfi, HPF1, BO1, WO1, BN1, WN1,
file_name
; INPUT:'
;
; OUTPUT:'
;   TCNNA output'
;
; KEYWORDS:'
;
; MODIFICATION
; 2014 Jun 18 Diana Villa-Hamilton. Initial Version
; 2014 Oct 17 Diana Villa-Hamilton. Mofidication of program, elimination of resizing
pro classification, rows, cols, cmod5, IncAngle, sigma, lpfi, HPF1, BO1, WO1, BN1, WN1,
file_name
  sigma_size=size(sigma,/dimensions)
  vector1=MAKE_ARRAY(11,1, /DOUBLE, value=5)
```

```
  classification_array=MAKE_ARRAY(sigma_size[0],sigma_size[1])
  TCNNA2=MAKE_ARRAY(sigma_size[0],sigma_size[1])
print, 'Classification....'
tic
ilv_col=0
imageSize = size(sigma, /dimensions)
new_cols=cols-1
new_rows=rows-1
for col=0, new_cols do begin
  for row=0, new_rows do begin
    col24right=col+24
    col24left=col-24
    row24down=row+24
    row24up=row-24
    if col24right gt new_cols then  col24right=new_cols
    if col24left lt 0 then col24left=0
    if row24down gt new_rows then row24down=new_rows
    if row24up lt 0 then row24up=0
    col12right=col+12
    col12left=col-12
    row12down=row+12
    row12up=row-12
```

```
if col12right gt new_cols then  col12right=new_cols
if col12left lt 0 then col12left=0
if row12down gt new_rows then row12down=new_rows
if row12up lt 0 then row12up=0
col6right=col+6
col6left=col-6
row6down=row+6
row6up=row-6
if col6right gt new_cols then  col6right=new_cols
if col6left lt 0 then col6left=0
if row6down gt new_rows then row6down=new_rows
if row6up lt 0 then row6up=0
 IncAng=IncAngle(row, col)
CMOD5s=CMOD5(row, col)
SIGMA1=sigma(row, col)
SIGMA_copy= Sigma
F1=HPF1(row, col)
F2=LPFi(row, col)
MS=mean(mean(sigma_copy(row24up:row24down, col24left:col24right,*) ))
Cavg1=mean(mean(CMOD5(row6up:row6down, col6left:col6right,*) ))
Cavg2=mean(mean(CMOD5(row12up:row12down, col12left:col12right,*) ))
Cavg3=mean(mean(CMOD5(row24up:row24down, col24left:col24right,*) ))
```

```
Cavg4=mean(mean(HPF1(row6up:row6down, col6left:col6right,*) ))
Cavg5=mean(mean(LPFi(row12up:row12down, col12left:col12right,*) ))
SIOMean1=mean(mean(sigma_copy(row12up:row12down, col12left:col12right,*) ))
;vector=zeros(12,1)
vector1(0)=CMOD5s
vector1(1)=IncAng
vector1(2)=SIGMA1
vector1(3)=F1
vector1(4)=F2
vector1(5)=MS
vector1(6)=Cavg1
vector1(7)=Cavg2
vector1(8)=Cavg3
vector1(9)=Cavg4
vector1(10)=Cavg5
y=FLTARR(9,1)
  y(0)=1 / (1 + exp(-(DOT_PRODUCT(vector1,WN1(0,*))+BN1(0))))
  y(1)=1 / (1 + exp(-(DOT_PRODUCT(vector1,WN1(1,*))+BN1(1))))
  y(2)=1 / (1 + exp(-(DOT_PRODUCT(vector1,WN1(2,*))+BN1(2))))
  y(3)=1 / (1 + exp(-(DOT_PRODUCT(vector1,WN1(3,*))+BN1(3))))
  y(4)=1 / (1 + exp(-(DOT_PRODUCT(vector1,WN1(4,*))+BN1(4))))
  y(5)=1 / (1 + exp(-(DOT_PRODUCT(vector1,WN1(5,*))+BN1(5))))
```

```
      y(6)=1 / (1 + exp(-(DOT_PRODUCT(vector1,WN1(6,*))+BN1(6))))
      y(7)=1 / (1 + exp(-(DOT_PRODUCT(vector1,WN1(7,*))+BN1(7))))
      y(8)=1 / (1 + exp(-(DOT_PRODUCT(vector1,WN1(8,*))+BN1(8))))
      CLASSIFICATION_array=DOT_PRODUCT(y,WO1)+BO1
      TCNNA2(row,col)=CLASSIFICATION_array
    end
end
toc
file_tcnna=file_name+'_TCNNA.csv'
print, 'Writing CSV'
openw, 3, file_tcnna
write_csv, file_tcnna, tcnna2
close, 3
end
```

READ COEFICIENTS ROUTINE:

```
;-------------------------------------------------------
;+
; NAME: read_coeficients'
; PURPOSE:'
;   This program read coefcients'
; CALLING SEQUENCE:'
;   read_coeficients, rows, cols, cmod5, NRCS_SIO, IncAngle, sigma, lpfi, HPF1, file_name
;
; INPUT:'
;
; OUTPUT:'
;   CLASSIFICATION array'
;
; KEYWORDS:'
;
; MODIFICATION
; 2014 Jun Diana Villa-Hamilton. Initial Version
pro read_coeficients, rows, cols, cmod5, NRCS_SIO, IncAngle, sigma, lpfi, HPF1, file_name
; Set Coeficients
BO1= -13.3253688618616
```

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WO1=[[-93.227539833642],[-43.7985234283257],[42.8259417072752],[37.7441531676778],[41.9305415454826],[-16.2013613430352],[-2.83612849486975],[30.0348766141072],[-27.2716949583266]]

BN1= [-3.786633854556850,5.956551471464330,-1.104959436742980,0.803649472322777,2.402071758939140,5.570115103803250,20.926421132608800,-2.755973540080610,-14.945759669143500]

WN1=[[0.124742211532309,0.010732341617733,0.192624557991469,-0.445636617318826,-0.548999627246588,0.040109158161504,7.110634941737720,0.596753977419841,-0.188976270518689],[0.133322577003224,-0.248145294372400,0.018343517826749,0.120727556218219,-0.053650893243425,0.591156283142312,-0.288326950305404,-0.097302115650607,-0.101208557910995],[-44.441933014597800,83.864328395375700,2.190311014563600,3.557071764658520,-9.007619743565420,-3.122023551390940,1.655866063116240,-7.800232016451930,18.835201209819600],[1.443990741589630,17.802756253070600,9.786092378257780,6.349939188173580,-0.199098352628198,-2.116424197476260,-42.150261788963600,-13.619219765553000,-11.405203954584300],[53.237297537112400,39.408216367836000,9.450154995395540,-4.635887948184520,46.708069946000700,-32.672539861563200,39.907242690925200,-49.161332770935000,-18.068786900862700],[1.177528225512800,-5.368676035929500,1.196508304264940,0.192146592158102,2.358021997552010,4.560943497747000,11.954820219638400,4.118782832238190,10.402538716993400],[0.197438295137855,-0.365132947012493,-1.834624375240530,-0.244105606379105,1.973575692046280,0.076816039349351,-4.728095414588420,0.375007223576600,2.599207310168760],[-0.466190506039083,0.337992768169372,-2.365928003659710,1.248895891372960,2.123113031187830,0.070566229932626,5.258123468498480,-1.222829703555440,18.869075338686600],[-0.910084602910825,1.593190479628860,4.146237882196830,-1.238194760758730,-3.776959654999590,0.063142428887749,-8.423232821590330,1.114879523101740,-19.863654108238900],[0.278732051460242,0.775944973321328,-10.561624288901600,-6.506057624304590,12.988939980748500,-1.826859287234940,-53.180164982829100,6.535308774870030,28.140989513279500],[-0.572526800436955,10.377779500009600,-

18.328552499425900,2.370791585629390,41.640399214760900,-11.789242656636500,32.531848421351300,8.318465783460300,37.618043101938200]]

classification, rows, cols, cmod5, IncAngle, sigma, lpfi, HPF1, BO1, WO1, BN1, WN1, file_name

end

```
Low PASS filter ROUTINE
PRO lowpass_filter, newImage, out1
  print, 'applying low-pass filter...'
  imageSize = size(newImage, /dimensions)
  kernelSize = [3, 3]
  kernel = REPLICATE((1./(kernelSize[0]*kernelSize[1])), kernelSize[0], kernelSize[1])
  out1 = CONVOL(FLOAT(newImage), kernel, /CENTER, /EDGE_TRUNCATE)
END
```

```
get_all_wind2oil_for_dir ROUTINE
;;;-----------------------------------------------------------
;+
; NAME: get_all_wind2oil_for_dir'
; PURPOSE:'
;   Loop through all files in directory and run ans_sio_12_wind2oil.pro
;
; CALLING SEQUENCE:'
;   get_all_wind2oil_for_dir, dir
;
; INPUT:'
;
; OUTPUT:'
;
; KEYWORDS:'
;
; MODIFICATION
; 2014 Jun DV-H. Initial Version
pro get_all_wind2oil_for_dir, dir
  fileArray = FILE_SEARCH(dir,'*_image.dat')
  print, N_ELEMENTS(fileArray)
  print, fileArray
```

```
ImageFile = fileArray[0]
 if(N_ELEMENTS(fileArray) GT 0 AND ImageFile NE '') THEN BEGIN
 FOR i=0,N_ELEMENTS(fileArray)-1 DO BEGIN
  ImageFile = fileArray[i]
  filestr = STRPOS(ImageFile, '_image.dat', /REVERSE_SEARCH)
  fileName = strmid(ImageFile, 0, filestr-1)
  print, fileName
  firstArg = ImageFile
  secondArg = fileName + 'C_mask.dat'
  thirdArg = fileName + 'C_ancil.txt'
  lastArg = fileName + 'C0_CFSRCDF_wind_level2.nc'
  print, 'Entering ans_sio_l2_wind2oil.pro'
  ans_sio_l2_wind2oil, firstArg, secondArg, thirdArg, lastArg, filename
  print, 'Exiting ans_sio_l2_wind2oil.pro'
 endfor
endif
end
```

HIGH PASS FILTER ROUTINE

```
PRO highpass_filter, newImage, out1
  print, 'applying high-pass filters...'
  imageSize = size(newImage, /dimensions)
  kernelSize = [3, 3]
  kernel = REPLICATE(-1., kernelSize[0], kernelSize[1])
  kernel[1, 1] = 1
  out1 = CONVOL(FLOAT(newImage), kernel, /CENTER, /EDGE_TRUNCATE)
END
```

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ANS SIO WIND ROUTINE

; NAME: ANS_SIO_L2_WIND2OIL

; PURPOSE:

; The purpose of this program is to read SIO data and the Level-2

; winds and compute an oil mask.

;---

; CALLING SEQUENCE

;+

; ans_sio_l2_wind2oil, sio_image_file, sio_land_file, sio_info_file, l2_wind_file, sio_oil_mask_file

; INPUT

; sio_image_file = NRCS file

; sio_land_file = Land mask file

; sio_info_file = Ancillary data file

; l2_wind_file = Level-2 wind netCDF file

; OUTPUT

; sio_oil_mask_file = Oil mask file in SIO format

; KEYWORDS:

; /quiet Do not show intermediate output

; /help Get help

; error: error, -1 is bad

; MODIFICATION HISTORY:

```
;   2013 Jun 18 Christopher Jackson / Frank Monaldo. Initial Version
;   2013 Feb 13 Frank Monaldo. Create template program for oil processing
;   2014 Apr 20 Diana Villa-Hamilton. Apply Filters
;   2014 Oct 17 Diana Villa-Hamilton. Read coeficients
; Copyright (C) 2014
;-
pro  ans_sio_l2_wind2oil, sio_image_file, sio_land_file, sio_info_file, l2_wind_file, $
                        file_name, help= help,  quiet= quiet, error=error
!quiet=    1
printflag= 1
if keyword_set(quiet) then printflag=0
quiet= printflag eq 0
error    =1
if keyword_set(help)  or (n_params(0) lt 1 ) then begin
  print, ' NAME: ANS_SIO_L2_WIND2OIL
  print, ' PURPOSE:
  print, '   The purpose of this program is to read SIO data and the Level-2
  print, '    winds and compute an oil mask.
  print, ' CALLING SEQUENCE
  print, '   ans_sio_l2_wind2oil, sio_image_file, sio_land_file, sio_info_file, l2_wind_file,
sio_oil_mask_file
  print, ' INPUT
```

```
  print, '   sio_image_file    =  NRCS file
  print, '   sio_land_file     =  Land mask file
  print, '   sio_info_file     =  Ancillary data file
  print, '   l2_wind_file      =  Level-2 wind netCDF file
  print, ' OUTPUT
  print, '   sio_oil_mask_file = Oil mask file in SIO format
  print, ' KEYWORDS:
  print, '   /quiet       Do not show intermediate output
  print, '   /help        Get help
  print, '   error:       error, -1 is bad
  error = -1
  return
endif


;
;-------------------------------------------------------------
;              Start oil mask processing
;-------------------------------------------------------------


if printflag then begin
  print,' '
  print, '************** Start oil mask processing  **************'
```

```
  print,"
endif
;
;
;
;
; Read netDF file
;
res=file_search(l2_wind_file, count=count)
if count eq 0 then begin
  print, 'Cannot find file: ' + l2_wind_file
  print, 'Exiting ans_l2cdf2icemask'
  return
endif
ans_read_wind_l2_cdf, l2_wind_file, info_l2, sigma, sar_wind, input_dir, model_speed, mask, $
  icemask= icemask
  ; Read NRCS data in SIO format
;
if not file_test(sio_image_file) then begin
  if printflag then begin
     print, 'Exiting ans_sio_l2_wind2oil'
     print, 'Cannot find ' + sio_image_file
```

```
  endif
    error=-1
    return
  endif
ans_read_sio_data, sio_image_file, nrcs, quiet=quiet, help=help, filter=1
;
; Read land data in SIO format
;
if not file_test(sio_land_file) then begin
  if printflag then begin
    print, 'Cannot find ' + sio_land_file
    print, 'Exiting ans_sio_l2_wind2oil'
  endif
  error=-1
  return
endif
ans_read_sio_data, sio_land_file, land_mask, quiet=quiet
;
; Read ASCII data in SIO format
;
if not file_test(sio_info_file) then begin
  if printflag then begin
```

```
    print, 'Cannot find ' + sio_info_file
    print, 'Exiting ans_sio_l2_wind2oil'
  endif
  error=-1
  return
endif

ans_read_sio_info, sio_info_file, info, quiet=quiet
;
; Re-size land mask if necessary
;
sz      = size(NRCS)
nx_NRCS = sz[1]
ny_NRCS = sz[2]
sz      = size(land_mask)
nx_land= sz[1]
ny_land = sz[2]

;if nx_nrcs ne nx_land or  ny_nrcs ne ny_land then begin
  ;
  ; if land mask array size not nrcs array size
  ;
```

```
 ; if printflag then print, 'Resizing land mask array to match nrcs array'
  ;if (nx_nrcs mod nx_land) eq 0 and (ny_nrcs mod ny_land) eq 0 then begin
   ; land_mask = rebin(   land_mask, nx_land, ny_land )
  ;endif else begin
  ;  land_mask = congrid( land_mask, nx_land, ny_land )
  ;endelse
;endif
;
; Compute incident angle array
;
;

if printflag then print, 'Computing incident angle array
i       =  dblarr(nx_NRCS,ny_NRCS)
j       =  dblarr(nx_NRCS,ny_NRCS)
iline   =  dindgen(nx_NRCS)
jline   =  dindgen(ny_NRCS)
for ii=0L, ny_NRCS-1 do i(*,ii) = iline
for ii=0L, nx_NRCS-1 do j(ii,*) = jline
incid   = ans_poly_cal(i, j, info.incid_coef, info.incid_xexp, info.incid_yexp)


sz      = size(sigma)
```

```
nx_sigma = sz[1]
ny_sigma = sz[2]
sz      = size(incid)
nx_incid = sz[1]
ny_incid = sz[2]

;RESIZE INCIDENT ANGLE

if printflag then print, 'Resizing land mask array to match nrcs array'
if (nx_sigma mod nx_incid) eq 0 and (ny_sigma mod ny_incid) eq 0 then begin
 incid = rebin(   incid, nx_sigma, ny_sigma )
endif else begin
  incid = congrid( incid, nx_sigma, ny_sigma )
endelse
print, 'applying filters...'
clipped_SIGMA = SIGMA < .1
highpass_filter, clipped_SIGMA, hpfilter_k1
lowpass_filter, clipped_SIGMA, lpfilter
;
; Note that all the arrays are at lower resolution than the SIO data
;
sz    =  size(sar_wind)
```

```
nx_l2 =  sz[1]

ny_l2 =  sz[2]

;print, 'Start CSV gather'

;get_csv_data, sio_image_file, INCID, SAR_WIND, NRCS, I, J, SIGMA, LAND_MASK,
MODEL_SPEED, INPUT_DIR, ICEMASK,  noisefilter, hpfilter_k1, lpfilter

;print, 'WROTE CSV FILES!'

; Generate Input Layer Vector

read_coeficients, nx_sigma, ny_sigma, sar_wind, NRCS, incid,sigma, lpfilter, hpfilter_k1,
file_name

end
```

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APPENDIX C: VISUAL/OPTICAL PROCESSING ROUTINE

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C.1 Oil Spill Classifier Algorithm Routine (OSCAR)

This section below describes the basic operation of OSCAR within the ArcMap interface. To fully understand this section, this quick guide requires the reader to be familiar with the ArcGIS software environment including the image classification and geostatistical analysis toolboxes. Lists of the 6 basic steps on using OSCAR are:

Step 1. Load a Raster file

Step 2. Verify Geo-rectification and projection

Step 3. Analysis of the image in search of oil

Step 4. Identification of the feature of interest

Step 5. Sampling the feature of interest (training sets and signature file)

Step 6. Supervised classification output and export.

In order to use the OSCAR GUI, a compatible ArcMap toolbox has been developed. This filename 'WaterMapping.tbx' needs to be imported as a tool within an ArcMap session (Figure C-1).

Step 1. Addition of Data to ArcMap

Once in ArcMap, the user must load a raster file (the satellite image). These raster files can be read from a variety of formats including Geotiff, HDF and NetCDF. Fig. 1 shows an example of loading an image file ('.IMD') from WorldView 2 using the 'Add data' tool.

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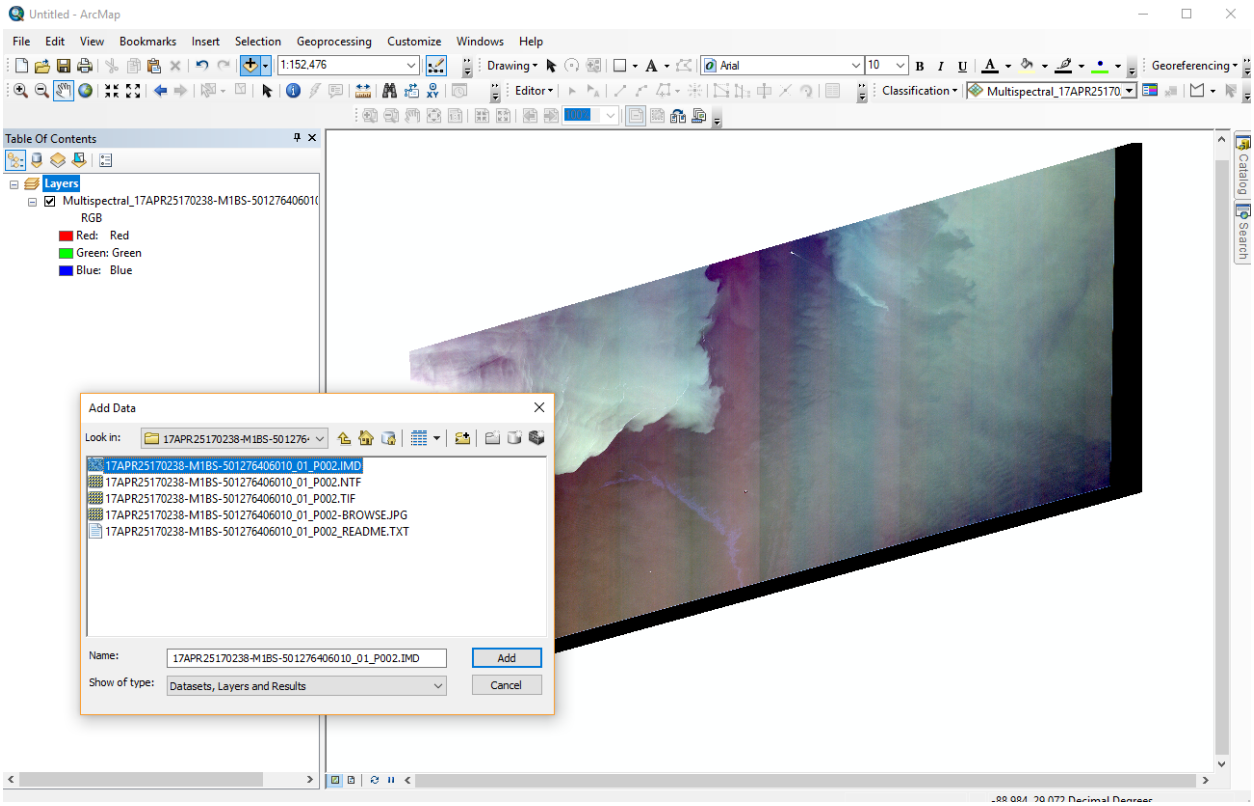

Figure C-1. Step 1, loading a file image.

It is important to make sure that the satellite image is georeferenced.

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Step 2. Verification of Registration and Projection

The second step consists of verifying the correct registration and projection of the satellite image. This process is done by adding points or features of reference that can be identified on the satellite image. In the example shown on Figure C-2, we used the pipelines and platforms database provided by BOEM to confirm that the projection of the satellite image is correct. Multiple points of reference are preferred. If the footprint of the satellite image covers an area over land, then a shoreline shapefile can be used as way of verification. The image and shapefiles need to be defined within a projection coordinate system. In this case we used the WGS 1984 datum.

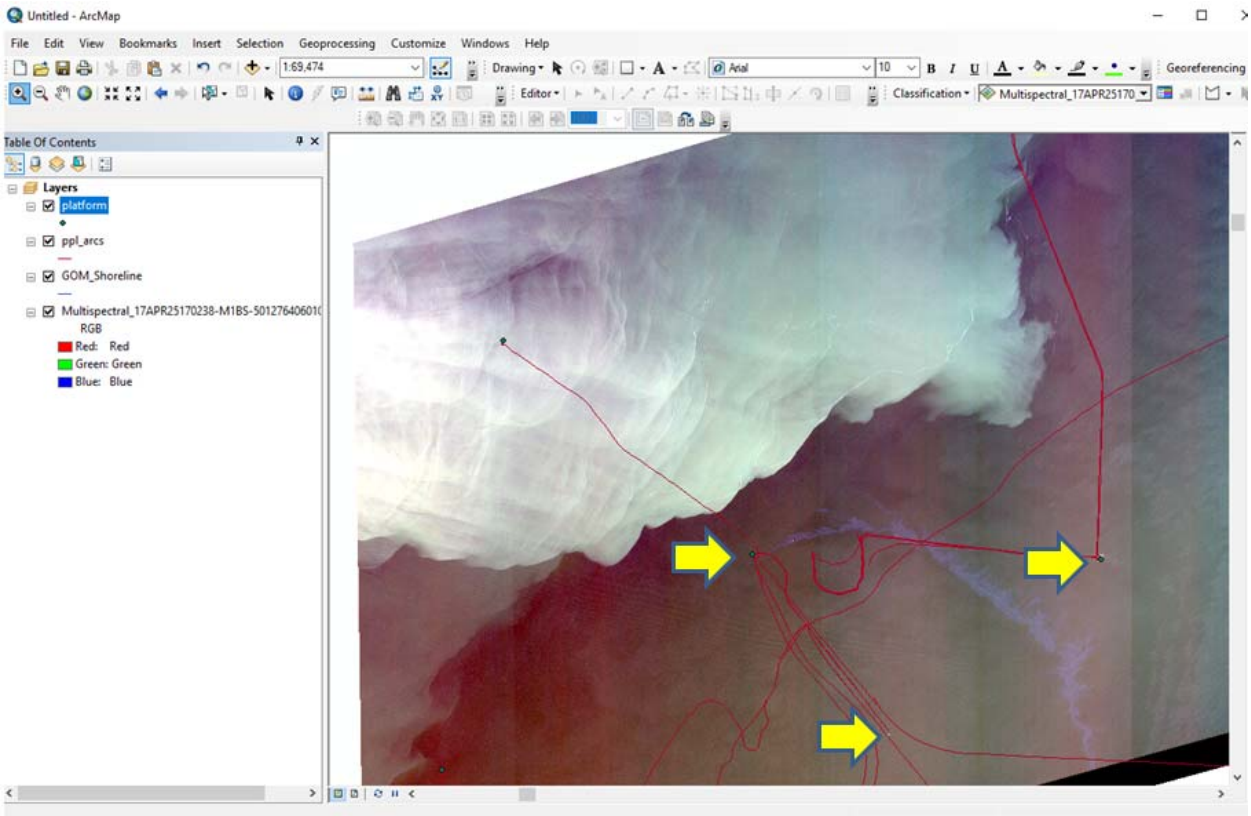

Figure C-2 Geo-location and projection verification.

Step 3. Analysis of the image in search for oil

In order to analyze the satellite image in search of oil, the user will follow the procedures described on the 'Standard Operating Procedures for the Marine Pollution Surveillance Program' (SOPMP). In a nutshell, the user will explore the satellite image by adjusting its contrast and brightness as needed. ArcMap provides multiple ways to enhance the features observed in the satellite images. In the example shown below (Figure C-3), the image contrast is stretched using the 'Percent Clip' option in the Layer properties window.

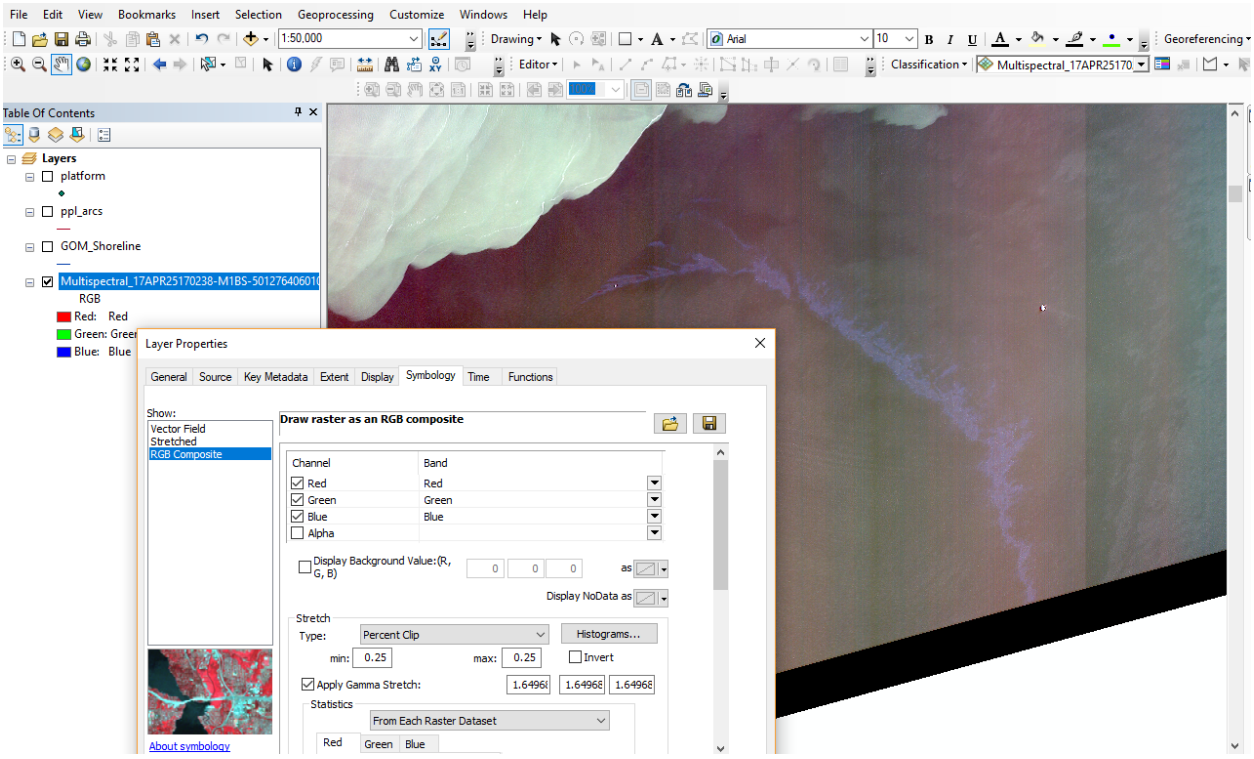

Figure C-3. Image enhancement and analysis on search of oil.

After the image has been enhanced, the user must conduct a careful review of the image in search for possible oil features. This is done by increasing the viewing display to its maximum resolution and panning the image left-right-north-south, zooming in-out in search for any features that could be associated with oil. This procedure is also fully explained in the SOPMP.

Step 4. Identification of a feature of interest

Once oil has been detected in a satellite image, the user will create a mask of the area of interest around the oil feature. This mask will make the OSCAR routine run only on the pixels inside the mask, allowing the process to run in less time than if processing the entire image. This mask will also help the classification process by excluding pixel characteristics that are not related to the oil signature (Figure C-4).

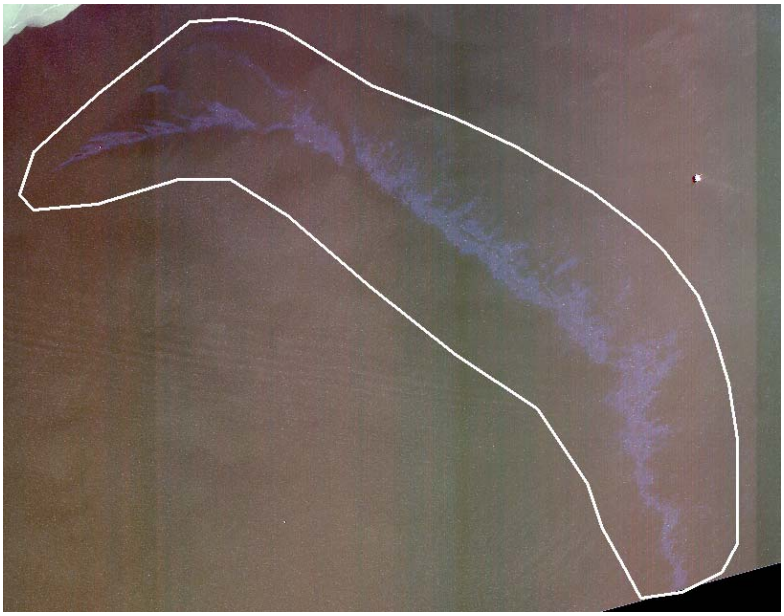

Figure C-4 Oil Mask

Step 5. Sampling the feature of interest (training sets and signature file)

Using the Training Sample Manager (Image Classification Toolbox) the user should select regions of pixels that would correspond to thick oil areas, and then other features that would correspond to non-thick oil areas. Samples are arranged on the Training Sample Manager and assigned a single 'Value' per class, and a signature file needs to be created based on the samples that were just created (Figure C-5).

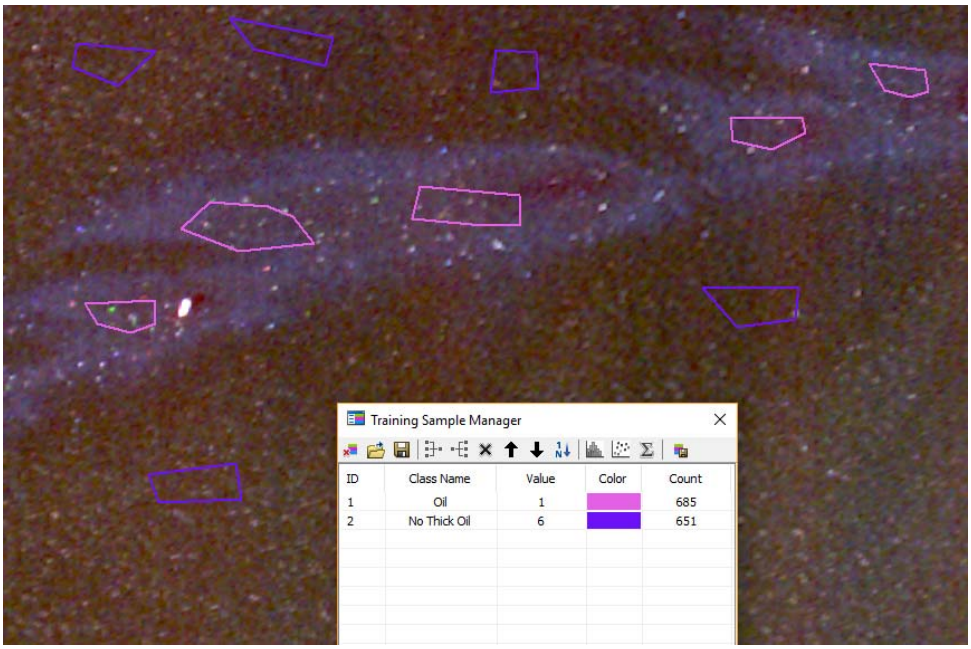

Figure C-5 Signature file creation from training samples.

Step 6. Supervised classification output and export.

Using the WaterMapping Toolbox (Figure C-6), the user opens the OSCAR tool and selects the raster file and the output filename. Similarly, the user has to provide the location of the signature file created in

Step 5, and the Mask file created in Step 4. The output file will be a shapefile created by the automatic classification made by the OSCAR routine.

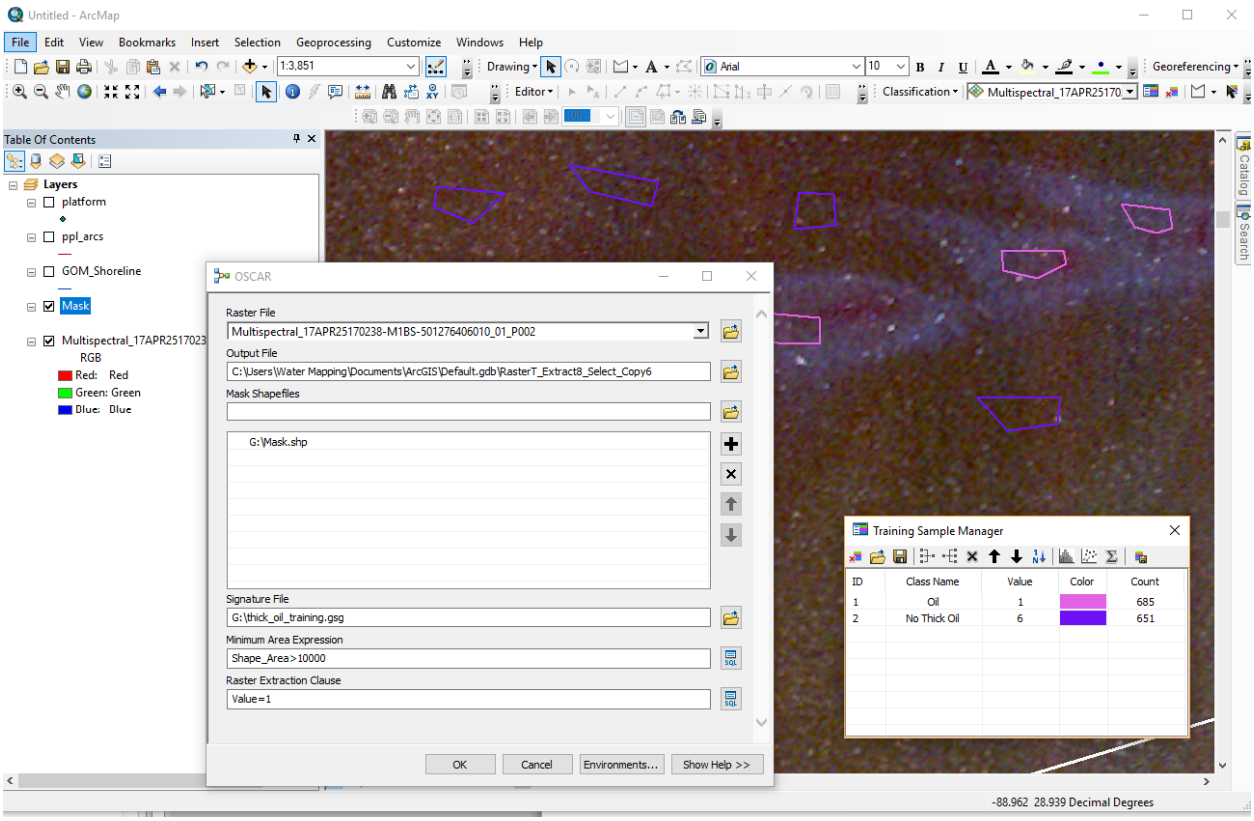

Figure C-6. WaterMapping toolbox and OSCAR routine.

C.2 RESULTS

The output of the WaterMapping toolbox will generate a delineation (polygon shapefile) of the area associated with the oil signature selected by the user (Figure C-7).

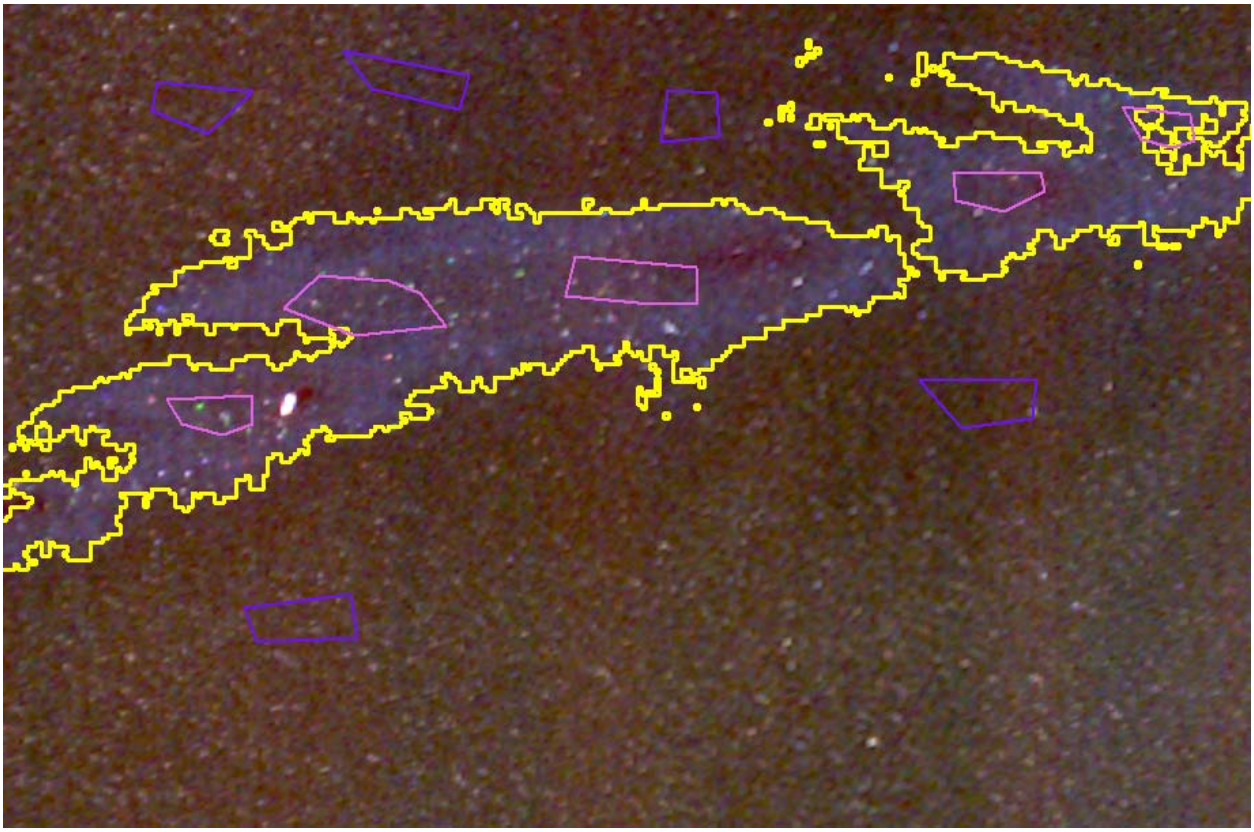

Figure C-7 Automatic delineation from the OSCAR routine in yellow.

The WaterMapping toolbox produces a rapid and high level classification of the features associated with oil. Figure C-8 shows a comparison of the Image before the classification and after the OSCAR routine has run over the area of interest (mask).

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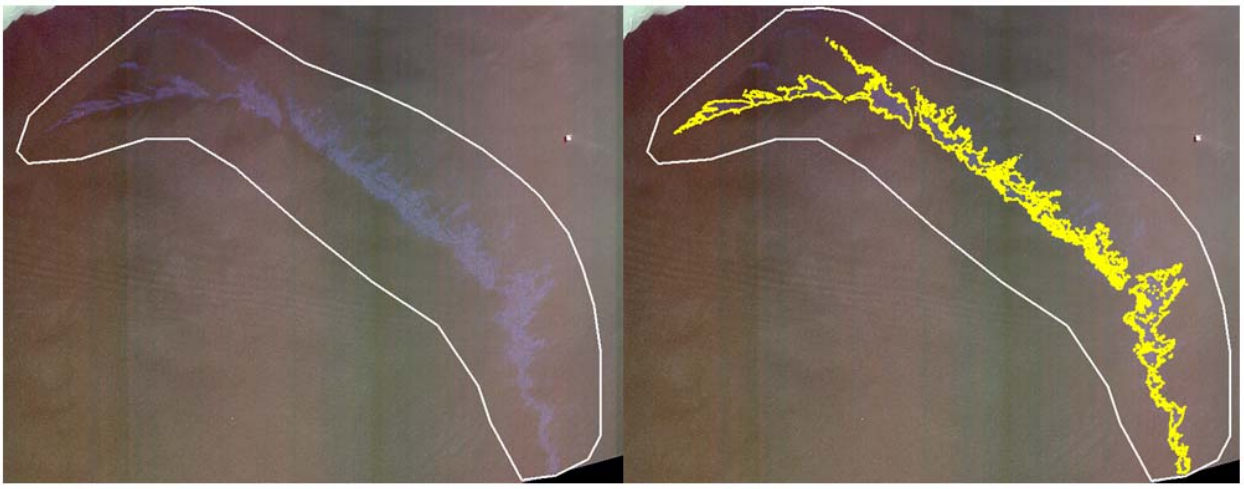

Figure C-8 Thick Oil Classification.

For a higher level of classification, the new oil output can be used then as a mask, and the user can repeat steps 4-6 in order to further classify the pixels inside the initial thick oil class. This would allow having multiple classes of thicker oil in the oil slick. By combining synoptic images from ASTER and Worldview, and using the WaterMapping toolbox, we can generate a map with multiple oil classes with high level of details as shown on Figure C-9.

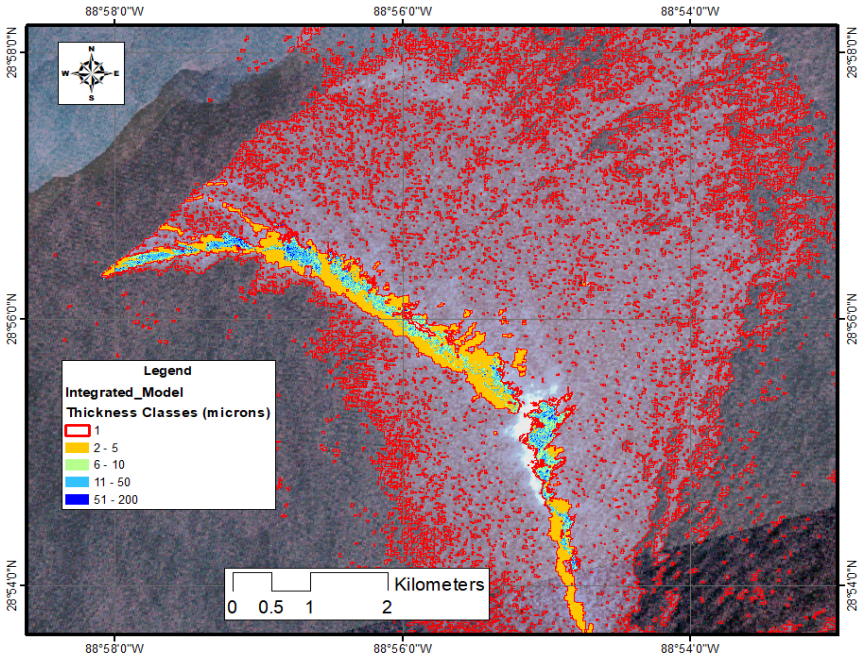

Figure C-9 Classification of oil thicknesses using the OSCAR routine integrating the outputs from two synoptic satellite images.

Attachment H. Fototerra MC20 November 2016 Report

Fototerra

Taylor Energy Site - Offshore Oil Spill Remote Sensing Test

Report

Rev.1 – December 1st 2016

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"The findings and opinions expressed in this report are solely those of the authors and do not necessarily reflect the views and policies of the Bureau of Safety and Environmental Enforcement, nor does mention of the trade names or commercial products constitute endorsement or recommendation for use."

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1 Executive Summary

Fototerra is taking part of a series of tests coordinated by BSEE and NOAA to support the Deepwater Horizon spill ongoing lessons learned with the aim to provide control and validation for surface oiling characterization efforts and to establish spatial and airborne data libraries necessary to use these techniques for future response and damage assessment. To advance the understanding for oil spill preparedness, BSEE and NOAA organized open water data collection experiments from multiple sensors and platforms. Aim of these experiments is to demonstrate how each sensor detects oil in the same physical and environmental conditions.

The open water collection took place between Nov 14th and Nov 17th in the area of the former Taylor Energy's production platform on Mississippi Canyon 20-A. The platform and its pipelines were destroyed in 2004, when Hurricane Ivan crossed the area. Since then, plumes of oil and gas are found seeping from the sea floor in the vicinity of both the well casings and the downed platform and oil has been spotted leaking at the site ever since. Fototerra participates in this event with the Poseidon platform equipped with its multi-sensors system. POSEIDON is an integrated system built on three blocks: multi-sensor platform, real time analysis and high-speed high-capacity communication. Capabilities include: detection of surface films (oil and pollutants); mapping of relative thickness; oil and pollutants type classification; measurement of absolute thickness and volume; determination of position, area, drift and spreading of the spill; preservation of evidence and real time data communication and mission coordination.

2 Introduction

The test campaign coordinated by BSEE and NOAA is composed of 3 Phases. Phase#1 - Controlled Experiment at Ohmsett, Phase#2 – Open Water testing at Taylor Energy site and Phase#3 - Operational Tools Algorithms and Training. Fototerra was involved in Phase#1 and Phase#2:

Phase#1 - Controlled experiment at Ohmsett Test Tank.

Between the 10th and the 21st of July 2016 Fototerra performed two series of tests: a bridge-mounted test in Ohmsett with Laser Fluorosensor (LFS) and Microwave Radiometer (MWR) and an overflight test with the entire suite of sensors. The LFS determined clearly the classification of the oil and the MWR determined with precision the thickness of the oil. The overflights, despite the challenging contained environment of the 200m by 20m test tank, provided very good results and the sensors from Medusa were imaging the area of the tank consistently. Results from Phase#1 were presented previously in a dedicated Report.

Phase#2 - Open Water testing at Taylor Energy site.

Between the 14th and the 18th of November 2016 Fototerra performed data acquisition with the full suite of sensors including SLAR, in daytime and nighttime conditions at the Taylor Energy Site in the Gulf of Mexico, about 90NM southeast of New Orleans. Data were collected and processed to obtain the following information: identification of the target, synoptic overview and overall aerial extend of the spill, area, center coordinates of the oil spill, oil distribution map, oil type classification, oil thickness, indication of hotspots when present, and dynamic properties of the spill (e.g., drift and spreading of the oil on the sea surface).

The above-mentioned information was made available in real-time during the flight. During real operations, this capacity enables the operator to continuously report to the Incident Command Center supporting the decision-making process with real-time data and so to greatly improve the oil recovery process. This preliminary report aims to show chronology and the preliminary results of Phase#2.

3 Chronology and Preliminary Results

3.1 General Objective

The general objective of the open water test in Taylor, in line with the BSEE / NOAA goals, was to present the capabilities of the Poseidon platform in a real oil spill scenario and acquire data for surface oil detection and characterization, and show how the information acquired and the methodologies adopted can be used in future oil spill responses, in permanent coastal surveillance and natural damage assessment.

3.2 Specific Objective

Fototerra's specific objective was to perform planned overflights over the Taylor Energy platform site during the week of the 14th of November 2016 per the following schedule set up by BSEE and NOAA and based on satellite acquisition times.

11/14 Collections

- 11/14 – EO-1 8:08 am
- 11/14 – WV2 10:42 am
- 11/14 – WV3 11:06 am
- 11/14 – OWOC 9:45 – 10:30 am Spotters: Holmes/Lankford
- 11/14 – TRACS 10:30 - 11:00 am
- 11/14 – Fototerra 11:00 – 11:30 am

11/15 Collections

- 11/15 – UAVSAR 5:30 am – 8:00 am
- 11/15 – Radarsat-2 5:56 am
- 11/15 – OWOC 7:30 – 8:15 am Spotters: Holmes/Lankford
- 11/15 – TRACS 6:30 – 7:00 am
- 11/15 – Fototerra 7:00 – 7:30 am Passenger: Gordon

11/16 Collections

- 11/16 – Aster 10:50 am
- 11/16 – OWOC 9:45 – 10:30 am Spotters: Lankford/Wall
- 11/16 – TRACS 10:30 – 11:00 am

- 11/16 – Fototerra 11:00 – 11:30 am

11/17 Morning Collections

- 11/17 – UAVSAR 9:00 am – 12:00 pm Passenger: Jay Cho
- 11/17 – Landsat 10:26 am
- 11/17 – OWOC 9:30 – 10:15 am Spotters: Lankford/Wall
- 11/17 – TRACS 10:15 - 10:45 am
- 11/17 – Fototerra 10:45 – 11:15 am
- 11/17 – WV2 10:31 am

11/17 Afternoon Collections

- 11/17 – UAVSAR 4:00 pm – 6:00 pm Passenger: Jay Cho
- 11/17 – OWOC On-scene: 3:45 – 4:30 pm Spotters: Lankford/Wall
- 11/17 – TRACS 4:30 - 5:00 pm
- 11/17 – Fototerra 5:00 – 5:30 pm (NIGHT DETECTION)
- 11/17 – Radarsat-2 5:48 pm

3.3 Poseidon Technology

For the open water test in Taylor, Fototerra utilized the full Poseidon platform.

Poseidon platform is built on three blocks: multisensor environment, real time data processing and communication.

POSEIDON's integrated multisensor platform is divided into far-range detection and near-range analysis. Far-range detection is based on the use of a real aperture radar system SLAR (side-looking airborne radar), which covers swaths of several tens of nautical miles (NM). Targets detected by the radar are then investigated on site using near-range sensors. Near-range analysis of oil spills includes visualization, quantification and classification of the type of oil. Near-range detection sensors include: IR/UV (infrared ultraviolet) scanner, VIS (visual line) scanner, EO/IR (electro-optical infrared), MWR (microwave radiometer), LFS (laser fluorosensor). For SAR (Search and Rescue) support the POSEIDON is equipped with: direction finder and AIS. The platform is completed by a mission control system for real-time data processing and analysis and communication systems—broadband radio, satellite, satellite phone, VHF.

Side Looking Airborne Radar (SLAR) is a X-band microwave radar. Flying at an altitude between 1,000 and 6,000 ft., SLAR has a cross-track swath between 35 and 50 NM. Oil spill detection by radar is based on the principle that oil spills and biogenic slicks or specific hydrodynamic effects may result in a reduction of the radar backscatter signal due to the dampening of surface wave structures. SLAR is an all-weather sensor: Microwaves can penetrate clouds, fog, drizzle and rain. SLAR allows POSEIDON to cover more than 7,500 square nautical miles per hour.

Infrared Ultraviolet (IR/UV) imaging device is a standard instrument for near-range monitoring of oil spills and has shown its reliability, stability and operability over decades. At the near-range operational altitude of about 1,000 ft the swath width is between 2,000 and 3,000 ft. Films of crude oil in water can be detected in thermal IR because oil has a lower integral emissivity than the surrounding water in the spectral region, and oil can be heated up through absorption of sunlight if there is enough thickness. Minimum detectable oil thickness in the thermal IR starts from 2 μm; hotspots that are generated through absorption of sunlight appear in the thickness range up to 500 μm. UV remote sensing of oil is based on the fact that the air/oil interface of the oil film has about twice the integral near UV reflectance of the water. The UV can detect very thin sheens of oil; the minimum detectable thickness amounts to 0.01 μm. The combined IR/UV device shows the area of large and intermediate film thickness, as well as the total extent of the oil spill.

Visual Line Scanner (VIS) is used for acquisition of highly resolved georeferenced RGB (Red Green Blue) images. The RGB line scanner combines high mapping and georeferencing accuracy with the acquisition of color information that allows volume estimations based on oil appearance codes. The Microwave Radiometer (MWR) is a passive microwave remote sensor used to map oil layers exceeding a thickness of 50 μm. Oil spills appear as a brighter object in the microwave region relative to the oil-free surface. The MWR allows determination of the absolute thickness of the oil spill and, therefore, the volume of the spill. In addition, the difference of sensitivity between MWR and IR/UV allows determination of the hotspots of the spill where the bulk of the oil is concentrated. This feature is greatly important for the responders. MWR is an all-weather sensor. At the near-range operational altitude, the swath width is about 2,000 ft.

The Laser Fluorosensor (LFS) is based on a high-power UV laser that sends short pulses toward the water surface. The laser-induced fluorescence and backscatter are received by a telescope and separate spectrally into a number of monochromatic signals. The detected discrete emission spectrum is used to estimate the oil class and classify the oil and to evaluate the absolute thickness of thin slicks in the range of 1 – 20 μm. The system has a pre-existing library of substances used to compare the actual detection.

Electro Optical Infrared (EO/IR) is an airborne observation system with HD sensors and HD video outputs. It is equipped with RGB and NIR (near-infrared) optics, multispectral zoom laser range finders, illuminators and pointers (red or NIR). The device delivers color and NIR images that allow situational awareness in all conditions day and night in critical SAR operations, navigation in challenging conditions, and clear images of the scene.

The mission control system computer provides sensor management, online visualization, real-time sensor fusion, data analysis and data storage in a central multimission unit. All operations are facilitated by an ergonomic graphical user interface (GUI). In contrast to traditional systems, which mainly perform visualization and storage of non-georeferenced sensor images, the system allows real-time data fusion, georeferencing and analysis of multisensor oil spill data.

3.4 Methodology

The methodology used during each flight follows the standard procedure that Fototerra adopt for an actual response operation, that includes: Step#1: Synoptic overview of the spill, Step#2: spill approach and Near Range Analysis, and Step#3: Data Processing and Data Communication.

Step#1: Poseidon approaches the Spill Area at an altitude of 3,000ft, scanning the area with the SLAR. At that altitude the Swath is about 50NM and the total area scanned is about 7,500 square nautical miles, the SLAR is a microwave real aperture radar effective in all weather, night and day conditions. The EO/IR sensor is also a good support on this phase giving the operator a night and day vision of the scene. During every operation Poseidon monitors possible marine and aviation distress frequencies with the Direction Finder, and ship traffic with the AIS (Automatic Information System).

After the identification, the target is analyzed and georeferenced, to allow for an immediate localization on the navigation map and successive detailed analysis with the near range sensors. In this stage a polygon is designed around the target and information as area, coverage, overall dimensions and coordinates of the spill are determined. As the aircraft approaches the spill for the overflights with the near range sensors, the operator records the video the overall spill with the EO/IR to have a visual, or thermal at night, overview of the spill.

Step#2: Based on the far range overall images of the spill, the operator determines the best approach to be used for the following low level overflights in order to make the best detailed analysis of the spill. When the flight pattern is determined, the aircraft overflies the spill at an altitude of 1,000ft operating all the near range sensor that at that altitude have a swath of about 2,000ft. Near range sensors include: IR, UV, VIS, MWR, LFS. EO/IR and Direction Finder at this stage are still operational giving the operator support where necessary.

3.5 Chronology

Fototerra Mission Base for the Test Campaign has been the Houma-Terrebonne airport (KHUM), conveniently located about 100NM NW of the Taylor location, and logistic support of most aviation offshore activities. Flight from KHUM to Taylor location required about 35' at 185KT of cruise airspeed. Every flight required to file a special DVFR (Defensive Visual Flight Rules) Flight Plan because the vicinity of Taylor to the ADIZ (Air Defense Interception Zone) that requires to follow special FAA rules. Extensive Helicopter and Aircraft Traffic Areas in the GoM required special attention, continuous contact with ATC (Air Traffic Control) and careful monitoring of local common traffic frequencies. Flights from Houma to New Orleans Lakefront airport (KNEW) has been performed the first day of operations to have a coordination briefing with the other participants involved in the test, and the second day to pick up an observer as requested by BSEE/NOAA.

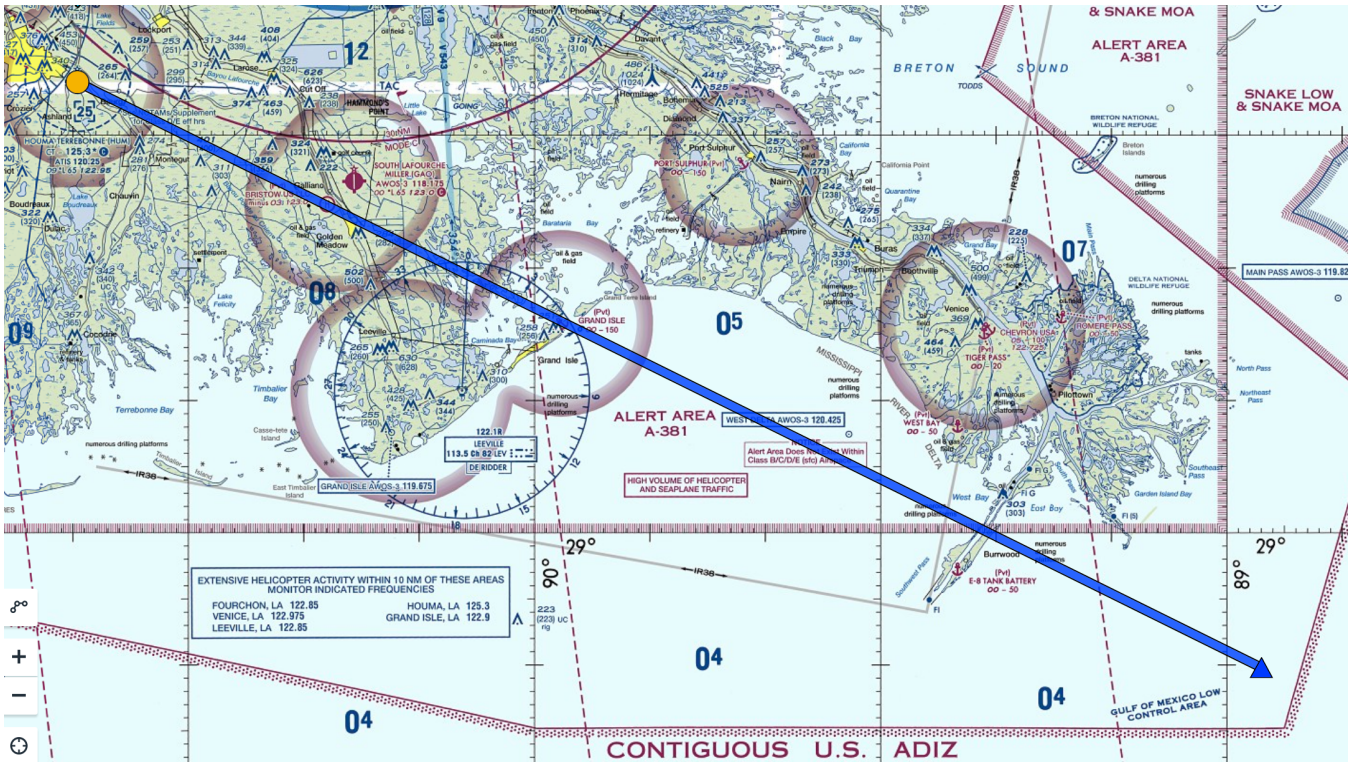


Fig.1 - Flight route from Houma-Terrebonne (KHUM) Airport to Taylor Energy site location.

The chronology of the flights (Mission IN – Mission OUT) has been the following:

November 14th Collections

Mission Start: 17:14Z (11:14 CST)

Mission End: 21:00Z (15:00 CST)

Mission Duration: 3h 46’

November 15th Collections

Mission Start: 13:18Z (07:18 CST)

Mission End: 16:02Z (10:02 CST)

Mission Duration: 2h 44’

November 16th Collections

Mission Start: 17:13Z (11:13 CST)

Mission End: 20:00Z (14:00 CST)

Mission Duration: 2h 47’

November 17th Collections

Mission Start: 17:14Z (11:14 CST)

Mission End: 19:20Z (13:20 CST)

Mission Duration: 2h 06'

Night Mission Start 22:44Z (16:44 CST)

Night Mission End: 01:23Z (19:23 CST)

Night Mission Duration: 2h 39'

3.5.1 Mission#1 – November 14th Collections

In the morning of November 14th EMB-110 Poseidon left Houma-Terrebonne airport at 7:00AM heading New Orleans Lakefront airport (KNEW) to have a coordination briefing with the crews of OWOC and Ocean Imaging. Briefing was considered particularly important to guarantee the safety of the overflights over the Taylor Platform site, because all the flights were planned in a very tight schedule, close to each other and flown at the same altitude.

The actual mission started at 11:14 CST. Poseidon approached the Taylor area with a SE track at 3,000 ft and about 185KT of cruise speed.

Step#1 - Synoptic Overview: the SLAR immediately detected a structure with strongly reduced backscatter that was identified as a surface target. The structure was delimited by a polygon of approximately 1.5x1.5NM with a coverage of 52% and a resultant area of the surface target of 1.17 square nautical miles. Polygon was centered on the following coordinates: N 28°56'30" W 088°58'24". The following figures show the SLAR images taken from two different flight directions, the georeferenced polygon, and the resultant SLAR georeferenced image with and without flight track (Fig.2 to Fig.5).

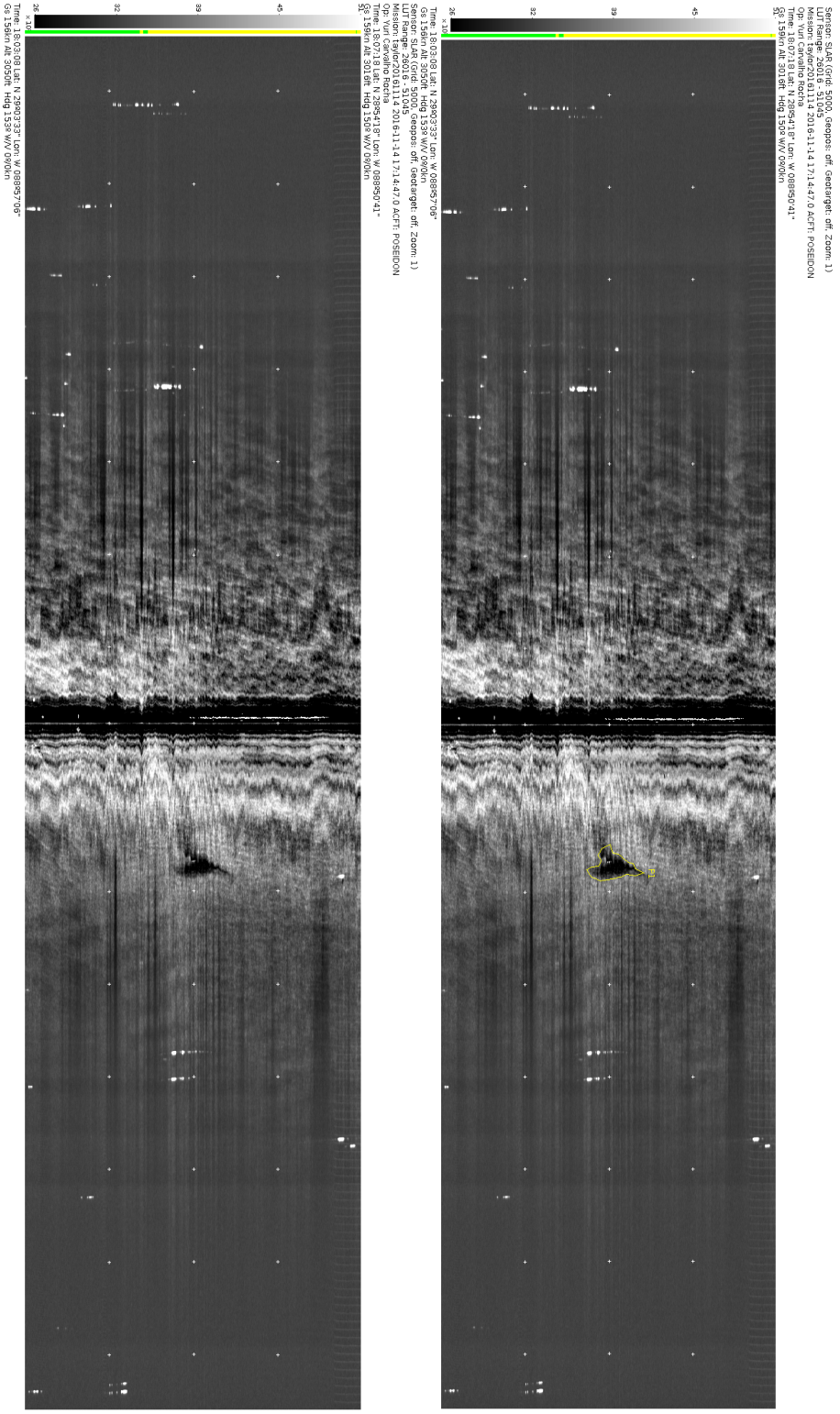


Fig.2 - SLAR images of the spill: NW to SE approach

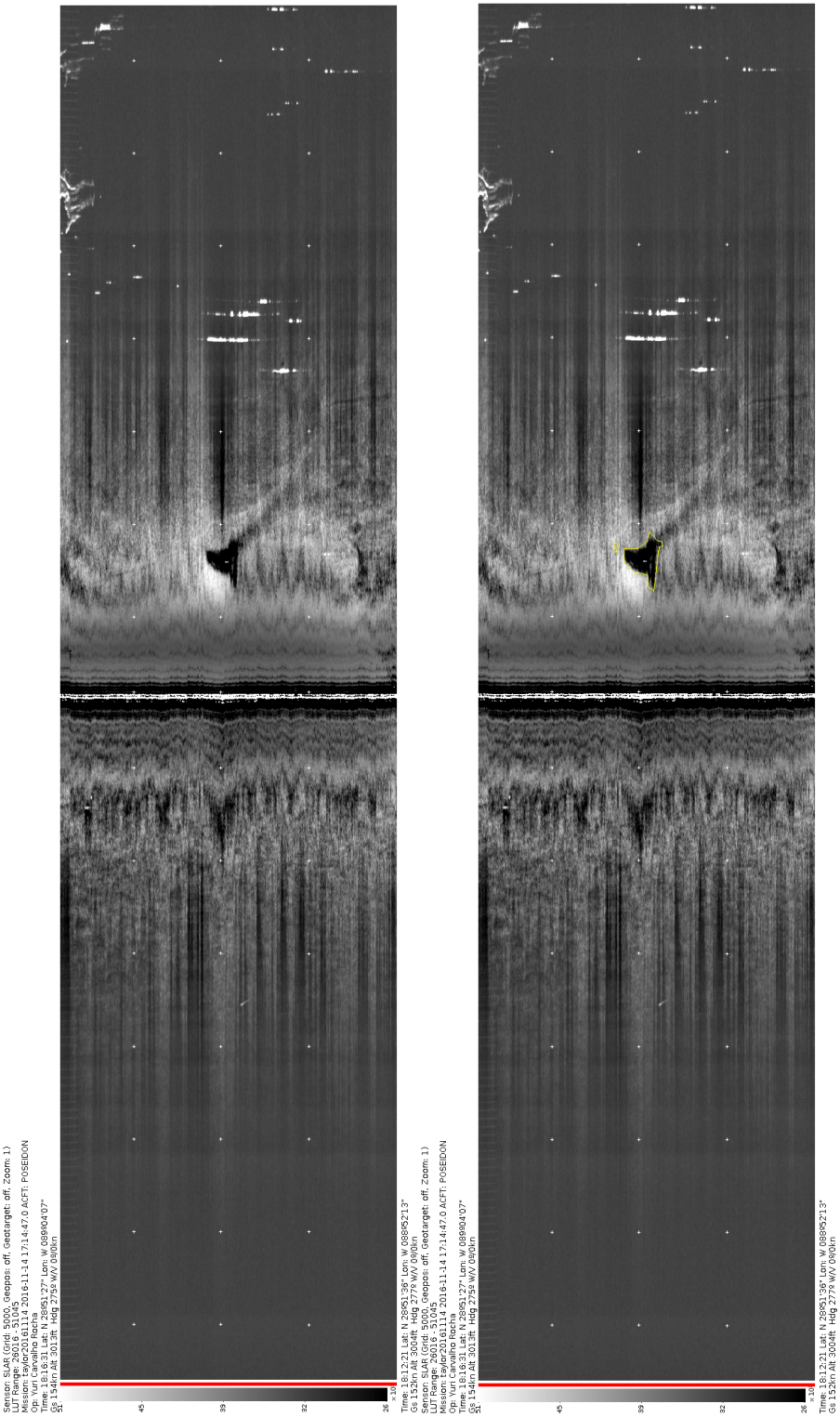


Fig.3 - SLAR images of the spill: E to W approach

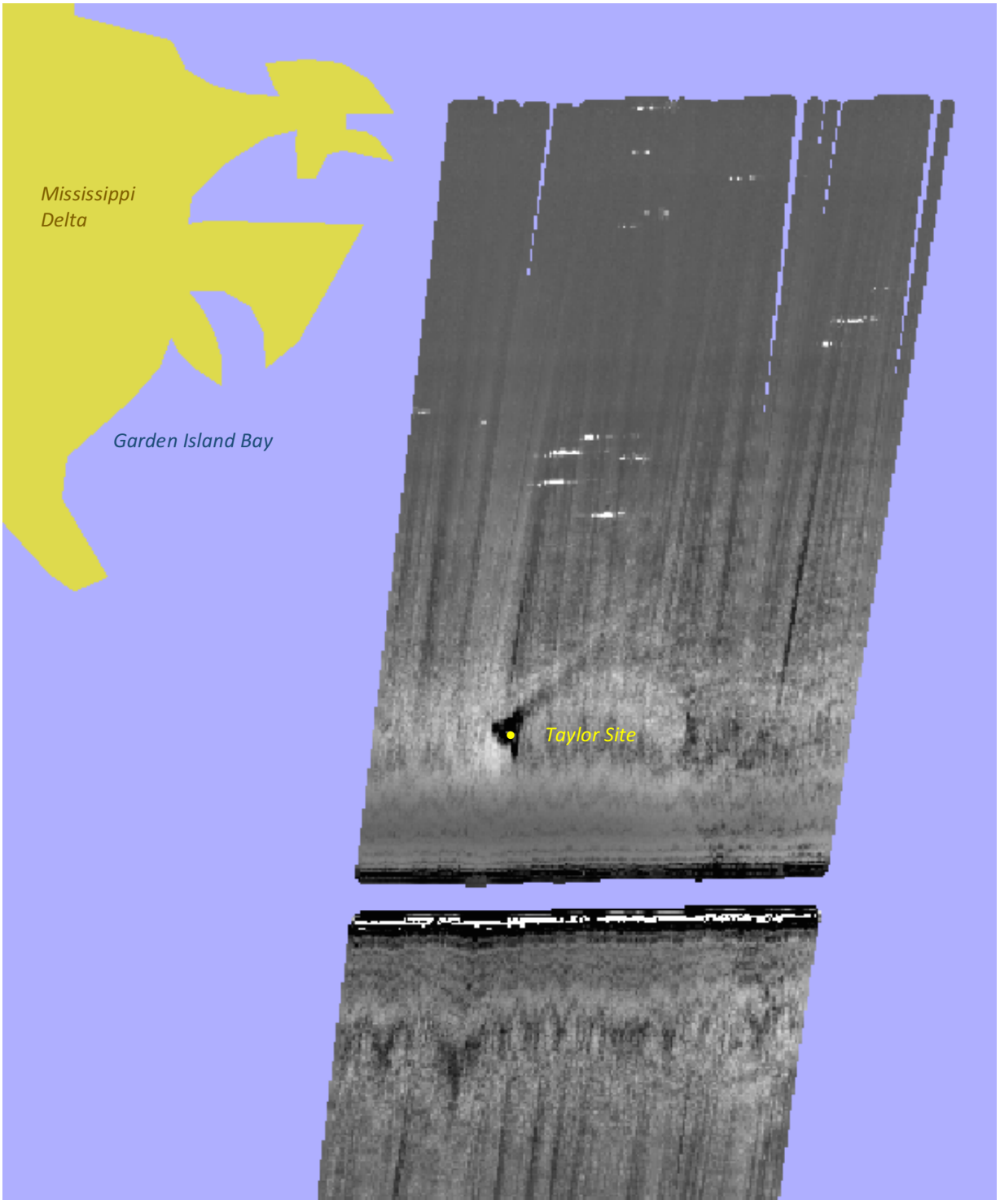


Fig.4 - SLAR georeferenced image

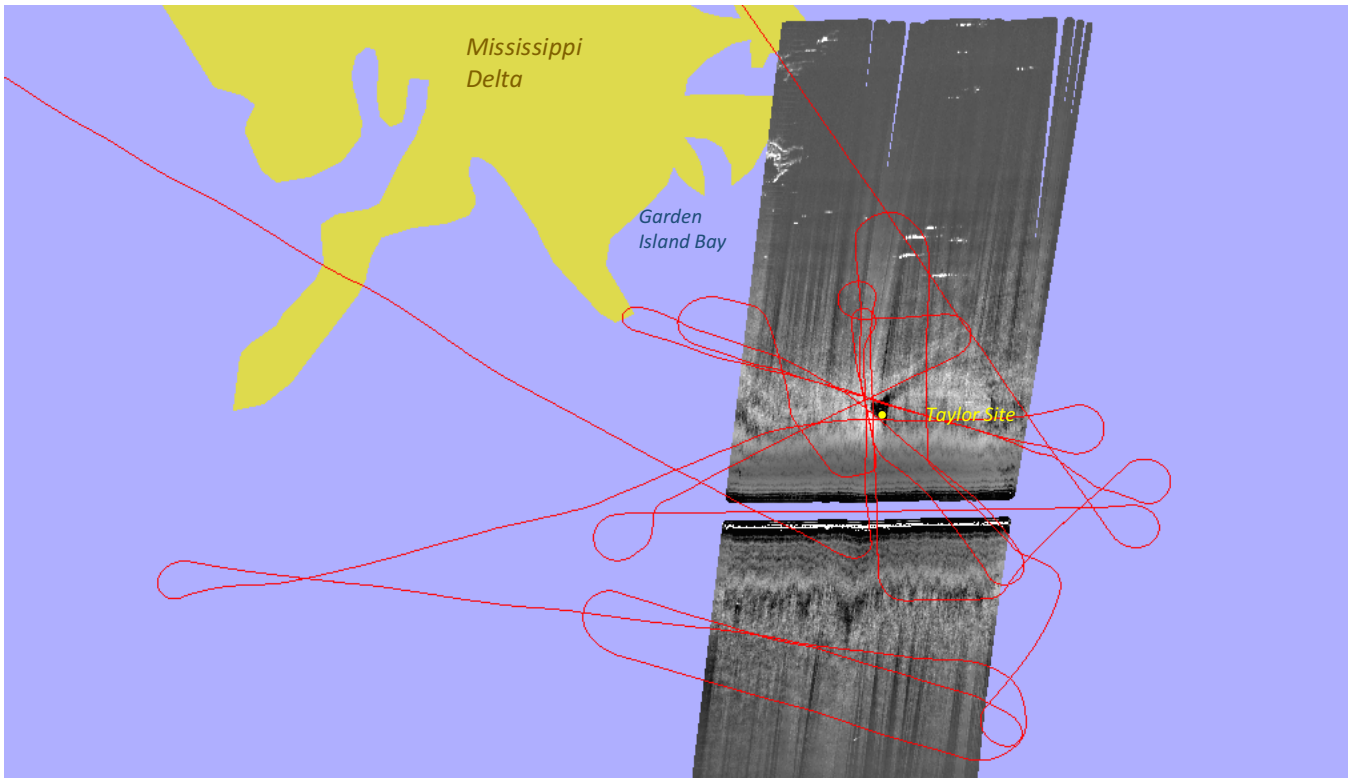


Fig.5 - SLAR georeferenced image with flight track.

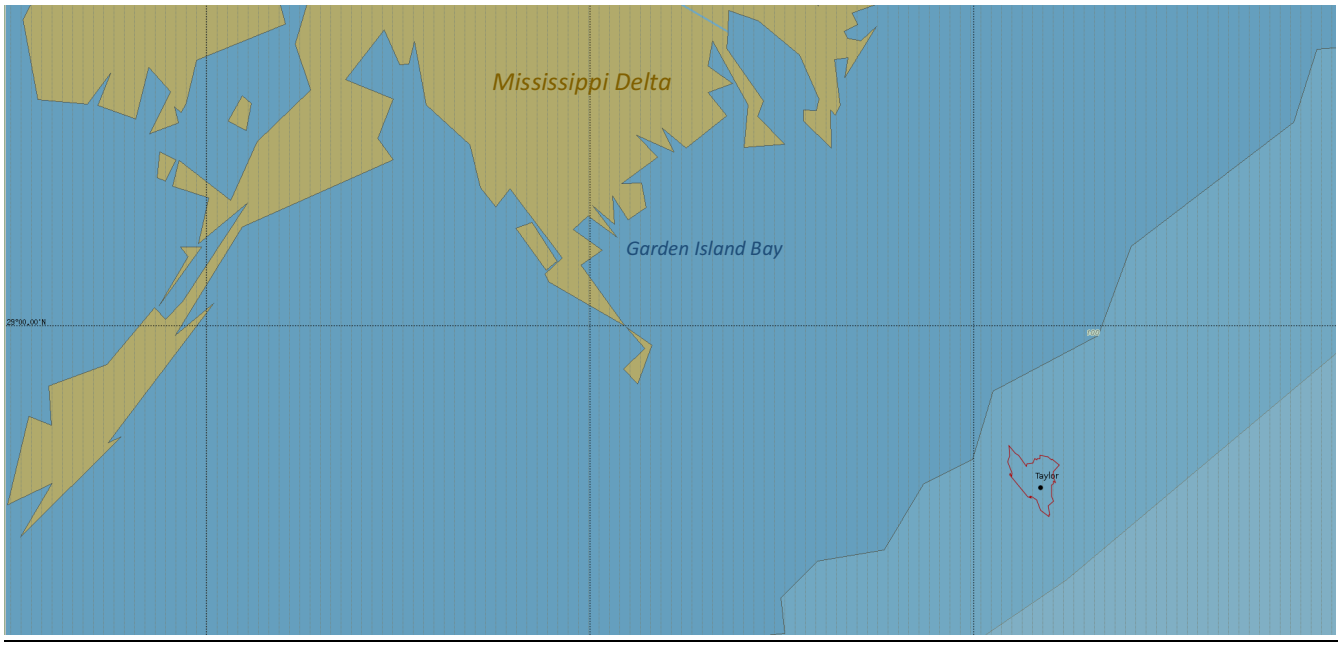


Fig.6 Position of the detected slick on the Navigation Map

After the detection, localization and georeferencing of the target Poseidon started the approach to the spill to perform the near range analysis. During the approach a video was recorded by the EO/IR sensor (Video files are attached to the Report), the slick showed a match with the SLAR image. The slick had an appearance sheen to metallic, with the direction along the prevalent wind (Fig.7).

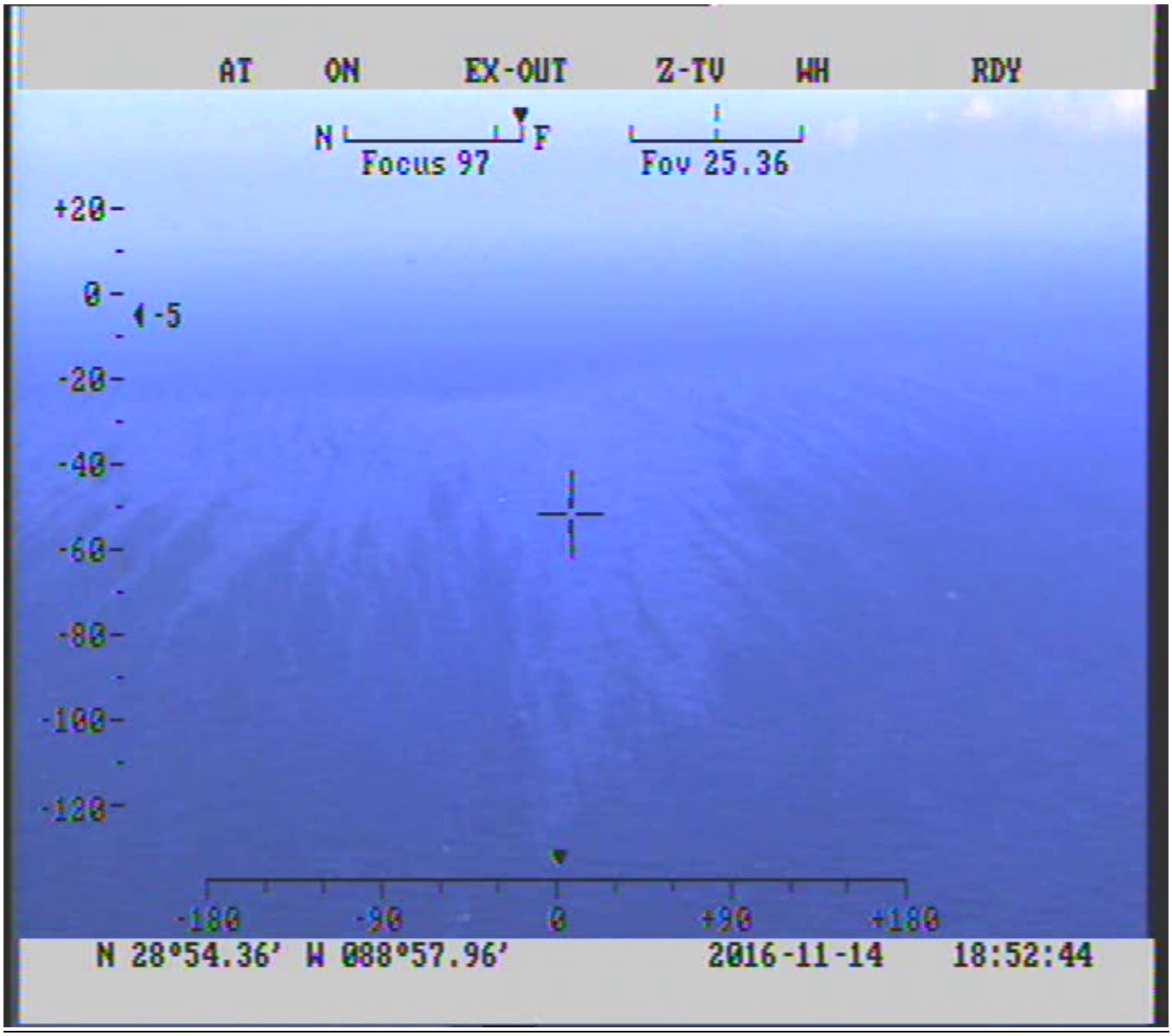


Fig.7 – Image from the EO/IR video SLAR footage.

Step#2: spill approach and Near Range Analysis.

At an altitude of 1,000ft Poseidon was directed over the slick to overfly it and analyze the slick features with the near range sensors in several determined points. Purpose of the Near Range analysis is to confirm the nature of the spill, oil or other substances, evaluate and map the thickness to estimate the volume, and determine the hot spots, areas where the oil is concentrated.

Fig.8 below shows the zones where the targets were set to perform the analysis.

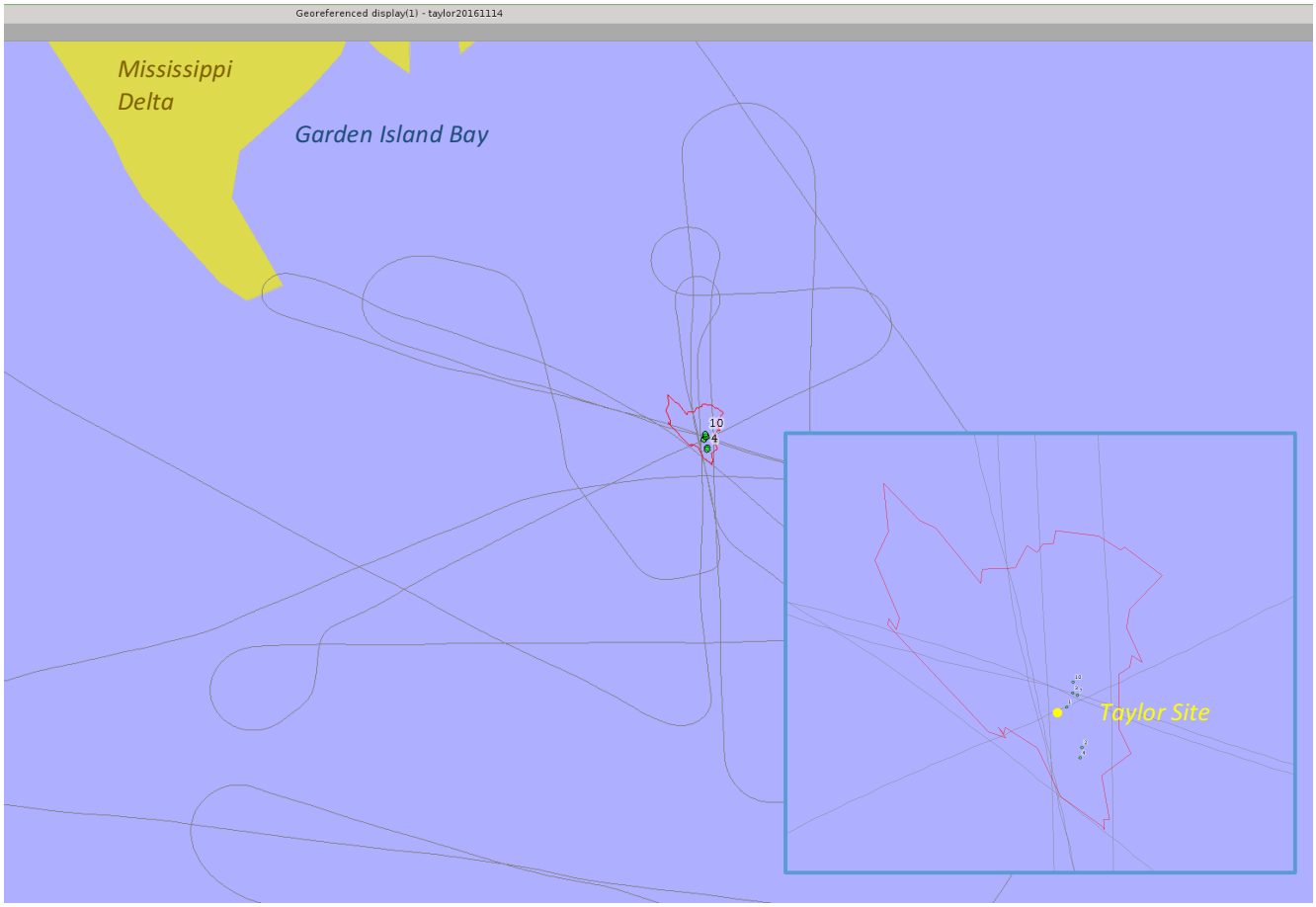


Fig.8 – Georeferenced Near Range Targets for Spill Analysis.

Fig.9 below shows the 'waterfall' images taken from the sensors, including IR, UV, VIS, MWR over Target#1. In the 'waterfall' display the length of the image is about 1.1 NM at 180 KT of cruise speed and the width is equivalent to the swath of the sensor, about 2,000 ft.

The response in the IR and UV bands was decisive to qualify mineral oil. The MWR response, suggested that the slick was very thin, less than 50µm, the IR showed an area of high relative thickness. VIS showed the appearance of the slick as a sheen.

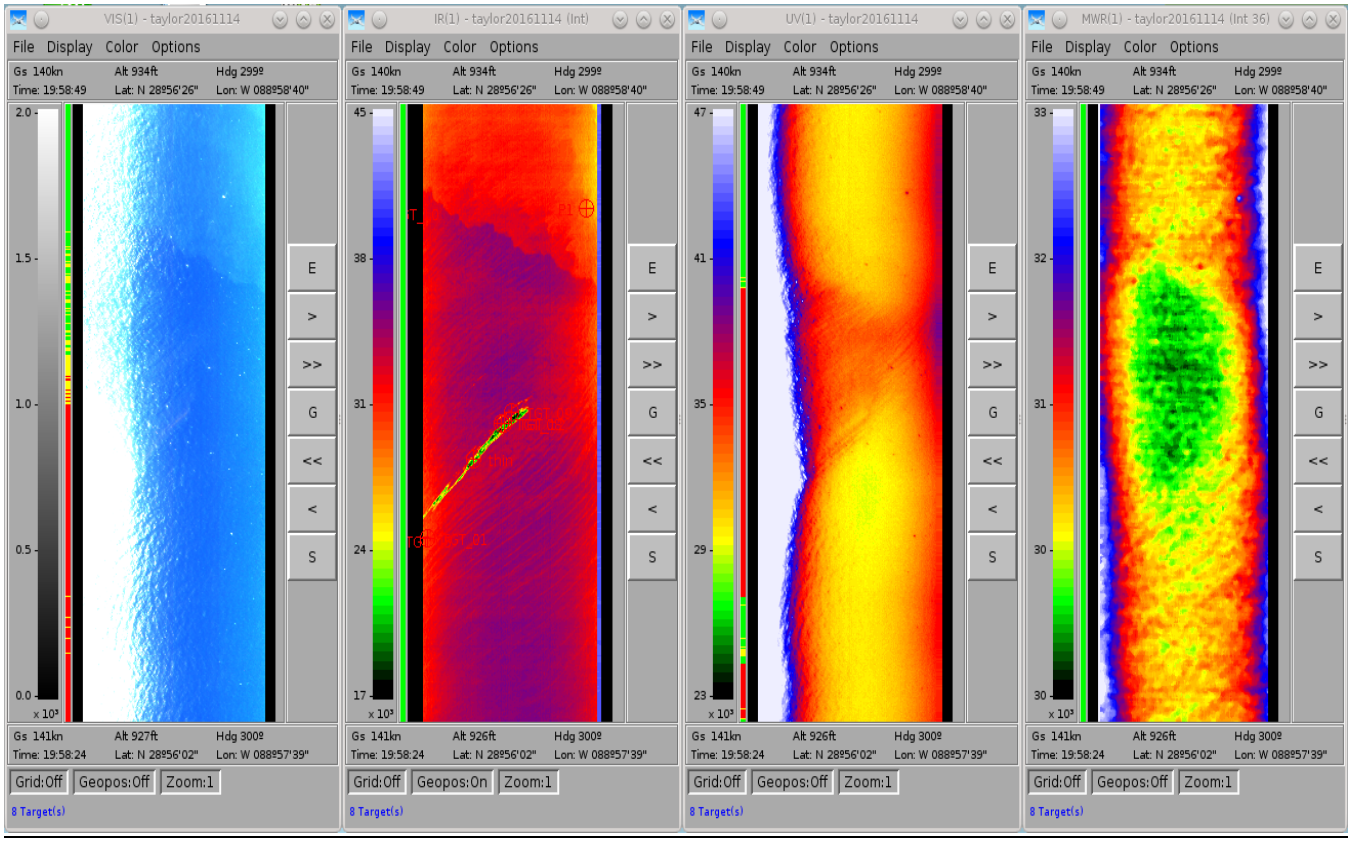


Fig.9 – Target#1 VIS, IR, UV, MWR images.

Near Range images can be georeferenced, and a 'mosaic' composition of the scene can be made if it is of interest. Fig.10 below show an example of georeferenced IR images.

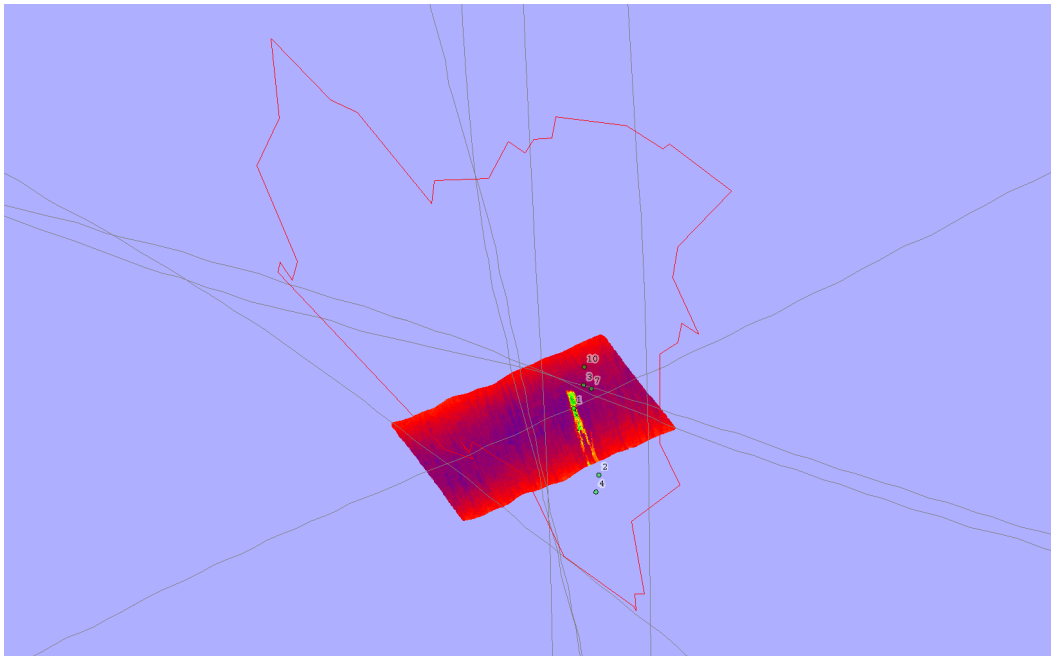


Fig.10 – Target#1 IR georeferenced image.

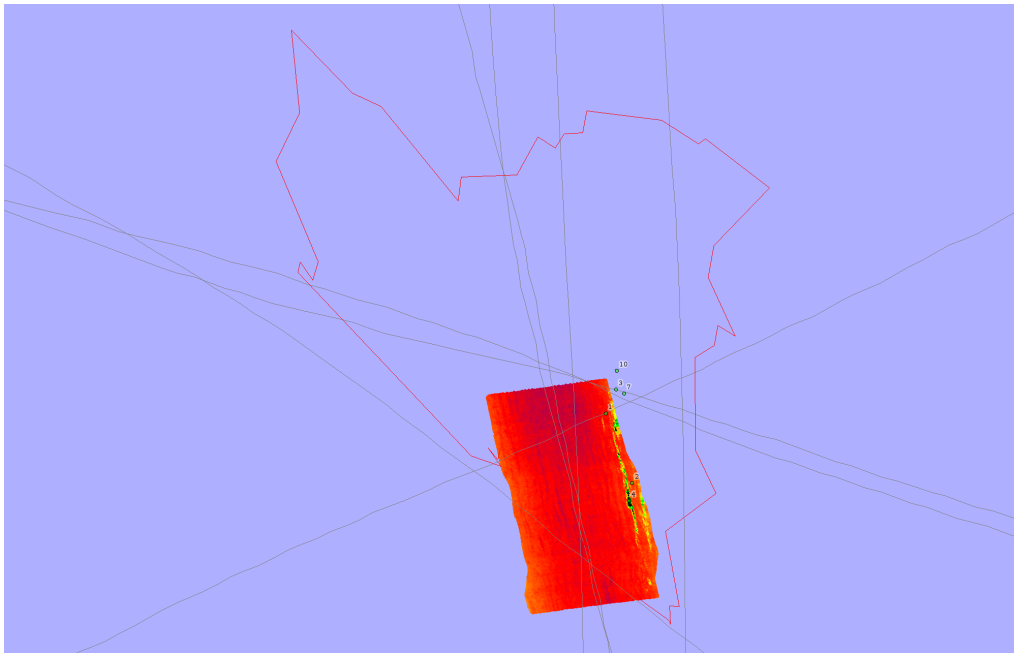


Fig.11 – Target#4 IR georeferenced image.

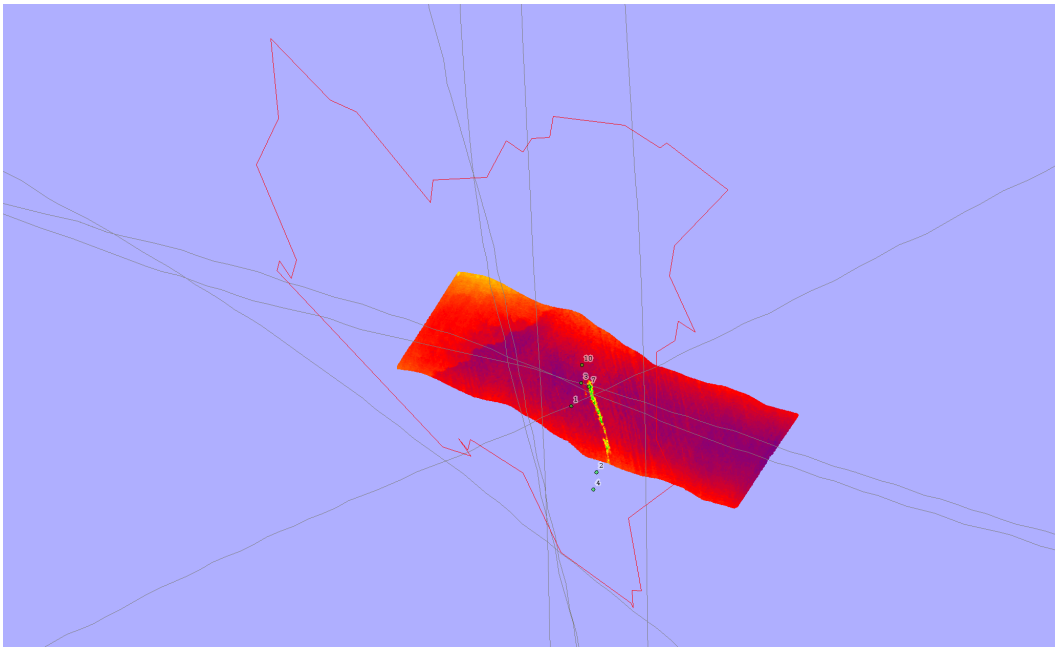


Fig.12 – Target#7 IR georeferenced image.

Conclusion: during Mission#1 Poseidon successfully located the slick and defined the synoptic characteristics with the SLAR, creating also a navigation reference for the successive low altitude passes. During the low altitude passes the near range sensors gave positive confirmation of the nature of the slick and determined relative thickness distribution and hot spot localization. Operators were able to analyze the spill scene during the flight in real time determining information as area, dimension, center coordinate, defining georeferenced targets and imageries. Files generated during the mission were sent via MBR microwave antenna to ground to test the antenna and data communication performances. Results were successful.

3.5.2 Mission#2 – November 15th Collections

In the morning of November 15th EMB-110 Poseidon left Houma-Terrebonne airport at 6:30AM heading New Orleans Lakefront airport (KNEW) to pick up Mr. Gordon Staples (MDA) as a passenger for the flight as requested by NOAA.

The actual mission started at 07:18 CST. During the flight about 50NM SE of Lakefront the SLAR detected a strong structure that was immediately investigated and classified as an oil spill. The detection was communicated promptly to USCG.

As the previous mission, Poseidon approached the Taylor area with a SE track at 3,000 ft and about 185KT of cruise speed.

Step#1 - Synoptic Overview: the SLAR detected a structure with strongly reduced backscatter that was identified as a surface target. The structure was different from the previous day, with a predominant N-S direction, determined possibly by the wind/current configuration. The area was delimited by a polygon of approximately 0.66x2.37NM with a coverage of 58% and a resultant area of the surface target of 0.89 square nautical miles. Polygon was centered on the following coordinates: N 28°56'38" W 088°56'48". The following figures show the SLAR images, the georeferenced polygon and the resultant SLAR georeferenced image with and without flight track (Fig.13 to Fig.16).

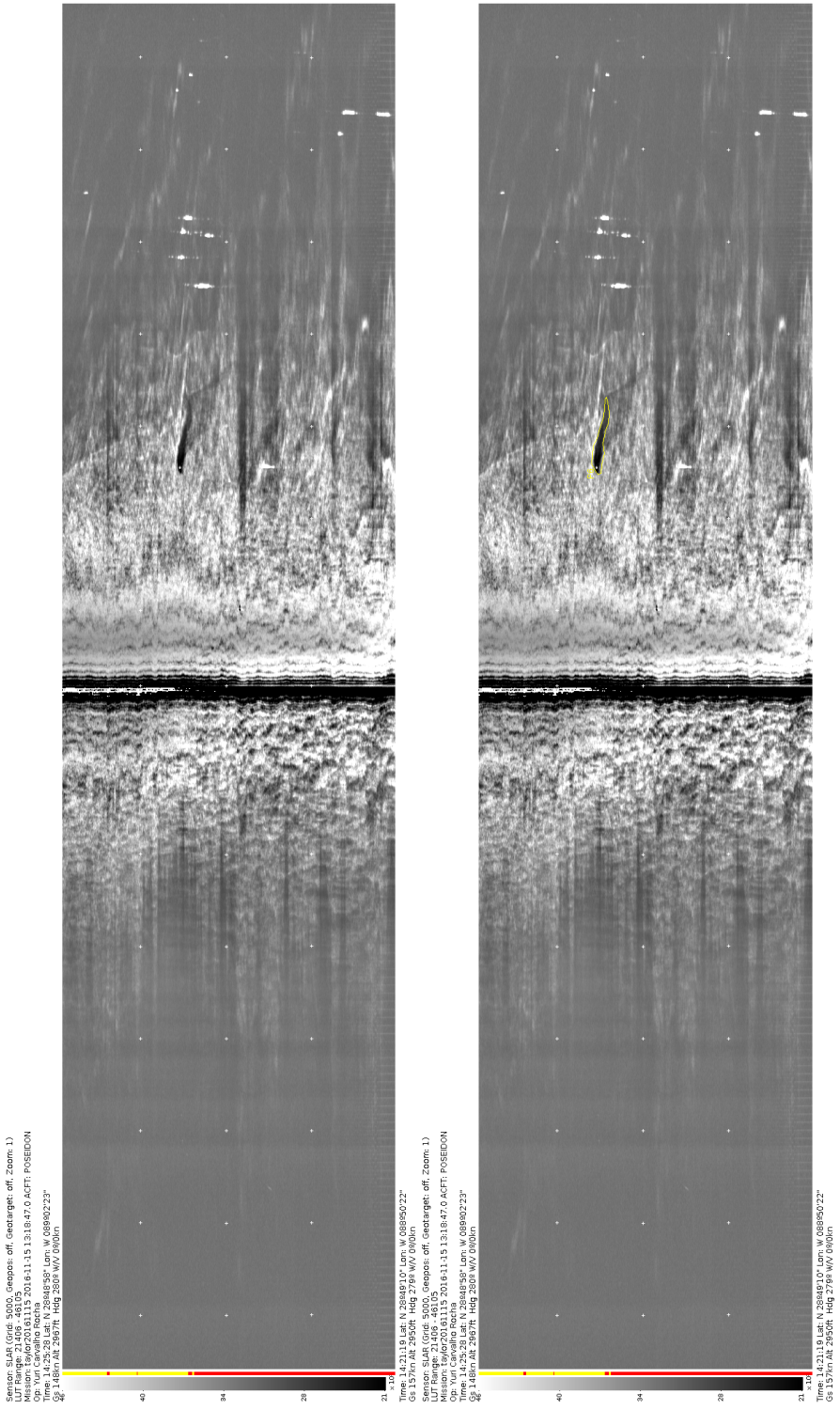


Fig.13 - SLAR images of the spill: E to W approach

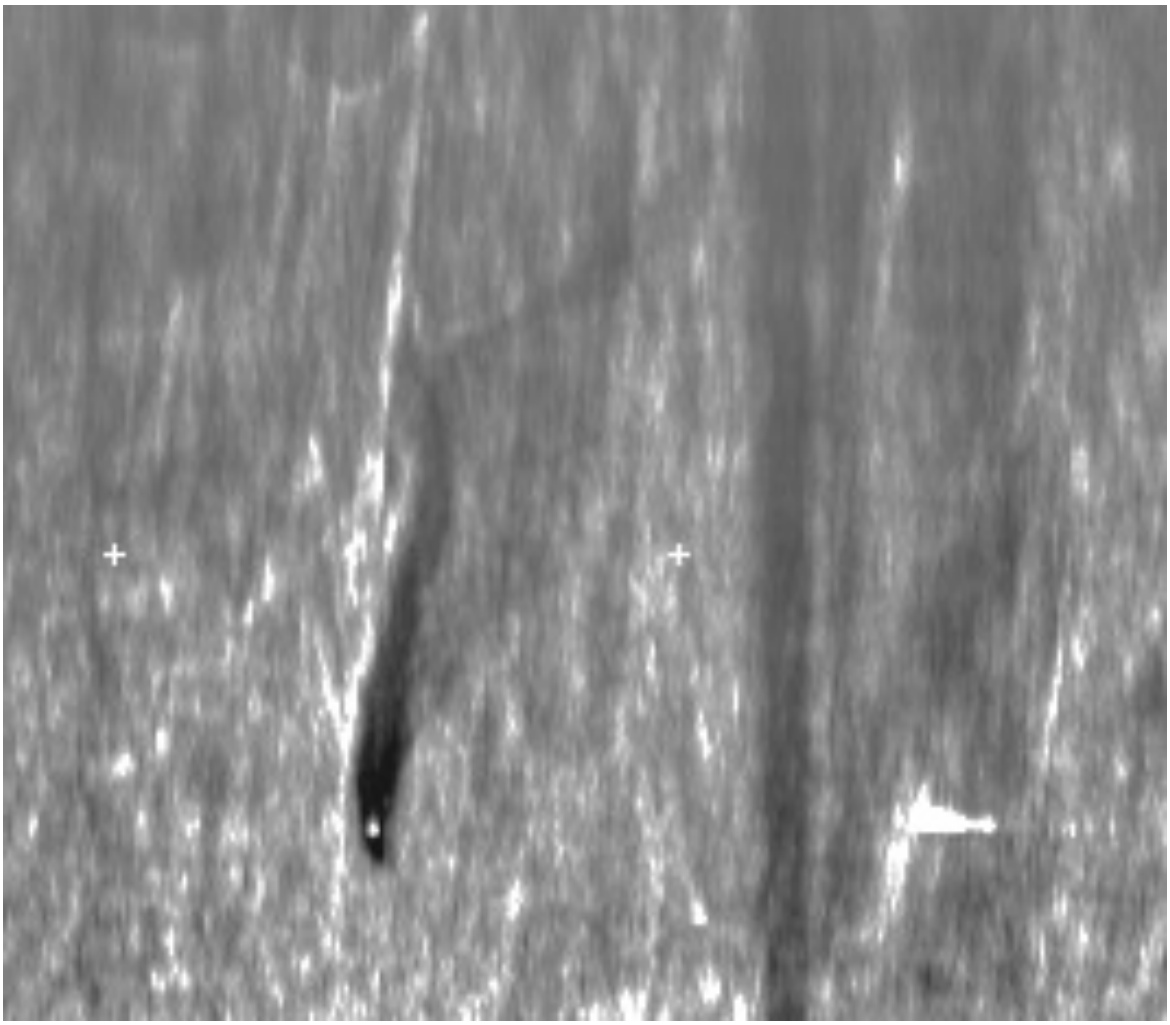


Fig.14 - SLAR image of the spill

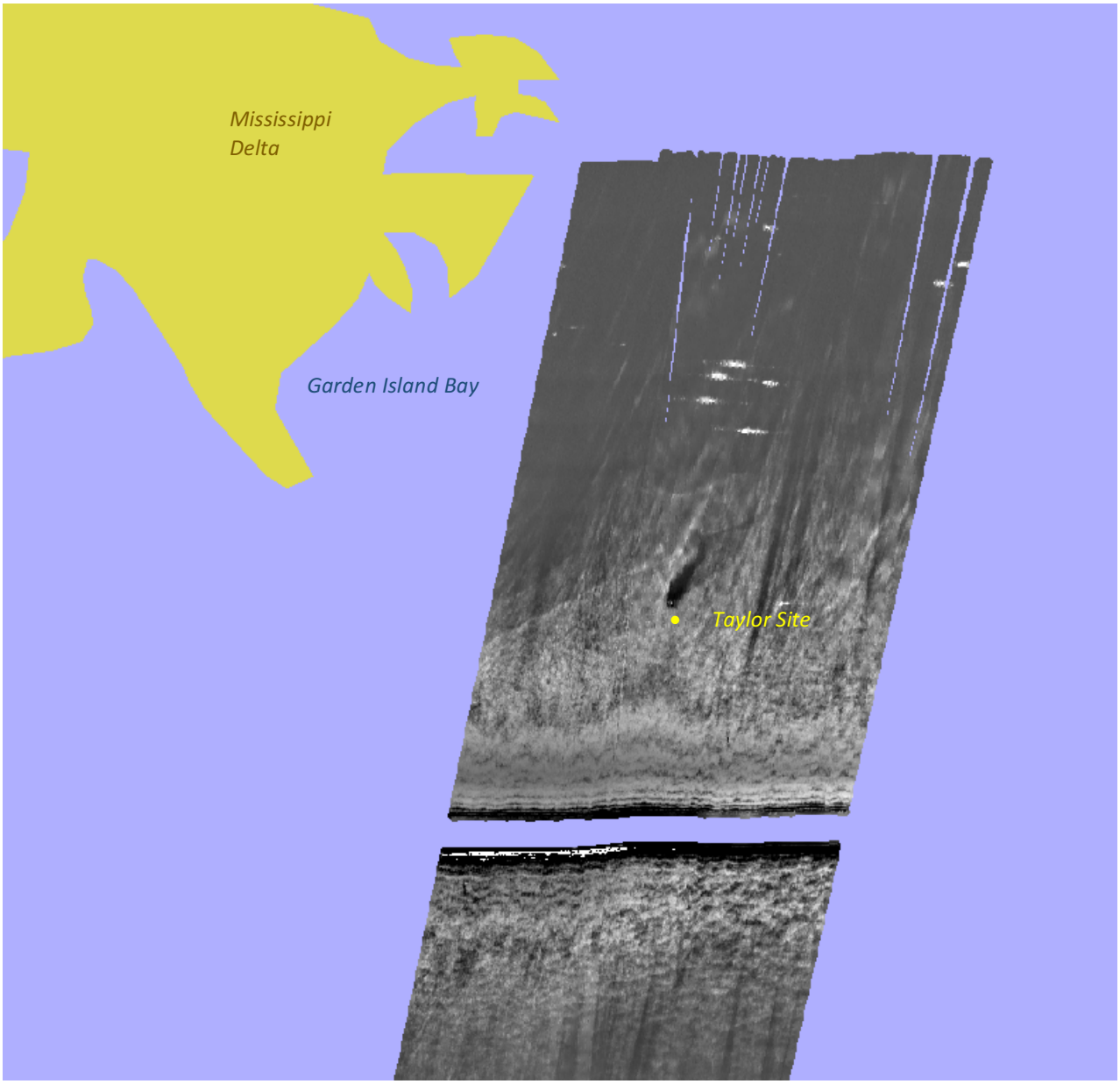


Fig.15 - SLAR georeferenced image

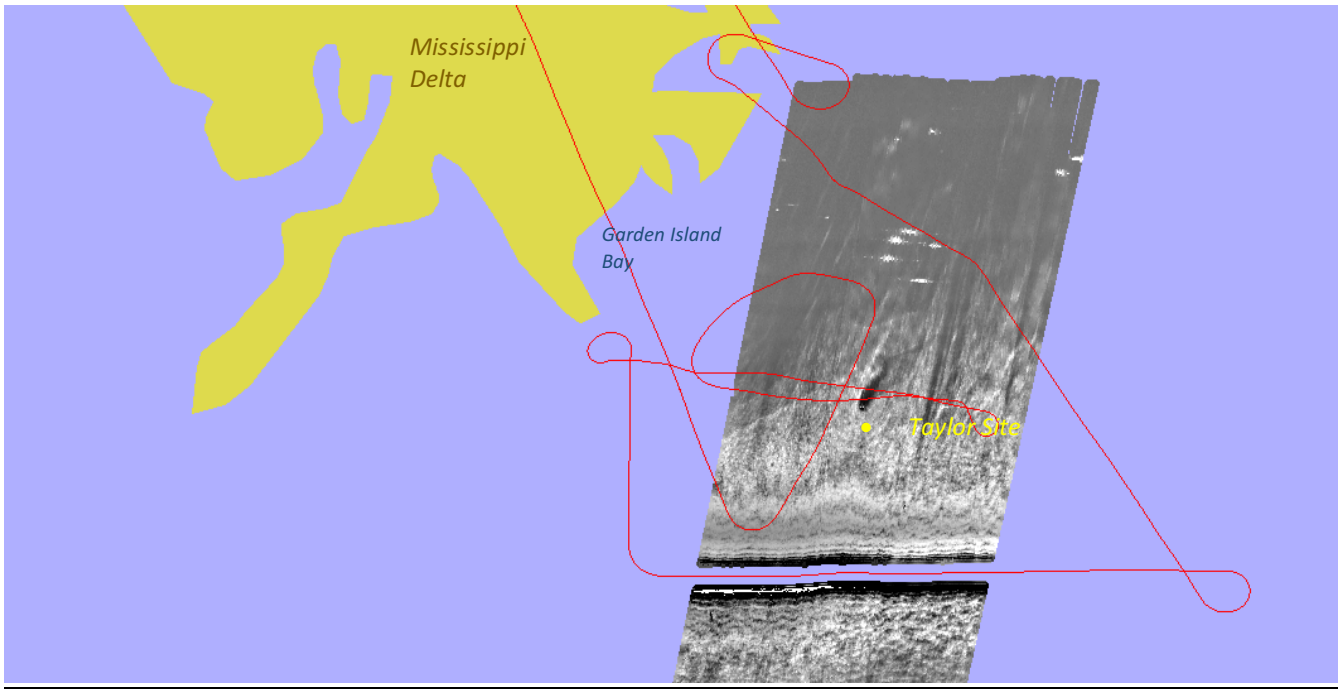


Fig.16 - SLAR georeferenced image with flight track.



Fig.17 Position of the detected slick on the Navigation Map

After the detection, localization and georeferencing of the target, Poseidon started the approach to the spill to perform the near range analysis. During the approach a video was recorded by the EO/IR sensor (Video files are attached to the Report), the slick showed a match with the SLAR image. The slick had an appearance sheen to metallic, and positioned along the N – S direction. IR image confirms the nature of the spill (Fig.18).

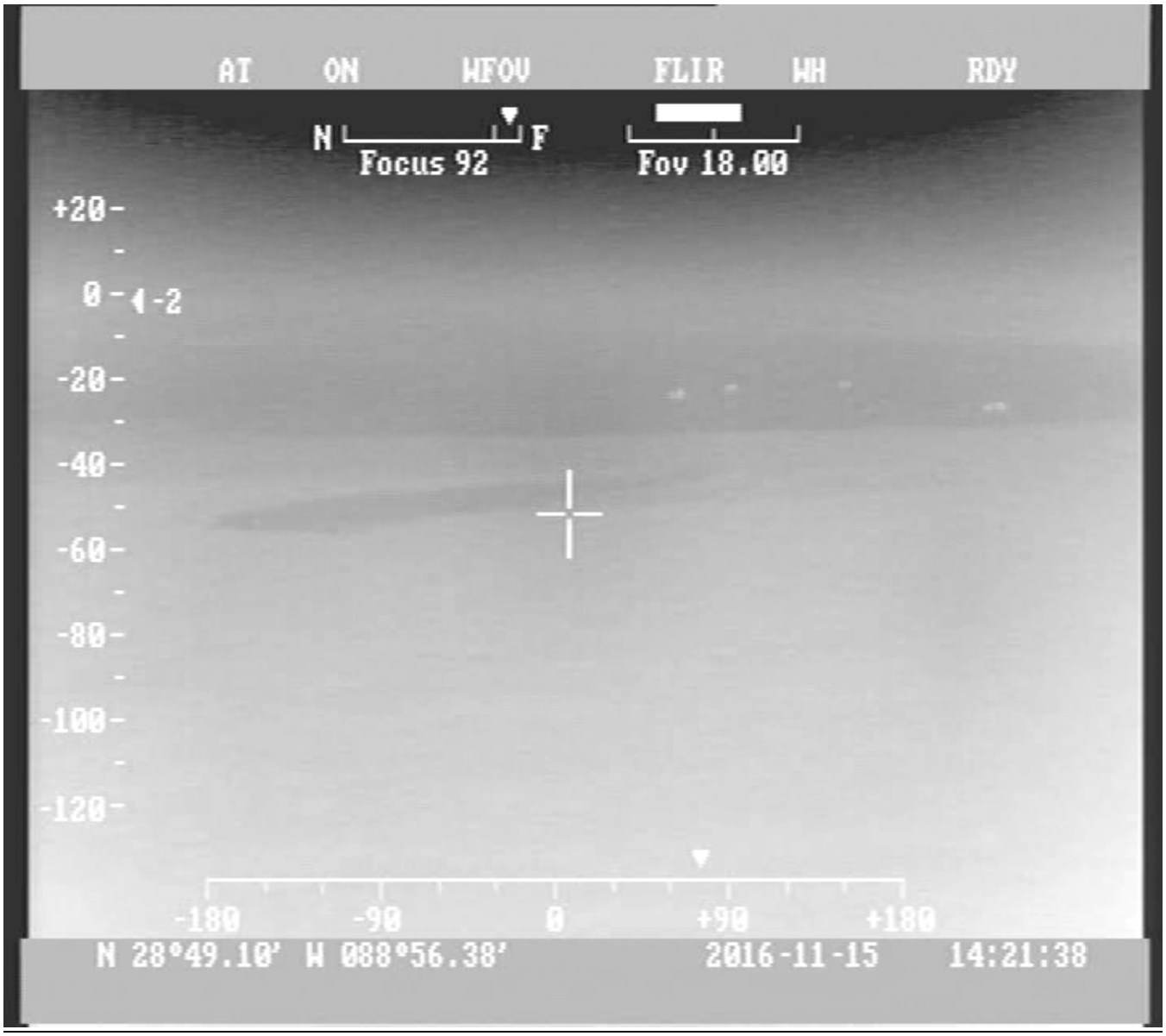


Fig.18 – IR image from the EO/IR video SLAR footage.

Step#2: spill approach and Near Range Analysis.

At an altitude of 1,000ft Poseidon was directed over the slick to overfly it and analyze the slick features with the near range sensors in several determined points. Purpose of the Near Range analysis is to confirm the nature of the spill, oil or other substances, evaluate and map the thickness to estimate the volume, and determine the hot spots, areas where the oil is concentrated.

Fig.19 below shows the zones where the targets were set to perform the analysis.

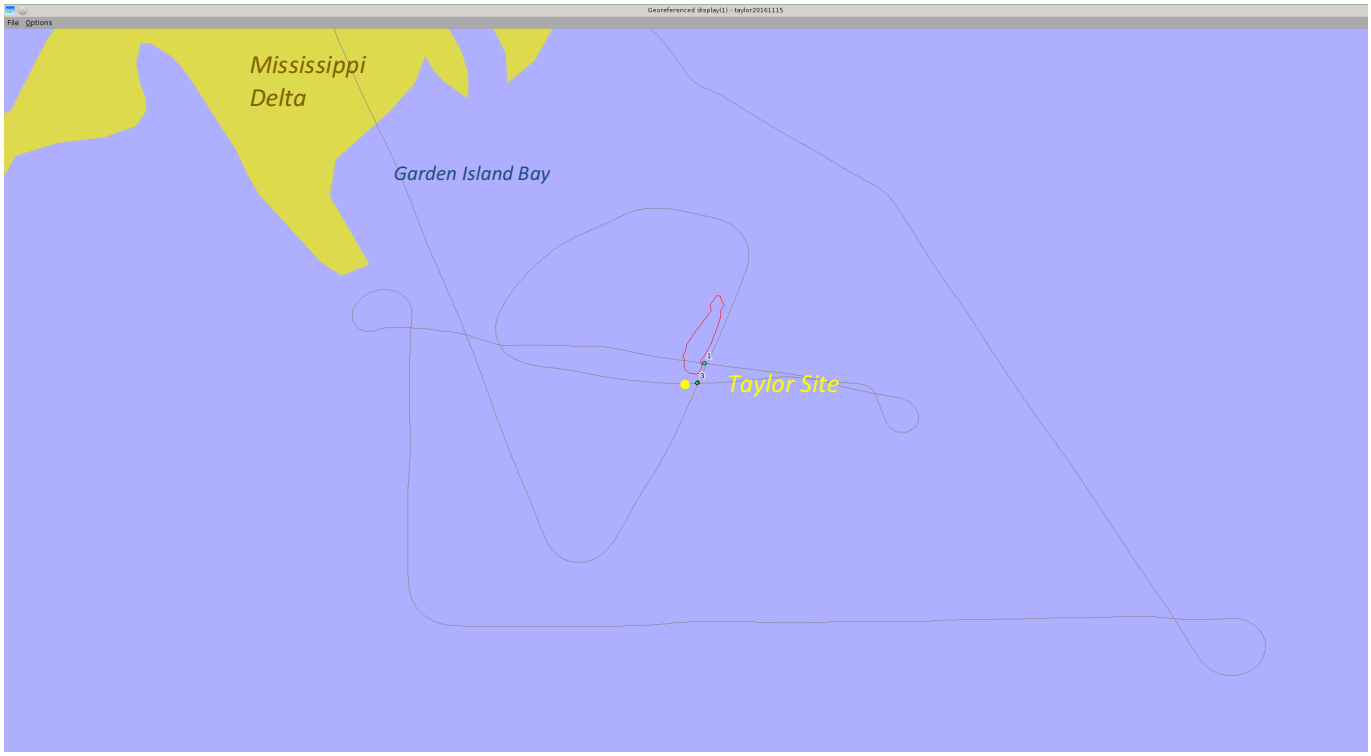


Fig.19 – Georeferenced Near Range Targets for Spill Analysis.

Fig.20 below shows the 'waterfall' images taken from the sensors, including IR, UV, VIS, MWR over Target#1. In the 'waterfall' display the length of the image is about 1.1 NM at 180 KT of cruise speed and the width is equivalent to the swath of the sensor, about 2,000 ft.

The response in the IR and UV bands was decisive to qualify mineral oil. The MWR response, suggested that the slick was very thin, less than 50µm, the IR showed an area of high relative thickness. VIS showed

the appearance of the slick as a sheen. The LFS characterized the composition of the spill as oil classified as Medium Crude with a thickness in that particular location of 6.9 µm.

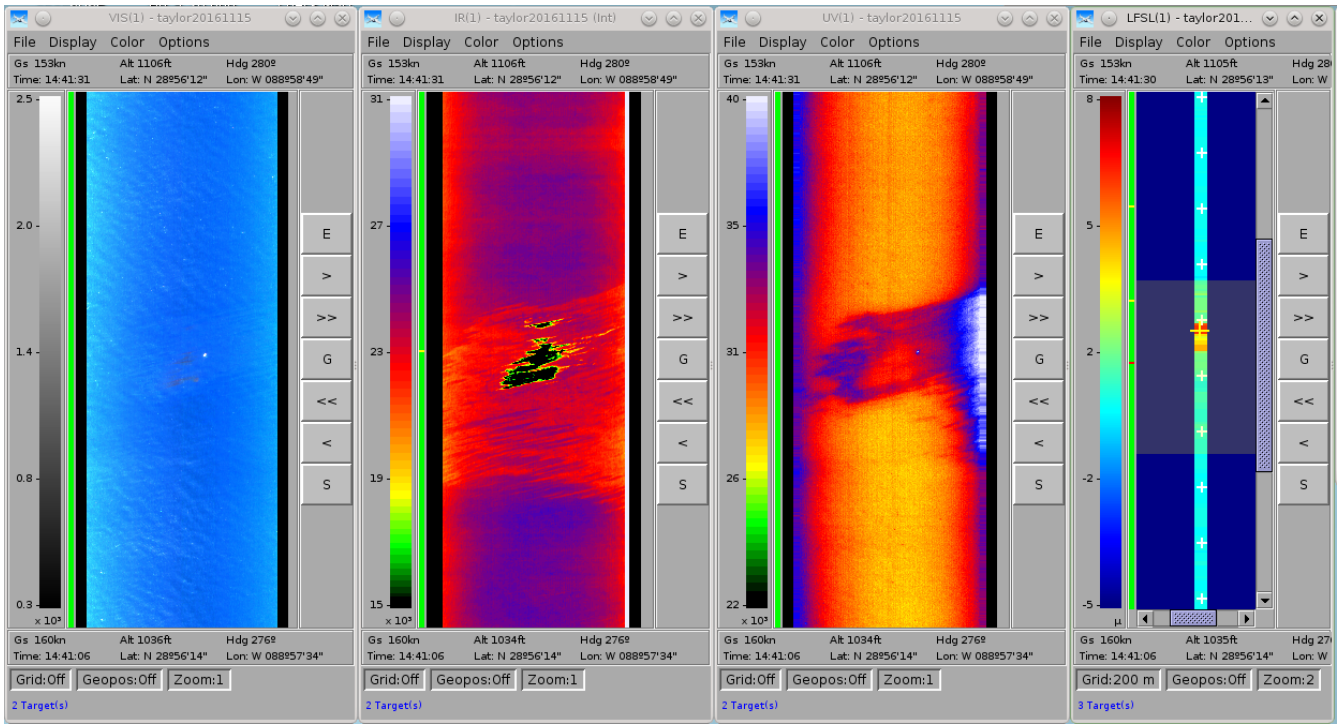


Fig.20 – Target#1 VIS, IR, UV, LFS images.

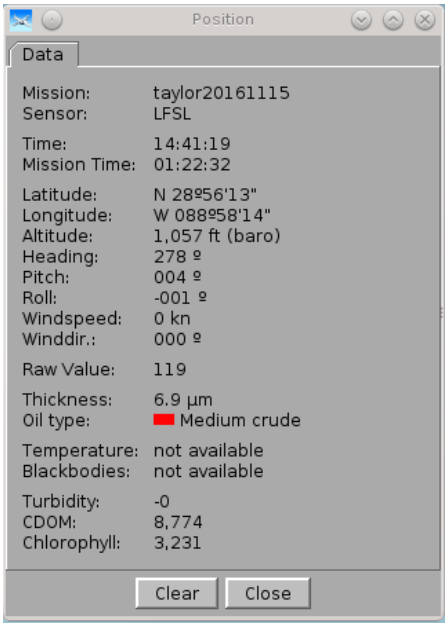


Fig.21 – Target#1 LFS information.

Near Range images can be georeferenced, and a 'mosaic' composition of the scene can be made if it is of interest. Fig.22 below shows an example of georeferenced IR images.

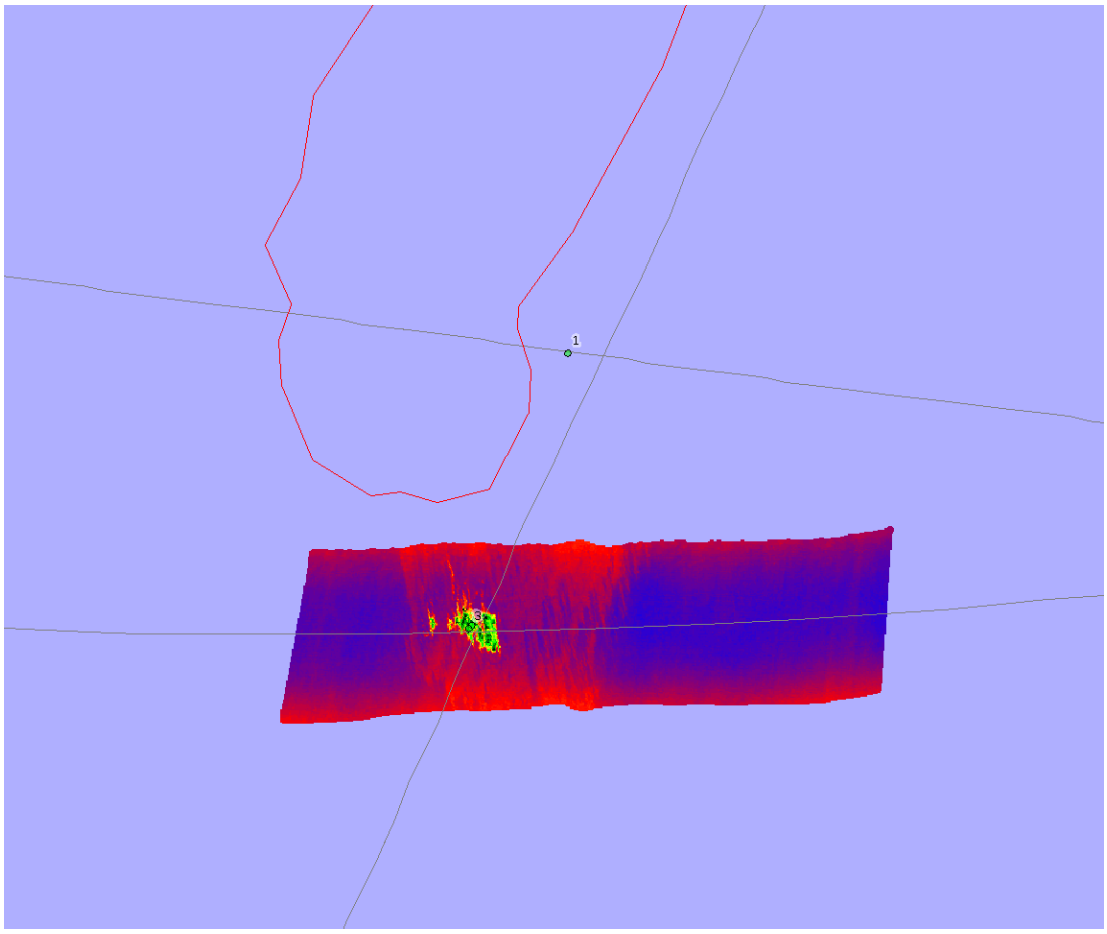


Fig.22 – Target#1 IR georeferenced image.

Conclusion: during Mission#2 Poseidon successfully located the slick and defined the synoptic characteristics with the SLAR, creating also a navigation reference for the successive low altitude passes. During the low altitude passes the near range sensors gave positive confirmation of the nature of the slick and determined type of oil, thickness, relative thickness distribution and hot spot localization. Operators were able to analyze the spill scene during the flight in real time determining information as area, dimension, center coordinate, defining georeferenced targets and imageries. Files generated during the mission were sent via MBR microwave antenna to ground to test the antenna and data communication performances. Results were successful.

3.5.3 Mission#3 – November 16th Collections

In the morning of November 16th EMB-110 Poseidon left Houma-Terrebonne airport at 11:10AM. The actual mission started at 11:13 CST. As the previous two missions, Poseidon approached the Taylor area with a SE track at 3,000 ft and about 185KT of cruise speed.

Step#1 - Synoptic Overview: the SLAR promptly detected a structure with strongly reduced backscatter that was identified as a surface target. The structure was different from the previous days; it was significantly spread, still with a predominant N-S direction, determined by the wind/current configuration. The area was delimited by a polygon of approximately 3.026x3.320 NM with a coverage of 36% and a resultant area of the surface target of 3.6 square nautical miles, almost 4 times the area measured in the previous two days. Polygon was centered on the following coordinates: N 28°55'17" W 088°56'36". The following figures show the SLAR images, the georeferenced polygon and the resultant SLAR georeferenced image with and without flight track (Fig.23 to Fig.27).

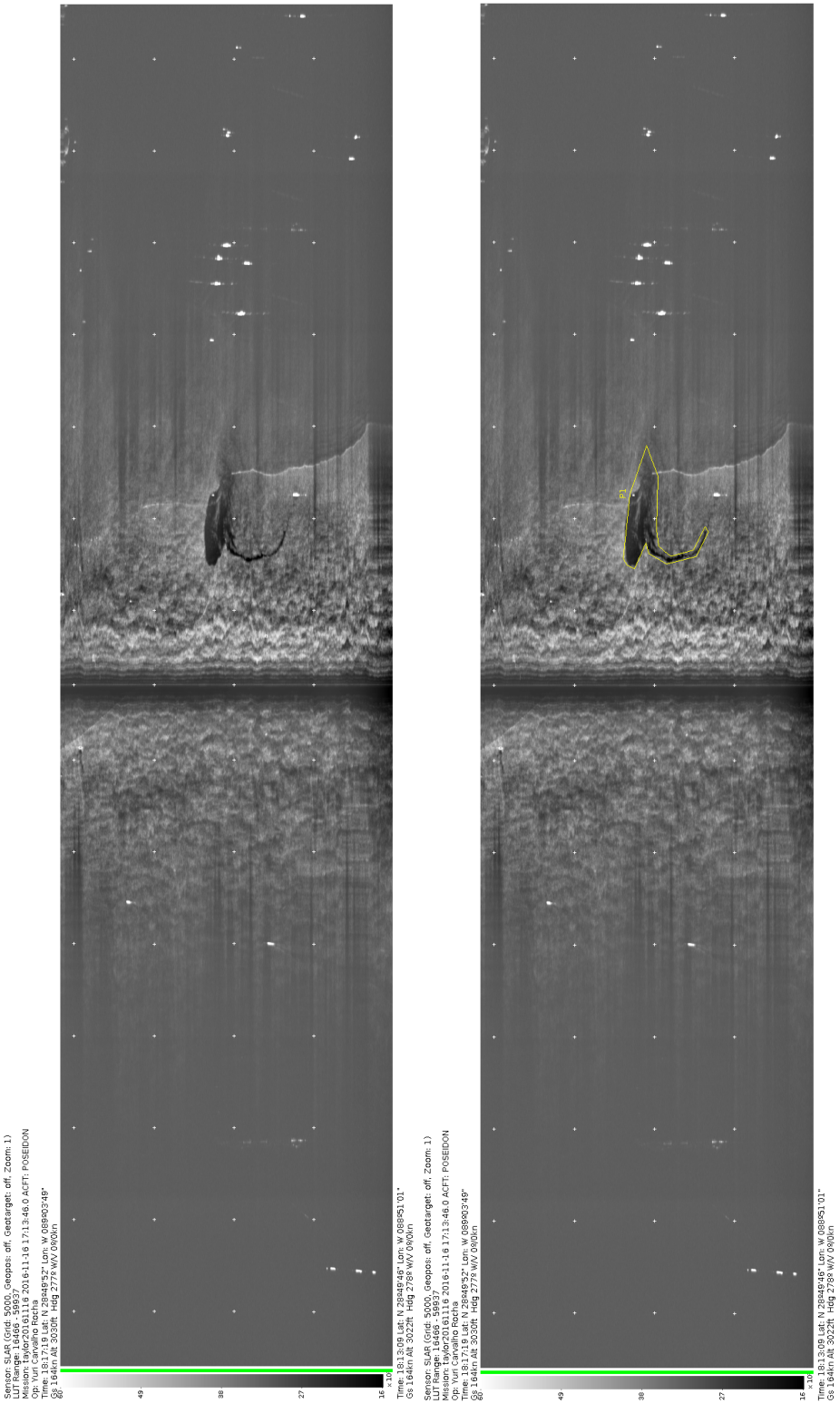


Fig.23 - SLAR images of the spill: E to W approach

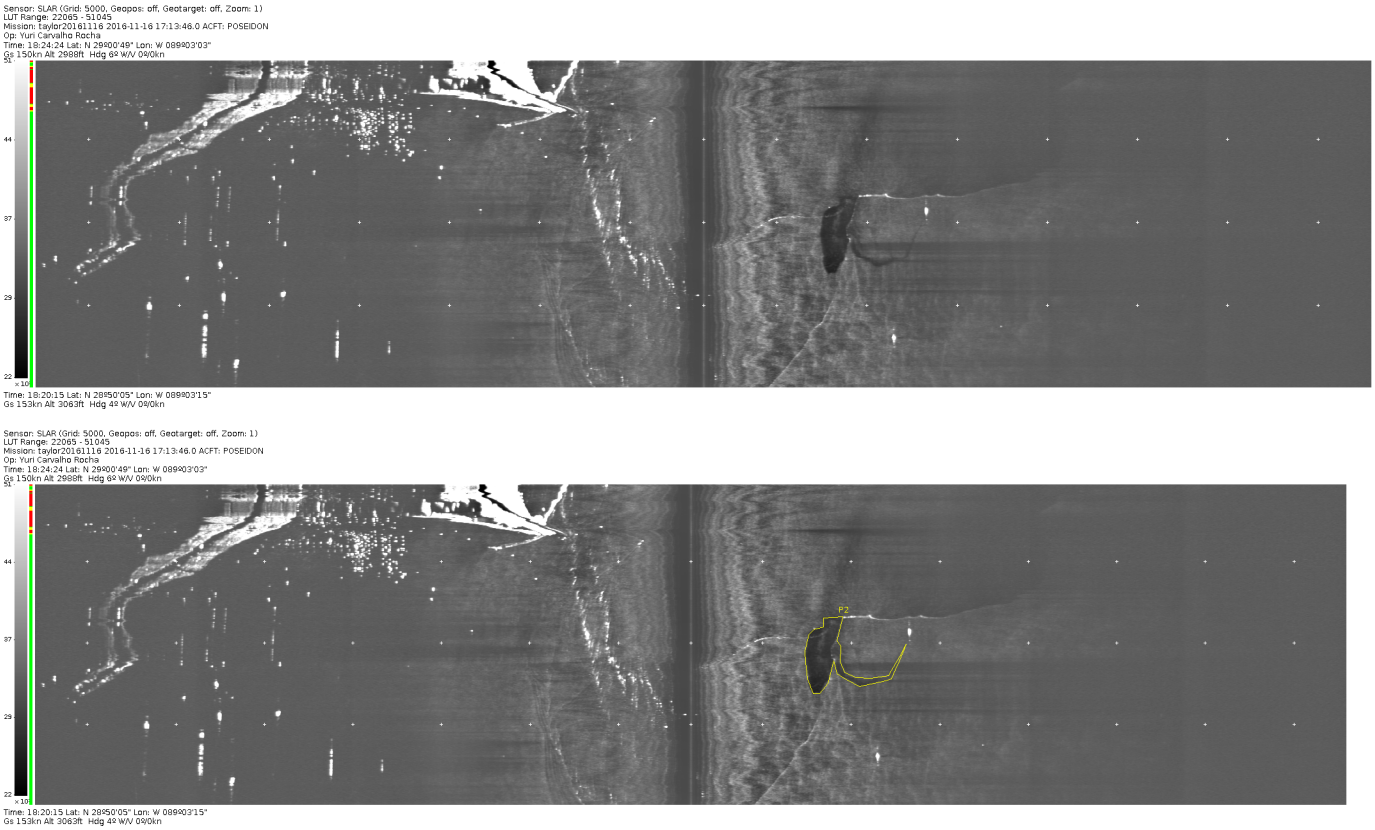


Fig.24 - SLAR images of the spill: S to N approach

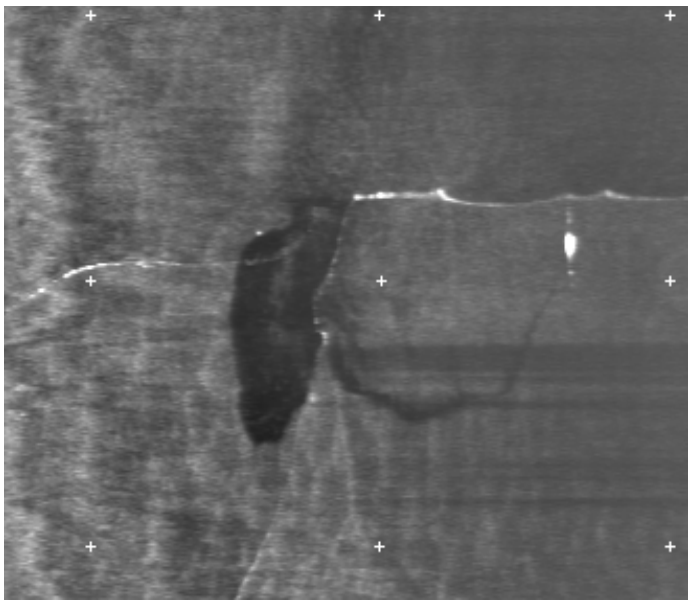


Fig.25 - SLAR image of the spill

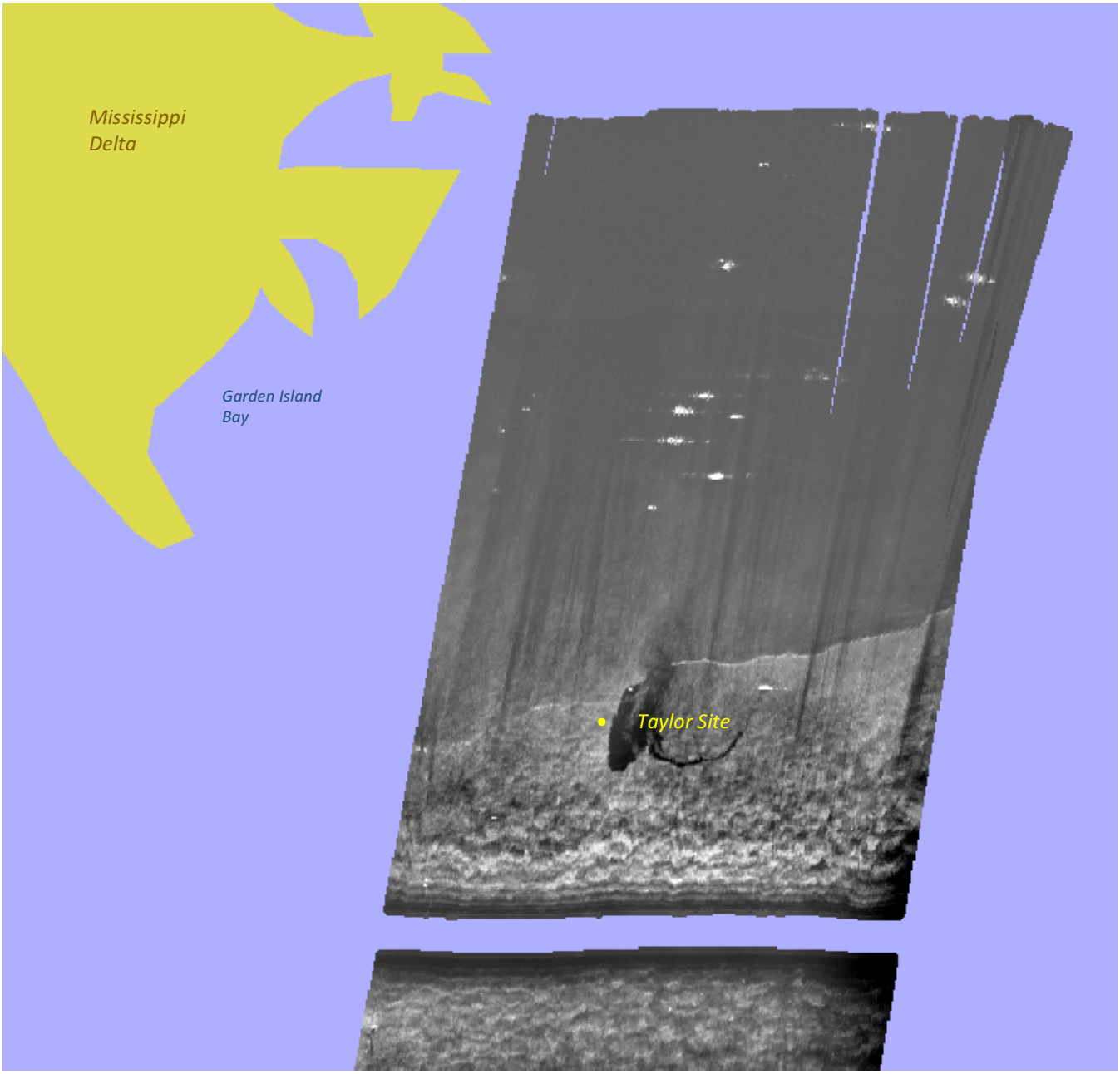


Fig.26 - SLAR georeferenced image

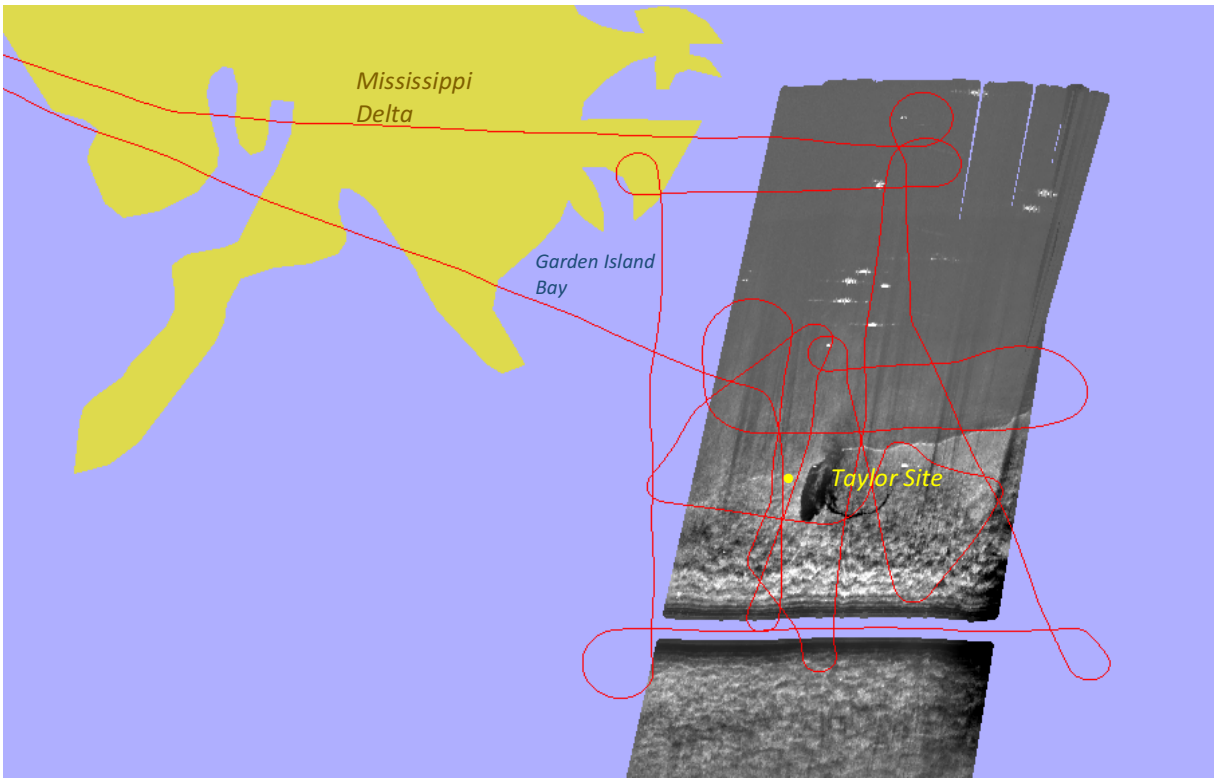


Fig.27 - SLAR georeferenced image with flight track.

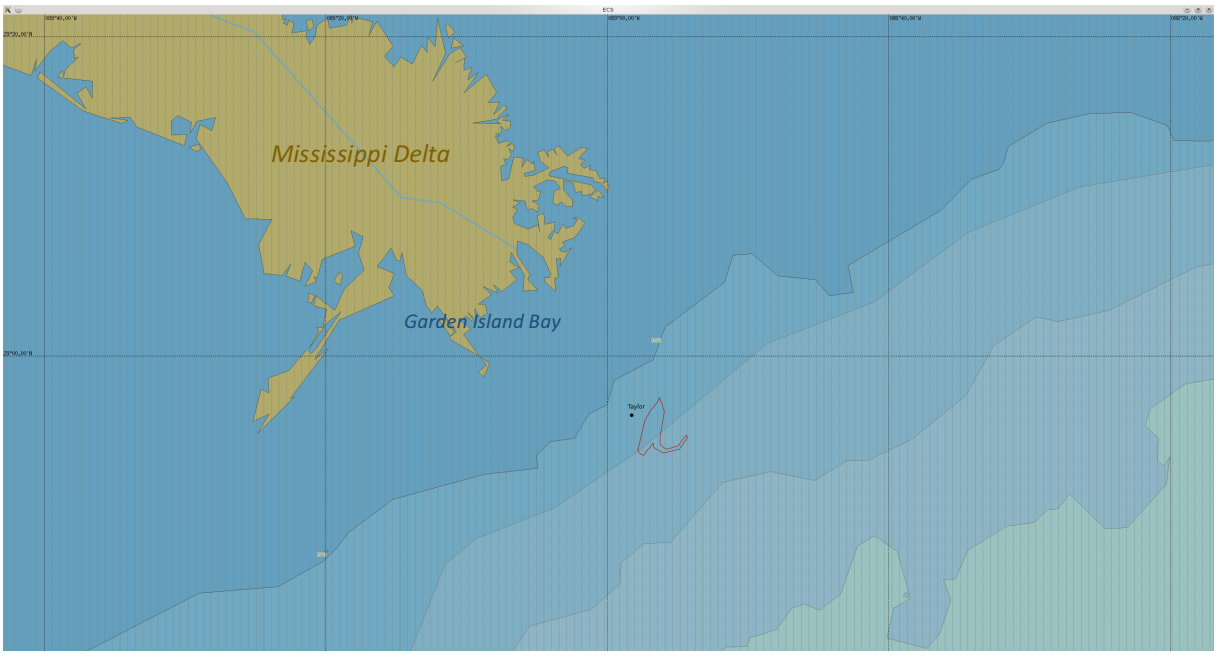


Fig.28 Position of the detected slick on the Navigation Map

After the detection, localization and georeferencing of the target Poseidon started the approach to the spill to perform the near range analysis. During the approach a video was recorded by the EO/IR sensor (Video files are attached to the Report), the slick showed a match with the SLAR image. The slick had an appearance sheen to metallic, and positioned along the N – S direction (Fig.29).

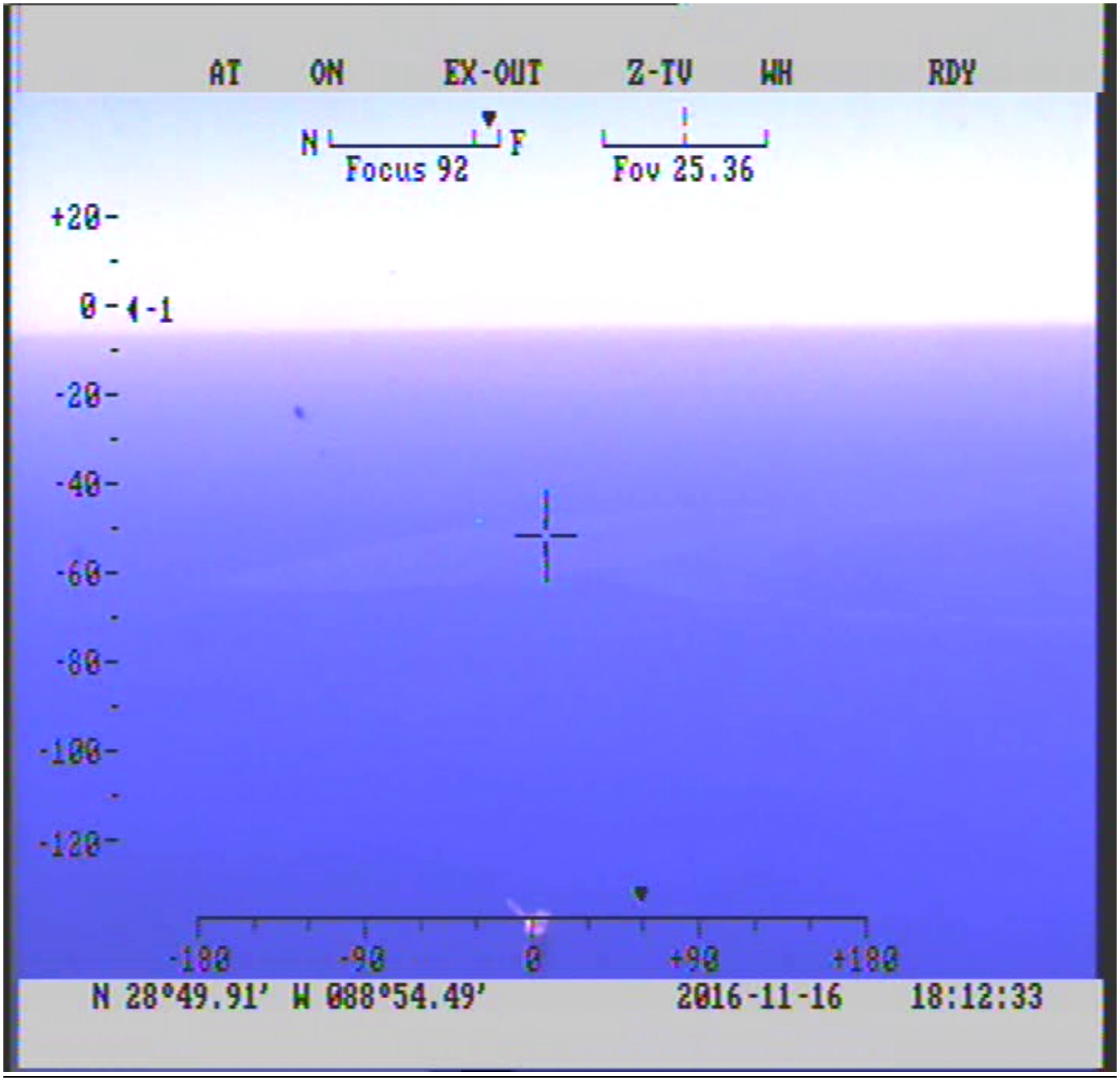


Fig.29 – Image from the EO/IR video SLAR footage.

Step#2: spill approach and Near Range Analysis.

At an altitude of 1,000ft Poseidon was directed over the slick to overfly it and analyze the slick features with the near range sensors in several determined points. Purpose of the Near Range analysis is to confirm the nature of the spill, oil or other substances, evaluate and map the thickness to estimate the volume, and determine the hot spots, areas where the oil is concentrated.

Fig.30 below shows the zones where the targets were set to perform the analysis.

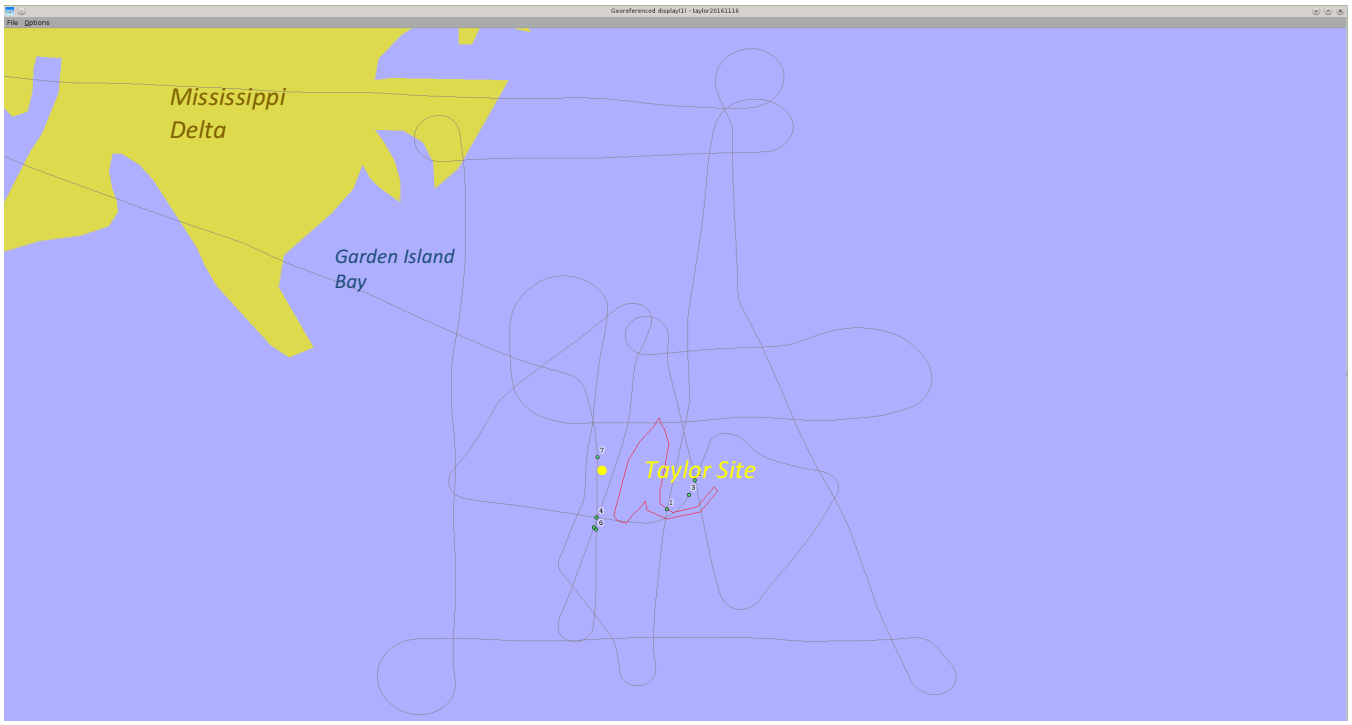


Fig.30 – Georeferenced Near Range Targets for Spill Analysis.

Fig.31 below shows the 'waterfall' images taken from the sensors, including IR, UV, VIS, and IR/UV fusion over Target#1. In the 'waterfall' display the length of the image is about 1.1 NM at 180 KT of cruise speed and the width is equivalent to the swath of the sensor, about 2,000 ft.

The response in the IR and UV bands was decisive to qualify mineral oil. The IR/UV fusion shows very well the relative thickness distribution on that particular location (Fig.31), the UV response shows the overall extension of the slick including also very thin layers from 0.01µm and the IR response, very localized, shows thicker areas of the spill from 2-5µm.

Again, the MWR response, suggested that the slick was very thin, less than 50µm. VIS showed the appearance of the slick as a sheen. As the previous day, the LFS characterized the composition of the spill as Oil classified as Medium Crude with max thickness in the order of 7µm.

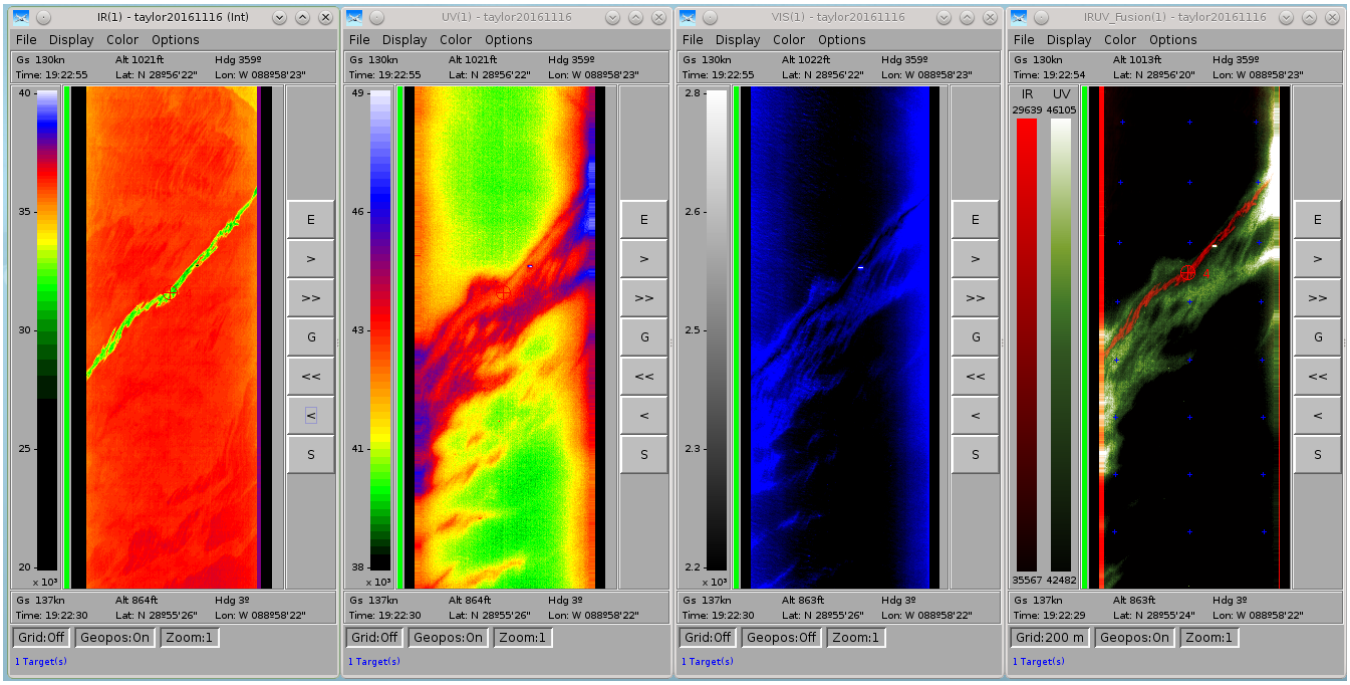


Fig.31 – Target#1 IR, UV, VIS, IR/UV fusion images.

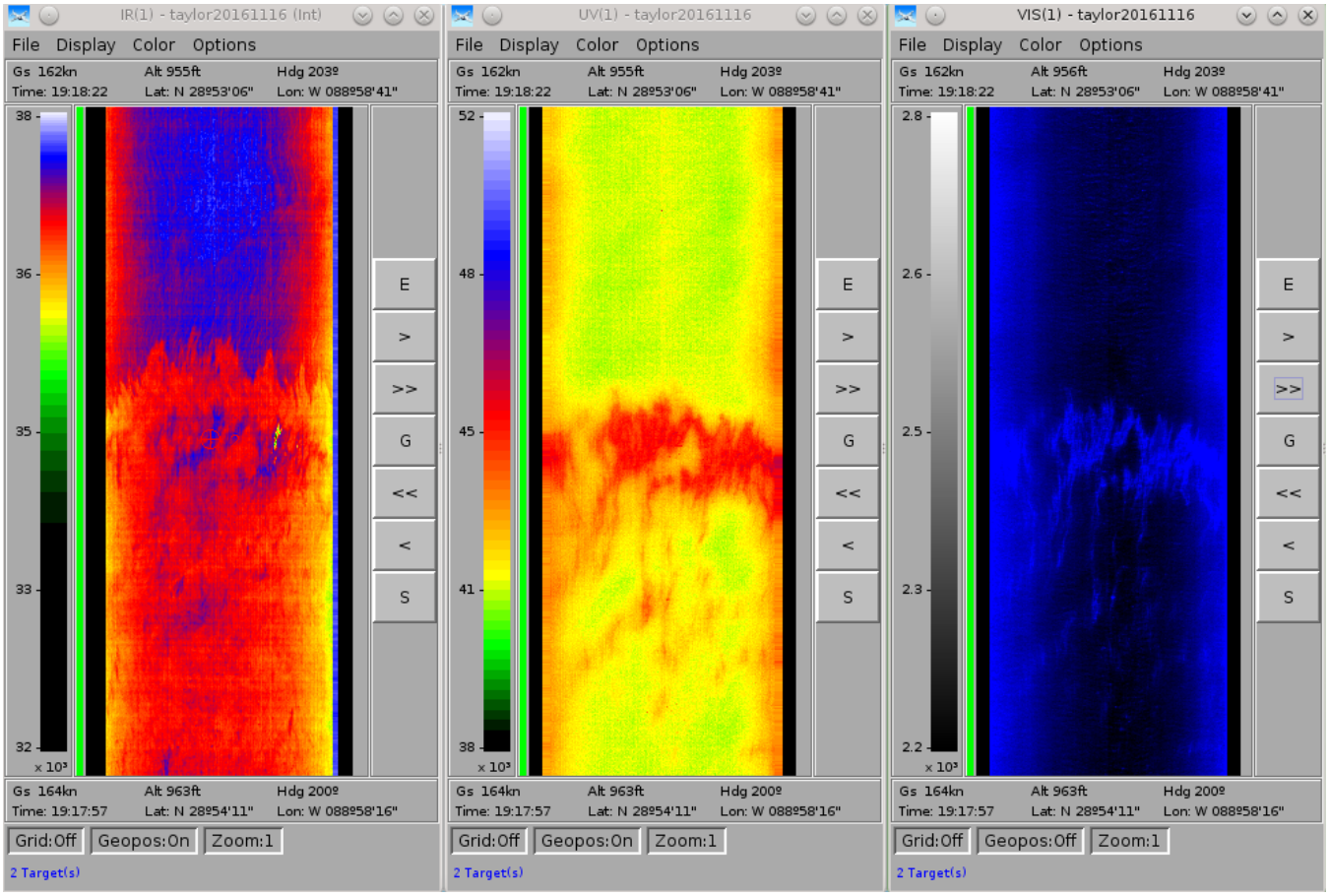


Fig.32 – Target#2 IR, UV, VIS, images.

Fig.32 shows waterfall images in correspondence of Target#2. Again, very thin slick, with a small concentrated area visible in the IR.

Fig.33 below show an example of georeferenced IR images related to the 16th of November acquisition.

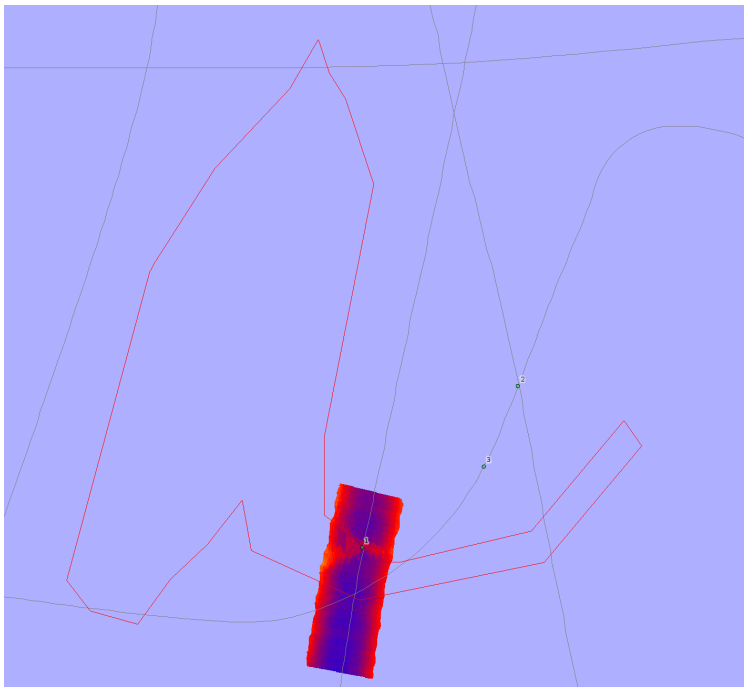


Fig.33 – Target#1 IR georeferenced image.

Conclusion: also during Mission#3 Poseidon successfully located the slick and defined the synoptic characteristics with the SLAR, creating also a navigation reference for the successive low altitude passes. During the low altitude passes the near range sensors gave positive confirmation of the nature of the slick and determined type of oil, thickness, relative thickness distribution and hot spot localization. Operators were able to analyze the spill scene during the flight in real time determining information as area, dimension, center coordinate, defining georeferenced targets and imageries. Files generated during the mission were sent via MBR microwave antenna to ground to test the antenna and data communication performances. Results were successful.

3.5.4 Mission#4 – November 17th Day Collections

In the morning of November 17th EMB-110 Poseidon left Houma-Terrebonne airport at 11:10AM. The actual mission started at 11:14 CST. As the previous three missions, Poseidon approached the Taylor area with a SE track at 3,000 ft and about 185KT of cruise speed.

Step#1 - Synoptic Overview: the SLAR detected a structure with strongly reduced backscatter that was identified as a surface target. The structure was again different from the previous days; it drifted significantly to the north due probably to the southerly winds and spread noticeably, probably because the proximity to the coast and local currents and waters from the Mississippi delta area. The area was delimited by a very irregular polygon of approximately 4.478 x 8.318 NM with a coverage of 36% and a resultant area of the surface target of 13 square nautical miles, almost 4 times the area measured the day before. Polygon was centered on the following coordinates: N 28°59'26" W 088°58'35". The following figures show the SLAR images, the georeferenced polygon and the resultant SLAR georeferenced image with and without flight track (Fig.34 to Fig.37).

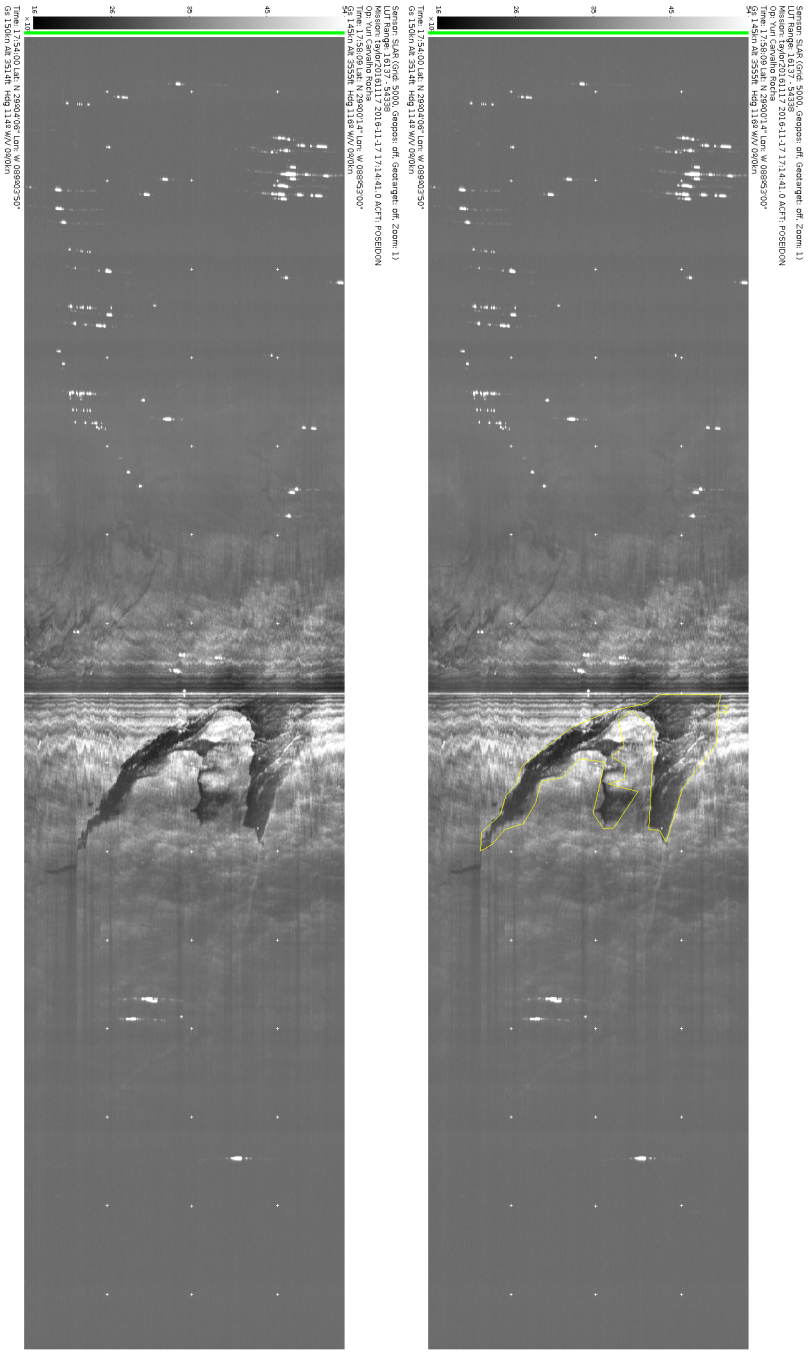


Fig.34 - SLAR images of the spill: NW to SE approach north of the spill.

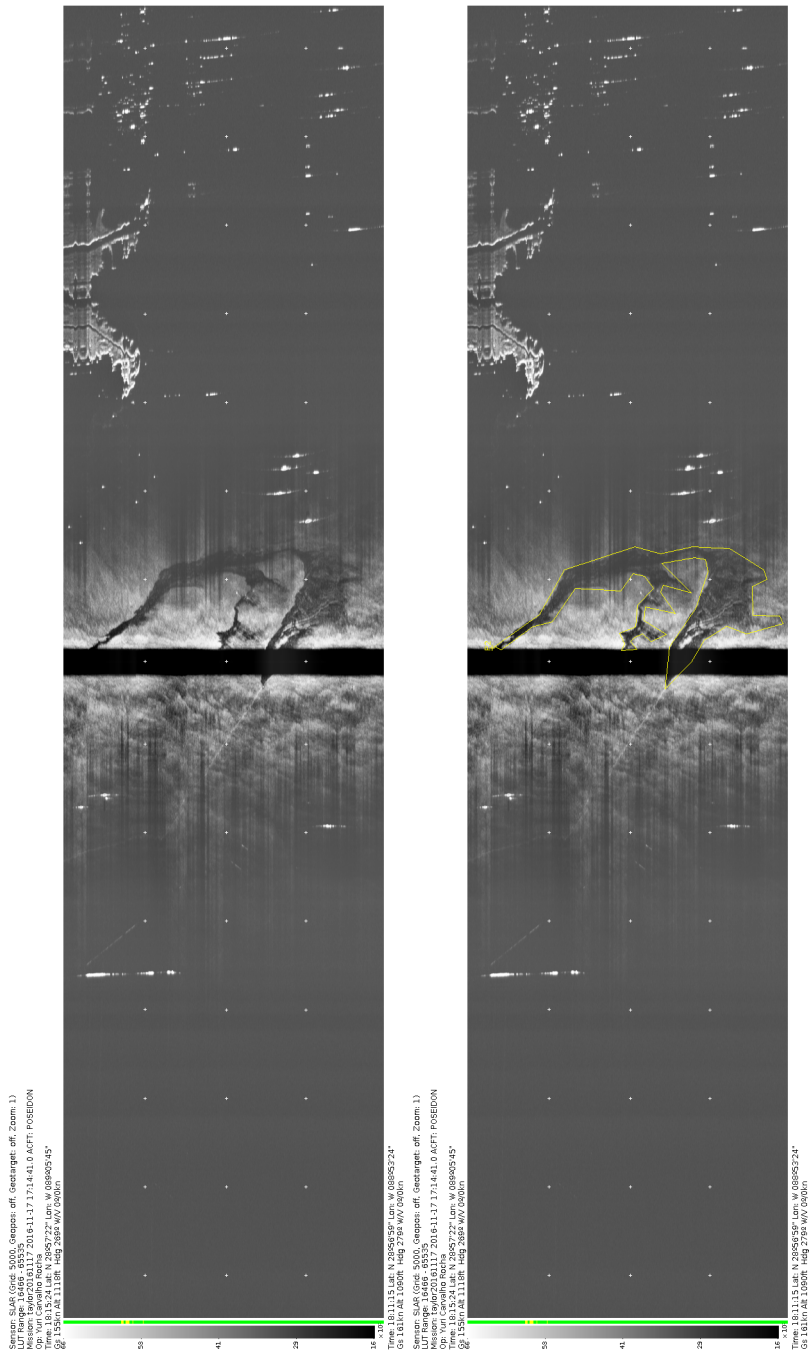


Fig.35 - SLAR images of the spill: E to W approach south of the spill

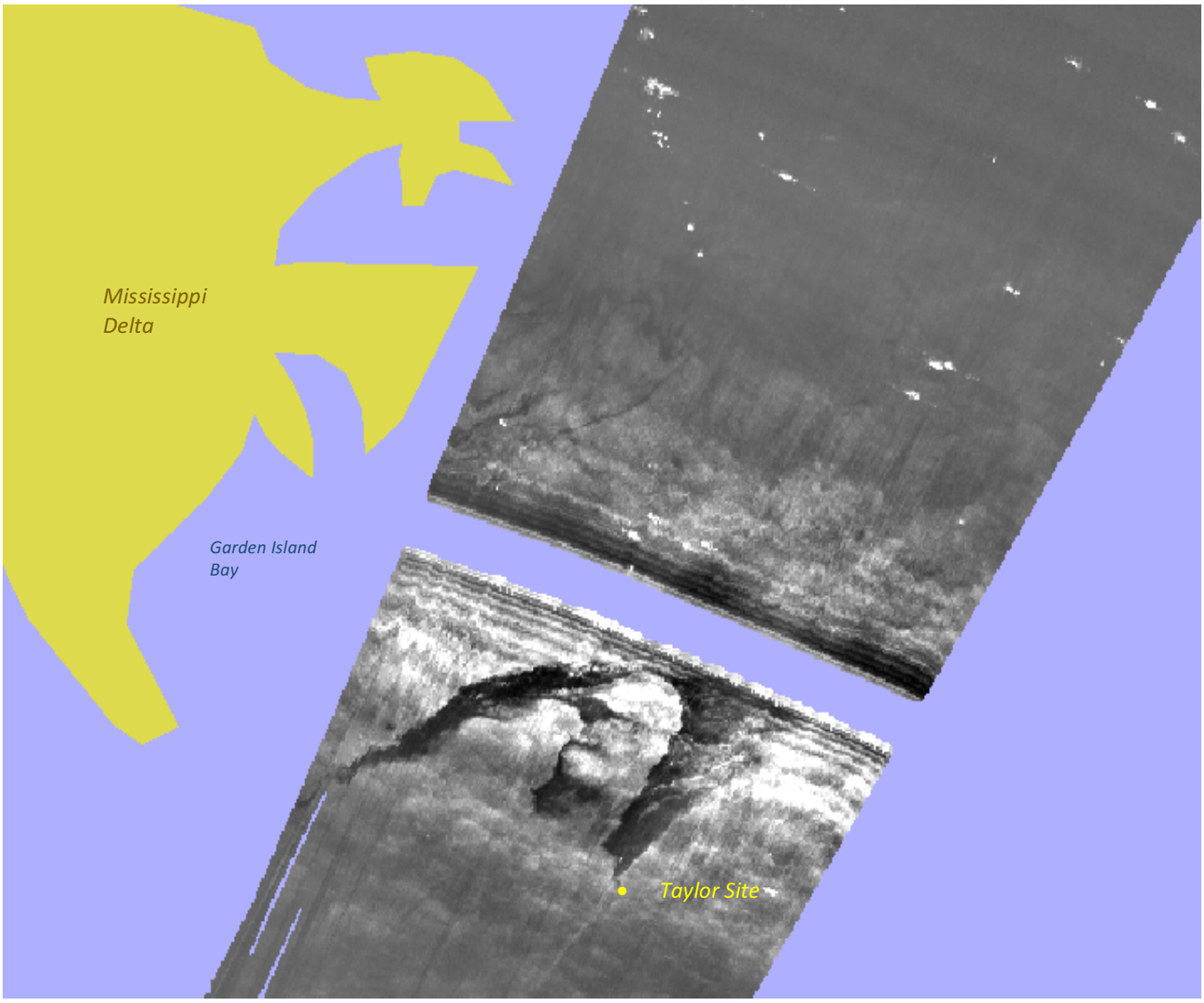


Fig.36 - SLAR georeferenced image

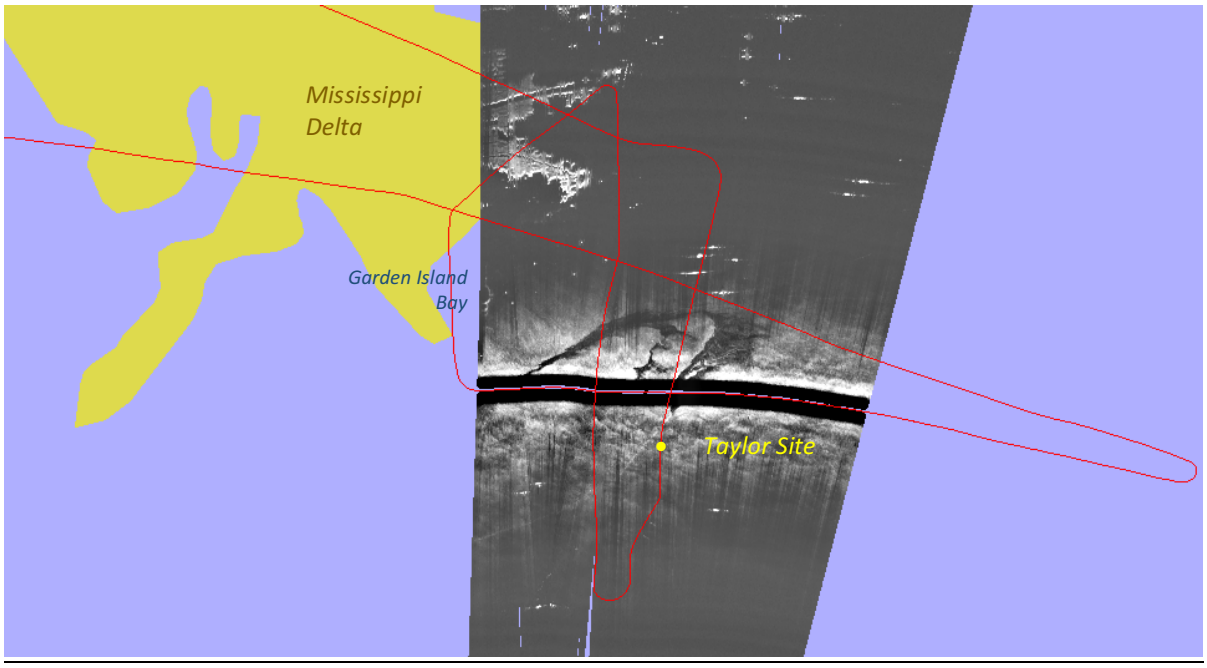


Fig.37 - SLAR georeferenced image with flight track.

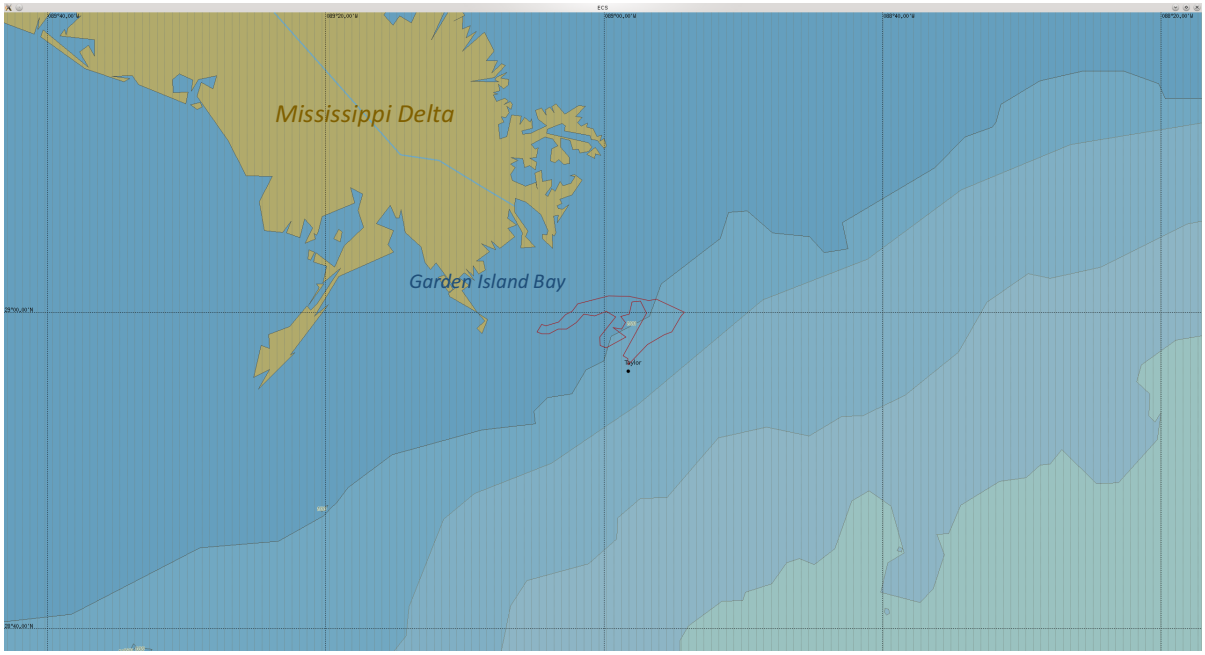


Fig.38 Position of the detected slick on the Navigation Map

After the detection, localization and georeferencing of the target, as usual Poseidon started the approach to the spill to perform the near range analysis. During the approach a video was recorded by

the EO/IR sensor (Video files are attached to the Report), the slick showed a match with the SLAR image. The slick had an appearance as sheen and very fragmented. (Fig.39).

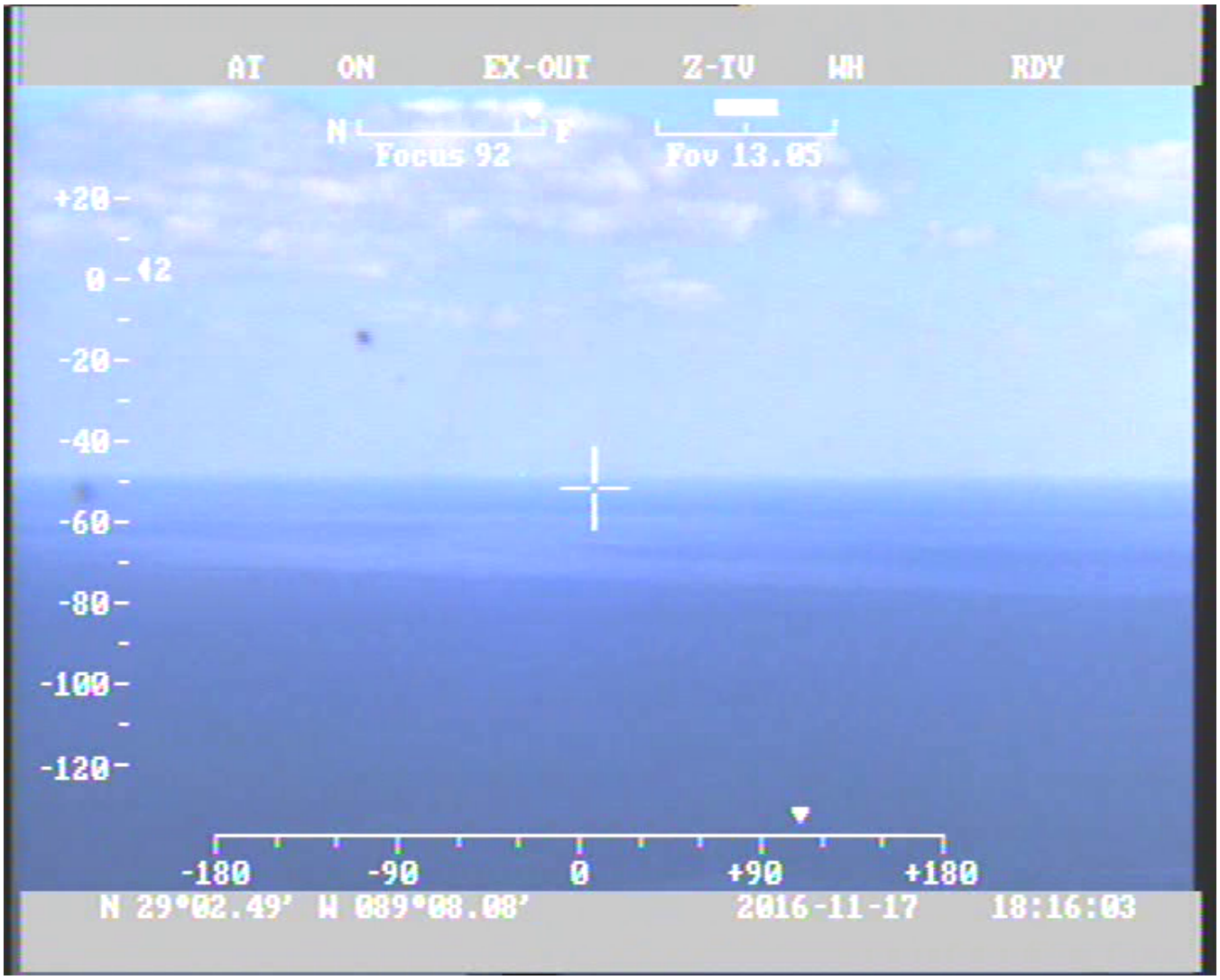


Fig.39 – Image from the EO/IR video SLAR footage.

Step#2: spill approach and Near Range Analysis.

At an altitude of 1,000ft Poseidon was directed over the slick to overfly it and analyze the slick features with the near range sensors in several determined points. Purpose of the Near Range analysis is to confirm the nature of the spill, oil or other substances, evaluate and map the thickness to estimate the volume, and determine the hot spots, areas where the oil is concentrated.

The Fig.40 below shows the zones where the targets were set to perform the analysis.

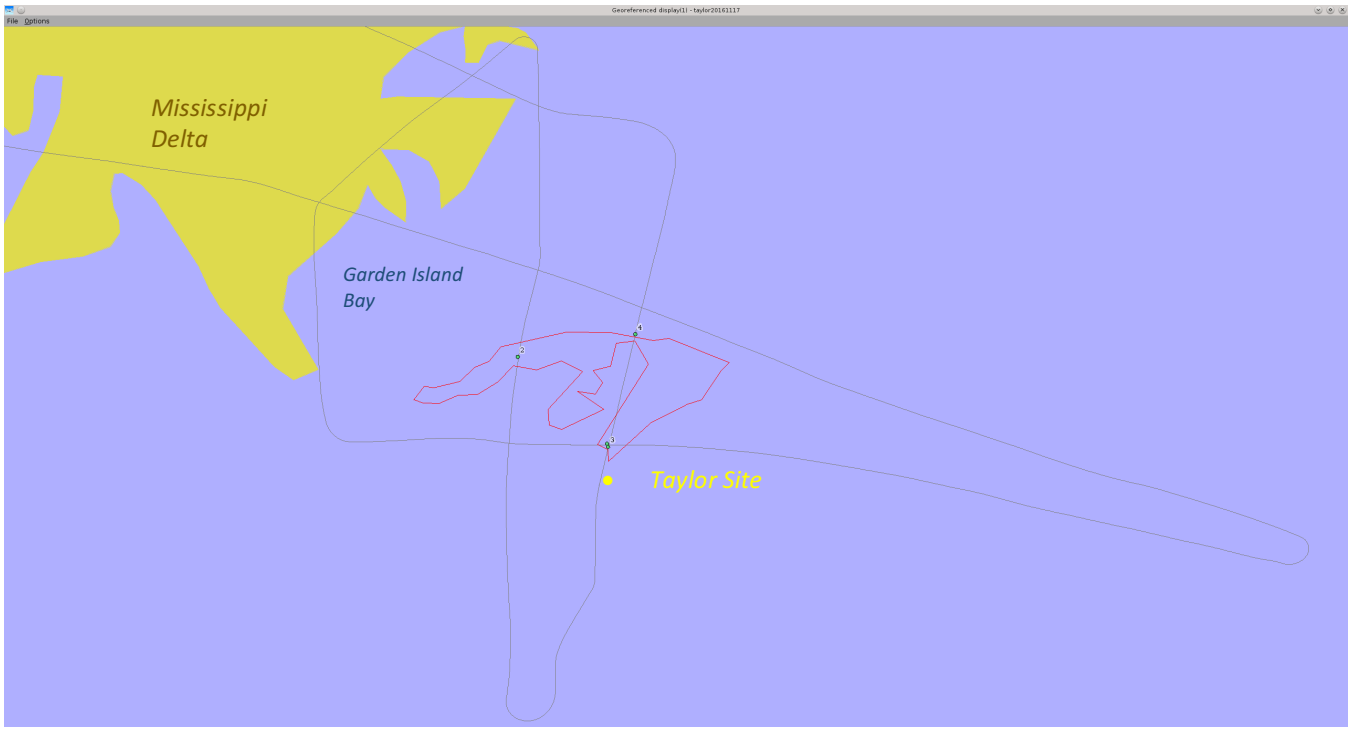


Fig.40 – Georeferenced Near Range Targets for Spill Analysis.

The Fig.41 below shows the 'waterfall' images taken from the sensors, including IR, UV, VIS, and IR/UV fusion over Target#1. In the 'waterfall' display the length of the image is about 1.1 NM at 180 KT of cruise speed and the width is equivalent to the swath of the sensor, about 2,000 ft.

The response in the IR and UV bands was decisive to qualify mineral oil. The IR shows very well the relative thickness distribution on that particular location (Fig.41), the UV response shows the overall extension of the slick including also very thin layers from 0.01µm and the IR response, very localized, shows thicker areas of the spill from 2-5µm.

Again, the MWR response, suggested that the slick was very thin, less than 50µm. VIS showed the appearance of the slick as a sheen. The LFS characterized the composition of the spill as oil classified as

Medium Crude with a thickness in that particular location of 12.3 µm (Fig.42).

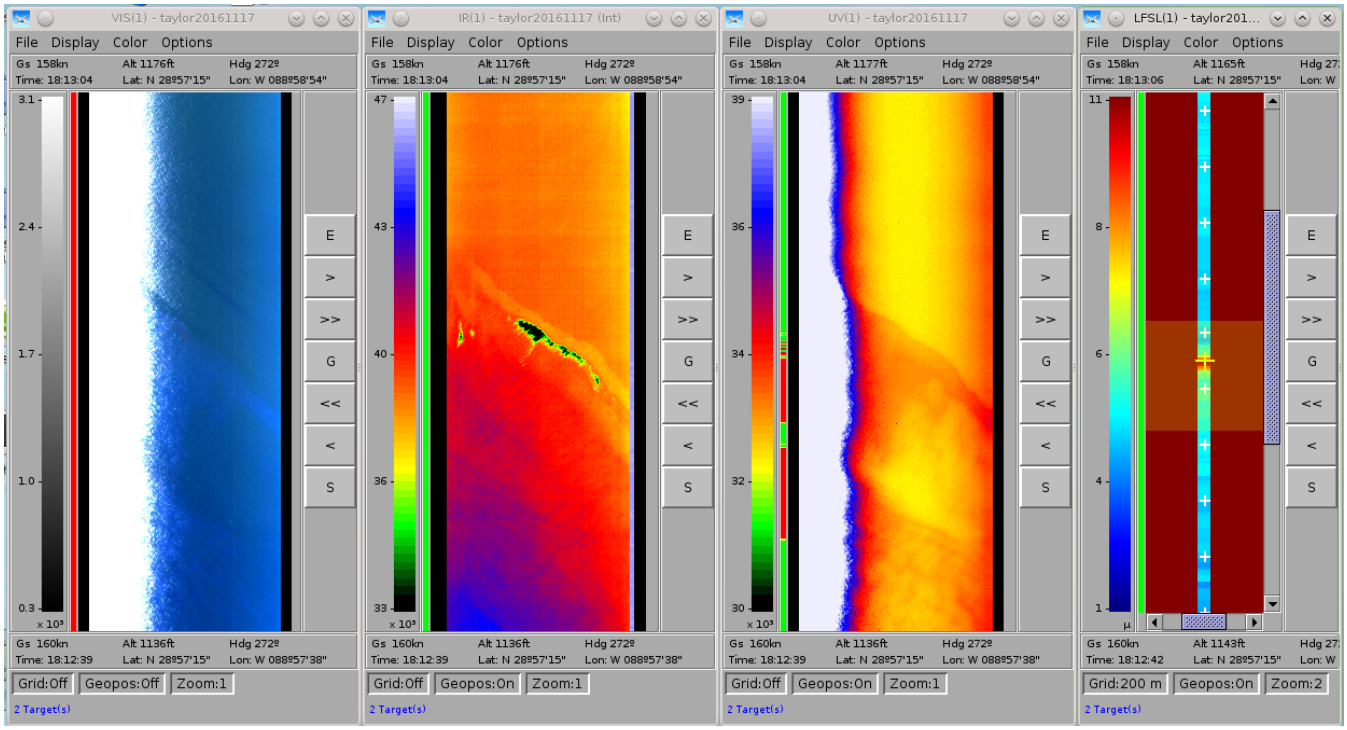


Fig.41 – Target#1 VIS, IR, UV, LFS images.

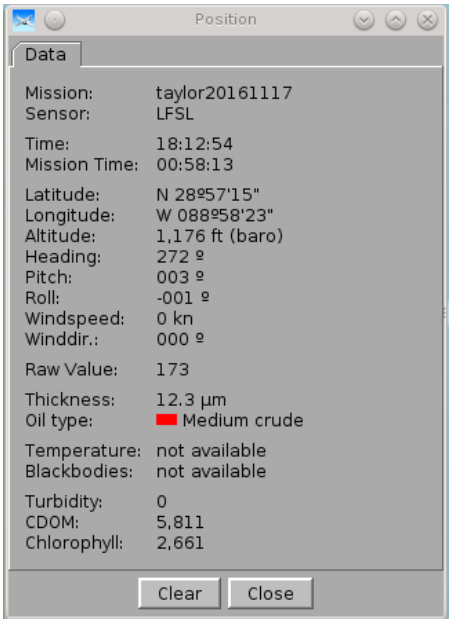


Fig.42 – Target#1 LFS information.

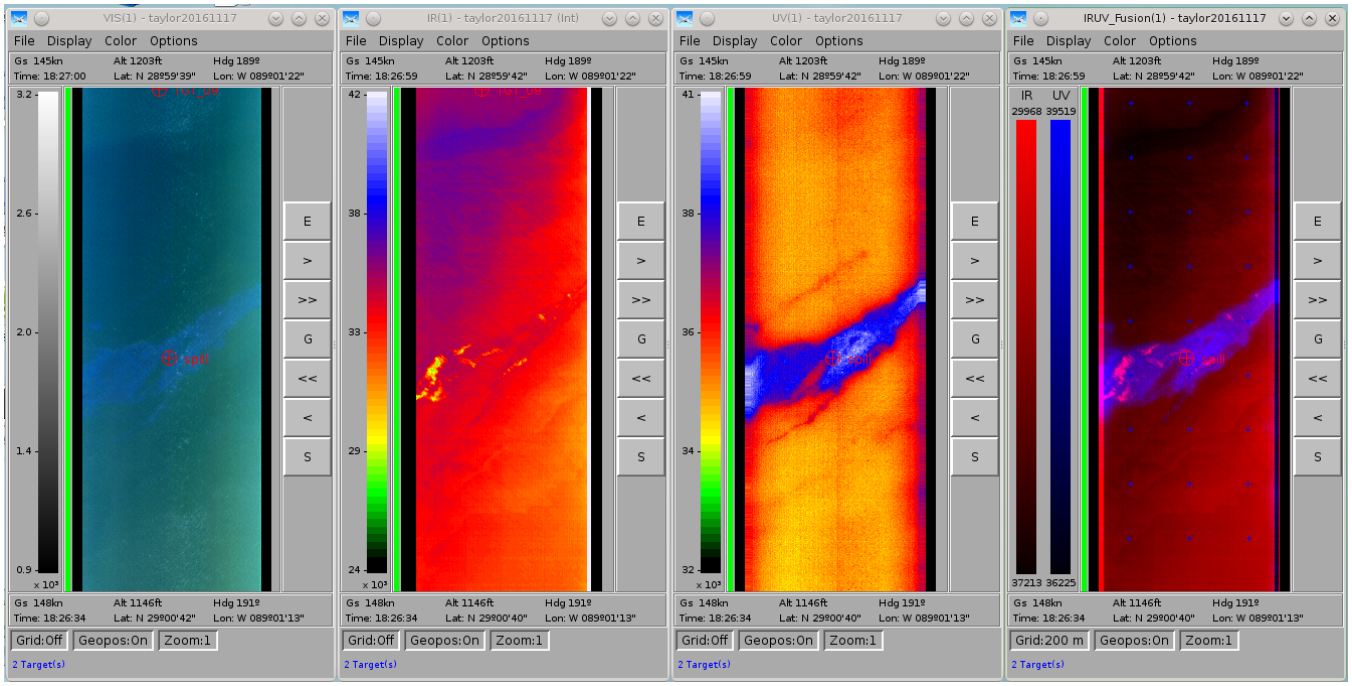


Fig.43 – Target#2 VIS, IR, UV, IR/UV fusion images.

Fig.43 shows waterfall images in correspondence of Target#2. Again very thin slick but well defined in the UV response, with a small concentrated hot spot visible in the IR.

Fig.44 below show an example of georeferenced IR images related to the 16th of November acquisition.

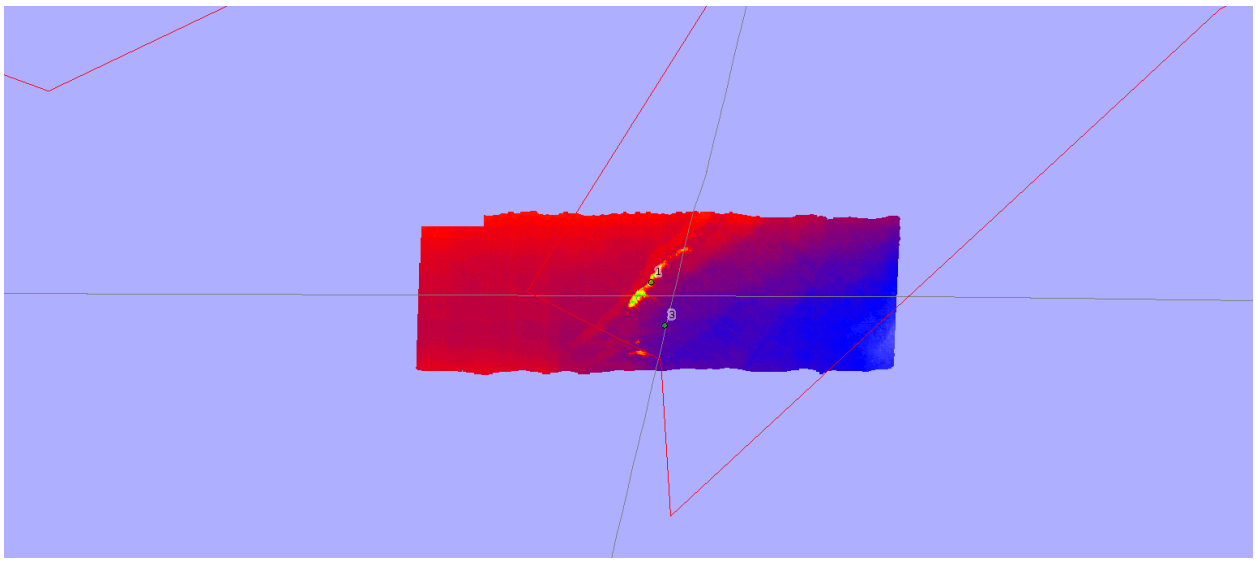


Fig.44 – Target#1 IR georeferenced image.

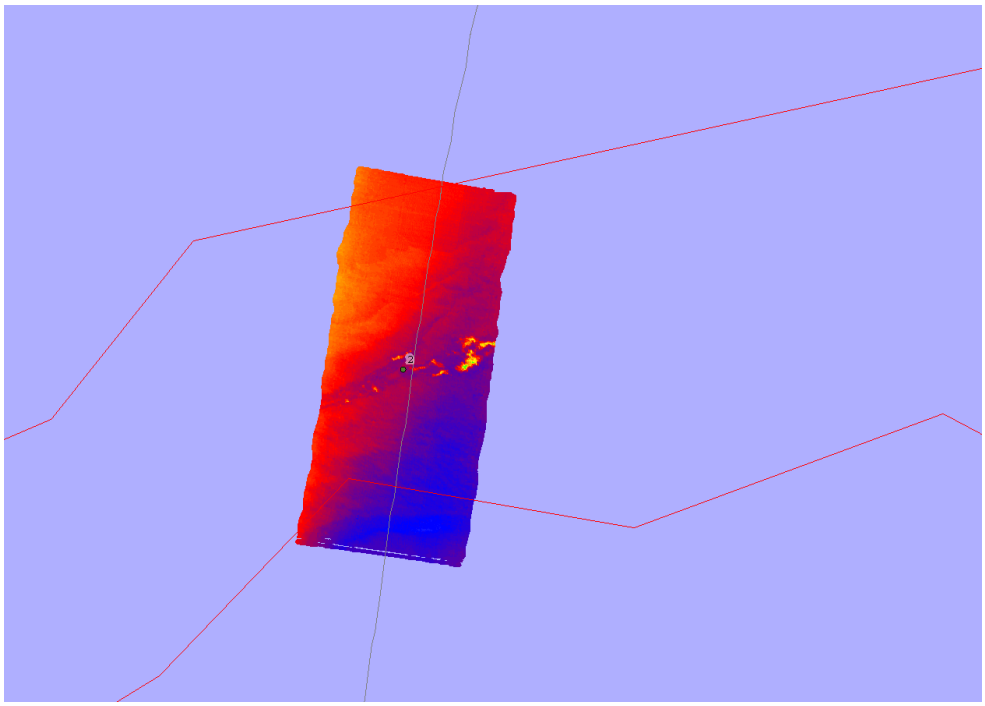


Fig.45 – Target#2 IR georeferenced image.

Conclusion: also during Mission#4 Poseidon successfully located the slick and defined the synoptic characteristics with the SLAR, creating also a navigation reference for the successive low altitude passes. During the low altitude passes the near range sensors gave positive confirmation of the nature of the slick and determined type of oil, thickness, relative thickness distribution and hot spot localization. Operators were able to analyze the spill scene during the flight in real time determining information as area, dimension, center coordinate, defining georeferenced targets and imageries. Files generated during the mission were sent via MBR microwave antenna to ground to test the antenna and data communication performances. Results were successful.

3.5.5 Mission#5 – November 17th Night Collections

In the evening of November 17th EMB-110 Poseidon left Houma-Terrebonne airport at 16:40PM. The actual mission started at 16:44 CST. Sunset was at 17:02 CST Twilight at 17:27 CST. Poseidon flown the mission for approximately 2h 40' mainly in night condition.

As the previous three missions, Poseidon approached the Taylor area with a SE track at 3,000 ft and about 185KT of cruise speed.

In low-light / night conditions Poseidon platform is fully operational. The only sensors requiring sunlight are in fact UV and VIS.

Step#1 - Synoptic Overview: the SLAR detected a structure with strongly reduced backscatter that was identified as a surface target. The structure was similar to the one detected during the morning flight the same day but even more fragmented and spread. The area was delimited by a very irregular polygon of approximately 5.892 x 13.146 NM with a coverage of 16% and a resultant area of the surface target of 12 square nautical miles, pretty much the same detected in the morning. Polygon was centered on the following coordinates: N 28°59'22" W 089°00'43". The following figures show the SLAR images, the georeferenced polygon and the resultant SLAR georeferenced image with and without flight track (Fig.46 to Fig.49).

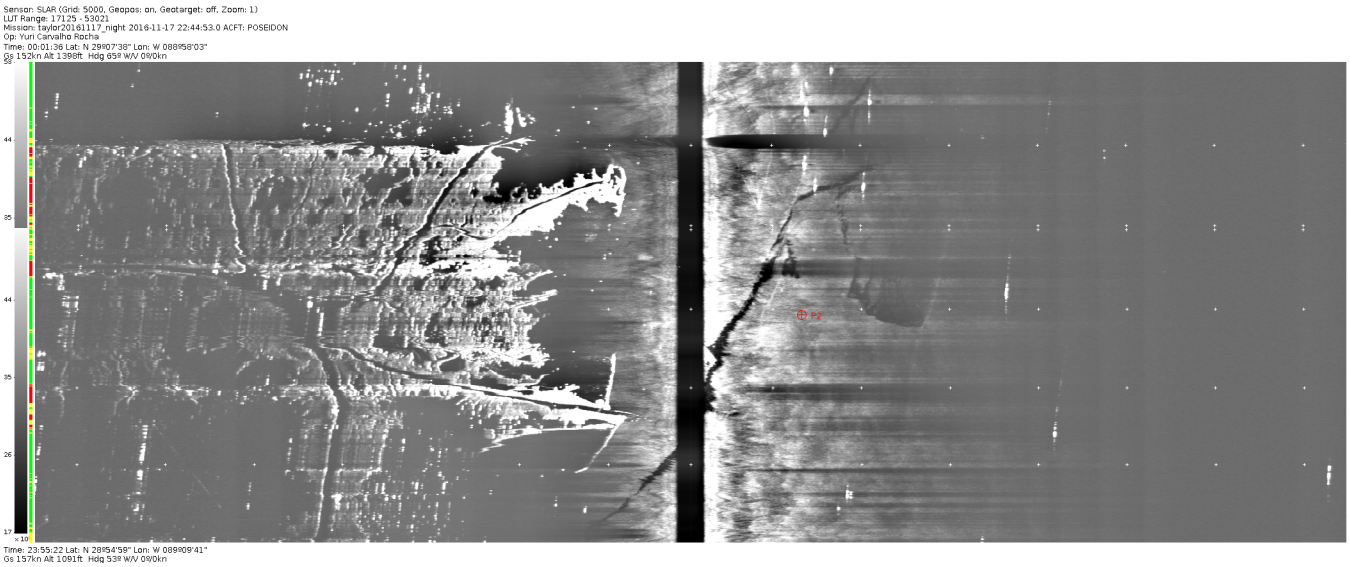


Fig.46 - SLAR images of the spill: NW to SE approach north of the spill.

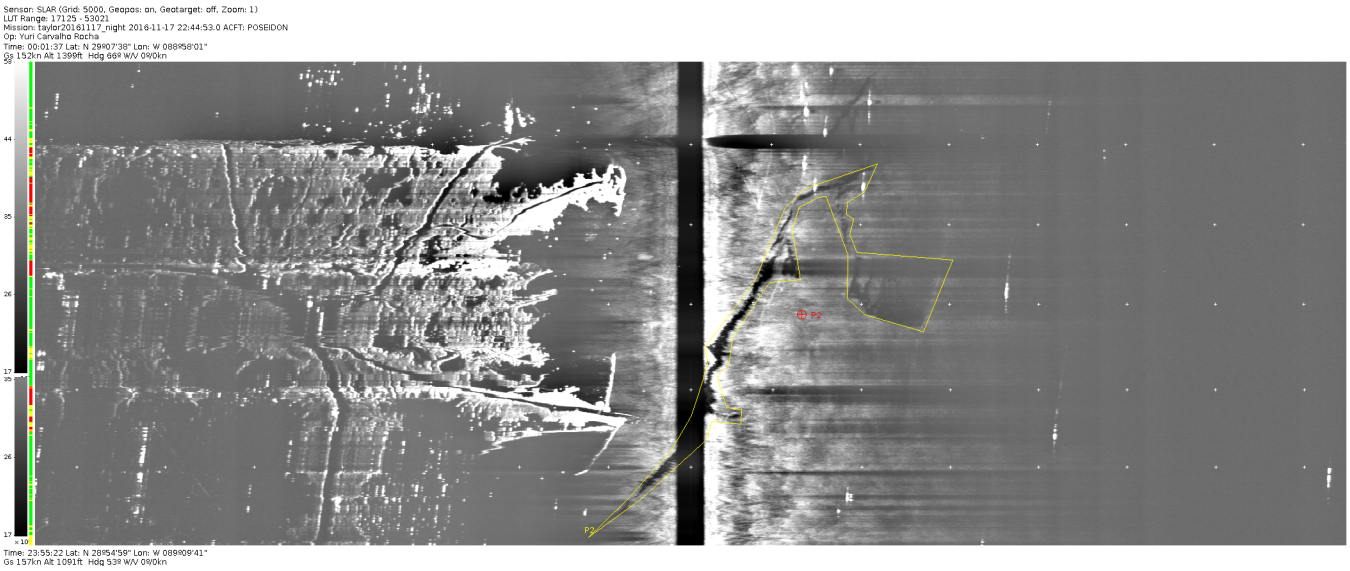


Fig.47 - SLAR images of the spill with polygon: NW to SE approach north of the spill.

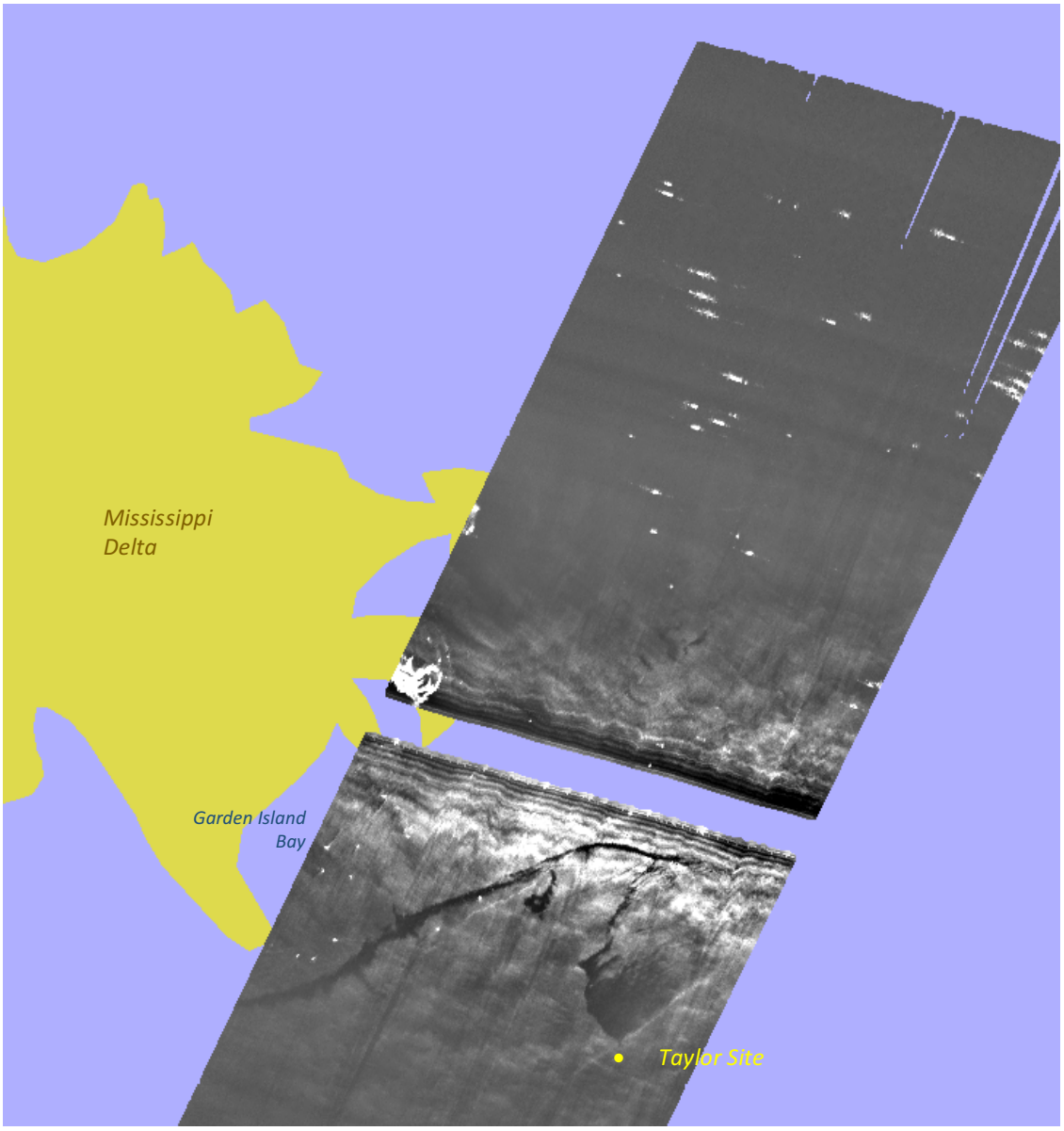


Fig.48 - SLAR georeferenced image

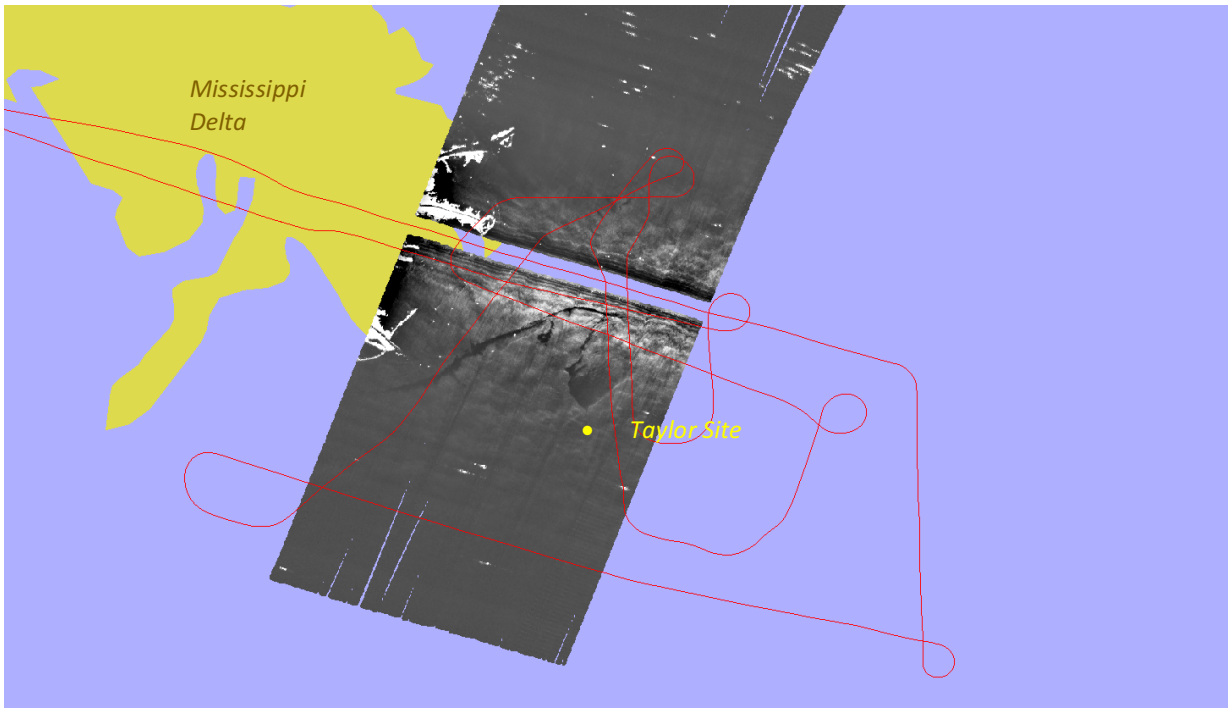


Fig.49 - SLAR georeferenced image with flight track.

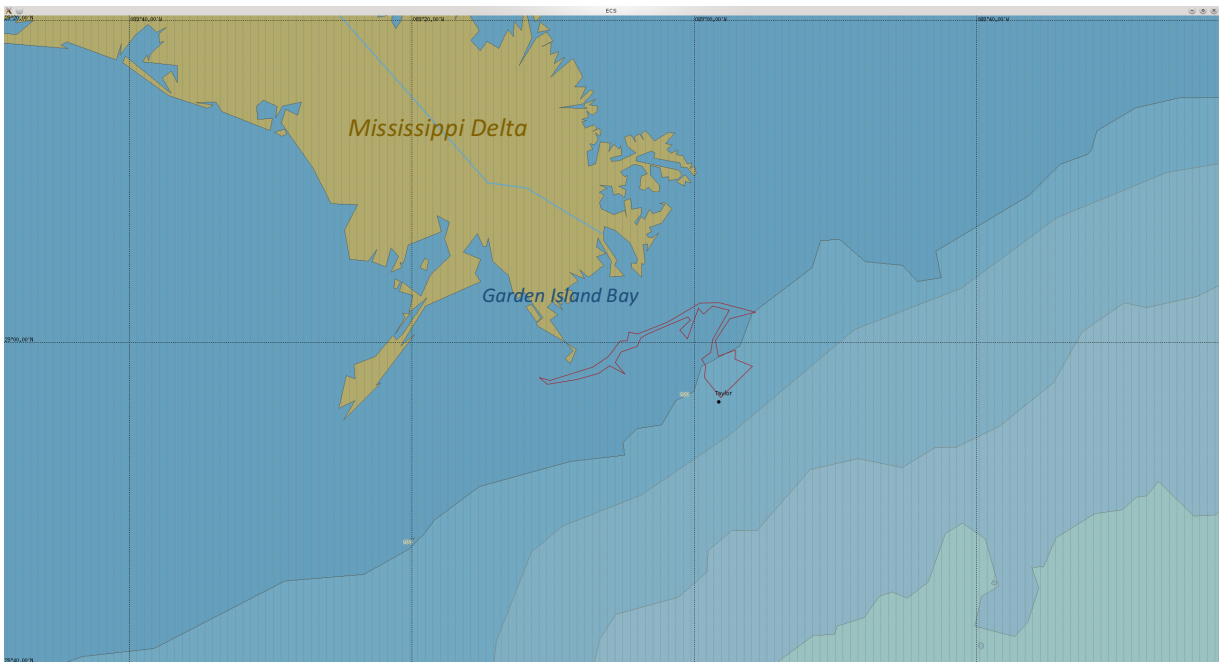


Fig.50 Position of the detected slick on the Navigation Map

After the detection, localization and georeferencing of the target, as usual Poseidon started the approach to the spill to perform the near range analysis. The IR capabilities of the EO/IR sensor allowed the operator to see and record the spill in night conditions. During the approach a night IR video was recorded by the EO/IR sensor (Video files are attached to the Report), the slick showed a match with the SLAR image.

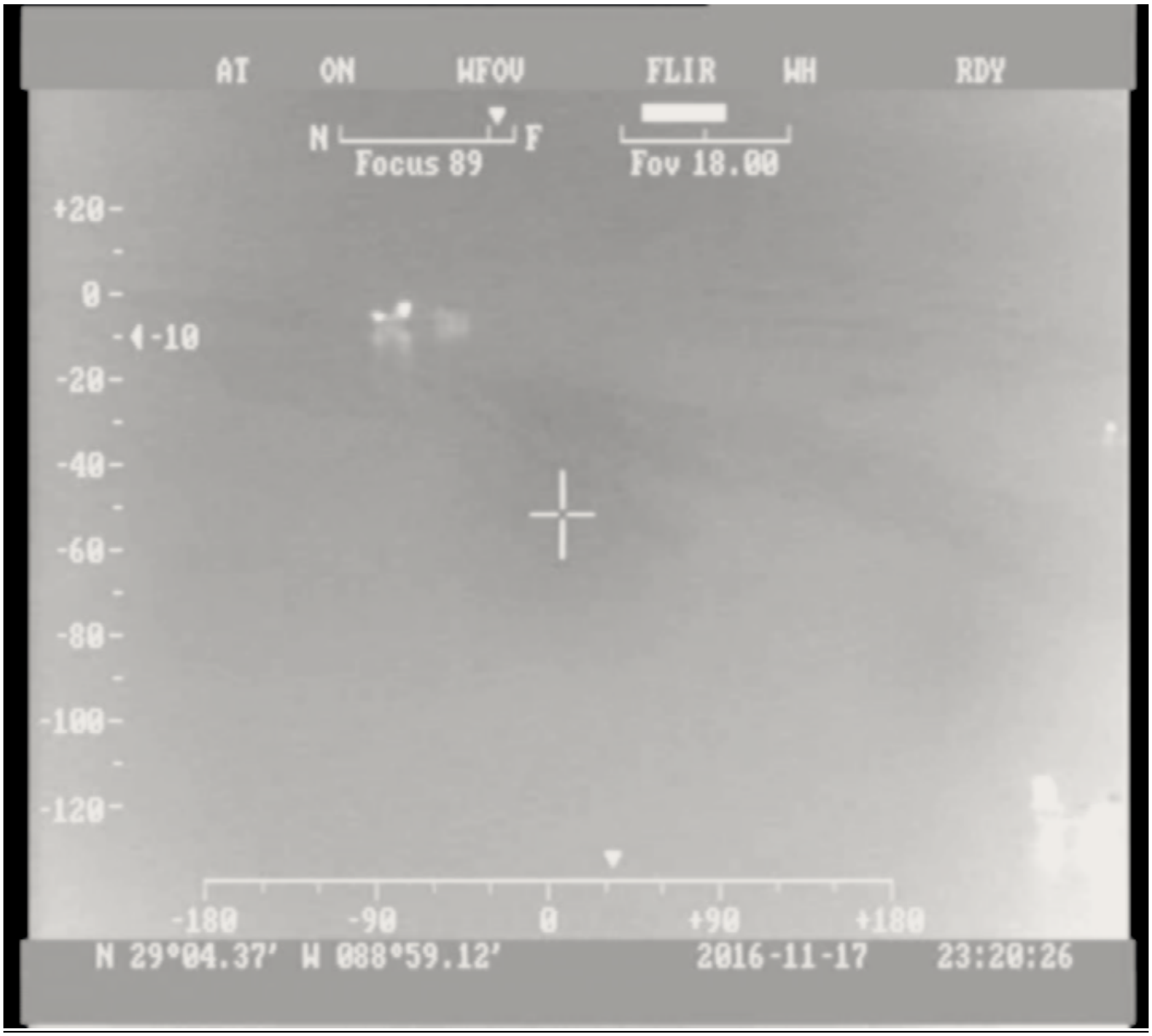


Fig.51 – Thermal image from the EO/IR video footage.

Step#2: spill approach and Near Range Analysis. At an altitude of 1,000ft Poseidon was directed over the slick to overfly it and analyze the slick features with the near range sensors in several determined points. Purpose of the Near Range analysis is to confirm the nature of the spill, oil or other substances, evaluate and map the thickness to estimate the volume, and determine the hot spots, areas where the oil is concentrated.

Fig.52 below shows the zones where the targets were set to perform the analysis. At night, the following sensors were fully operational: IR, MWR, LFS, SLAR, EO/IR. The complementarity and redundancy of the information allows Poseidon to operate effectively at night also without the information from UV and VIS.

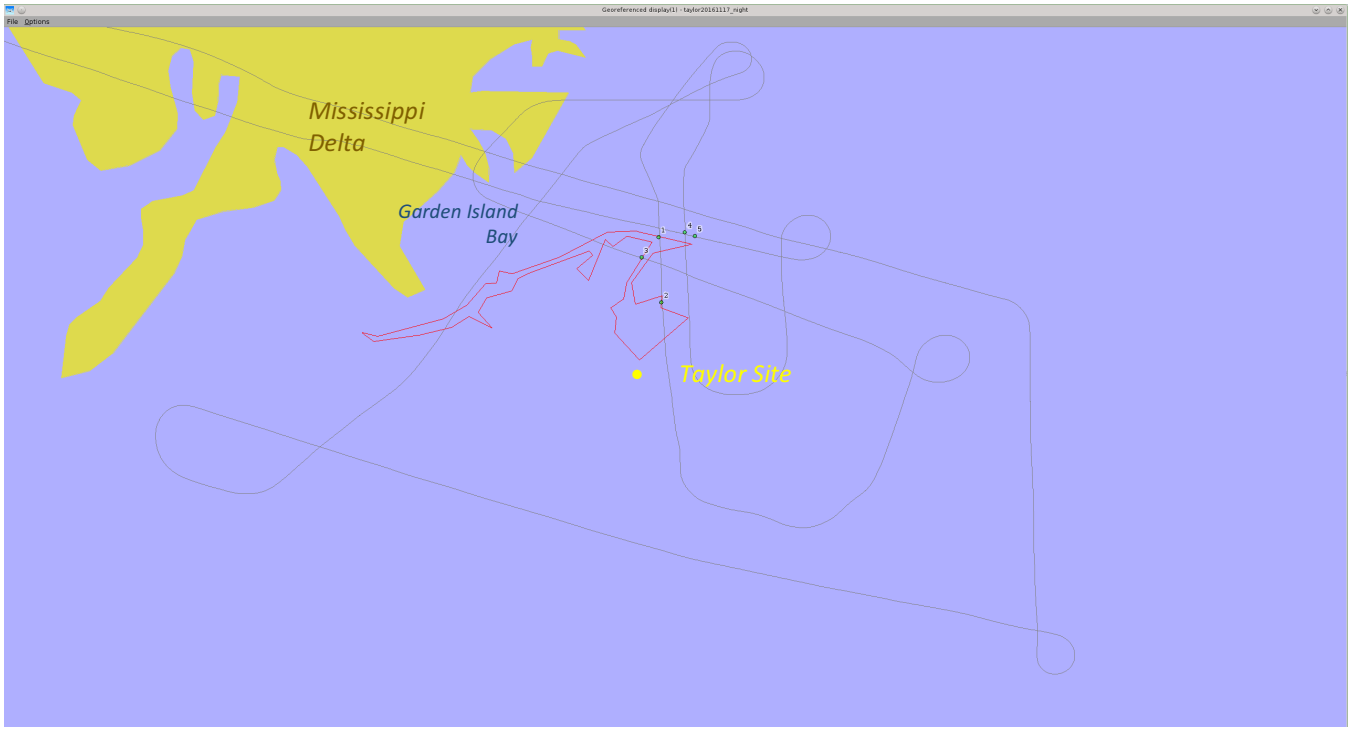


Fig.52 – Georeferenced Near Range Targets for Spill Analysis.

FIG.53 below shows the 'waterfall' images taken from the IR over Target#1. In the 'waterfall' display the length of the image is about 1.1 NM at 180 KT of cruise speed and the width is equivalent to the swath of the sensor, about 2,000 ft.

The response in the IR band was decisive to qualify mineral oil. The IR shows very well the relative thickness distribution on that particular location (Fig.53).

Again, the MWR response, suggested that the slick was very thin, less than 50µm. The LFS characterized the composition of the spill as oil classified as Medium Crude with a thickness in the same order of magnitude of the one measured during the day.

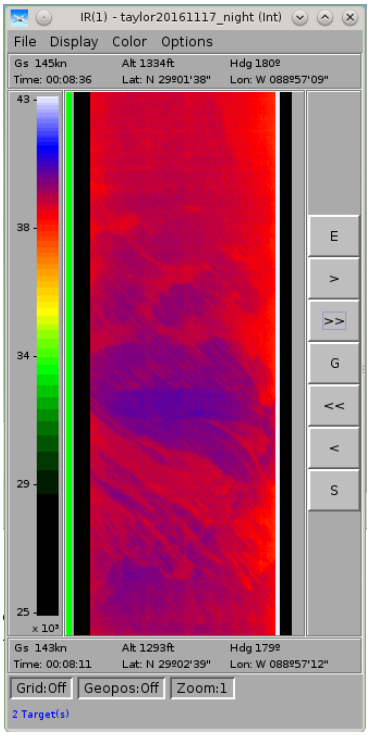


Fig.53 – Target#1 IR image.

Fig.54 below show an example of georeferenced IR images related to the 17th of November night acquisition.

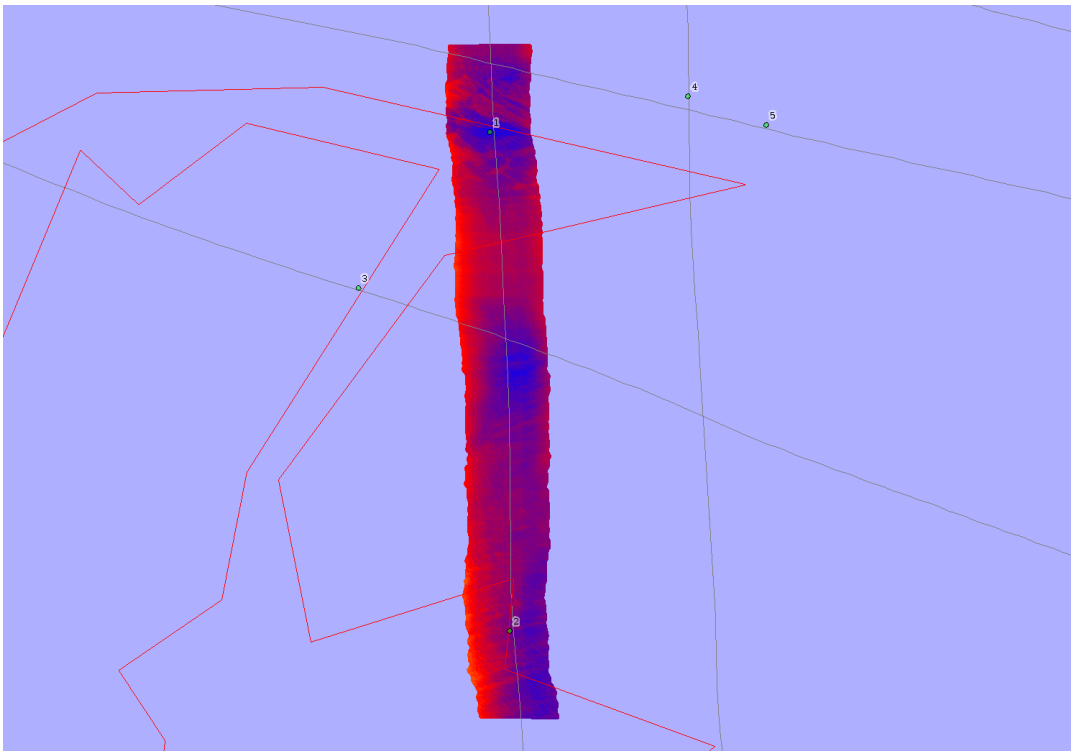


Fig.54 – Target#1 IR georeferenced image.

Conclusion: also during the night mission Poseidon successfully located the slick and defined the synoptic characteristics with the SLAR. During the low altitude passes the near range sensors gave positive confirmation of the nature of the slick and determined type of oil, thickness, relative thickness distribution and hot spot localization. Also at night the operators were able to analyze the spill scene during the flight in real time determining information as area, dimension, center coordinate, defining georeferenced targets and imageries. Files generated during the mission were sent via MBR microwave antenna to ground to test the antenna and data communication performances. Results were successful showing the capability of the system to operate in night conditions.

3.6 Metocean Conditions and Dynamic of the Spill

The opportunity to fly 5 consecutive missions in 4 days gave an interesting perspective also on the dynamic behavior of the spill related to the metocean conditions.

3.6.1 Metocean Analysis Methodology

Between November 14th and 17th, during the test over Taylor Energy site, a set of Metocean data (Sea Surface Temperature - SST; Wind and Surface Current Data) were acquired to understand the environmental conditions in the region of interest, and possibly relate the dynamic behavior of the spill to the environmental conditions.

SST data has been acquired from the Advanced Very High Resolution Radiometer (AVHRR) sensor onboard NOAA satellites and available in .tif format at http://coastwatch.noaa.gov/-cwn/search/interface.html and has been georeferenced for later Interpretation by Fototerra technicians.

Two types of wind data were used, those obtained from the Advanced Scatterometer (ASCAT) sensor on board the MetOp-B satellite, obtained from the website ftp://podaac-ftp.jpl.nasa.gov/allData/ascat-/preview/L2/metop_b/coastal_opt/2016/. When these data were not available because the passage of the satellite orbit did not coincide with the position of the the area of interest, wind data were obtained from in situ stations from oil platforms and buoys linked to the National Data Buoy Center - NDBC at http://www.ndbc.noaa.gov/. In the case of wind data obtained by buoys, the maps were generated from the tables with the surface wind hour averages available for download.

For ocean surface current information, data obtained from the NOAA HF Radar National Server were used. HF Radar is used to remotely measure ocean surface currents on the website http://hfradar.ndbc.noaa.gov/ and it is considered a very important data for predicting the trajectory of oil leakage at sea and an optimized flight plan. In our case, the HF data used were on average between 45 and 50 NM (83.3 to 92.6 km) from the area of interest, however, the surface circulation

pattern in this region of the Gulf of Mexico was very close to the current patterns conditions found near the Taylor area.

3.6.2 Metocean Conditions November 14th

- Mission Start: 17:14 UTC (11:14 CST)
- Mission End: 21:00 UTC (15:00 CST)

Due to the high cloudiness over the region of interest, the images of the field of Sea Surface Temperature - SST did not present information about the Taylor's region near the overflight time (17:00 UTC). However, it was possible to obtain an image of the overflight area at 15:50 UTC when it was possible to measure SST between 22-25 ° C (Fig.55a and 55b).

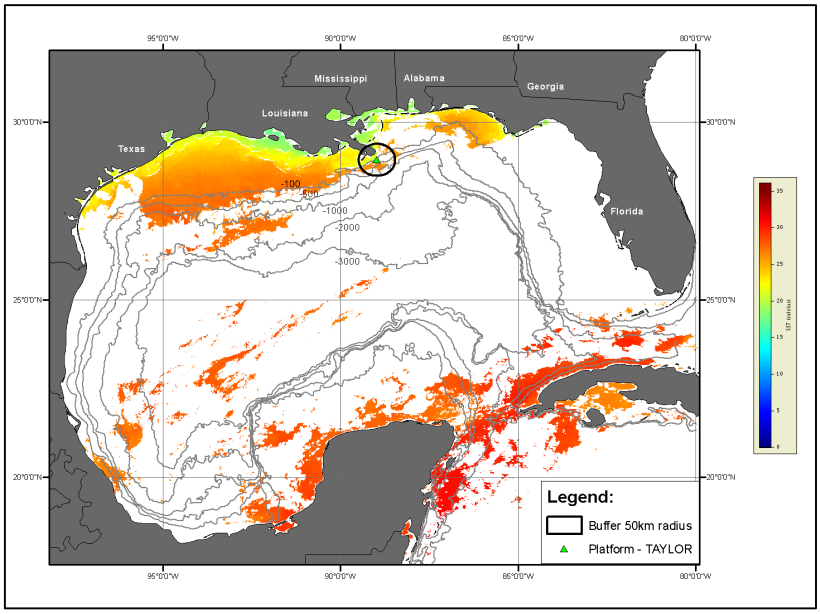


Fig.55a - SST image at 15:50 UTC

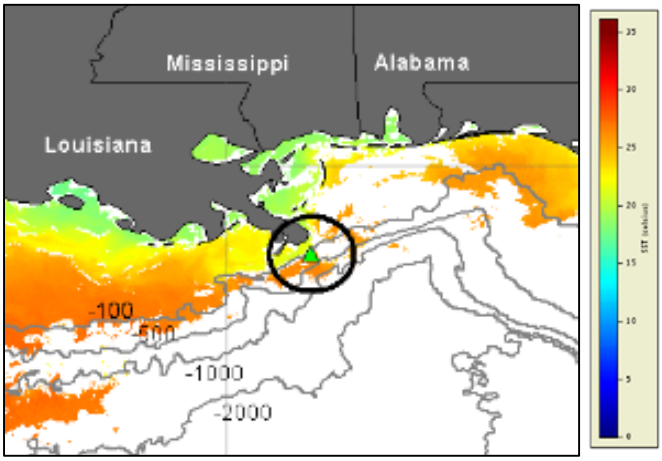


Fig.55b – SST details in Taylor area at 15:50UTC

Two types of wind data were used for 11-14-2016. The first was the data obtained by the ASCAT at 15:15 UTC, showing E winds with intensity ranging from 4 to 5 knots as we can see in figure 56a. Wind data obtained at 17:00 UTC by the buoy 42040 indicated N-NW winds with intensity of 5.8 knots on Figure 56b.

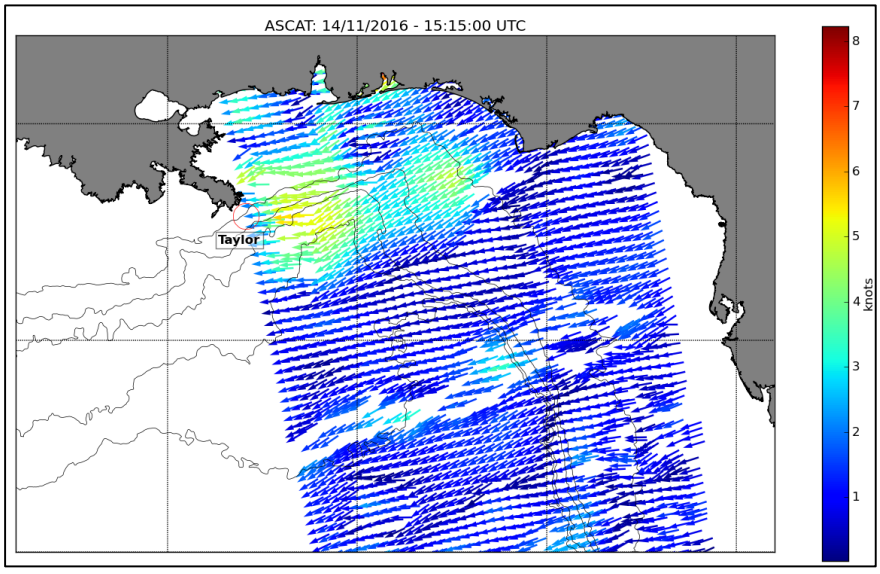


Fig.56a - wind field obtained by ASCAT at 15:15 UTC

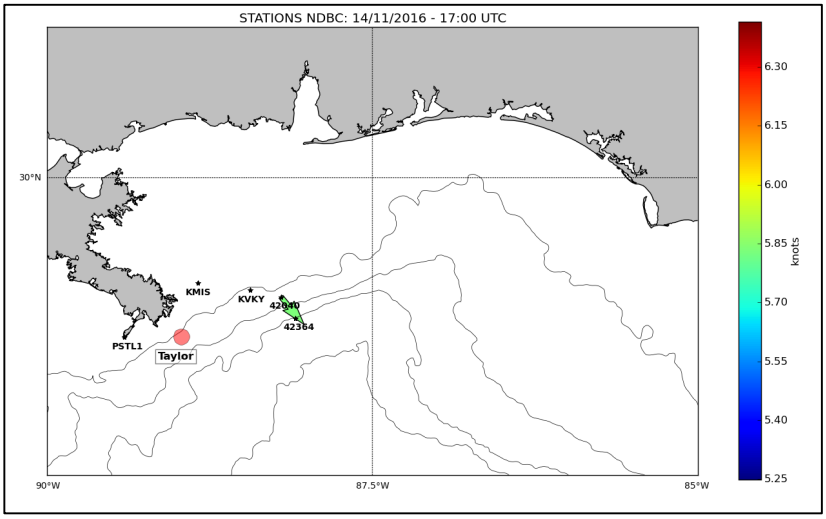


Fig.56b - wind field obtained by buoy 42040 at 17:00 UTC

It is interesting to note that in a period of 105 minutes there was a significant variation in the direction of the wind field in the region, however, in terms of intensity the variation was not so significant.

The current data obtained at 17:00 UTC by the HF radar indicate near Taylor area that there was a current flow going to S-SE with intensity between 20-25 cm / s (Fig.57).

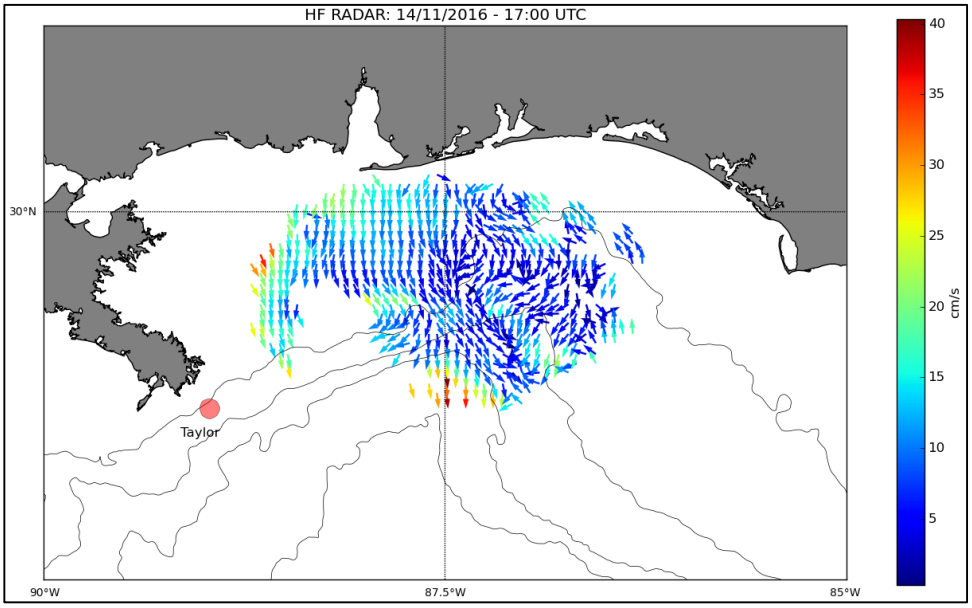


Fig.57 – Data from surface current obtained near Taylor at 17:00 UTC

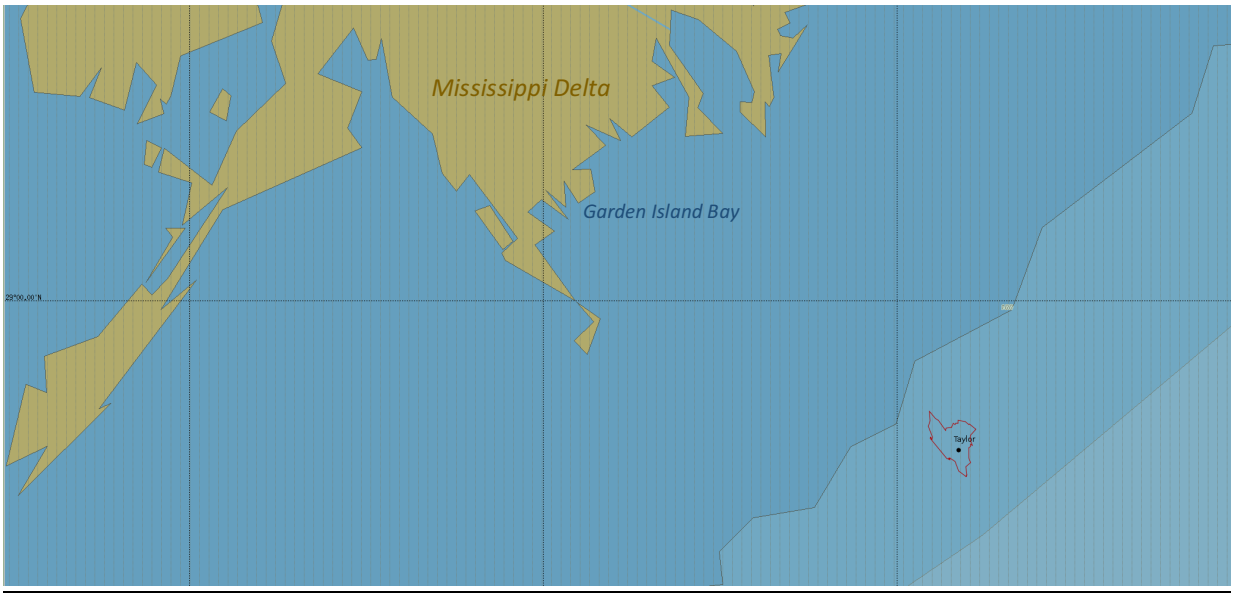


Fig.58 – November 14th slick position

Metocean data analysis shows that during the flyover in the Taylor region we had an SST between 23-25°C (73.4-77°F) and a wind that started at 15:15 UTC blowing from E with intensity of 4.5 knots and in a period of 105 minutes changed to NW with the intensity of 5.8 knots. With this wind speed the backscattering of the sea surface allowed a good measure with the SLAR in identifying the features of the leaked oil. The currents flowing to SE-S with intensities between 20-25 cm/s. Both the wind that was blowing from NW and the current that was drifting towards S influenced the spread and drift of the spill from north to south.

3.6.3 Metocean Conditions November 15th

- Mission Start: 13:18 UTC (07:18 CST)
- Mission End: 16:02 UTC (10:02 CST)

Once again the region of interest was in high cloudiness, which prevented good images from the SST field on overflight area. The best image obtained was at 15:29 UTC. It is possible to observe in the image that the field of SST presented with temperatures between 24 and 25 °C (fig. 59a and b).

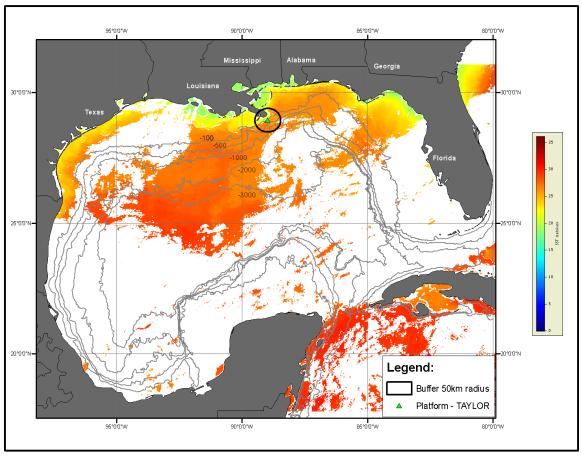
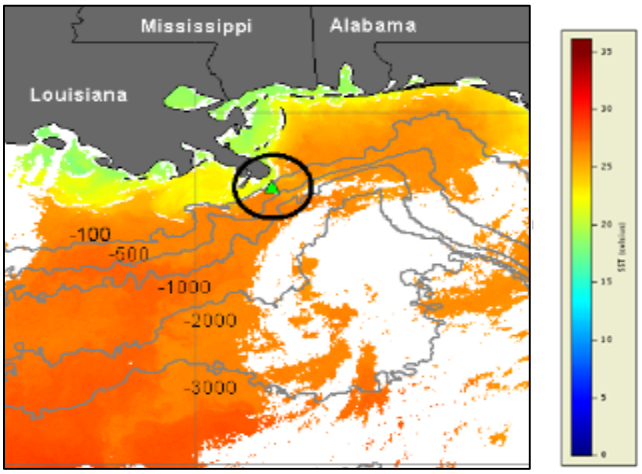


Fig.59a - SST image at 15:29 UTC



Fgura 59b –SST field in detail on Taylor area at 15:29 UTC

The orbit of the MetOp-B satellite that carries the ASCAT sensor did not exactly cross over the area of interest and did not collect the wind field at the time of flight of the Poseidon platform over the Taylor area (Fig.60a), however, the stations with insitu measurements (Fig.60b), obtained by buoys showed that at 13:00 UTC winds predominantly from N presented values between 2 and 9 knots (Fig. 60b).

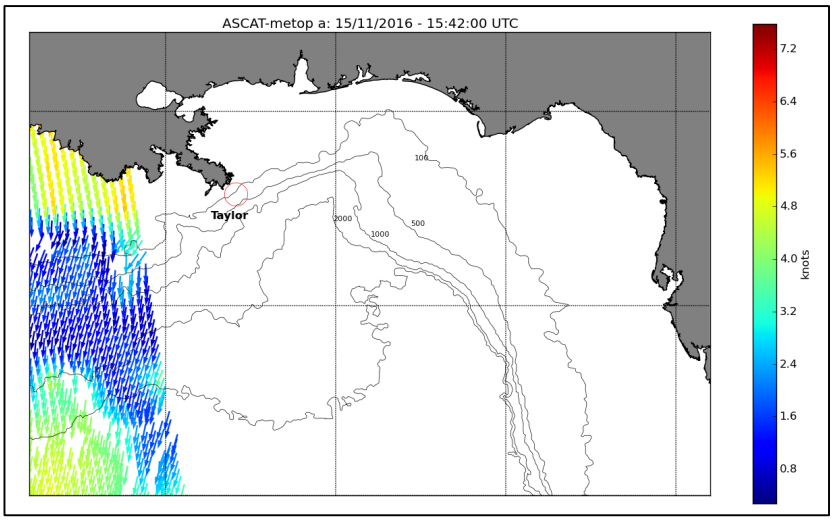


Fig.60a - wind field obtained by ASCAT near the area of interest at 15: 29UTC

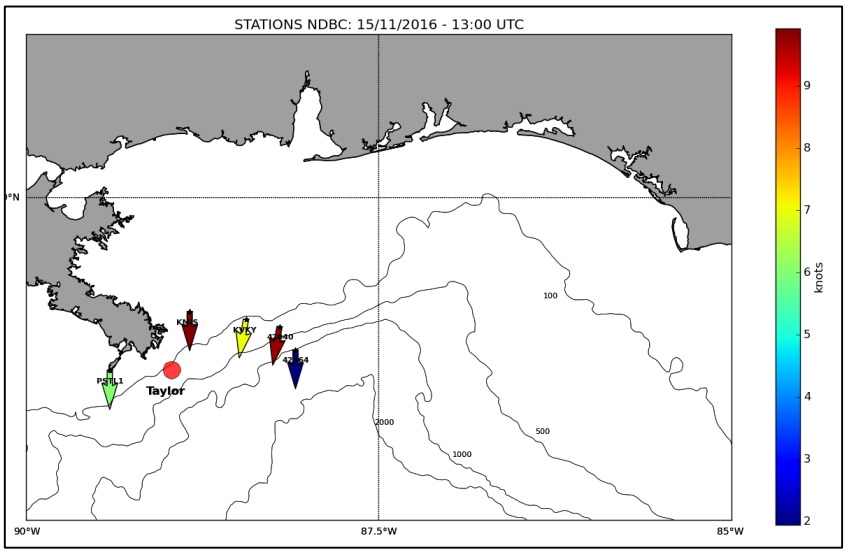


Fig.60b - wind field insitu obtained by buoys near the area of interest at 15: 29UTC

The surface current data obtained by HF radar presented a very reduced coverage area and far from the Taylor area, which is not a good data to be used in our current drift analysis. However, considering the wind field obtained by the buoys and the associated Ekman transport, it is possible to infer a current in the area flowing to SW-S with values between 10 and 15 cm/s.

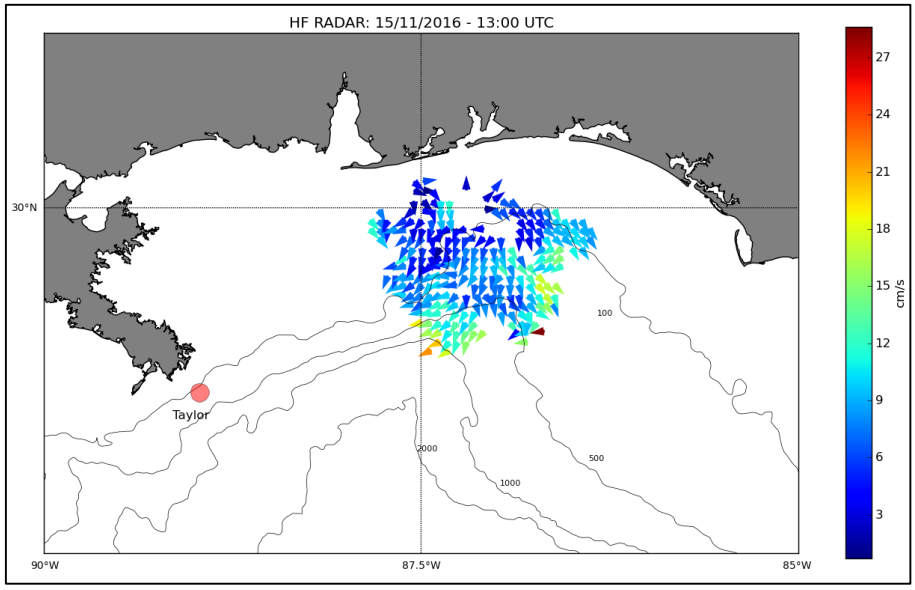


Figure 61 - current data obtained by HF radar far from Taylor at 13:00 UTC

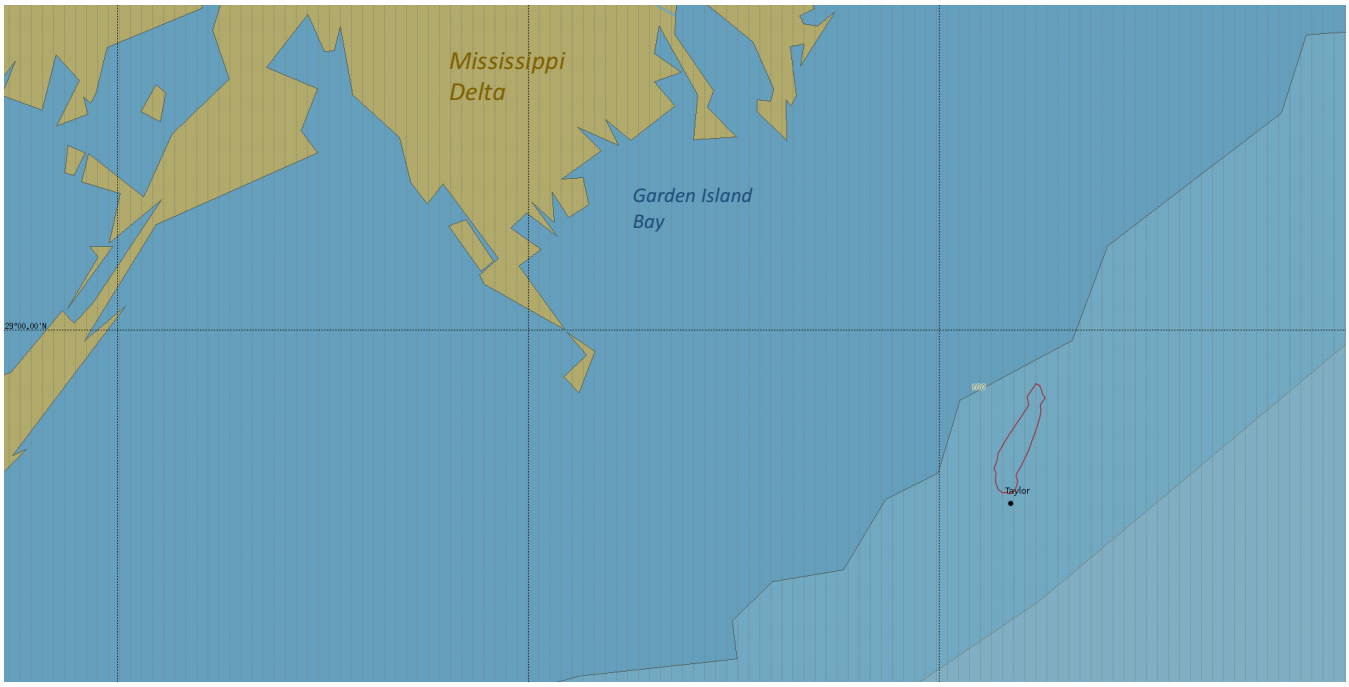


Fig.62 – November 15th slick position

Metocean data showed the SST fields with values between 24-25 °C or 75.2-77 °F, consistent with what is expected in the region as well as with the data obtained by the IR sensor on board the

Poseidon platform. Winds over the area of interest were blowing from N with speeds between 3 and 9 knots, so with a good intensity to obtain information using the SLAR sensor. With these values of wind it was expected that the oil spot in the Taylor region would drift to S, however, what was seen was the drift to N. As it was not possible to obtain current data close to the Taylor region at the moment of the overfly, is not possible to attest that the current responded only to the wind field, or if there was another component such as the tide component itself, influencing the drift of this spill.

3.6.4 Metocean Conditions November 16th

- Mission Start: 17:13UTC (11:13 CST);
- Mission End: 20:00UTC (14:00 CST);

Two images of the SST field of the area of interest were obtained with good conditions at 15:08 UTC and 20:27 UTC respectively. It is possible to observe in the image that the SST field presented temperatures between 22 - 25° C in the Taylor area, maintaining the pattern of the previous days (Fig.63a and 63b).

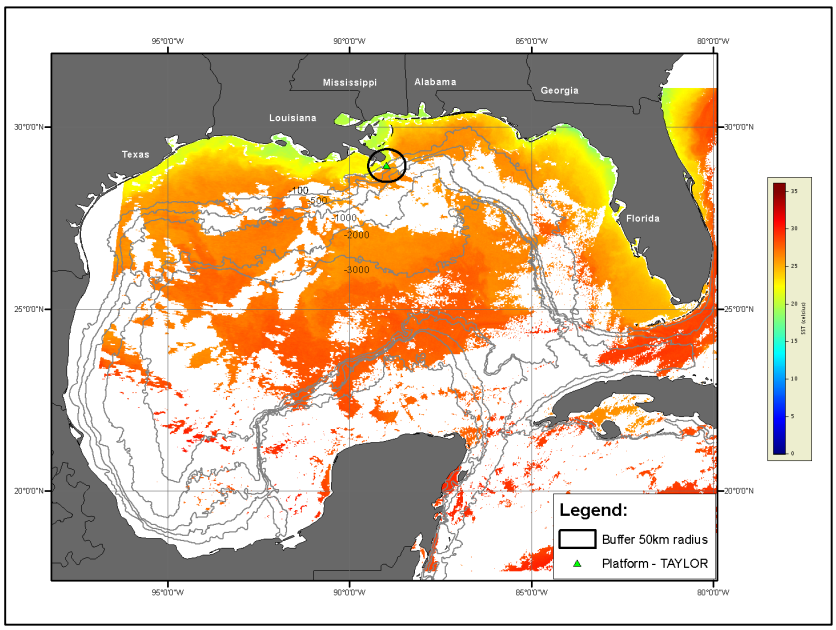


Fig.63a - SST image at 15:08 UTC

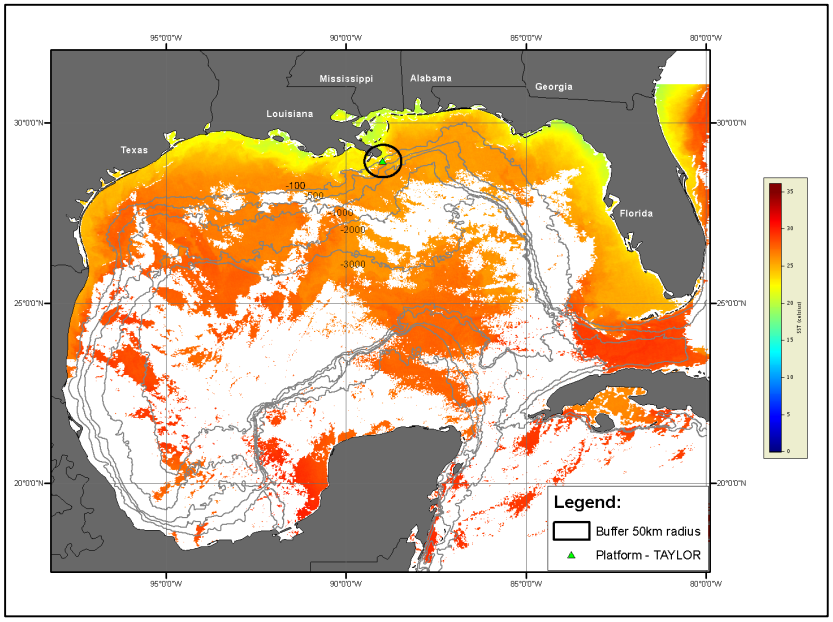


Fig.63b - SST image at 20:27 UTC

For the wind field it was used ASCAT sensor data that crossed the area of interest at 15:21 UTC on the 16th showing a wind blowing from N with intensity between 4 - 2 knots. On the other hand, the data obtained by 10 meteorological buoys showed that 9 of these buoys the wind was blowing from NE and in only one the wind blew to S with intensities ranging from 2 - 6 knots.

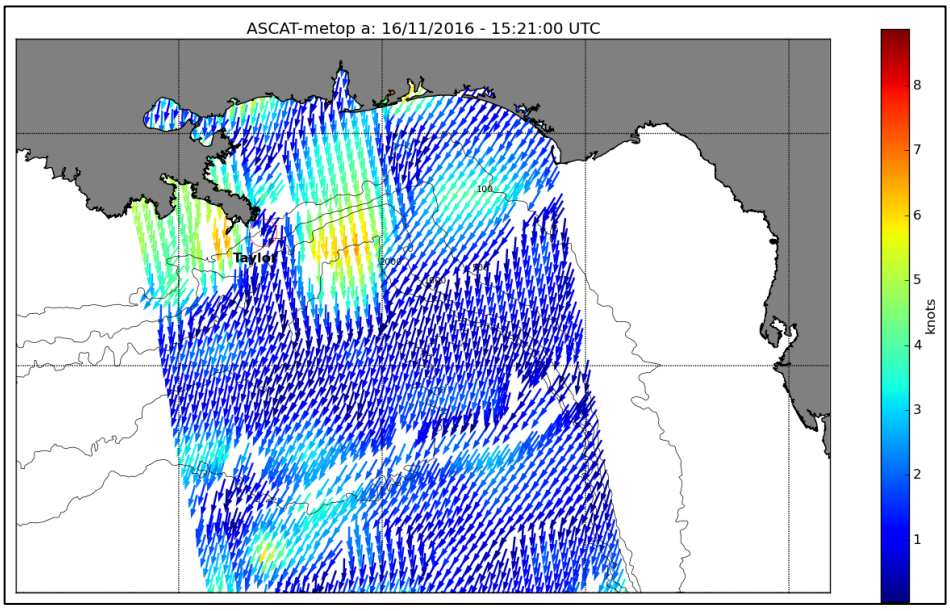


Fig.64a - wind field obtained by ASCAT near the area of interest at 15:21 UTC

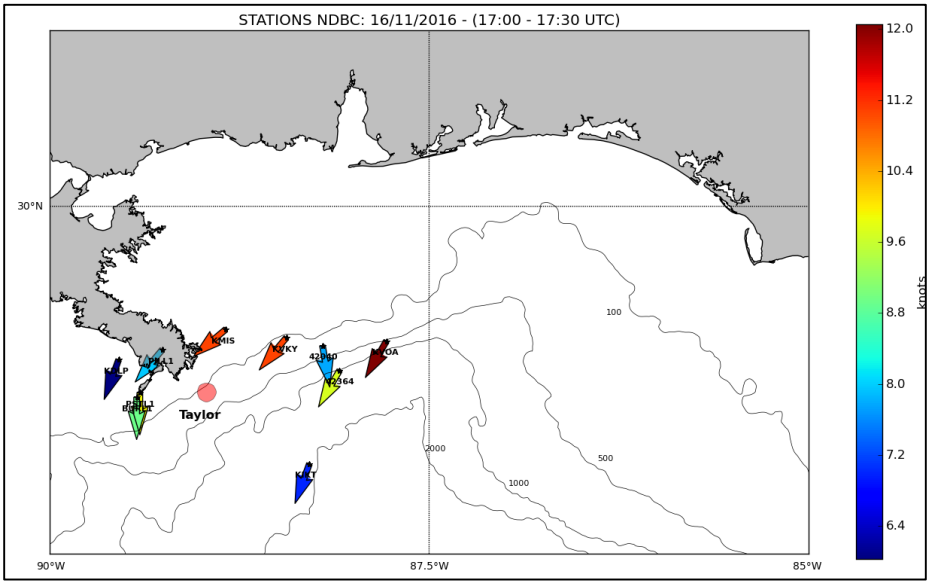


Fig.64b - wind field insitu obtained by buoys near the area of interest at 00: 00UTC

The currents obtained through the HF radar showed a predominant current from E, and closest to the Taylor region currents from S-SE with velocities ranging from 6-10 cm/s.

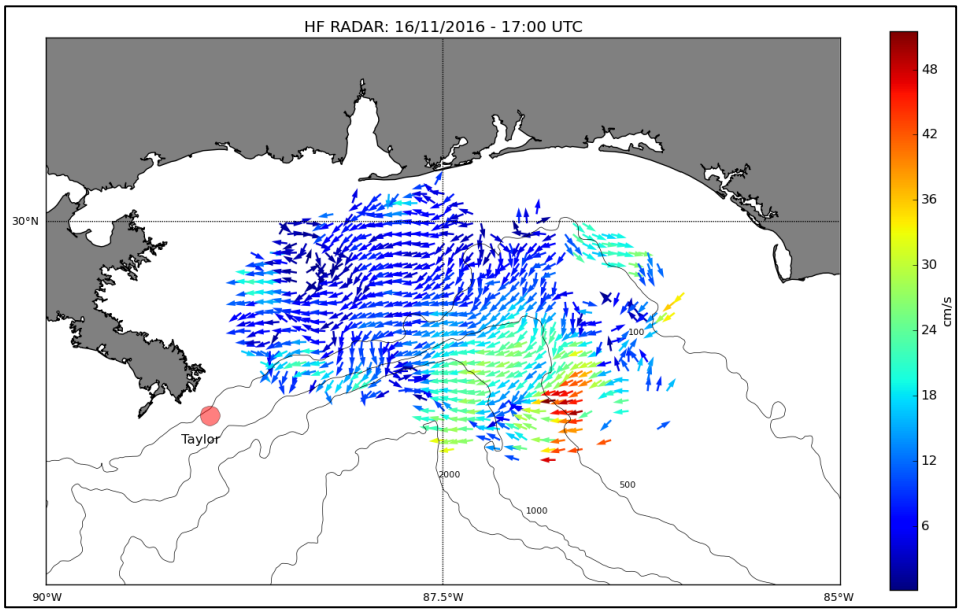


Fig.65a - current data obtained by HF radar closest to the Taylor area at 17:00 UTC

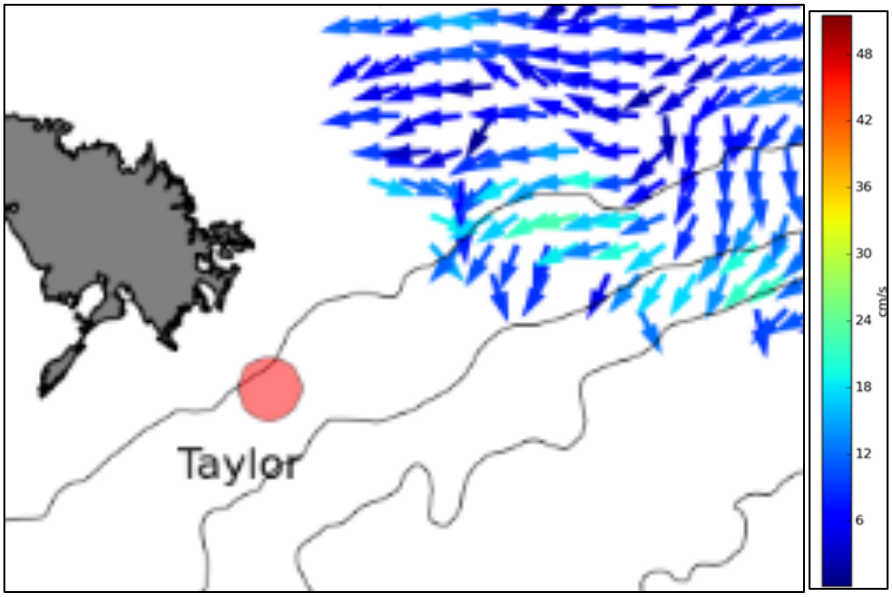


Fig.65b - current data close to the Taylor area showing a reversal in the current direction.

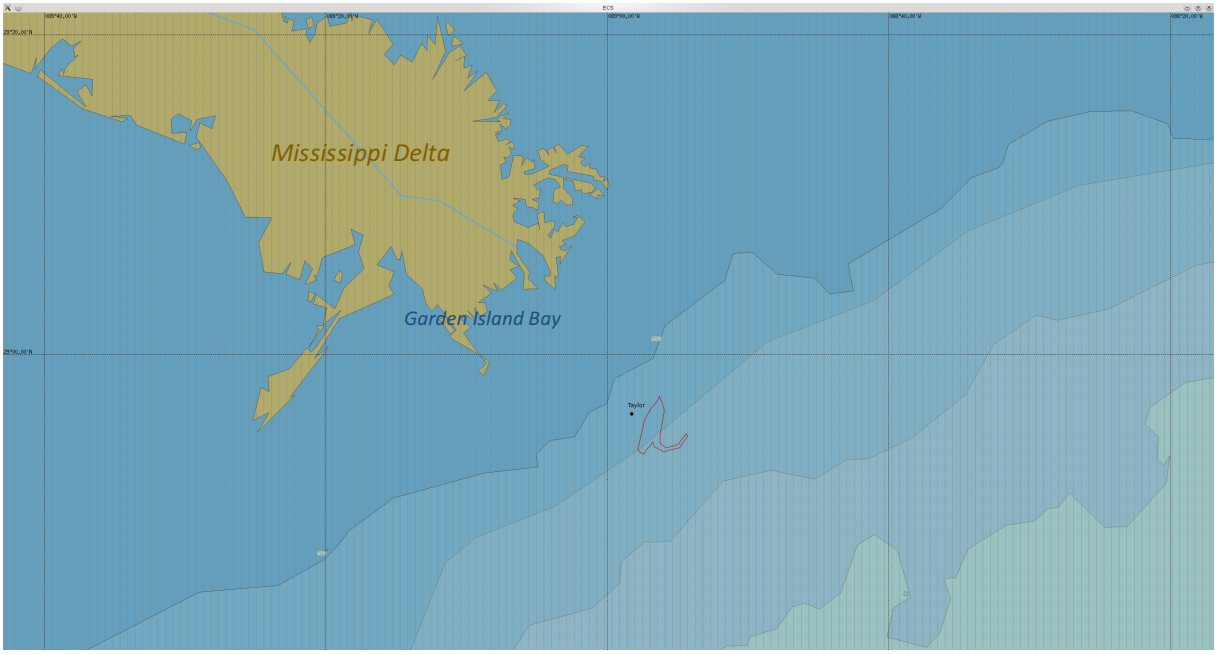


Fig.66 – November 16th slick position

Metocean data showed the SST field with values between 23 - 25 °C or 73, 4 - 77 °F, presenting the expected value for region. Winds were blowing from N-NE with intensities of 2-6 knots and currents flowing from SW-S with velocities ranging from 6-10 cm / s. Taking Taylor's position as our source of

leakage, it became very clear that the oil drift was for SE showing that the Poseidon Platform sensors associated with the meteocean data were able to map the oil drift in the region of interest.

3.6.5 Metocean Conditions November 17th

- Day Mission Start: 5:14 p.m. (11:14 CST)
- Day Mission End: 7:20 p.m. (13:20 CST)
- Night Mission Start 22: 44Z (16:44 CST)
- Night Mission End: 01: 23Z (19:23 CST)

An image of the SST field of the area of interest was obtained at 20:16 UTC. Despite the cloudiness that contaminated the image a little, it was possible to observe the field of SST with temperatures varying between 22-25 °C in the Taylor area (Fig.67a and 67b).

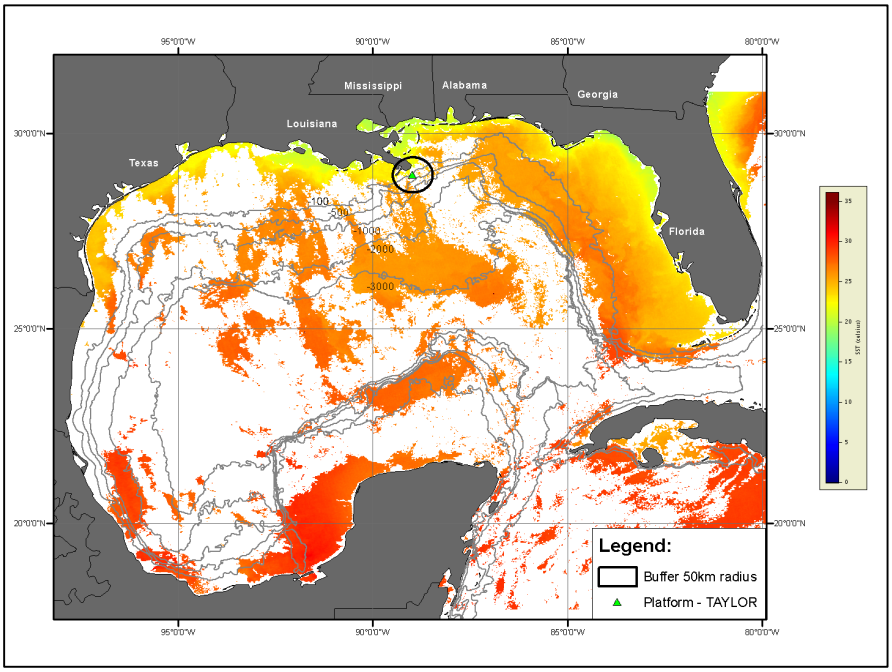


Fig.67a - SST image at 20:16 UTC

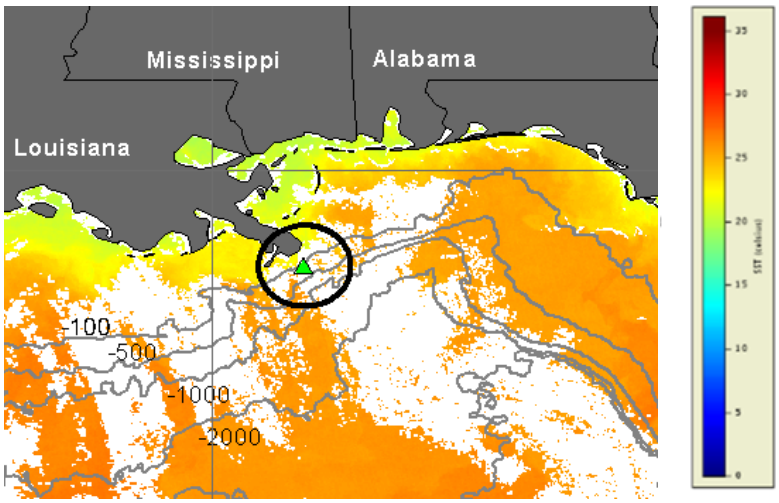


Fig.67b - Details of the SST field in Taylor area at 20:16 UTC

For the image obtained at 00:14 UTC the 18th of November the dominant temperature in the region was between 24 and 25° C (Fig.67c and 67d).

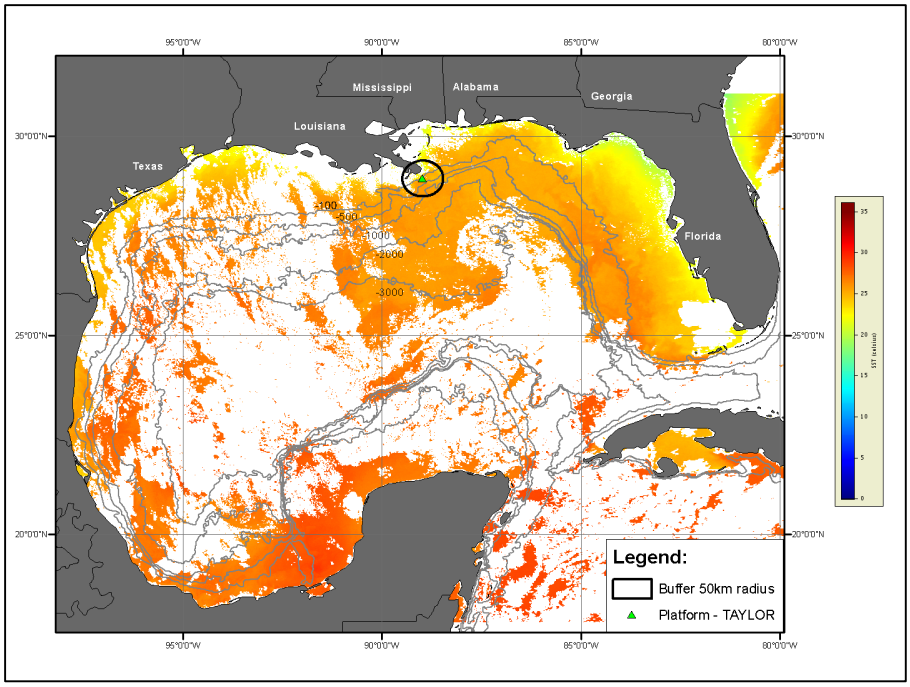


Fig.67c - SST image at 00:14 UTC

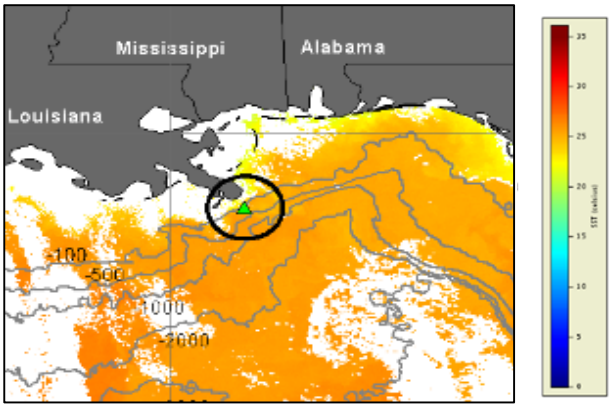


Fig.67d - Details of the SST field in the Taylor area 00:14 UTC

No image of the ASCAT sensor could be obtained for this date. However, it was possible to obtain insitu data collected by the meteorological buoys in the region of interest. The meteorological stations showed winds blowing from SE between 6 and 12 knots.

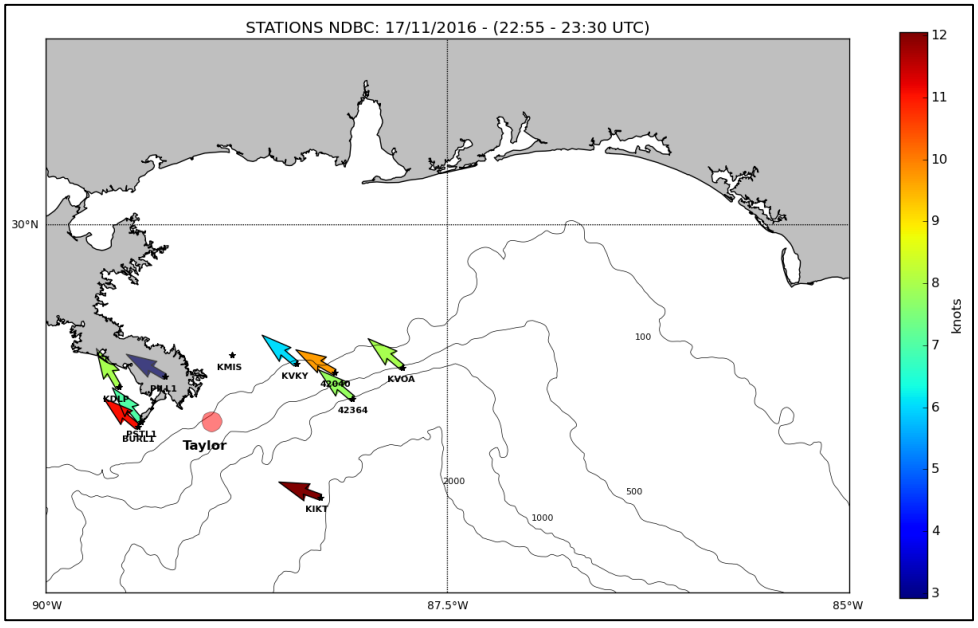


Figure 68 - wind field insitu obtained by buoys near the area of interest at 22:55 - 23:30 UTC

The data of currents obtained by the HF Radar were not enough to cover the area near Taylor, so cannot be used to make a more accurate analysis of the current drift in the region (Fig.69).

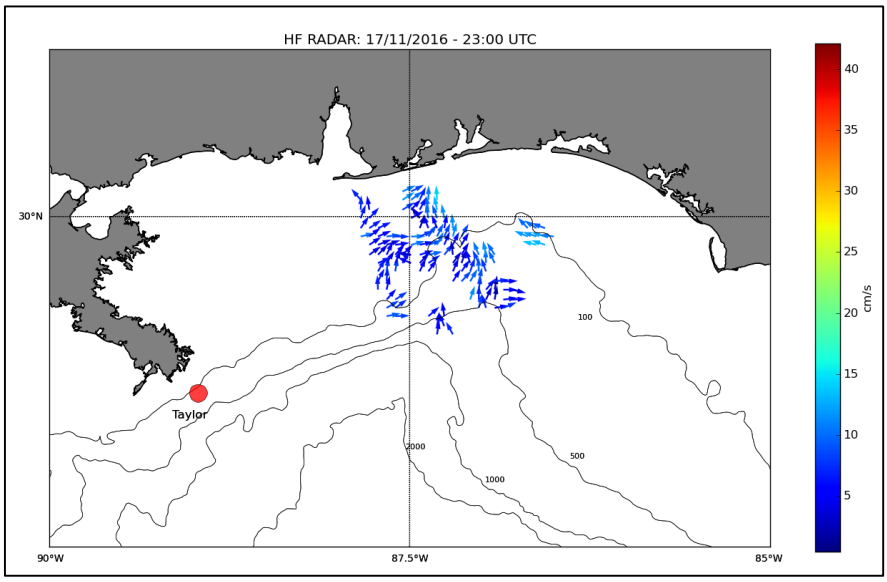


Figure 69- data from currents obtained by HF radar distant from the Taylor area at 23:00 UTC

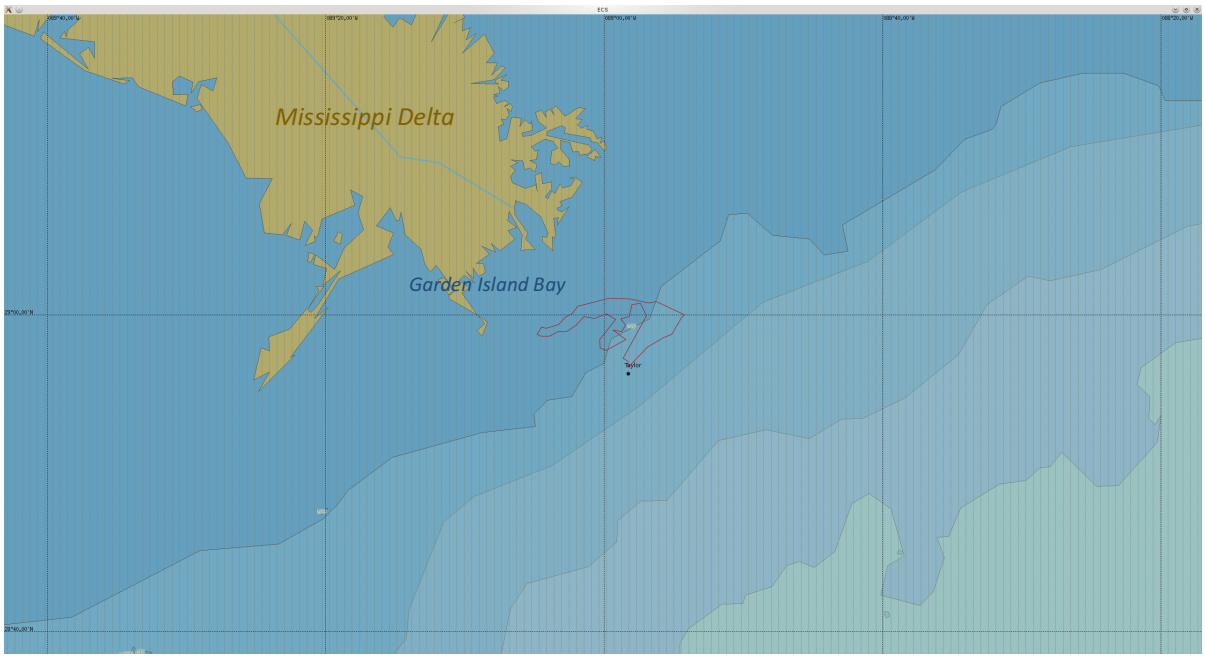


Fig.70 – November 17th slick position – day mission

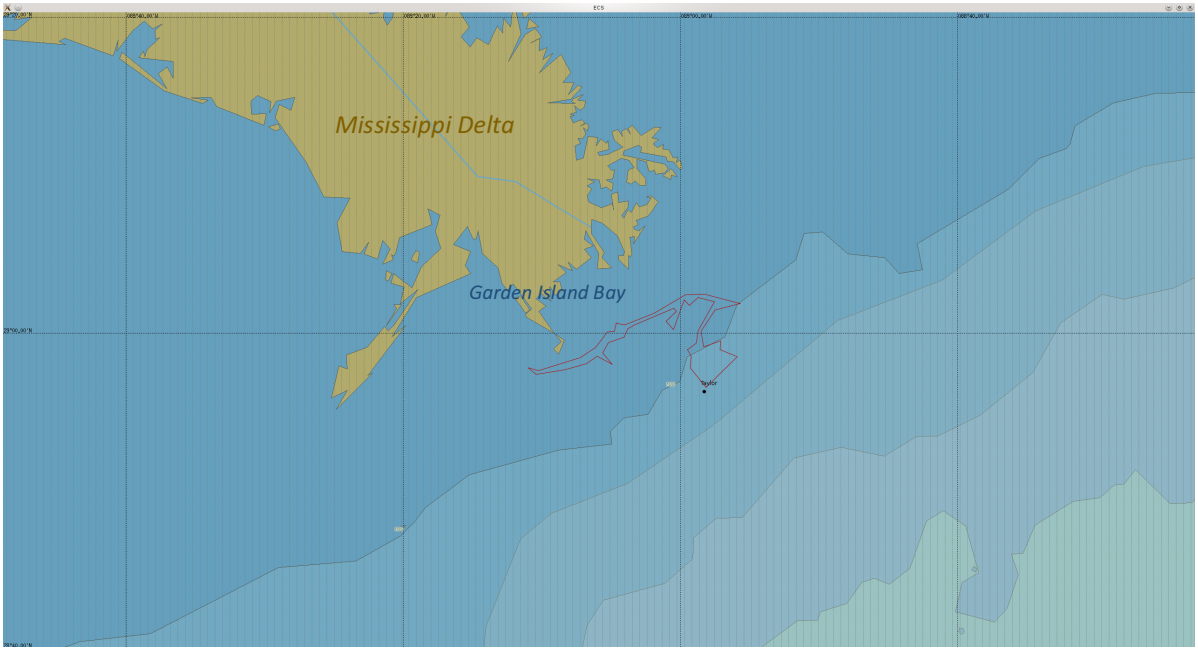


Fig.71 – November 17th slick position – night mission

Considering the last two flights over Taylor region we can note that the SST field remained in the same conditions of the last days with values between 24 and 25 °C or 75, 2 - 77 °F. The wind in the region was blowing from SE with intensities of 6 - 12 knots. Unfortunately, it was not possible to obtain current data for region.

Regarding the drift of the spot, it seems that at the moment of both overflights the wind was blowing from SE and a possible current flowing to N-NW forced the Taylor spill to drift in this direction. If it was possible to have current data during the flights it could reinforce the analysis. However it has been proven that the combination of the data obtained from the Poseidon platform with Metocean data is a powerful tool in the identification and prediction of oil leaks at sea.

3.6.6 Dynamic Behavior of the Spill

The following table summarizes the position and configuration of the slick between the 14th and the 17th of November.

Collection	Centroid LAT	Centroid LON	Area [Square NM]	Dimensions [NM]
Mission#1	28°56'30" N	088°58'24" W	0.89	1.5 x 1.5
Mission#2	28°56'38" N	088°56'48" W	0.89	0.66 x 2.37
Mission#3	28°55'17" N	088°56'36" W	3.60	3.03 x 3.32
Mission#4	28°59'26" N	088°58'35" W	13.00	4.48 x 8.32
Mission#5	28°59'22" N	089°00'43" W	12.00	5.89 x 13.15

Table 1 – Slick position and geometry during the 5 Missions

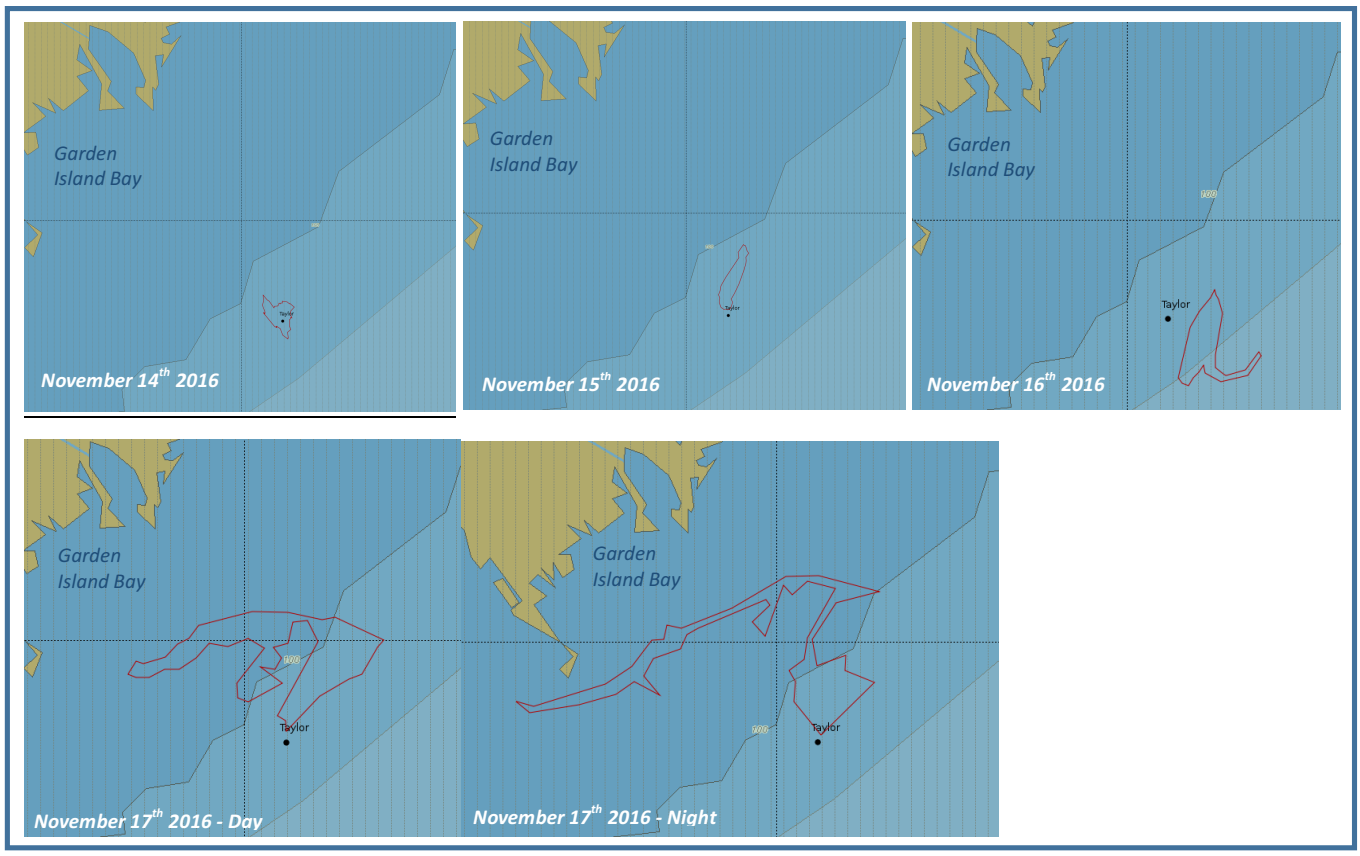


Fig.72 – Slick evolution during the 5 Missions

3.7 Thickness 3D map and Volume Calculation

The information collected during the flights allow to have a good estimate of the volume of the spilled oil in the area. As an example, the mission of the 15th of November has been considered.

3.7.1 Volume Estimation Methodology

Among other capabilities, POSEIDON Sensors allow for real time Absolute Oil Thickness and quantitative Volume estimation, Hot-Spots identification and determination of oil as recoverable and non-recoverable, and accurate Post Spill Analysis for NRDA (Natural Resources Damage Assessment).
Absolute Oil Thickness is measured by the Microwave Radiometer (MWR) that measures the absolute thickness in the 50µm - 3mm range and by the Laser Fluorosensor (LFS) that measures absolute thickness in the 0.1µm – 20µm range depending on the type of oil.
IR/UV sensor complements the information with Relative Thickness Mapping: Ultraviolet Line Scanner UV is sensitive from 0.01µm, Infrared Line Scanner IR is sensitive from 2µm.
The fusion of the information from MWR, LFS, IR/UV allows to build accurate Thickness Maps in the 0.01µm to 3mm range.
The Thickness Map, and the area of the polygons that enclose the spill, or the patches of the spill, determined with the Far or Near Range Sensors allows the quantification of the Volume of the spill. Typical accuracy is 70-90% depending on the environmental conditions. The methodology for the estimate of the volume follows three steps:

- Synoptic Overview: the far range SLAR acquisition allows to determine the overall extent of the spill and to plan the next steps for near range analysis.
- To build a 'Thickness Map' the overall spill area is overflown in parallel patterns with overlaps to ensure the complete coverage of the area. Flight Lines are 2,000ft apart. In case of small and medium spills the standard flight altitude is 1,000ft that allows for coverage swath of 2,000ft. In case of extended spills the altitude can increase to 3,000ft to guarantee a wider

sensor swath of 1NM. In case of spills with exceptional dimensions, other techniques can be put in place to ensure wider coverage without increase excessively the flight time.

- Scan rate of the sensors is 20Hz that means that the sensors can acquire thickness information each 4.5 meters at a cruise speed of 180 Kts.

3.7.2 Example of Volume Estimation – November 15th Collection

The 15th of November the spill structure had a predominant N-S direction, determined possibly by the wind/current configuration. The area was delimited by a polygon of approximately 0.66x2.37NM with a coverage of 58% and a resultant area of the surface target of 0.89 square nautical miles. Polygon was centered on the following coordinates: N 28°56'38" W 088°56'48".

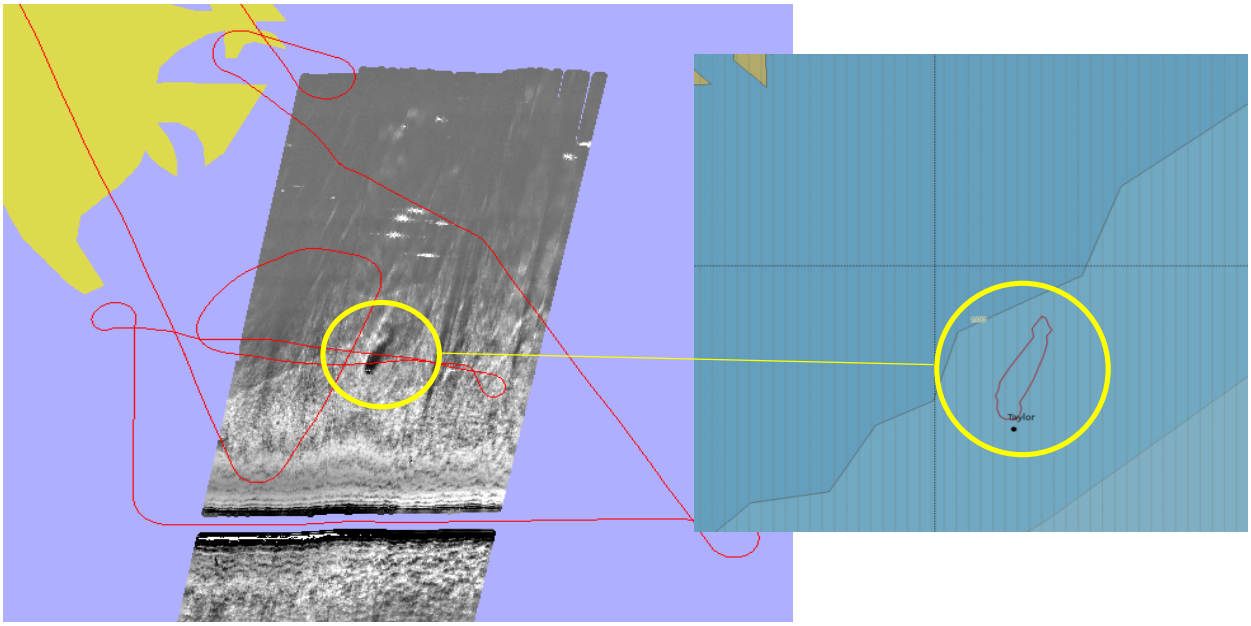


Fig.73 – Spill structure the 15th of November

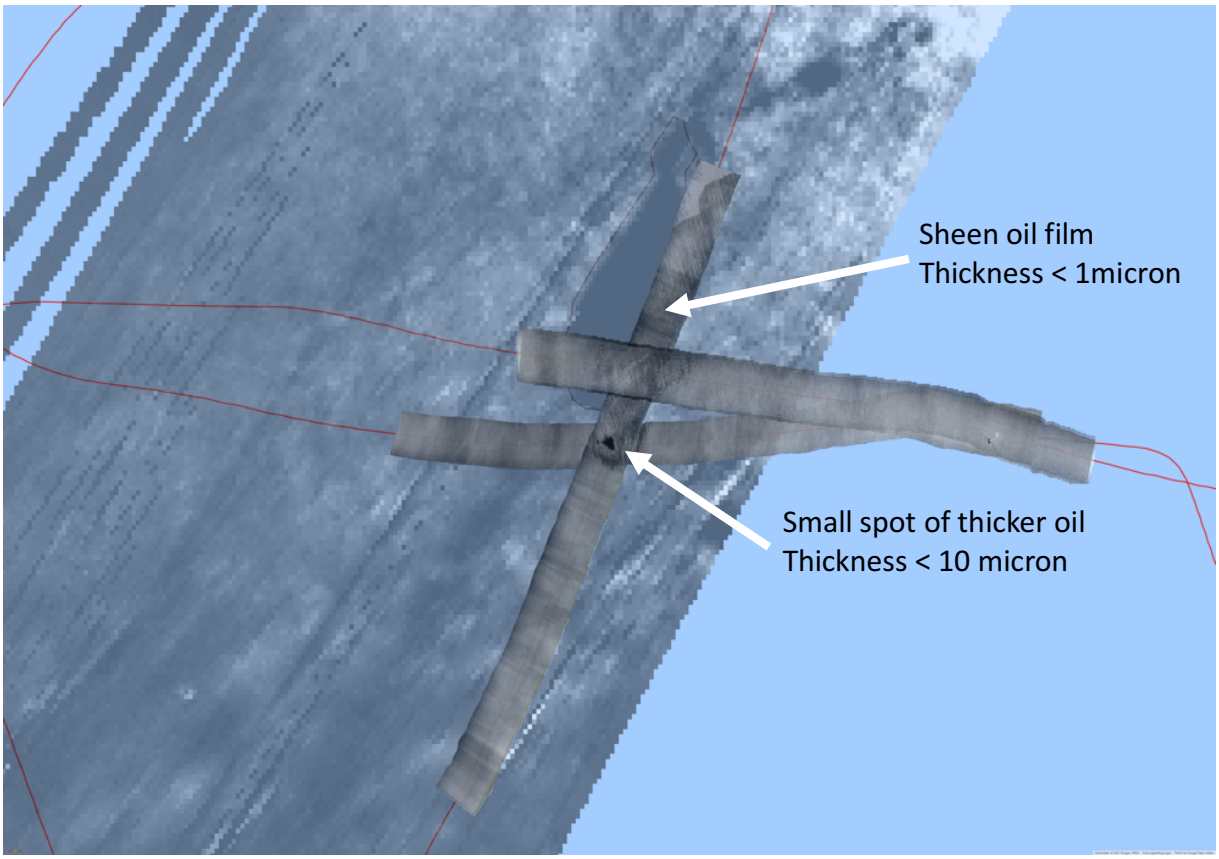


Fig.74 – Georeferenced image of the flight path and the IR scan swath

Fig.74 shows the georeferenced image of the flight path and the IR scan over the Taylor area the 15th of November. Set of data were acquired with LFS, IR/UV, VIS, SLAR. Image show a prevalent light sheen about 1 µm with a spot of thicker oil with thickness less that 10 µm.

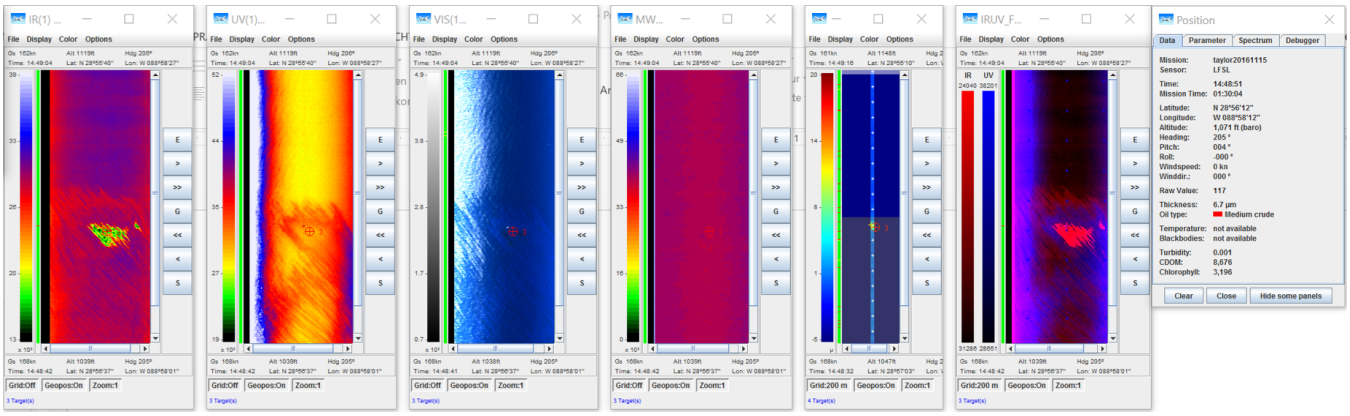


Fig.75 - Sensor Data waterfall

Fig.75 shows the data waterfall from all the Near Range sensors, IR, UV, VIS, MWR, LFS, Fusion IR/UV. LFS was used to determine the absolute thickness of the spill. In this particular location it shows a thickness of 6.7µm. MWR is sensitive starting for thickness > 50µm, in this case the thickness was less than 10µm in most of the area, so far below the MWR sensitivity.

Based on the LFS and IR/UV data a thickness map has been built, Fig.76 below.

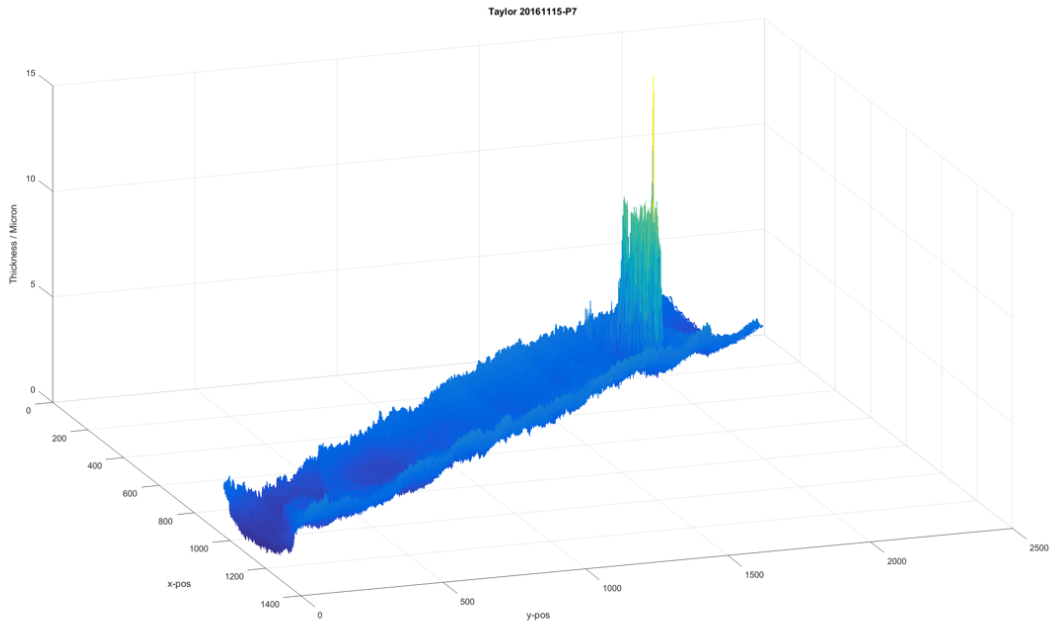


Fig.76 – Thickness Map

The map has been originated with data acquired with the IR/UV an the LFS that measured the absolute thickness with a scan frequency of 20Hz (thickness point every 4.5 meters).

It shows a thin sheen of about less than 2 µm, quite uniform in the overall spill area (3.05 sq.km), and a limited area (about 10% of the total) with a higher concentration of oil, and a thickness peak of about 12µm. This pattern was confirmed by the signature of all the sensors, IR, UV, VIS, LFS.

Based on the area of the polygon, 3.05 sq.km and the thickness distribution from the 3D map, during the mission of the 15th of November the estimated volume was **4.880 m^3** equivalent to **1,290 Gal**.

4 Conclusions

Between the 14th and the 17th of November tests were promoted by BSEE and NOAA at the former Taylor Platform Site in order to assess and better understand the capabilities of remote sensing tools and other ways of collecting data, in an effort to enhance the ability to detect and measure oil spills offshore. Fototerra was invited to take part of the project with the airborne remote sensing platform Poseidon.
The general objective of the open water test in Taylor, in line with the BSEE / NOAA goals, was to present the capabilities of the Poseidon platform in a real oil spill scenario and acquire data for surface oil detection and characterization, and show how the information and the methodologies can be effectively used in future oil spill responses, in permanent coastal surveillance, and natural damage assessment.
All the missions flown provided particularly significant results, the sensors were imaging the spill consistently providing the operators with detailed information of the spill on the far range and near range environments. Poseidon was capable to provide synoptic information of the overall spill as well as detailed spill analysis. The integrated navigation system, data processing and communication system complemented the sensor capabilities, making the operations extremely effective and efficient and showing how the platform will be effective in a real spill response.
Data were collected and processed in flight to obtain the following information: Synoptic overview and overall aerial extend of the spill, area of the spill, center coordinates of the oil spill, oil distribution map, oil type classification, oil thickness, indication of hotspots when present, and dynamic properties of the spill (e.g., drift and spreading of the oil on the sea surface).
The above-mentioned information was made available in real-time during the flight. During real operations, this capacity enables the operator to continuously report to the Incident Command Center and to the Responders to support the decision-making process with real-time data and so to dramatically improve the oil recovery process. This Document describes basic physical principles of the sensors and reports the first results of the data collections as well as the combination with metocean data that improve also the prediction of dynamic behavior of the spill.

Attachment I. Fototerra MC20 April 2017 Report

Fototerra

Taylor Energy Site 2nd Campaign - Offshore Oil Spill Remote Sensing Test

Report

Rev.1 – May 2nd 2017

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"The findings and opinions expressed in this report are solely those of the authors and do not necessarily reflect the views and policies of the Bureau of Safety and Environmental Enforcement, nor does mention of the trade names or commercial products constitute endorsement or recommendation for use."

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1 Executive Summary

Fototerra is taking part of a series of tests coordinated by BSEE and NOAA to support the Deepwater Horizon spill ongoing lessons learned with the aim to provide control and validation for surface oiling characterization efforts and to establish spatial and airborne data libraries necessary to use these techniques for future response and damage assessment. To advance the understanding for oil spill preparedness, BSEE and NOAA organized open water data collection experiments from multiple sensors and platforms. Aim of these experiments is to demonstrate how each sensor detects oil in the same physical and environmental conditions.

The open water collection took place between Apr 25th and Apr 27th 2017 in the area of the former Taylor Energy's production platform on Mississippi Canyon 20-A. The platform and its pipelines were destroyed in 2004, when Hurricane Ivan crossed the area. Since then, plumes of oil and gas are found seeping from the sea floor in the vicinity of both the well casings and the downed platform and oil has been spotted leaking at the site ever since. Fototerra participates in this event with the Poseidon platform equipped with its multi-sensors system. POSEIDON is an integrated system built on three blocks: multi-sensor platform, real time analysis and high-speed high-capacity communication. Capabilities include: detection of surface films (oil and pollutants); mapping of relative thickness; oil and pollutants type classification; measurement of absolute thickness and volume; determination of position, area, drift and spreading of the spill; preservation of evidence and real time data communication and mission coordination.

2 Introduction

The test campaign coordinated by BSEE and NOAA is composed of 3 Phases. Phase#1 - Controlled Experiment at Ohmsett, Phase#2 – Open Water testing at Taylor Energy site and Phase#3 - Operational Tools Algorithms and Training. Fototerra was involved in Phase#1 and Phase#2:

Phase#1 - Controlled experiment at Ohmsett Test Tank.

Between the 10th and the 21st of July 2016 Fototerra performed two series of tests: a bridge-mounted test in Ohmsett with Laser Fluorosensor (LFS) and Microwave Radiometer (MWR) and an overflight test with the entire suite of sensors. The LFS determined clearly the classification of the oil and the MWR determined with precision the thickness of the oil. The overflights, despite the challenging contained environment of the 200m by 20m test tank, provided very good results and the sensors from Medusa were imaging the area of the tank consistently. Results from Phase#1 were presented previously in a dedicated Report.

Phase#2 - Open Water testing at Taylor Energy site.

Between the 14th and the 18th of November 2016 (1st Offshore Campaign) and between the 25th and the 27th of April 2017 (2nd Offshore Campaign) Fototerra performed data acquisition with the full suite of sensors including SLAR, in daytime and nighttime conditions at the Taylor Energy Site in the Gulf of Mexico, about 90NM southeast of New Orleans. Data were collected and processed to obtain the following information: identification of the target, synoptic overview and overall aerial extend of the spill, area, center coordinates of the oil spill, oil distribution map, oil type classification, oil thickness, indication of hotspots when present, and dynamic properties of the spill (e.g., drift and spreading of the oil on the sea surface).

The above-mentioned information was made available in real-time during the flight. During real operations, this capacity enables the operator to continuously report to the Incident Command Center supporting the decision-making process with real-time data and so to greatly improve the oil recovery process. This preliminary report aims to show chronology and the preliminary results of Phase#2.

3 Chronology and Preliminary Results

3.1 General Objective

The general objective of the open water test in Taylor, in line with the BSEE / NOAA goals, was to present the capabilities of the Poseidon platform in a real oil spill scenario and acquire data for surface oil detection and characterization, and show how the information acquired and the methodologies adopted can be used in future oil spill responses, in permanent coastal surveillance and natural damage assessment.

3.2 Specific Objective

Fototerra's specific objective was to perform planned overflights over the Taylor Energy platform site during the week of the 24th of April 2017 per the following schedule set up by BSEE and NOAA and based on satellite acquisition times. A specific objective of the 2nd Campaign was to demonstrate the capability to transmit data during the flight to ground stations preset along the route.

3.3 Poseidon Technology

For the open water test in Taylor, Fototerra utilized the full Poseidon platform.

Poseidon platform is built on three blocks: multisensor environment, real time data processing and communication.

POSEIDON's integrated multisensor platform is divided into far-range detection and near-range analysis. Far-range detection is based on the use of a real aperture radar system SLAR (side-looking airborne radar), which covers swaths of several tens of nautical miles (NM). Targets detected by the radar are then investigated on site using near-range sensors. Near-range analysis of oil spills includes visualization, quantification and classification of the type of oil. Near-range detection sensors include: IR/UV (infrared ultraviolet) scanner, VIS (visual line) scanner, EO/IR (electro-optical infrared), MWR (microwave radiometer), LFS (laser fluorosensor). For SAR (Search and Rescue) support the POSEIDON is equipped with: direction finder and AIS. The platform is completed by a mission control system for real-time data processing and analysis and communication systems—broadband radio, satellite, satellite phone, VHF.

Side Looking Airborne Radar (SLAR) is a X-band microwave radar. Flying at an altitude between 1,000 and 6,000 ft., SLAR has a cross-track swath between 35 and 50 NM. Oil spill detection by radar is based on the principle that oil spills and biogenic slicks or specific hydrodynamic effects may result in a reduction of the radar backscatter signal due to the dampening of surface wave structures. SLAR is an all-weather sensor: Microwaves can penetrate clouds, fog, drizzle and rain. SLAR allows POSEIDON to cover more than 7,500 square nautical miles per hour.

Infrared Ultraviolet (IR/UV) imaging device is a standard instrument for near-range monitoring of oil spills and has shown its reliability, stability and operability over decades. At the near-range operational altitude of about 1,000 ft the swath width is between 2,000 and 3,000 ft. Films of crude oil in water can be detected in thermal IR because oil has a lower integral emissivity than the surrounding water in the spectral region, and oil can be heated up through absorption of sunlight if there is enough thickness. Minimum detectable oil thickness in the thermal IR starts from 2 μm; hotspots that are generated through absorption of sunlight appear in the thickness range up to 500

μm. UV remote sensing of oil is based on the fact that the air/oil interface of the oil film has about twice the integral near UV reflectance of the water. The UV can detect very thin sheens of oil; the minimum detectable thickness amounts to 0.01 μm. The combined IR/UV device shows the area of large and intermediate film thickness, as well as the total extent of the oil spill.

Visual Line Scanner (VIS) is used for acquisition of highly resolved georeferenced RGB (Red Green Blue) images. The RGB line scanner combines high mapping and georeferencing accuracy with the acquisition of color information that allows volume estimations based on oil appearance codes. The Microwave Radiometer (MWR) is a passive microwave remote sensor used to map oil layers exceeding a thickness of 50 μm. Oil spills appear as a brighter object in the microwave region relative to the oil-free surface. The MWR allows determination of the absolute thickness of the oil spill and, therefore, the volume of the spill. In addition, the difference of sensitivity between MWR and IR/UV allows determination of the hotspots of the spill where the bulk of the oil is concentrated. This feature is greatly important for the responders. MWR is an all-weather sensor. At the near-range operational altitude, the swath width is about 2,000 ft.

The Laser Fluorosensor (LFS) is based on a high-power UV laser that sends short pulses toward the water surface. The laser-induced fluorescence and backscatter are received by a telescope and separate spectrally into a number of monochromatic signals. The detected discrete emission spectrum is used to estimate the oil class and classify the oil and to evaluate the absolute thickness of thin slicks in the range of 1 – 20 μm. The system has a pre-existing library of substances used to compare the actual detection.

Electro Optical Infrared (EO/IR) is an airborne observation system with HD sensors and HD video outputs. It is equipped with RGB and NIR (near-infrared) optics, multispectral zoom laser range finders, illuminators and pointers (red or NIR). The device delivers color and NIR images that allow situational awareness in all conditions day and night in critical SAR operations, navigation in challenging conditions, and clear images of the scene.

The mission control system computer provides sensor management, online visualization, real-time sensor fusion, data analysis and data storage in a central multimission unit. All operations are

facilitated by an ergonomic graphical user interface (GUI). In contrast to traditional systems, which mainly perform visualization and storage of non-georeferenced sensor images, the system allows real-time data fusion, georeferencing and analysis of multisensor oil spill data.

3.4 Methodology

The methodology used during each flight follows the standard procedure that Fototerra adopt for an actual response operation, that includes: Step#1: Synoptic overview of the spill, Step#2: spill approach and Near Range Analysis, and Step#3: Data Processing and Data Communication.

Step#1: Poseidon approaches the Spill Area at an altitude of 3,000ft, scanning the area with the SLAR. At that altitude the Swath is about 50NM and the total area scanned is about 7,500 square nautical miles, the SLAR is a microwave real aperture radar effective in all weather, night and day conditions. The EO/IR sensor is also a good support on this phase giving the operator a night and day vision of the scene. During every operation Poseidon monitors possible marine and aviation distress frequencies with the Direction Finder, and ship traffic with the AIS (Automatic Information System). After the identification, the target is analyzed and georeferenced, to allow for an immediate localization on the navigation map and successive detailed analysis with the near range sensors. In this stage a polygon is designed around the target and information as area, coverage, overall dimensions and coordinates of the spill are determined. As the aircraft approaches the spill for the overflights with the near range sensors, the operator records the video the overall spill with the EO/IR to have a visual, or thermal at night, overview of the spill.

Step#2: Based on the far range overall images of the spill, the operator determines the best approach to be used for the following low level overflights in order to make the best detailed analysis of the spill. When the flight pattern is determined, the aircraft overflies the spill at an altitude of 1,000ft operating all the near range sensor that at that altitude have a swath of about 2,000ft. Near range sensors include: IR, UV, VIS, MWR, LFS. EO/IR and Direction Finder at this stage are still operational giving the operator support where necessary.

3.5 Chronology

Fototerra Mission Base for the Test Campaign has been the Houma-Terrebonne airport (KHUM), conveniently located about 100NM NW of the Taylor location, and logistic support of most aviation offshore activities. Flight from KHUM to Taylor location required about 35' at 185KT of cruise airspeed. Every flight required to file a special DVFR (Defensive Visual Flight Rules) Flight Plan because the vicinity of Taylor to the ADIZ (Air Defense Interception Zone) that requires to follow special FAA rules. Extensive Helicopter and Aircraft Traffic Areas in the GoM required special attention, continuous contact with ATC (Air Traffic Control) and careful monitoring of local common traffic frequencies.

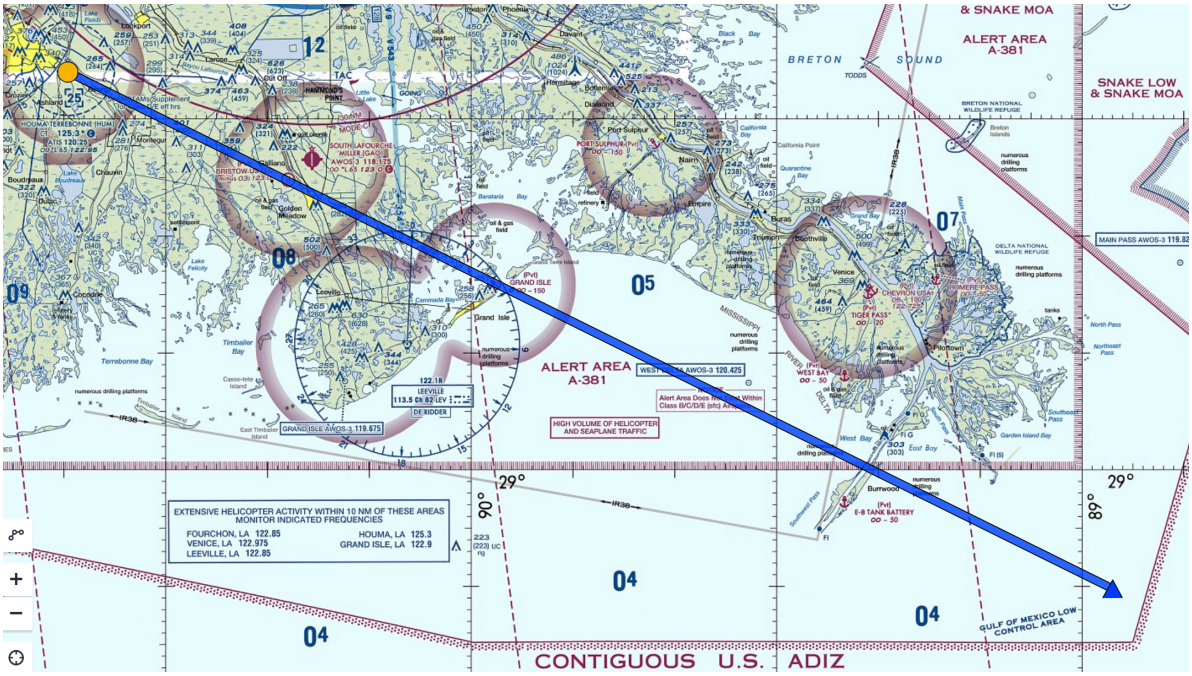

Fig.1 - Flight route from Houma-Terrebonne (KHUM) Airport to Taylor Energy site location.

The chronology of the flights (Mission IN – Mission OUT) has been the following:

April 25th Collections

Mission Start: 16:30Z (11:30 CST)

Mission End: 19:15Z (14:15 CST)

Mission Duration: 2h 45'

April 26th Collections

Mission Start: 16:35Z (11:35 CST)

Mission End: 18:40Z (13:40 CST)

Mission Duration: 2h 05'

April 27th Collections

Mission Start: 22:45Z (17:45 CST)

Mission End: 01:35Z (20:35 CST)

Mission Duration: 2h 50'

3.5.1 Mission#1 – April 25th Collections

In the morning of April 25th EMB-110 Poseidon left Houma-Terrebonne airport at 11:30 CST. Poseidon approached the Taylor area with a SE track at 3,000 ft and about 185KT of cruise speed.

Step#1 - Synoptic Overview: the SLAR immediately detected a structure with strongly reduced backscatter that was identified as a surface target. The structure was delimited by a polygon of approximately 3.86x7.11 NM with a coverage of 48% and a resultant area of the surface target of 13.1 square nautical miles. Polygon was centered on the following coordinates: N 28°55'43" W 088°55'14". The following figures show the SLAR images taken from two different flight directions, the georeferenced polygon, and the resultant SLAR georeferenced image with and without flight track (Fig.2 to Fig.5).

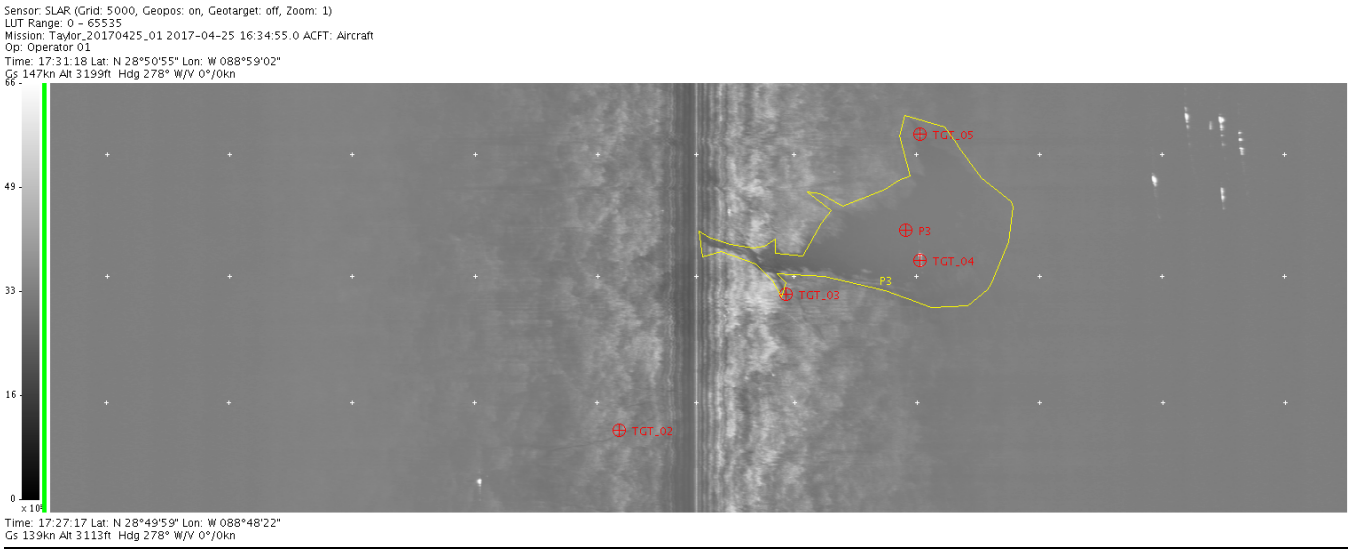

Fig.2 - SLAR images of the spill: NW to SE approach

During the same mission two more oil slick were identified with the SLAR. The first about 55NM NW of Taylor, of about 0.6 square nautical miles, the second 12NM SW of Taylor of about 1.2 square nautical miles (Fig.3).

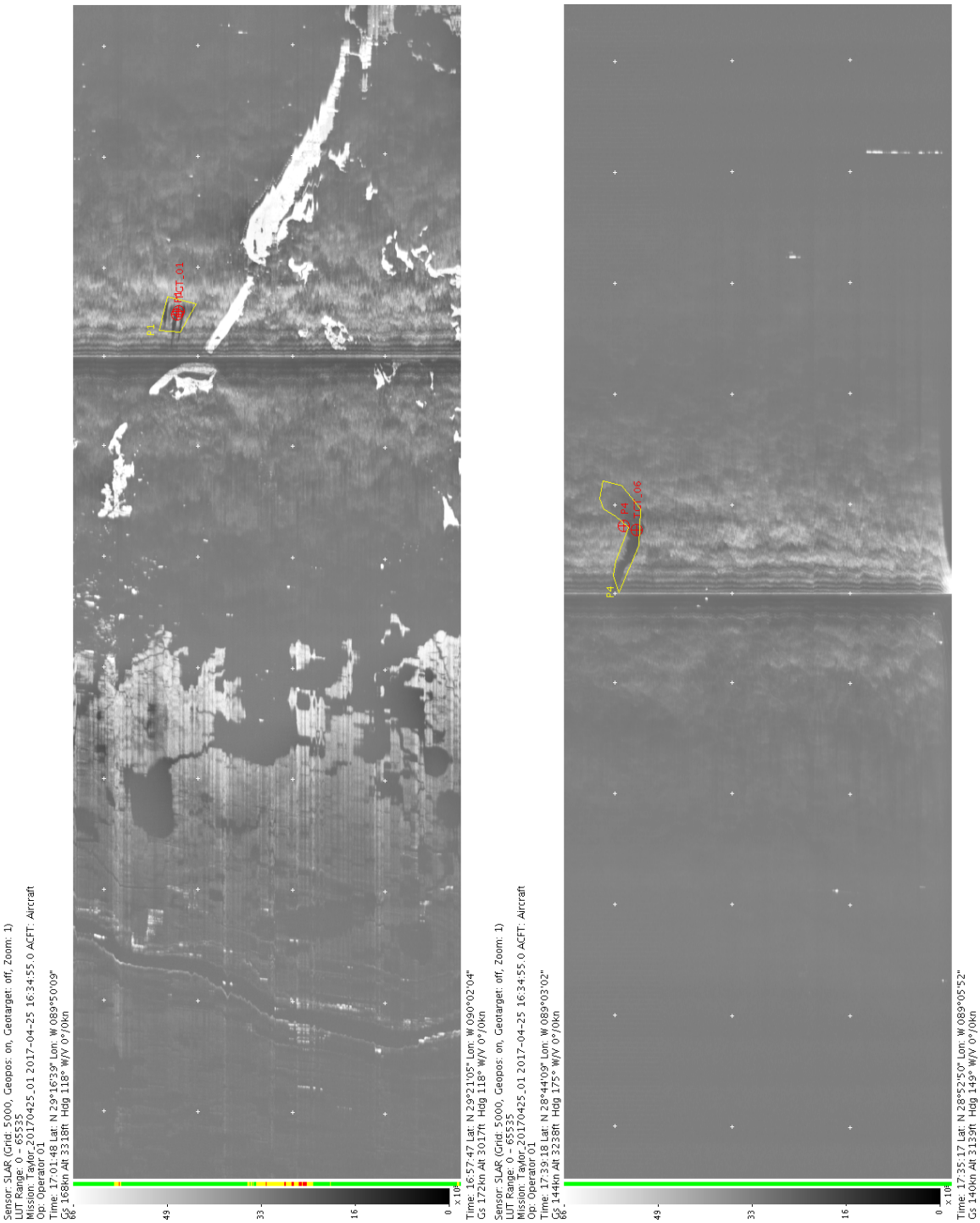

Fig.3 - SLAR images of two spills encountered during the mission

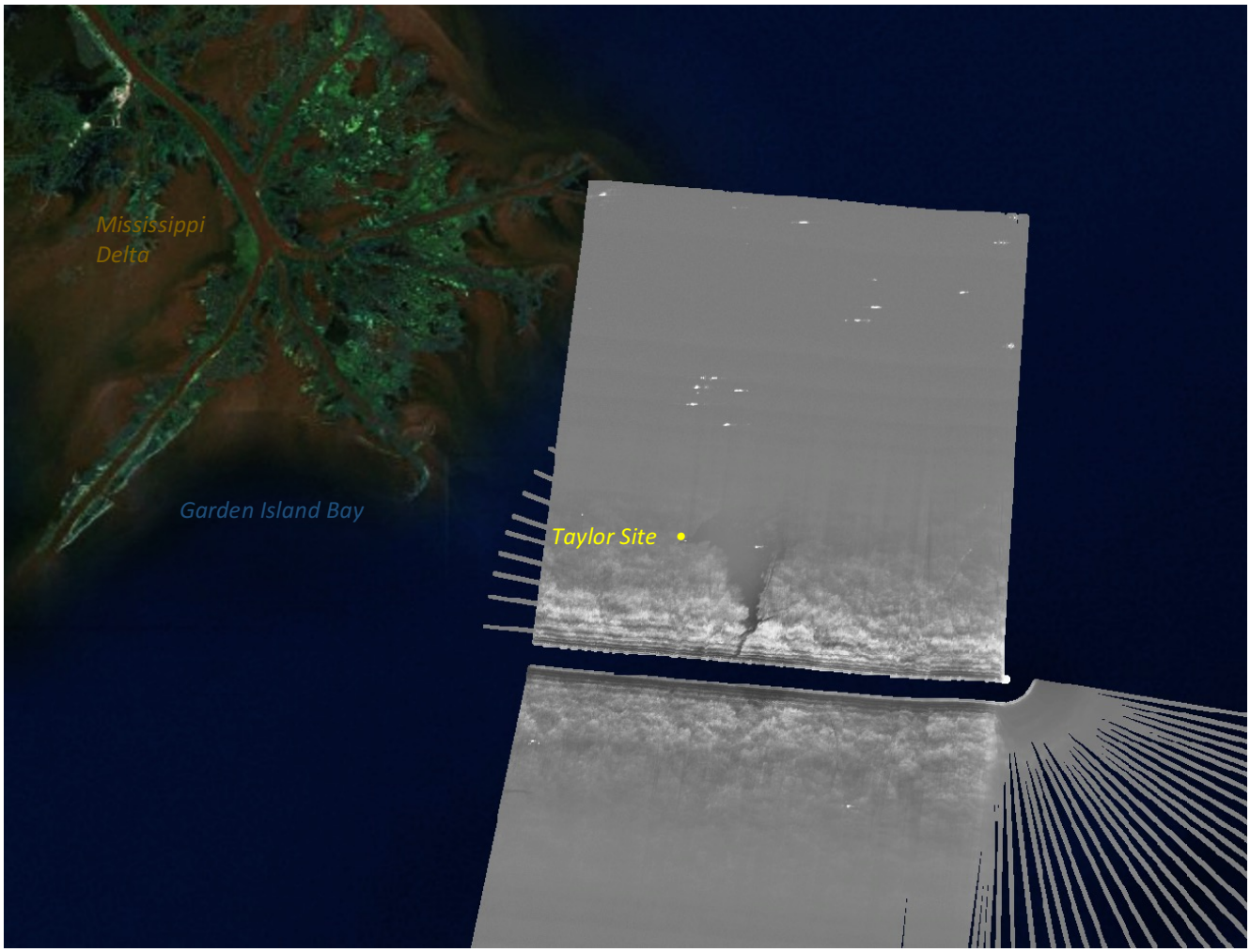

Fig.4 - SLAR georeferenced image

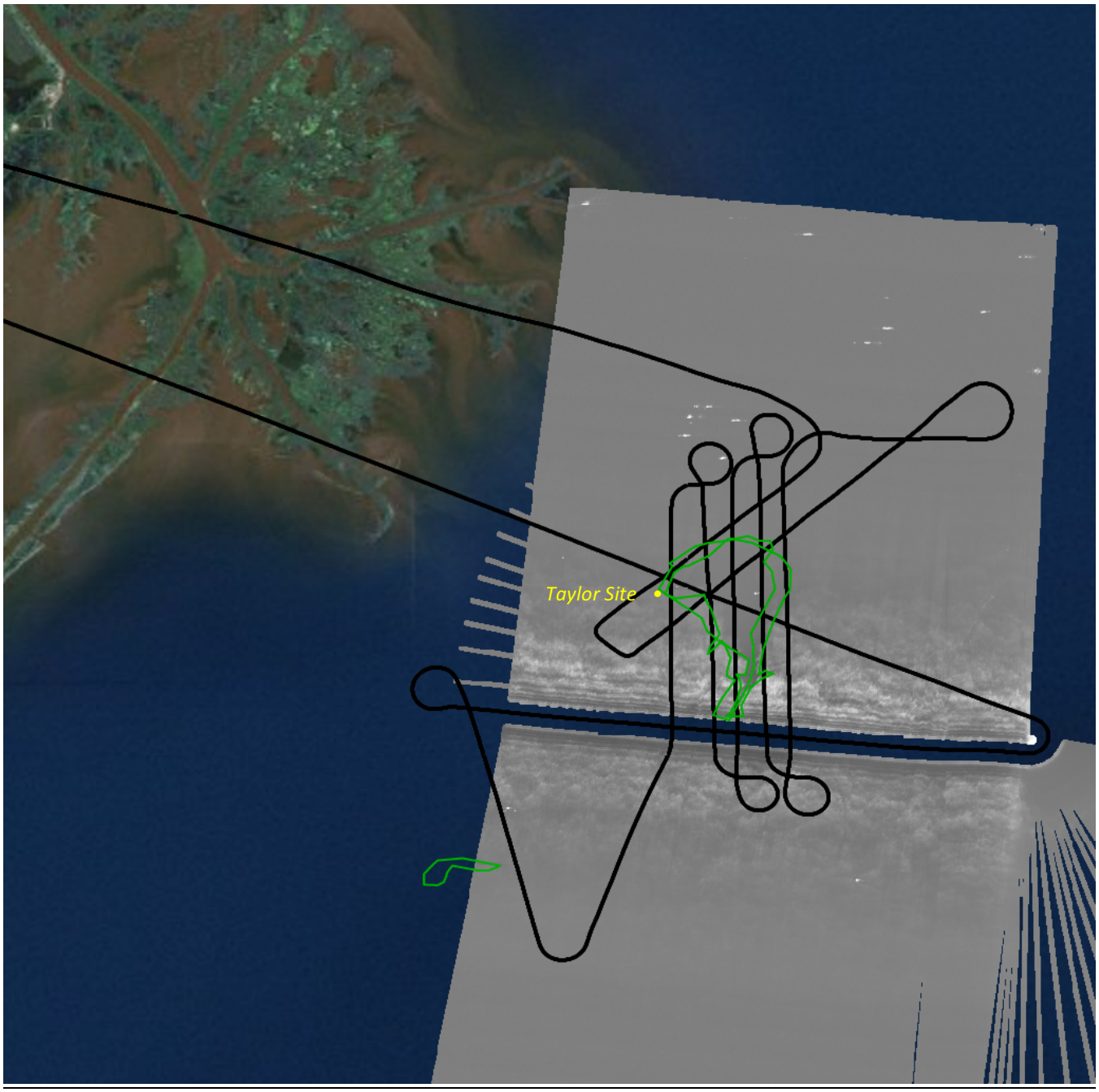

Fig.5 - SLAR georeferenced image with flight track.



Fig.6 Position of the detected slick on the Navigation Map

After the detection, localization and georeferencing of the target Poseidon started the approach to the spill to perform the near range analysis, the slick showed a match with the SLAR image. The slick had an appearance sheen to metallic, with the direction along the prevalent wind (Fig.7).



Fig.7 – Picture of the spill.

Step#2: spill approach and Near Range Analysis.

At an altitude of 3,000ft Poseidon was directed over the slick to overfly it in parallel patterns to obtain a complete coverage and analyze the slick features with the near range sensors. Purpose of the Near Range analysis is to confirm the nature of the spill, oil or other substances, evaluate and map the thickness to estimate the volume, and determine the hot spots, areas where the oil is concentrated.

Fig.8 below shows the zones where the targets were set to perform the analysis and the parallel pattern flown to insure maximum coverage.

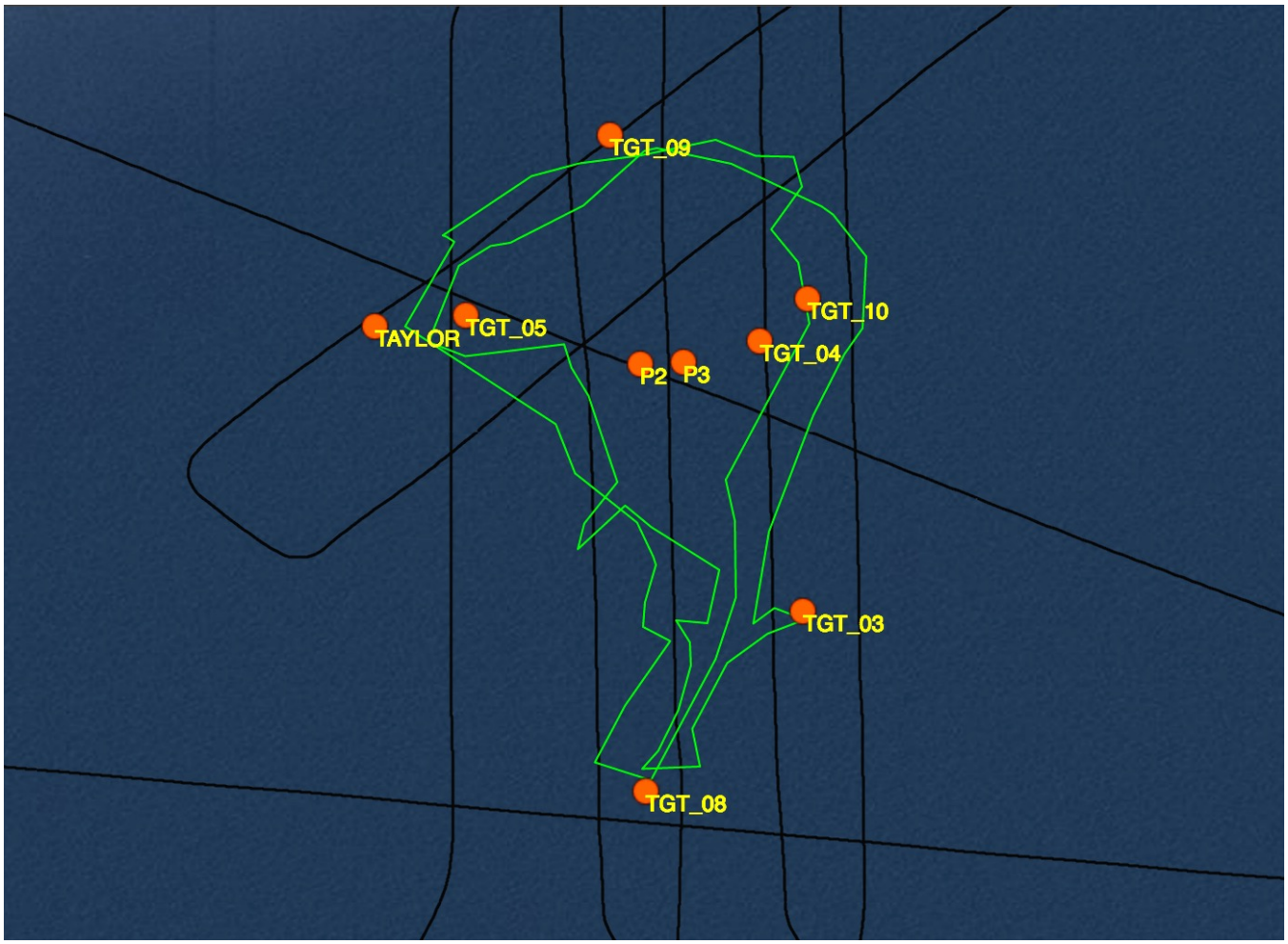

Fig.8 – Georeferenced Near Range Targets for Spill Analysis.

Fig.9 below shows the 'waterfall' images taken from the sensors, including IR, UV, VIS, MWR over the point P2. In the 'waterfall' display the length of the image is about 1.1 NM at 180 KT of cruise speed and the width is equivalent to the swath of the sensor, about 6,000 ft.

The response in the IR and UV bands was decisive to qualify mineral oil. The MWR response, suggested that the slick was very thin, less than 50µm, the IR showed an area of high relative thickness. VIS showed the appearance of the slick as a sheen.

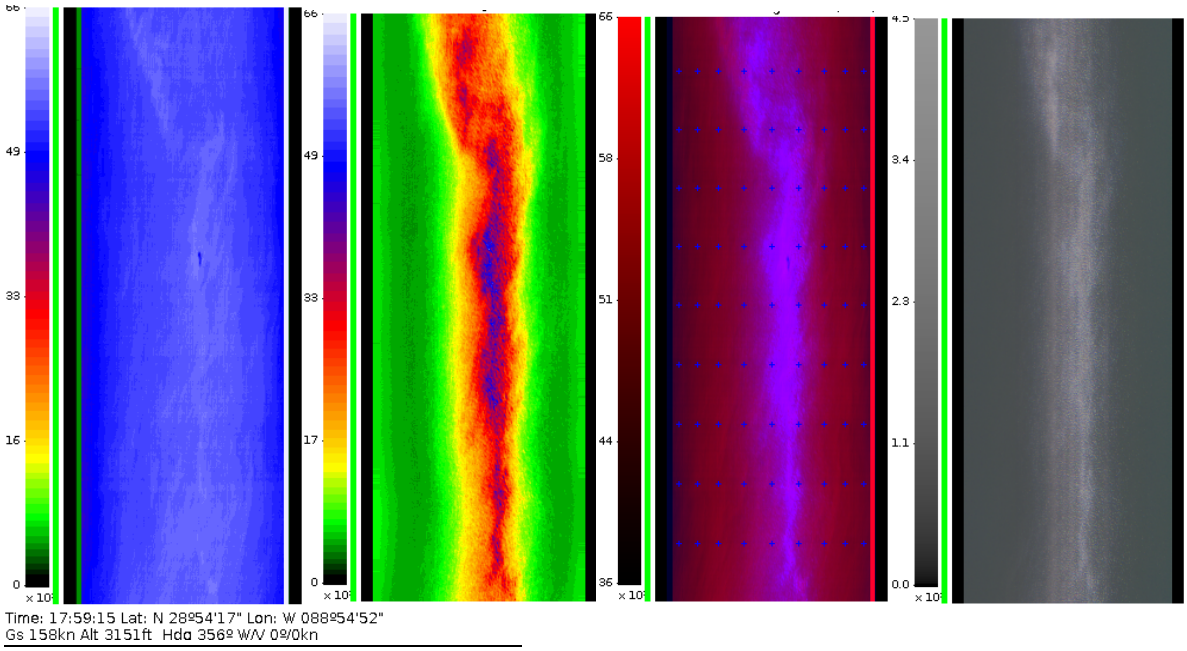

Fig.9 – Target#1, IR, UV, FUSION IR/UV, VIS images.

Near Range images can be georeferenced, and a 'mosaic' composition of the scene can be made if it is of interest. Fig.10 below show an example of georeferenced IR images.

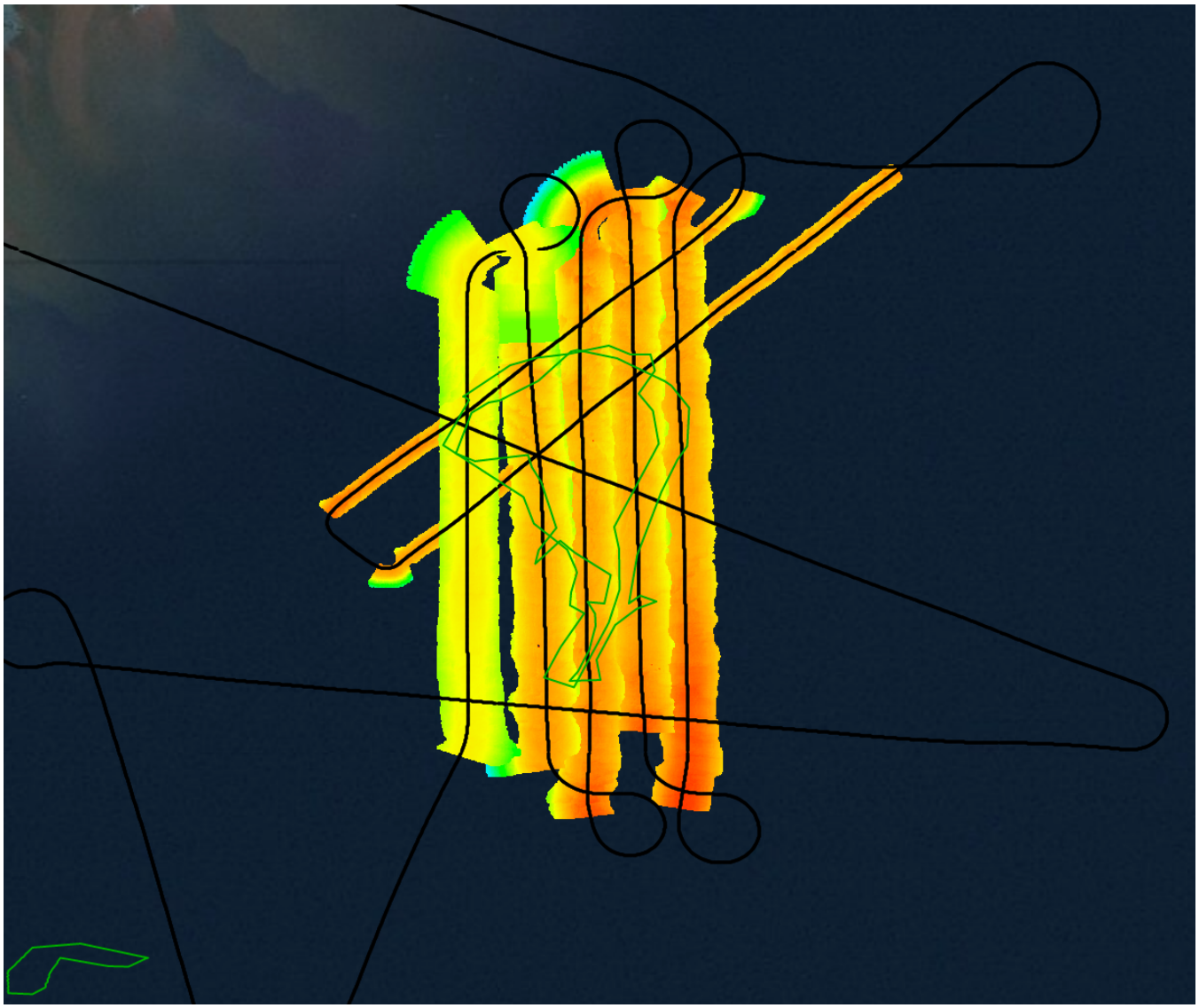

Fig.10 –IR georeferenced image.

Fig.11 to 13 show the area around the Taylor site. The IR image shows few spots where the oil is thicker in proximity of the former platform site. UV and VIS show the extent of the sheen that appears very thin. Classification of the oil from the LFS in proximity of the Taylor sit eposition was 'Very Light Crude' consistent with a fresh spill. The overall sheen was very thin; the max thickness measured by the LFS was in the order of 4.5µm.

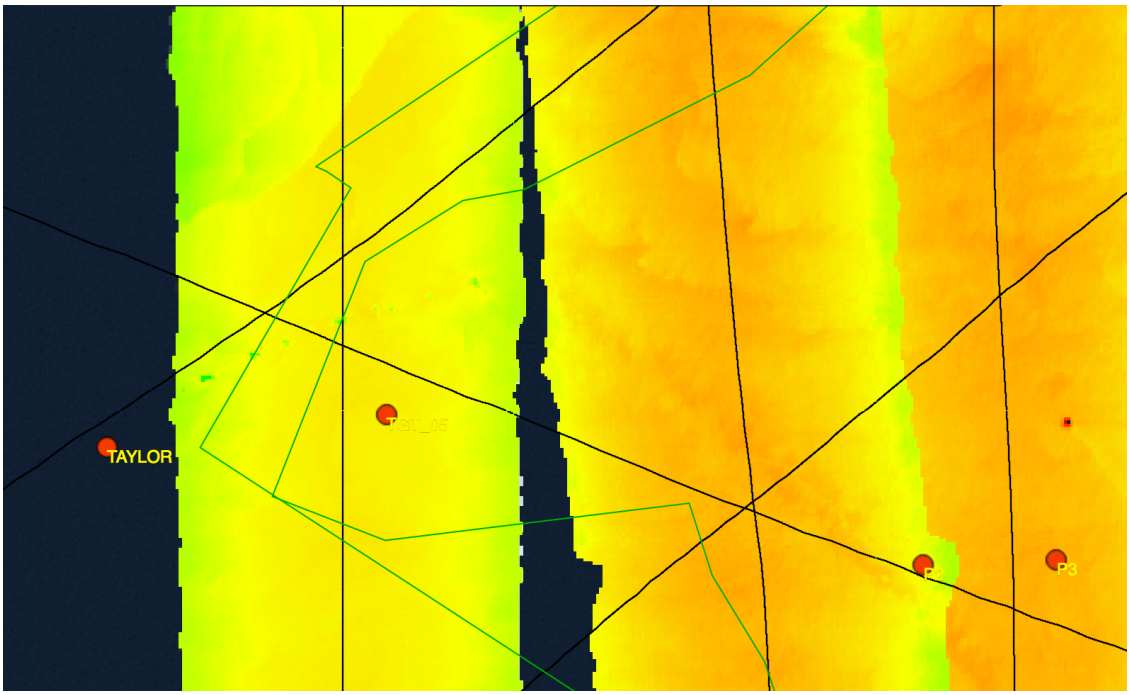

Fig.11 – Target#5 IR georeferenced image.

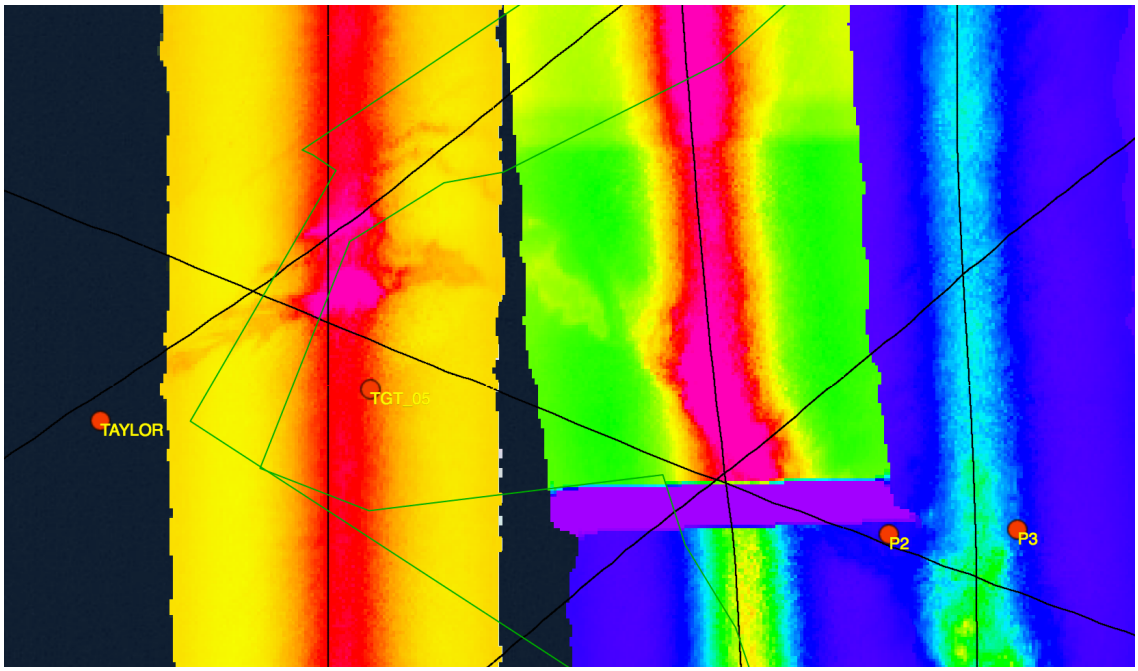

Fig.12 – Target#5 UV georeferenced image.

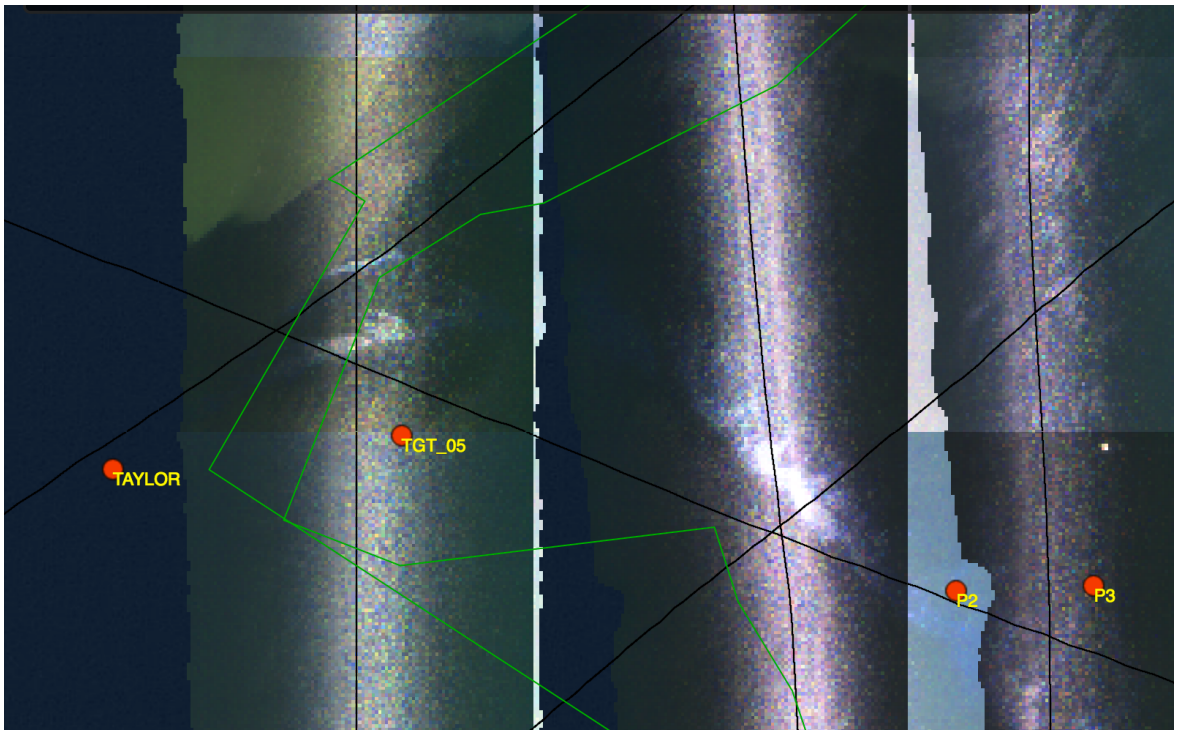

Fig.13 – Target#5 UV georeferenced image.

Data Processing and Transmission: on the 24th of April, before the flying missions two MBR ground antennas were installed at the Houma airport and in Venice, LA, about 75NM SE of Houma. The ground antenna in Houma was installed at a height of 30' on the ASI Hangar (Fig.14). The ground antenna in Venice was installed at the Lighthouse Hotel at about 12' with good field of view in the SW-S-SE directions but with significant obstruction on the other directions (Fig.15). Performance of the MBR antennas depends on the height of installation and on the unobstructed field of view.



Fig.14 – MBR antenna installation in Houma, LA.

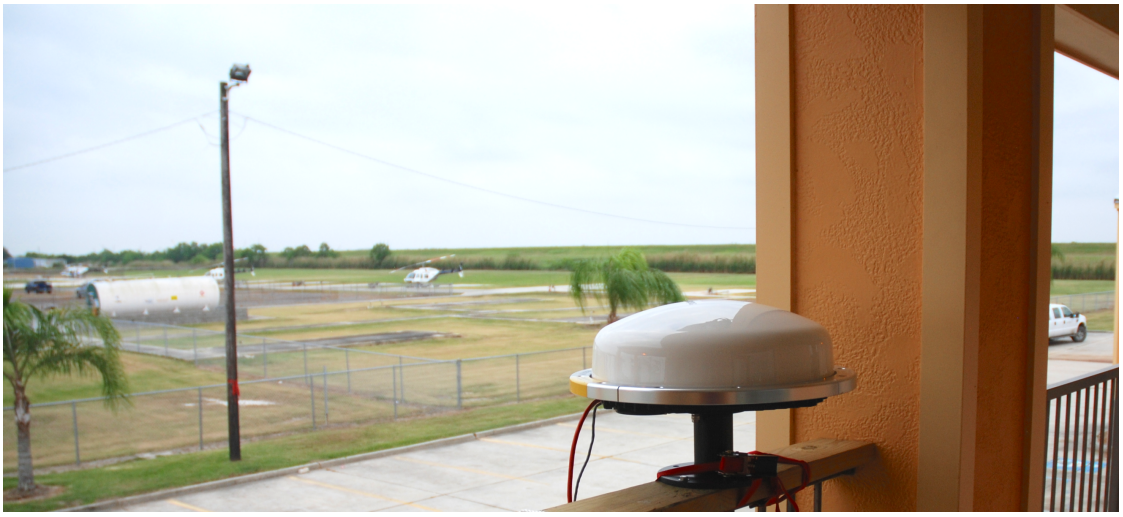

Fig.15 – MBR antenna installation in Venice, LA.

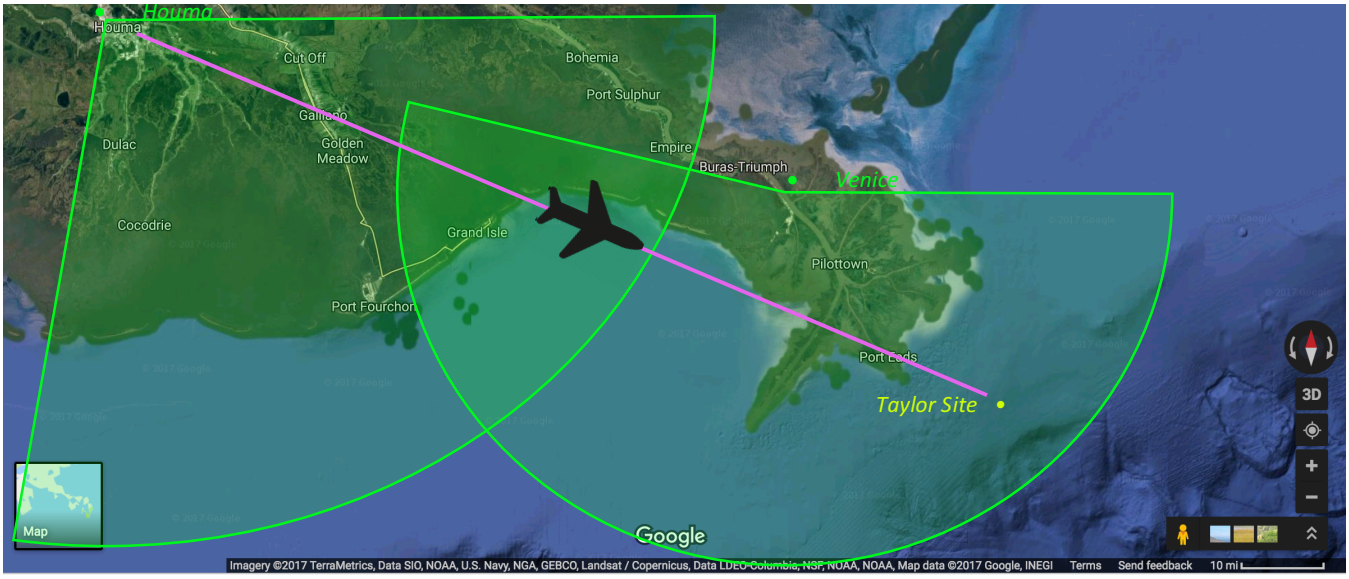

Fig.16 – MBR antenna coverage during the missions.

With two ground antennas installed a continuous high-speed high-capacity data-link was established, allowing a real time data transmission between the aircraft and the ground base. Aircraft antenna was configured to transmit data up to 8Mbit. The data were transmitted via FTP to the ground stations and from there relayed to the final users via FTP or Email. Other methods as ArcREST services can be setup but were not used during this campaign.

During mission#1 the 25th of April, 38 files were transmitted during the mission (Fig.17):

- Shapefiles: Polygon from the SLAR detection; Flighpath, Targets.
- Geotiff: SLAR Georeferenced images, IR georeferenced Images.

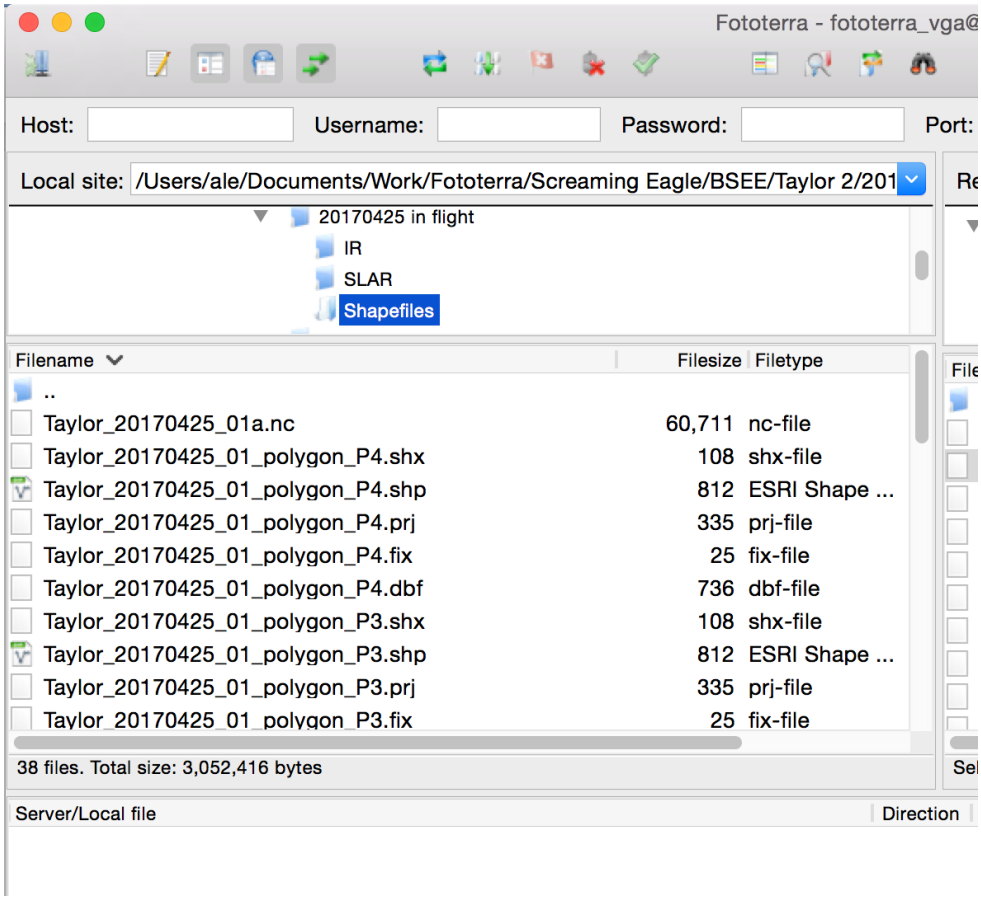

Fig.17 – Files transmitted during the mission

Conclusion: during Mission#1 Poseidon successfully located the slick and defined the synoptic characteristics with the SLAR, creating also a navigation reference for the successive low altitude passes. During the low altitude passes the near range sensors gave positive confirmation of the nature of the slick and determined relative thickness distribution and hot spot localization. Operators could analyze the spill scene during the flight in real time determining information as area, dimension, center coordinate, defining georeferenced targets and imageries. Data were processed in real time during the flight and the files generated were sent via MBR microwave antenna to the ground station. Poseidon was able to keep continuous data-link with one or both the ground antennas set in Houma and Venice. Results were considered successful.

3.5.2 Mission#2 – April 26th Collections

In the morning of April 26th EMB-110 Poseidon left Houma-Terrebonne airport at 11:35 CST.

As the previous mission, Poseidon approached the Taylor area with a SE track at 3,000 ft and about 185KT of cruise speed.

Step#1 - Synoptic Overview: the SLAR detected a structure with strongly reduced backscatter that was identified as a surface target. The structure was different from the previous day, with a smaller size, a predominant SW-NE direction, determined possibly by the wind/current configuration. The area was delimited by a polygon of approximately 1.23x3.59NM with a coverage of 60% and a resultant area of the surface target of 2.64 square nautical miles. Polygon was centered on the following coordinates: N 28°58'03" W 088°57'21". The following figures show the SLAR images, the georeferenced polygon and the resultant SLAR georeferenced image with and without flight track (Fig.18 to Fig.21).

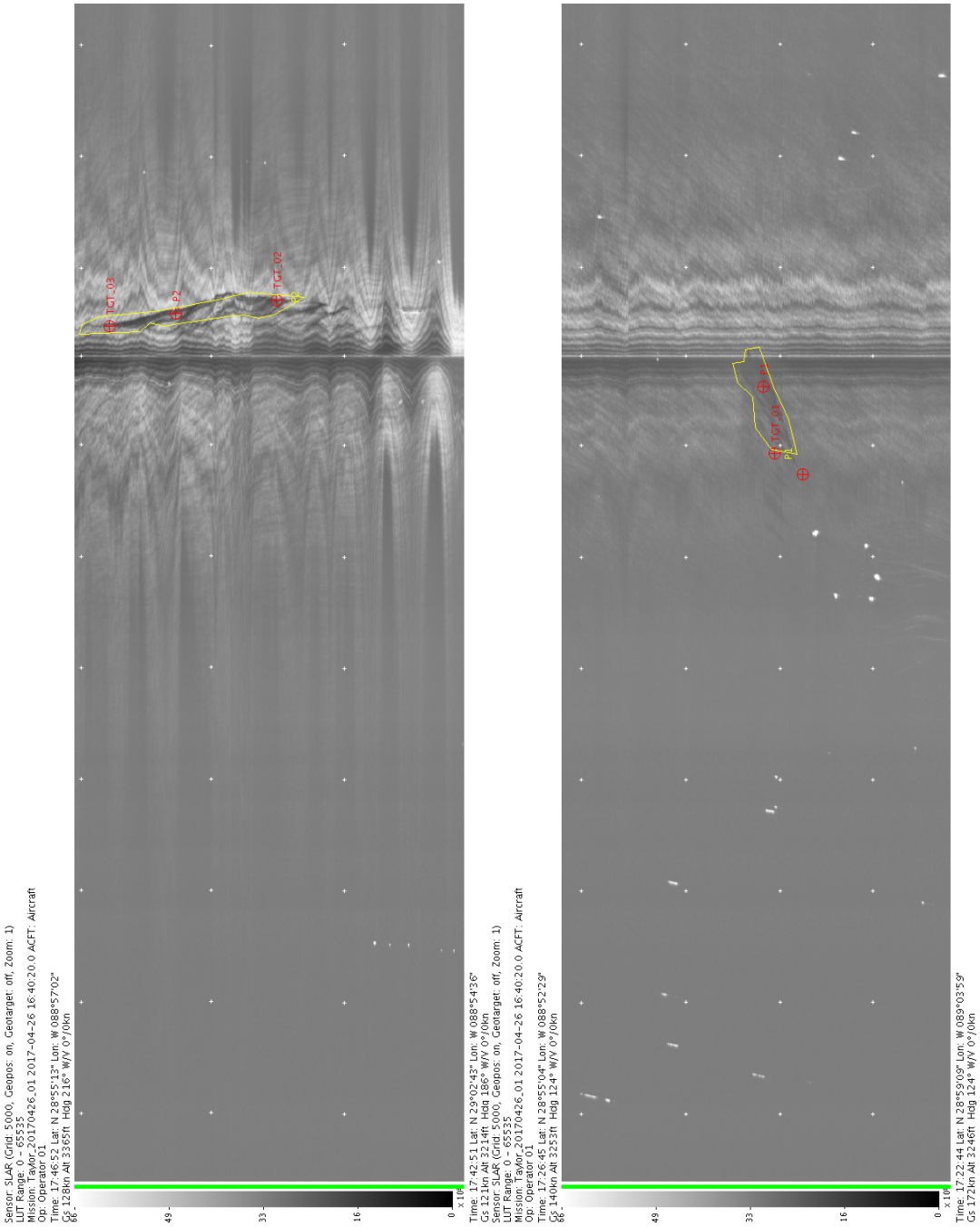

Fig.18 - SLAR images of the spill: N to S and E to W approaches

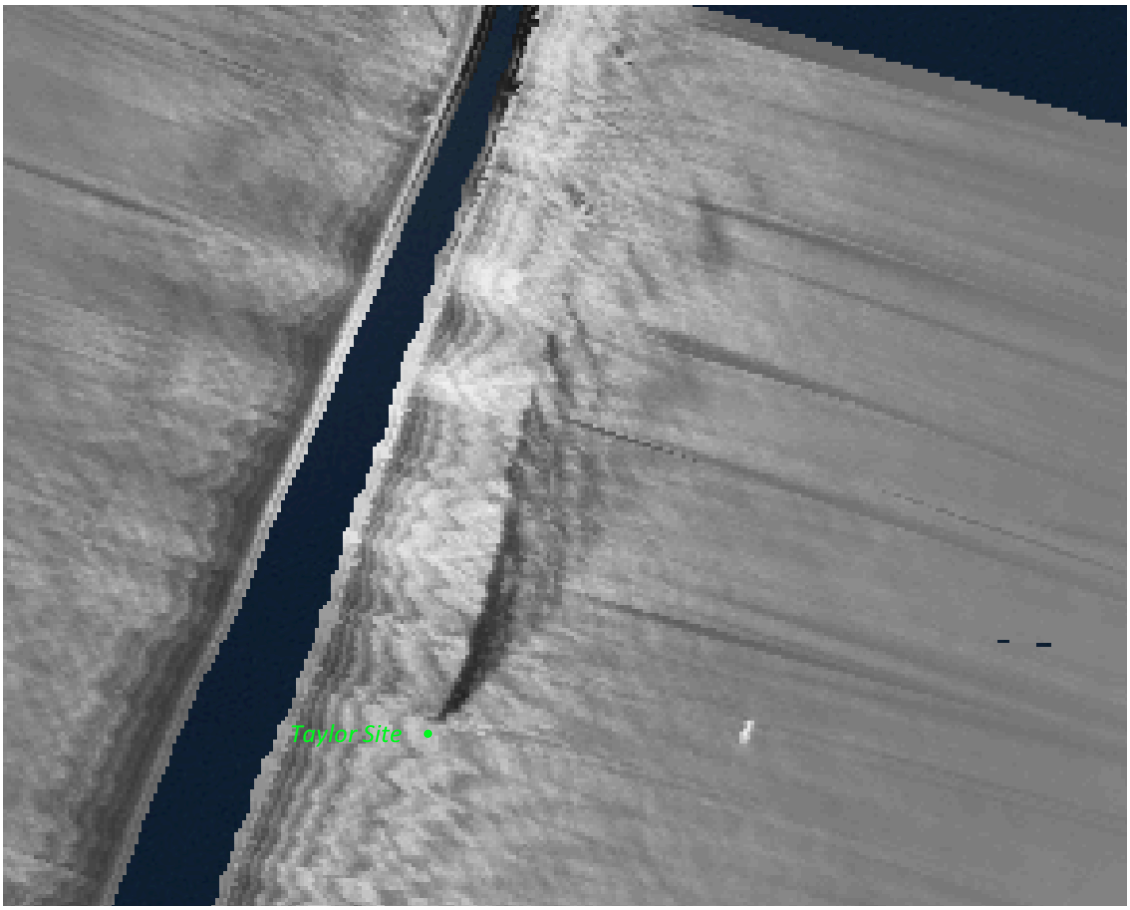

Fig.19 - SLAR image of the spill

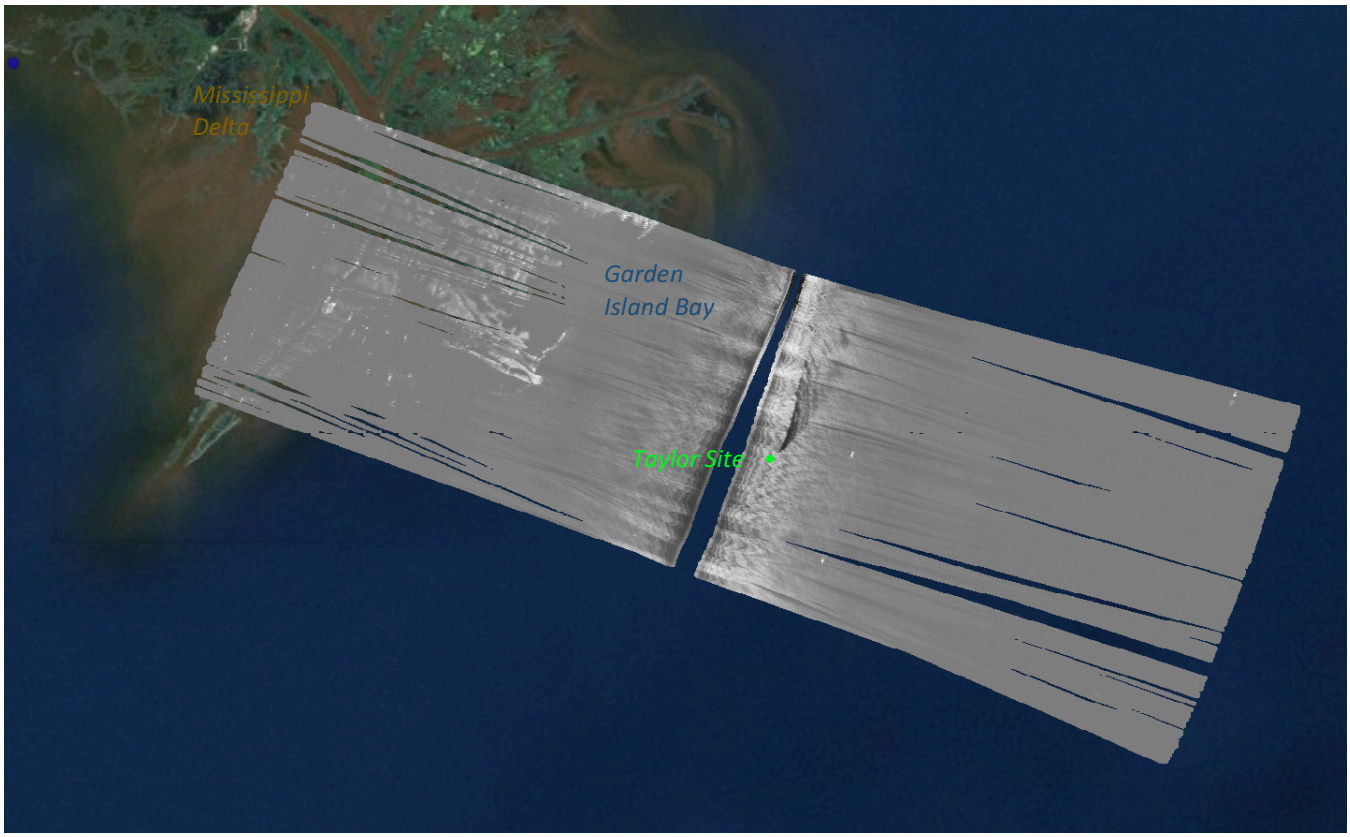

Fig.20 - SLAR georeferenced image

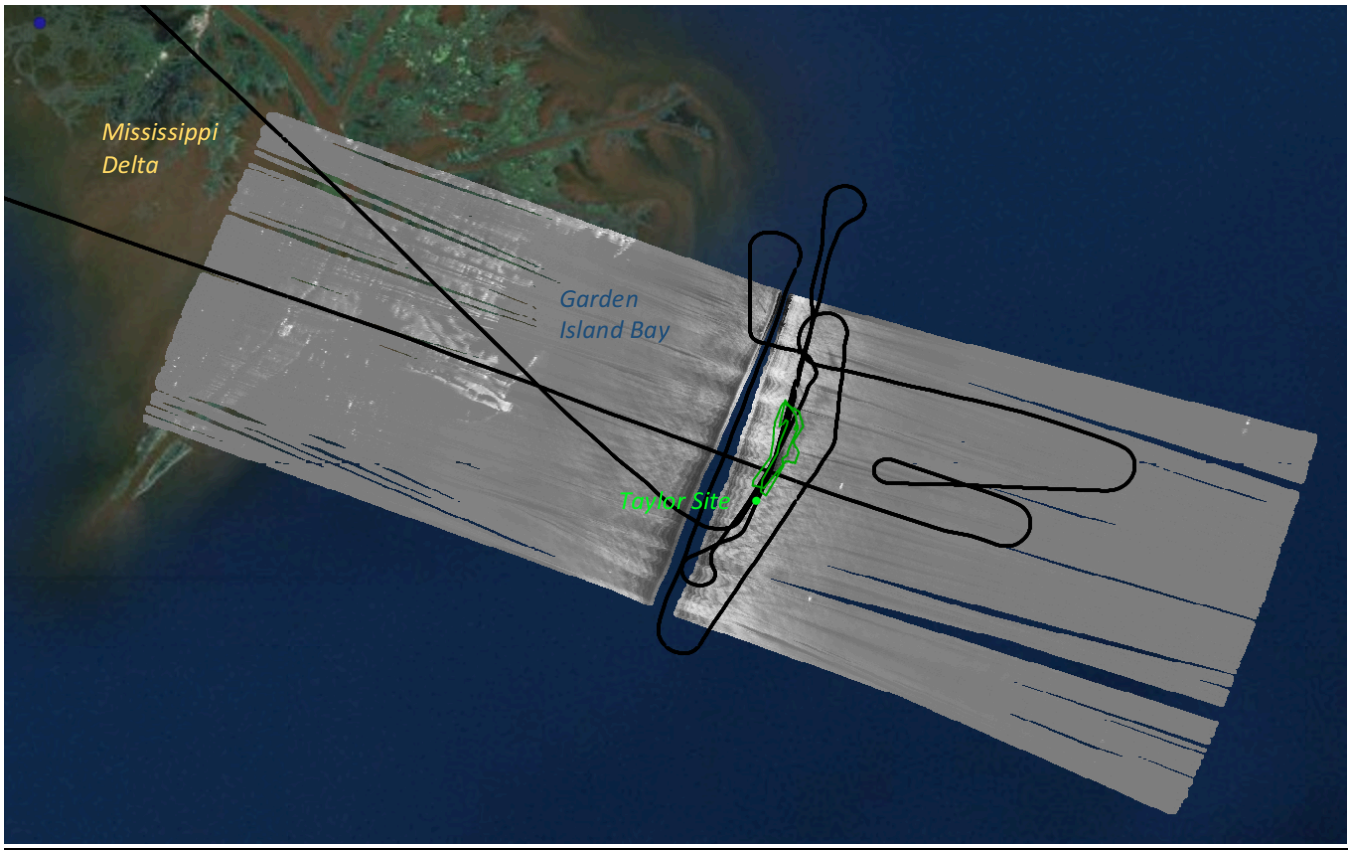

Fig.21 - SLAR georeferenced image with flight track.



Fig.22 Position of the detected slick on the Navigation Map

After the detection, localization and georeferencing of the target, Poseidon started the approach to the spill to perform the near range analysis. During the approach a video was recorded by the EO/IR sensor (Video files are attached to the Report), the slick showed a match with the SLAR image. The slick had an appearance sheen to metallic, and positioned along the SW – NE direction.



Fig.23 – Image of the spill.

Step#2: spill approach and Near Range Analysis.

At an altitude of 1,000ft Poseidon was directed over the slick to overfly it and analyze the slick features with the near range sensors in several determined points. Purpose of the Near Range analysis is to confirm the nature of the spill, oil or other substances, evaluate and map the thickness to estimate the volume, and determine the hot spots, areas where the oil is concentrated.

Fig.24 below shows the zones where the targets were set to perform the analysis.

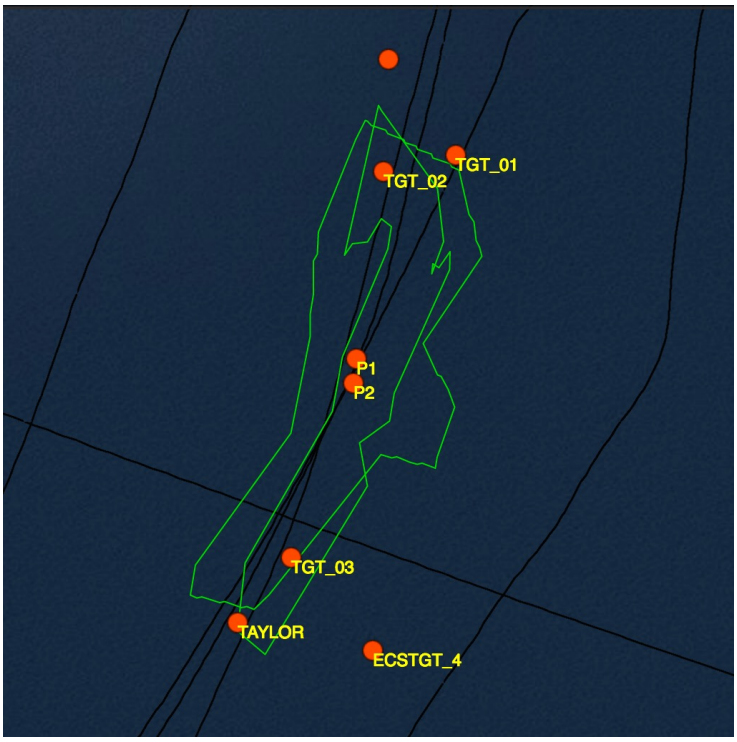

Fig.24 – Georeferenced Near Range Targets for Spill Analysis.

Fig.25 below shows the 'waterfall' images taken from the sensors, including IR, UV, VIS, MWR over Target#3. In the 'waterfall' display the length of the image is about 1.1 NM at 180 KT of cruise speed and the width is equivalent to the swath of the sensor, about 2,000 ft.

The response in the IR and UV bands was decisive to qualify mineral oil. The IR/UV fusion shows very well the relative thickness distribution on that particular location, the UV response shows the overall extension of the slick including also very thin layers from 0.01µm and the IR response, very localized, shows thicker areas of the spill from 2-5µm.

The MWR response, suggested that the slick was very thin, less than 50µm. VIS showed the appearance of the slick as a sheen. The LFS characterized the composition of the spill as oil classified as Light Crude with a maximum thickness in the proximity of Target#3 of 4.5 µm.

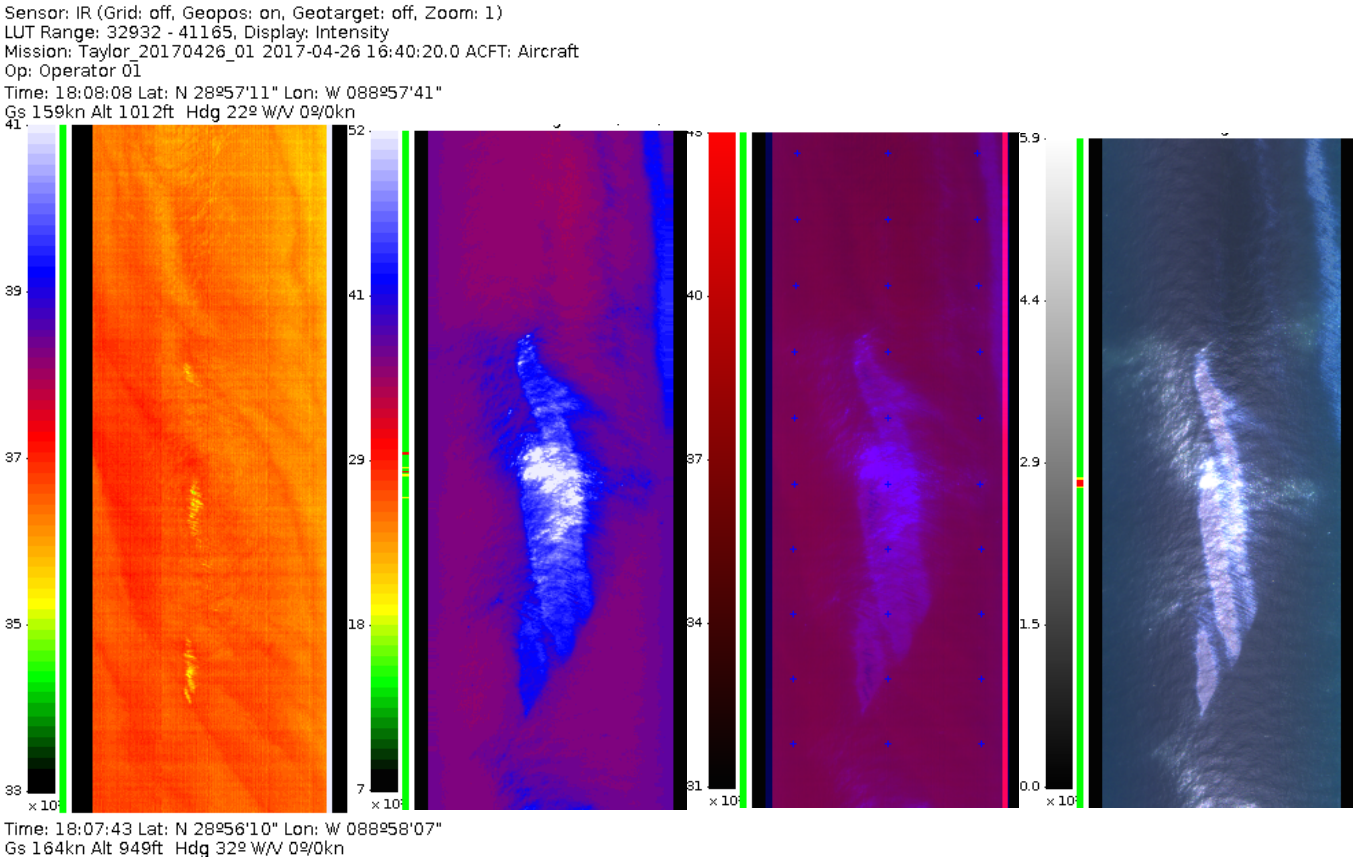

Fig.25 – Target#3: IR, UV IR/UV fusion, VIS

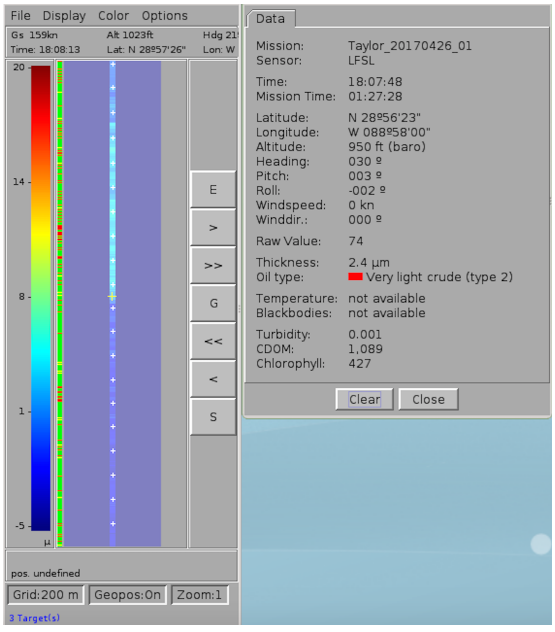

Fig.26 – Target#3 LFS information.

Near Range images can be georeferenced, and a 'mosaic' composition of the scene can be made if it is of interest. Fig.27-30 below show georeferenced IR, UV, VIS images.

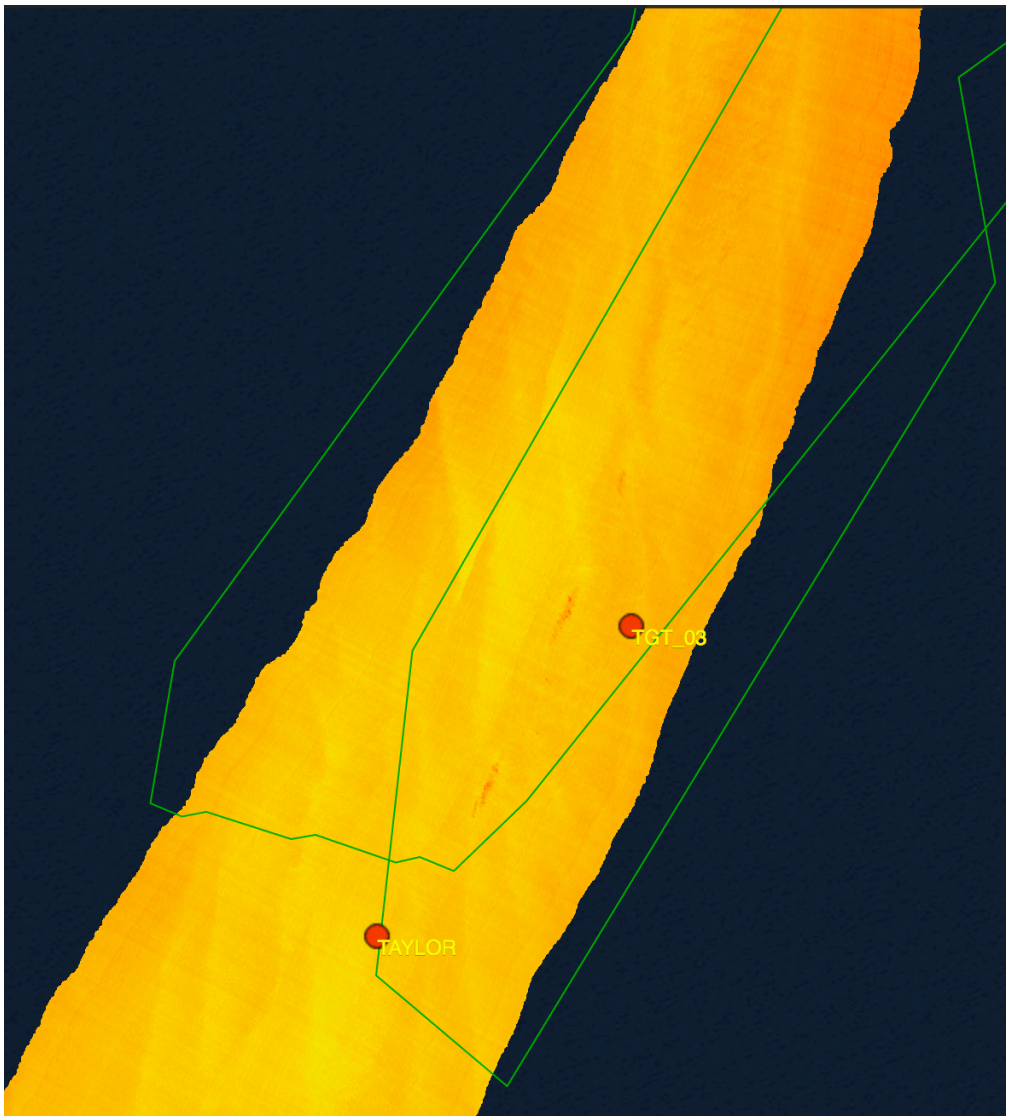

Fig.27 – IR georeferenced image.

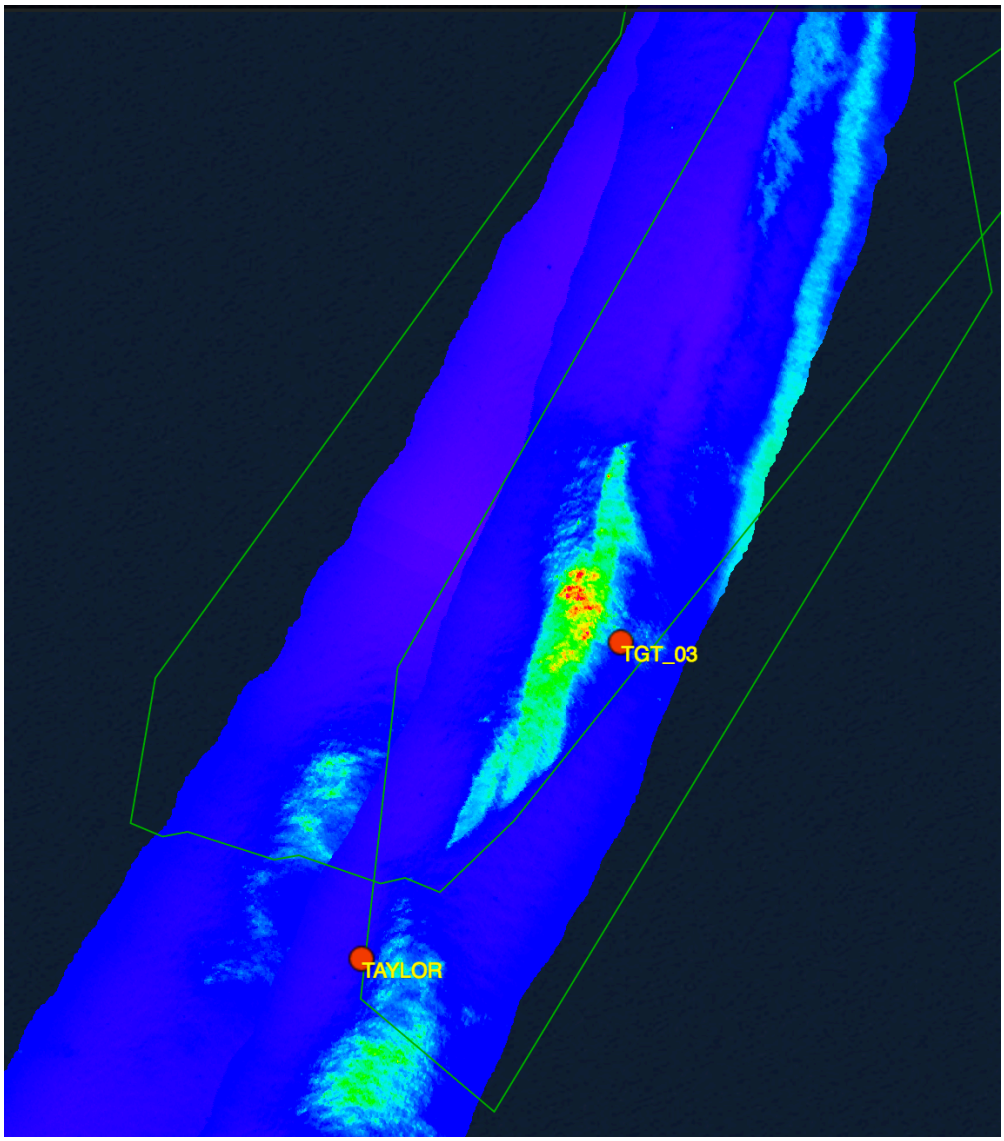

Fig.28 – UV georeferenced image.

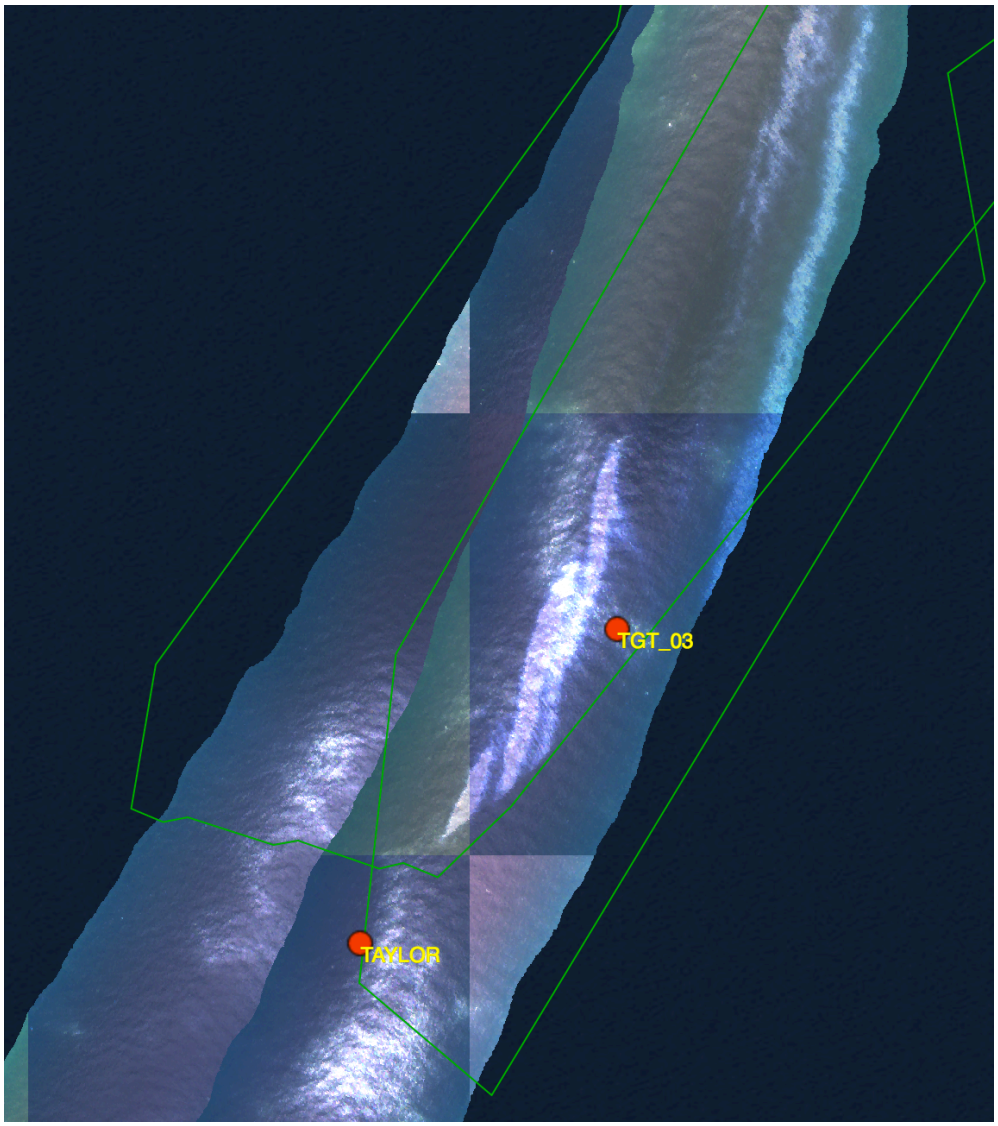

Fig.29 – VIS georeferenced image.

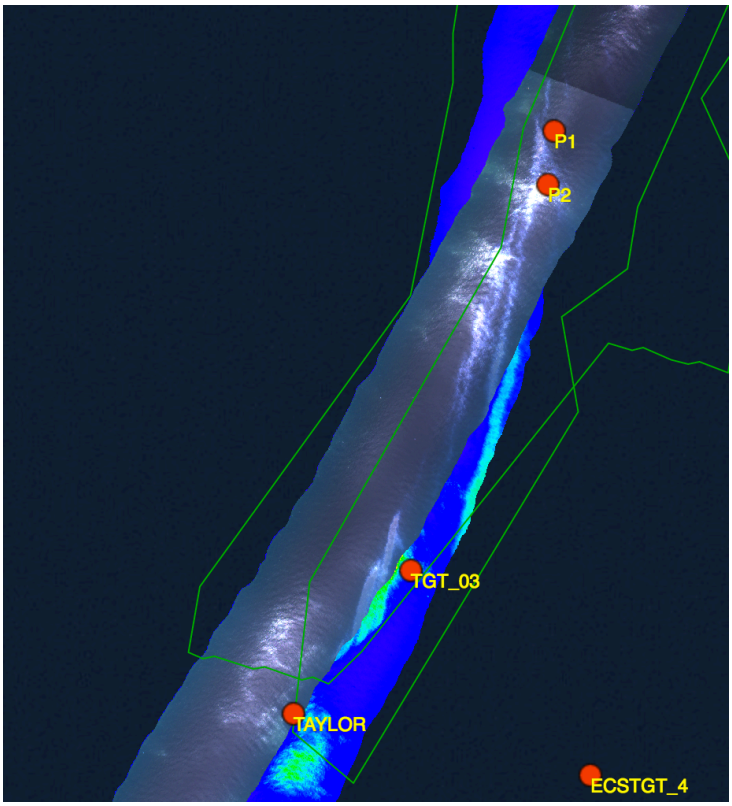

Fig.30 – VIS/UV georeferenced image.

During mission#1 the 26th of April, 17 following files were transfered during the mission (Fig.31):

- Shapefiles: Polygon from the SLAR detection; Flighpath, Targets.
- Geotiff: SLAR Georeferenced images.

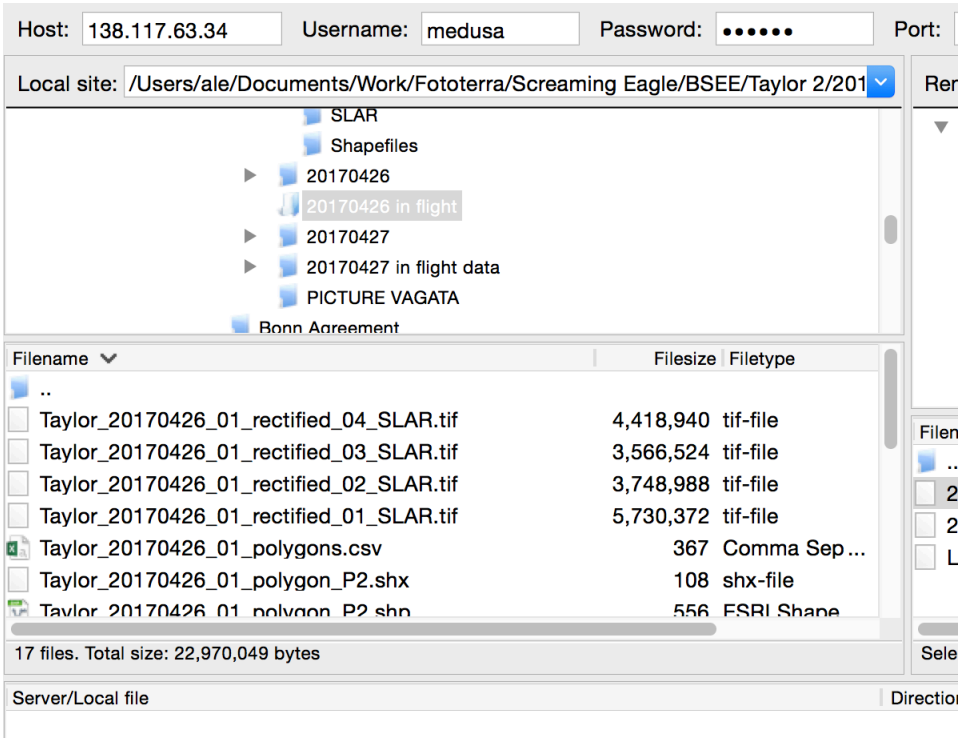

Fig.31 – Files transmitted during the mission

Conclusion: during Mission#2 Poseidon successfully located the slick and defined the synoptic characteristics with the SLAR, creating a navigation reference for the successive low altitude passes. During the low altitude passes the near range sensors gave positive confirmation of the nature of the slick and determined type of oil, thickness, relative thickness distribution and hot spot localization. Operators could analyze the spill scene during the flight in real time determining information as area, dimension, center coordinate, defining georeferenced targets and imageries. Files generated during the mission were sent via MBR microwave antenna to ground. Results were successful.

3.5.3 Mission#3 – April 27th Collections

In the afternoon of April 27th EMB-110 Poseidon left Houma-Terrebonne airport at 17:45 CST.

As the previous two missions, Poseidon approached the Taylor area with a SE track at 3,000 ft and about 185KT of cruise speed.

Step#1 - Synoptic Overview: the SLAR promptly detected a structure with strongly reduced backscatter that was identified as a surface target. The structure was again different from the previous days; it was slightly spread compared with the previous day, and with a predominant W-E direction, determined by the wind/current configuration. The area was delimited by a polygon of approximately 2.01x4.58 NM with a coverage of 81% and a resultant area of the surface target of 7.51 square nautical miles, almost 3 times the area measured in the previous day. Polygon was centered on the following coordinates: N 29°35'24" W 090°19'21". The following figures show the SLAR images, the georeferenced polygon and the resultant SLAR georeferenced image with and without flight track (Fig.32 to Fig.36).

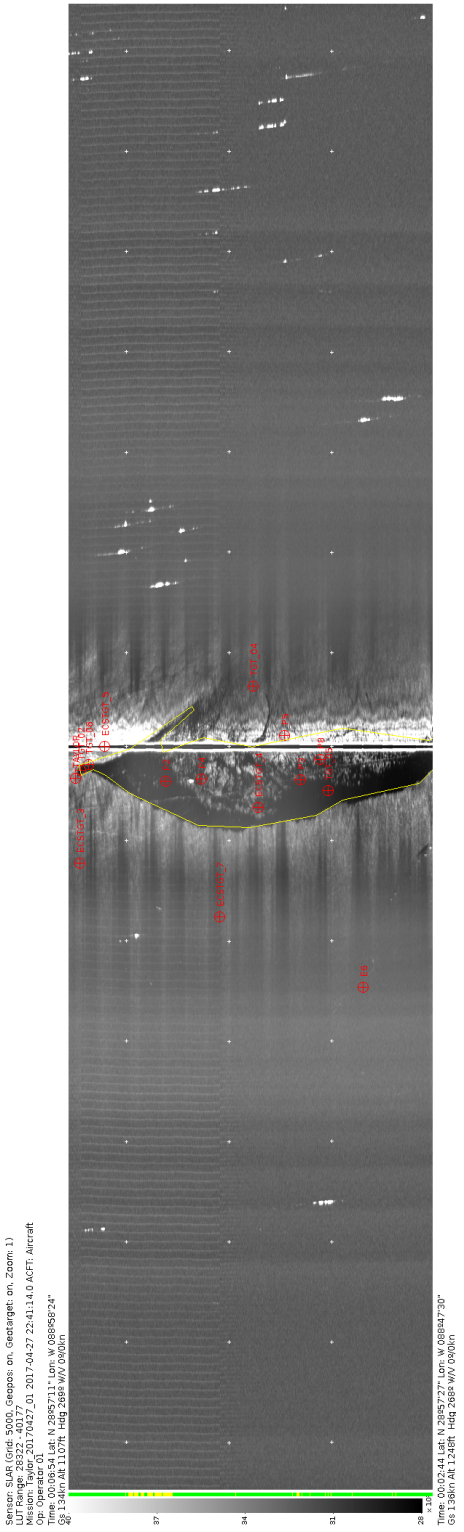

Fig.32 - SLAR images of the spill: W to E approach

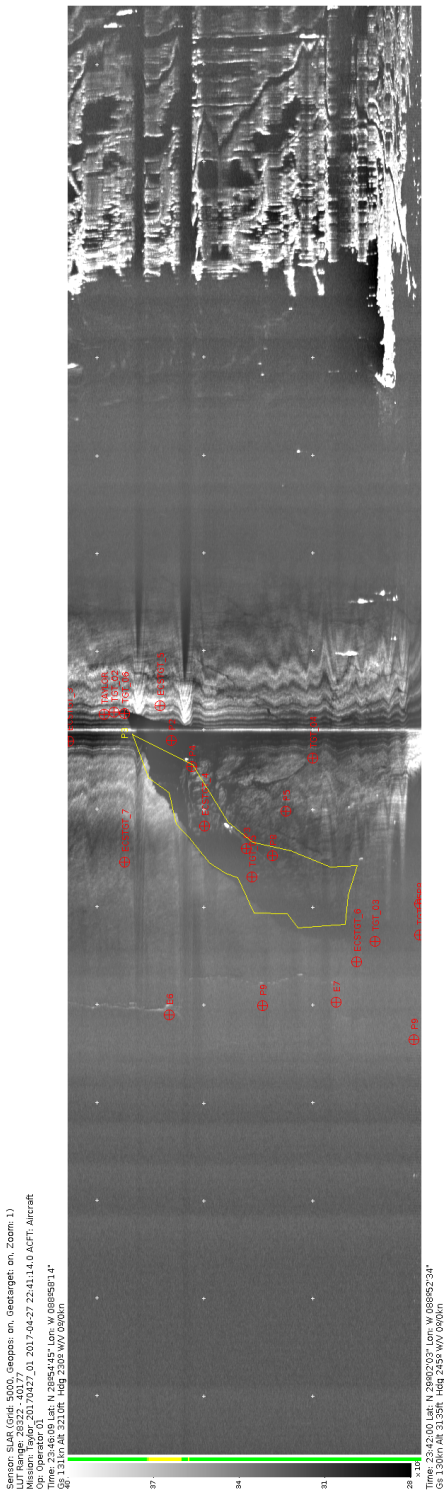

Fig.33 - SLAR images of the spill: SW to NE approach

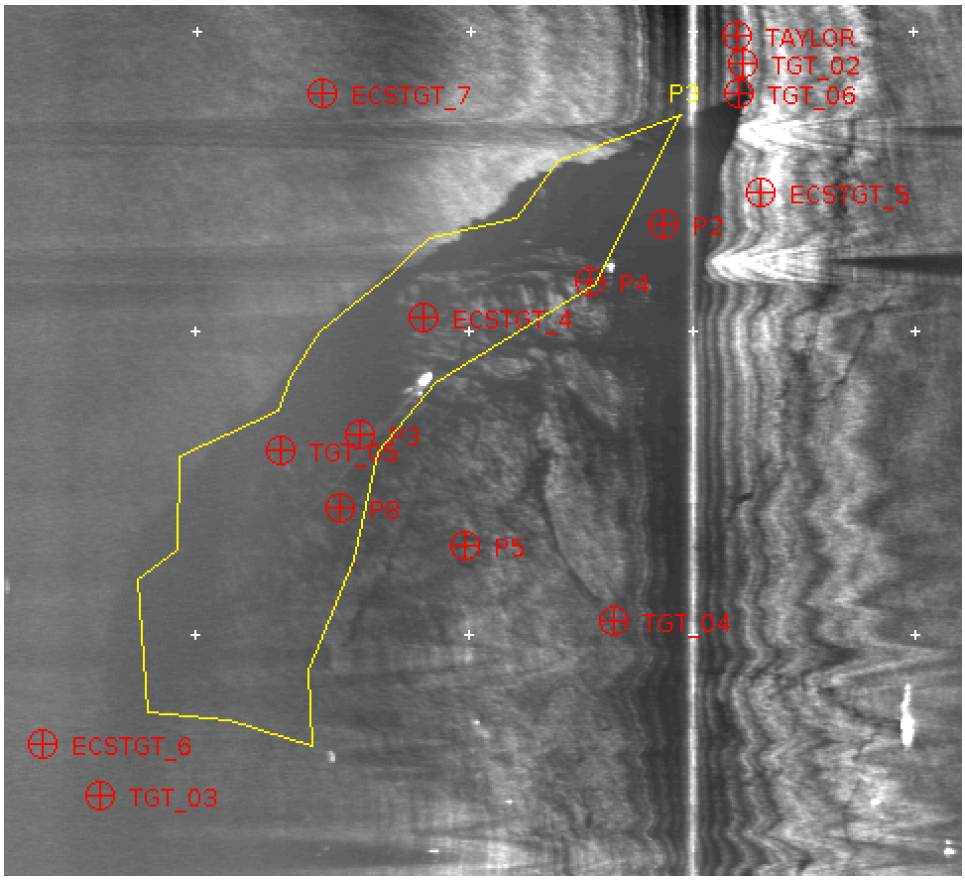

Fig.34 - SLAR image of the spill

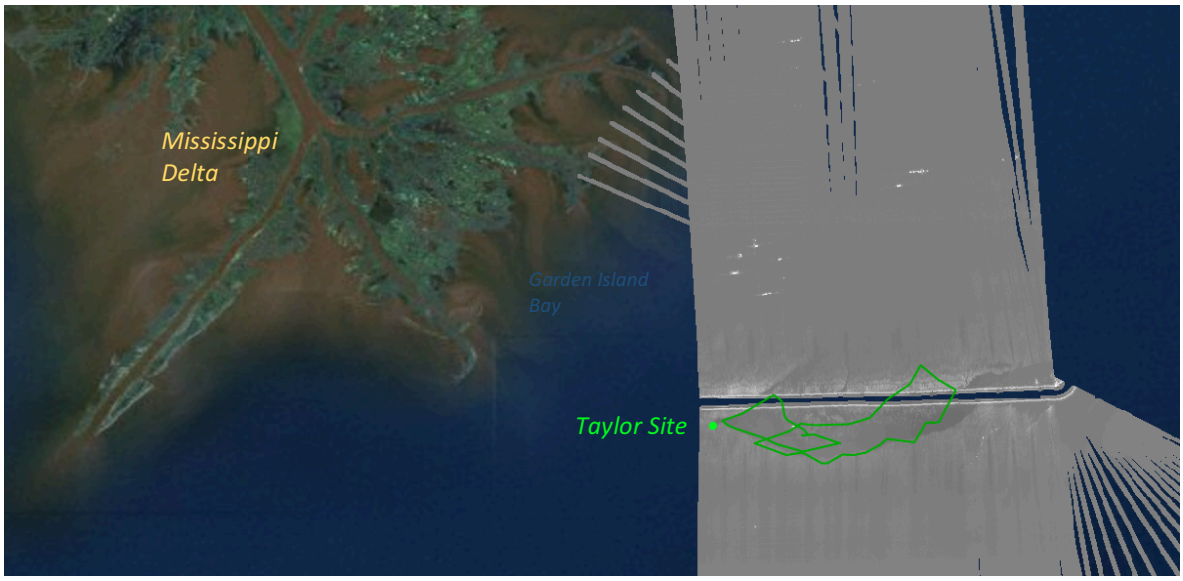

Fig.35 - SLAR georeferenced image

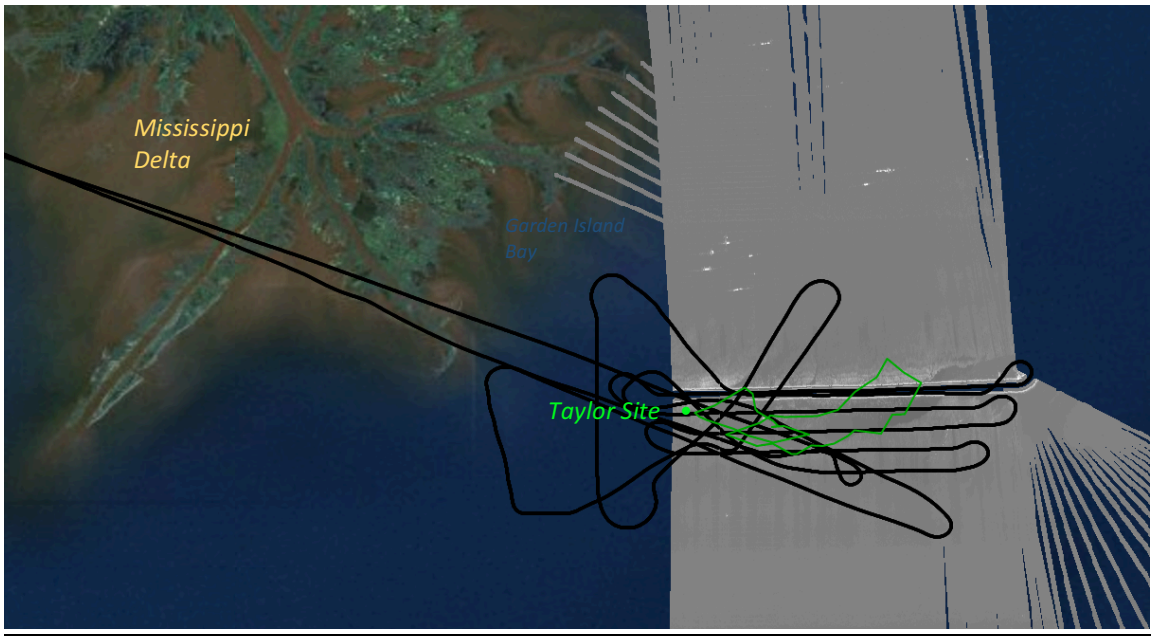

Fig.36 - SLAR georeferenced image with flight track.



Fig.37 Position of the detected slick on the Navigation Map

After the detection, localization and georeferencing of the target Poseidon started the approach to the spill to perform the near range analysis. During the approach a video was recorded by the EO/IR sensor (Video files are attached to the Report), the slick showed a match with the SLAR image. The slick had an appearance sheen to metallic, and positioned along the W – E direction (Fig.38).

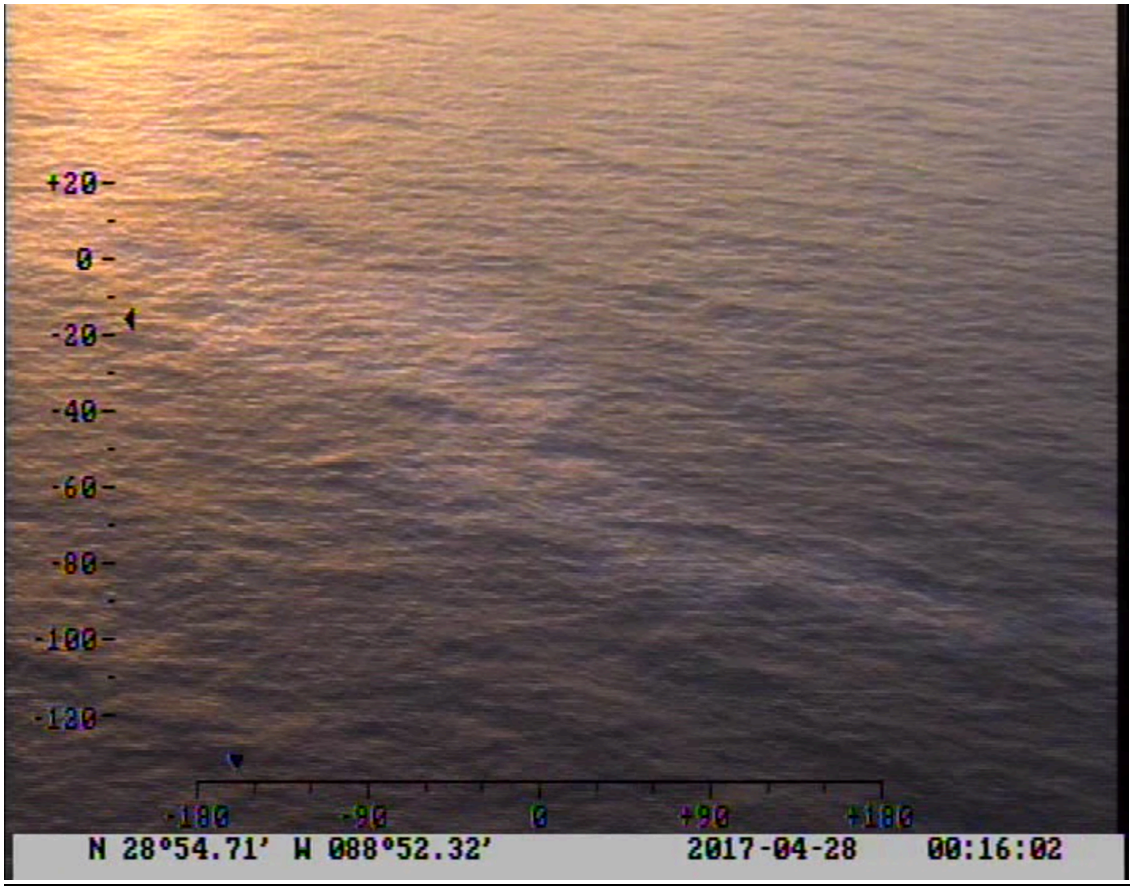

Fig.38 – Image from the EO/IR video SLAR footage.

Step#2: spill approach and Near Range Analysis.

At an altitude of 1,000ft Poseidon was directed over the slick to overfly it and analyze the slick features with the near range sensors in several determined points. Purpose of the Near Range analysis is to confirm the nature of the spill, oil or other substances, evaluate and map the thickness to estimate the volume, and determine the hot spots, areas where the oil is concentrated.

Fig.39 below shows the zones where the targets were set to perform the analysis.

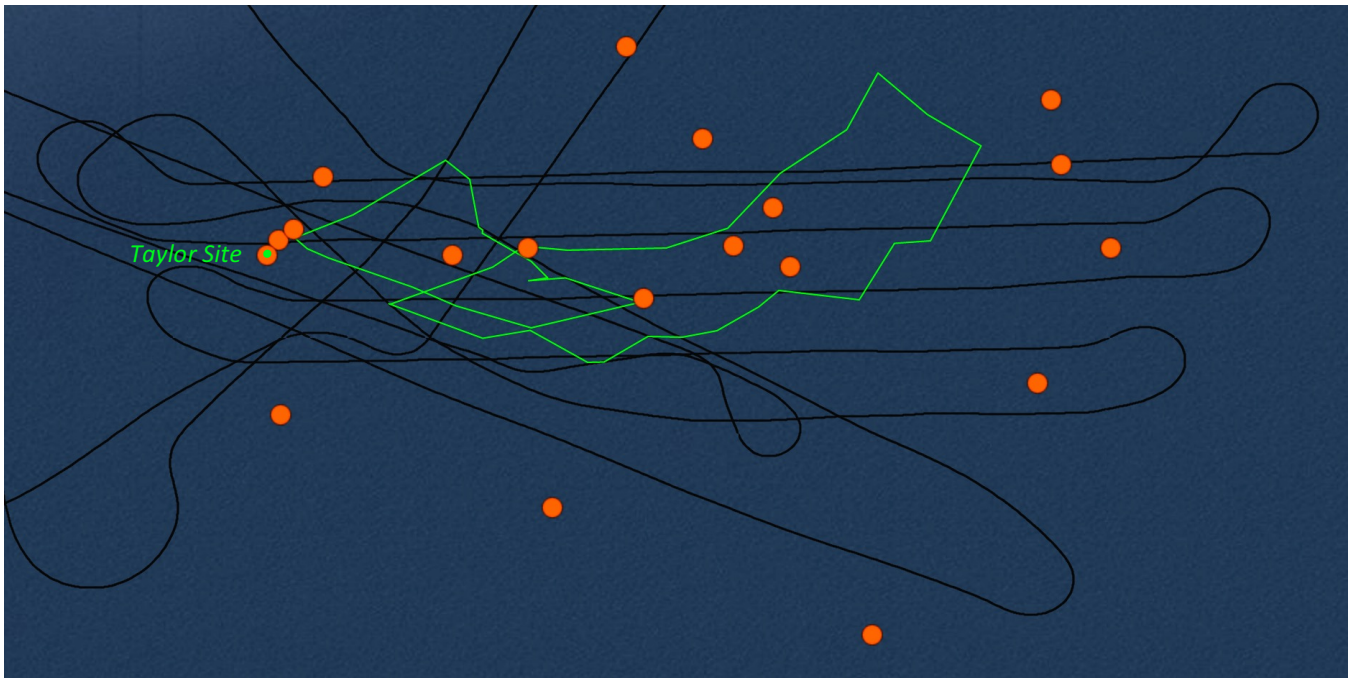

Fig.39 – Georeferenced Near Range Targets for Spill Analysis.

Fig.40 below shows the 'waterfall' images taken from the sensors, including IR, UV, VIS, and IR/UV fusion in proximity of the Taylor site. In the 'waterfall' display the length of the image is about 1.1 NM at 180 KT of cruise speed and the width is equivalent to the swath of the sensor, about 2,000 ft.

The response in the IR and UV bands was decisive to qualify mineral oil. The IR/UV fusion shows very well the relative thickness distribution on that particular location (Fig.40), the UV response shows the overall extension of the slick including also very thin layers from 0.01µm and the IR response, very localized, shows thicker areas of the spill from 2-5µm.

Again, the MWR response, suggested that the slick was very thin, less than 50µm. VIS showed the appearance of the slick as a sheen. As the previous day, the LFS characterized the composition of the spill as Oil classified as Medium Crude with max thickness in the order of 5µm.

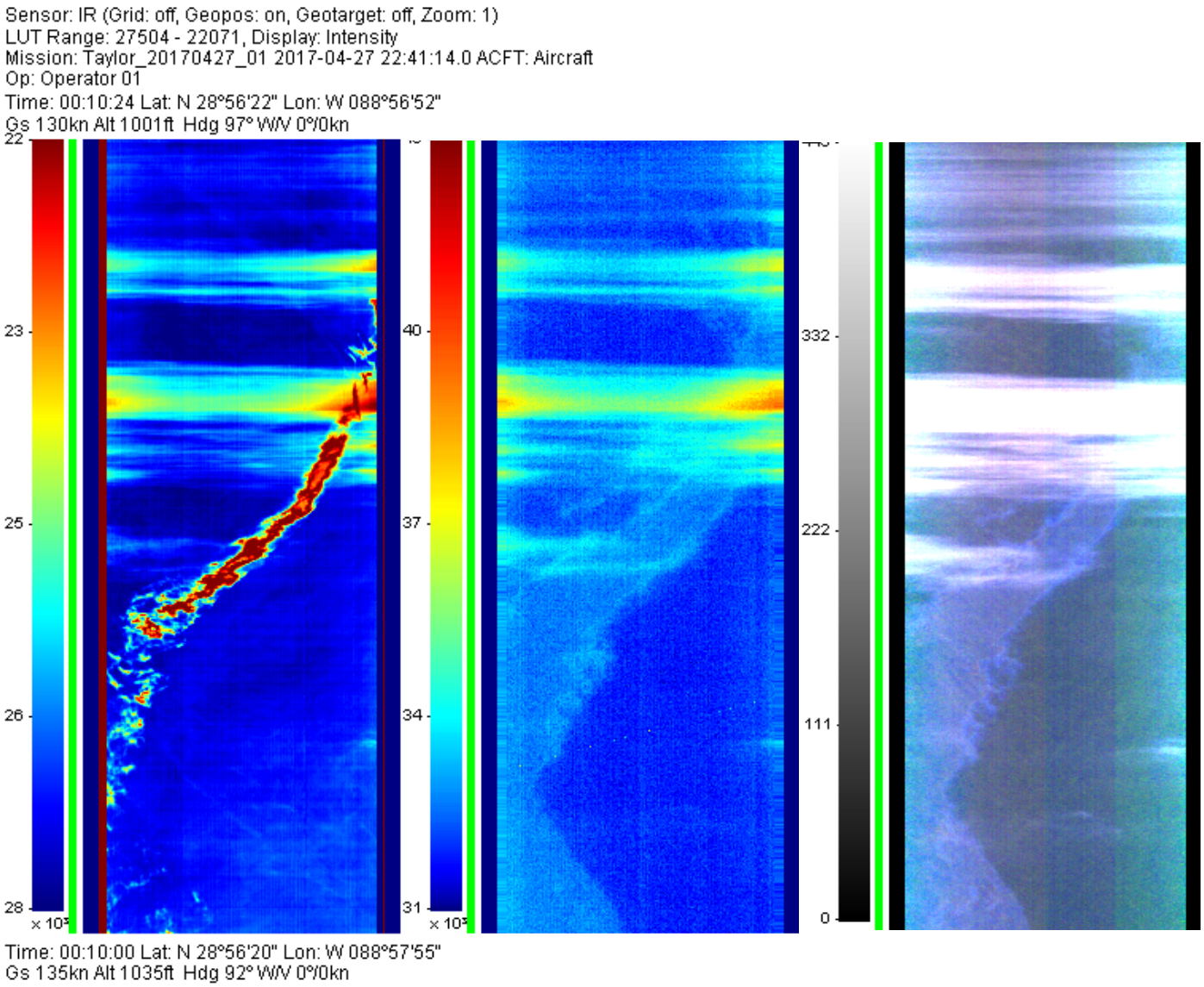

Fig.40 – IR, UV, VIS, images.

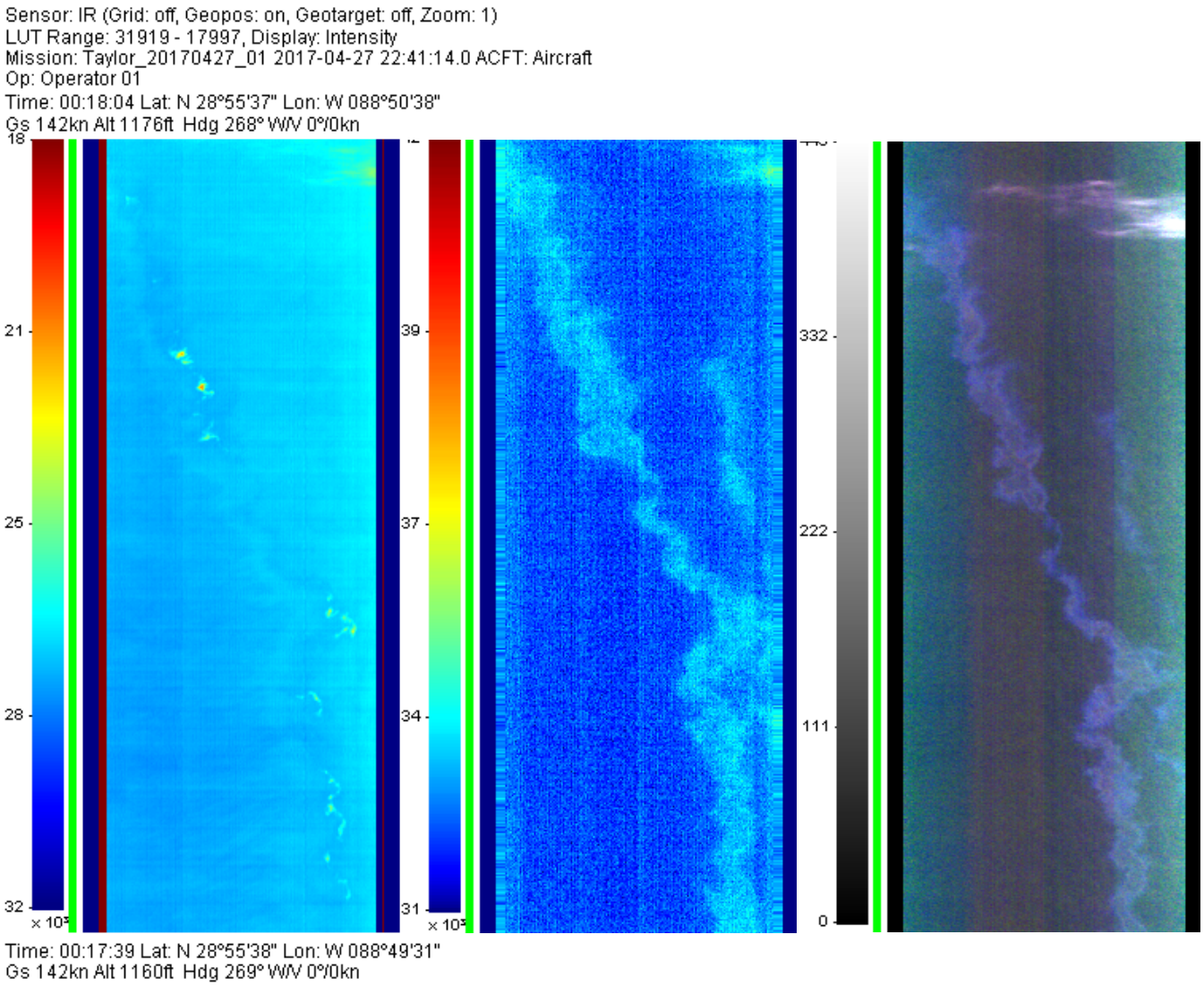

Fig.41 –IR, UV, VIS, images.

Fig.41 shows waterfall images in correspondence of a target positioned 2.7 NM SW of the Taylor site. Again, very thin slick, with some small concentrated areas visible in the IR.

Fig.42-44 below show an example of georeferenced IR, UV and VIS images related to the 27th of April acquisition.

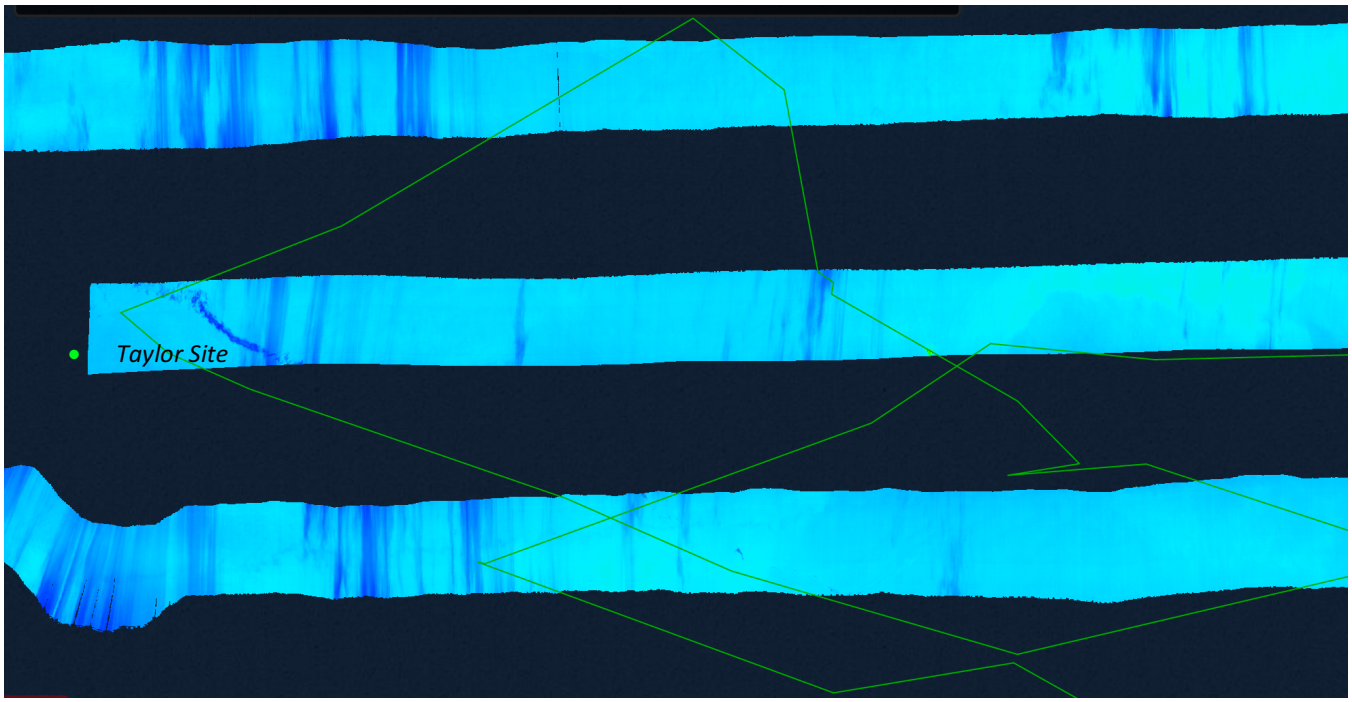

Fig.42 –IR georeferenced image.

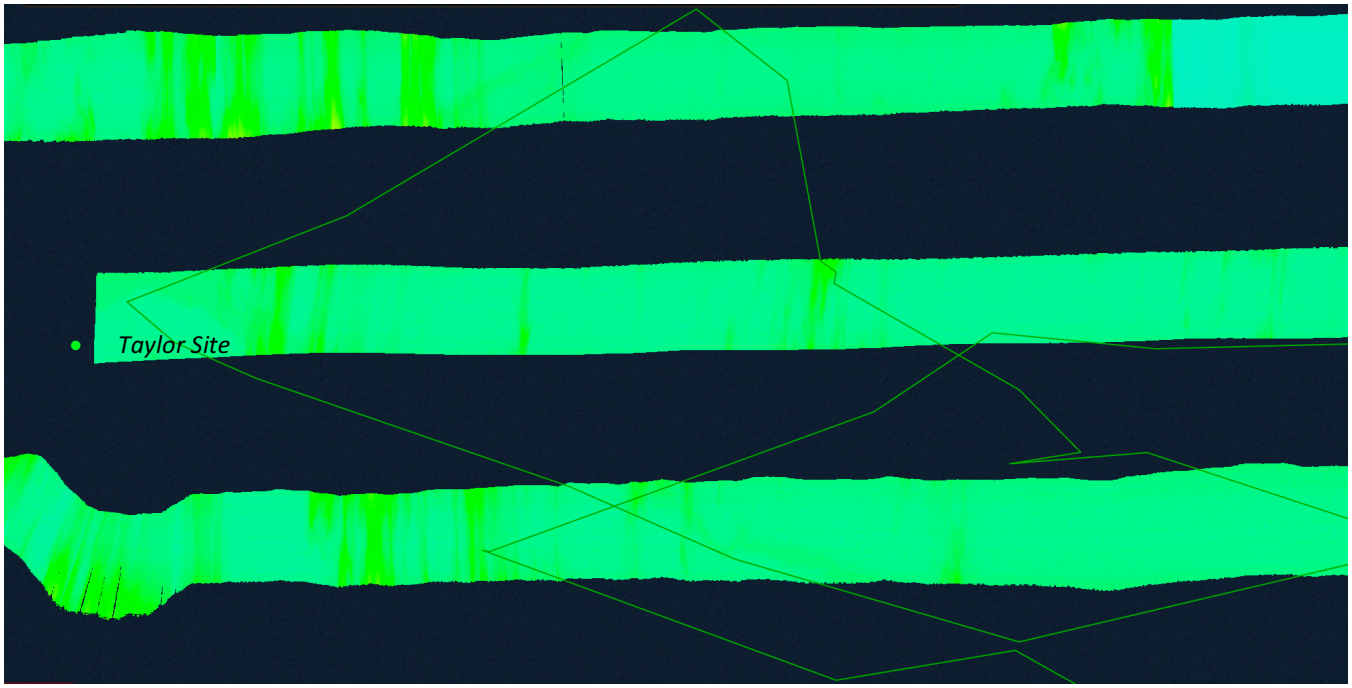

Fig.43 –UV georeferenced image.

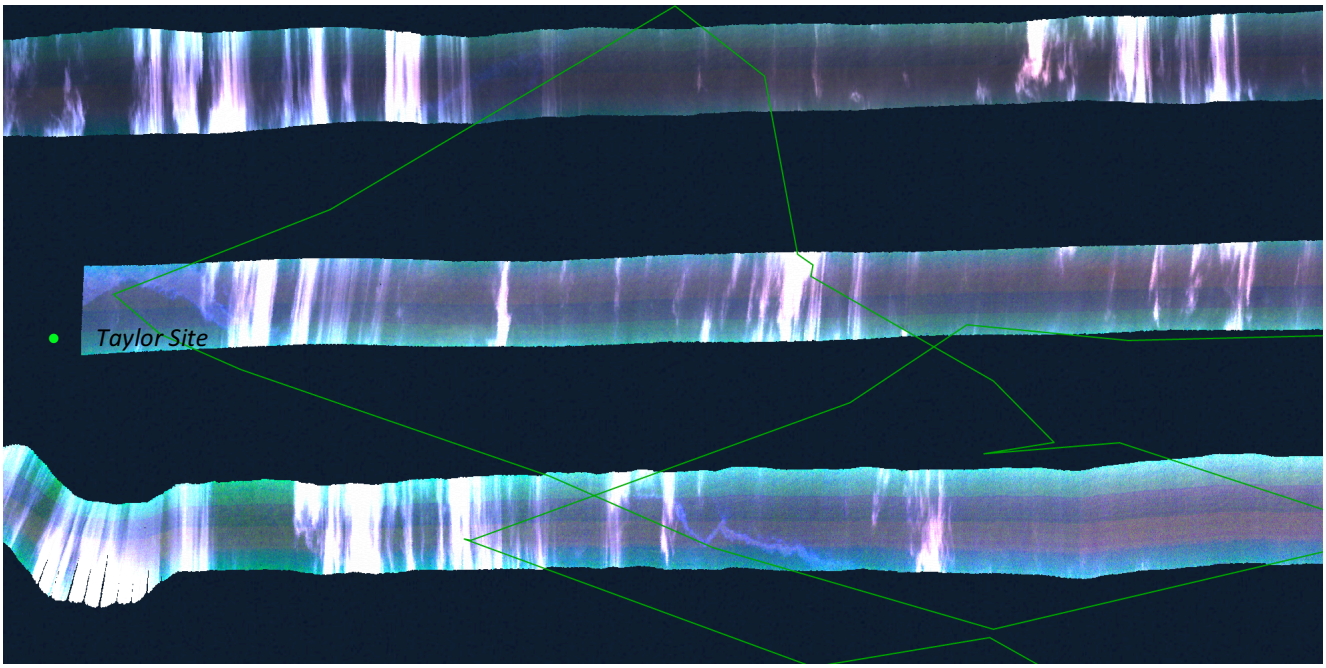

Fig.44 –VIS georeferenced image.

During mission#3 the 27th of April, 17 following files were transfered during the mission (Fig.45):

- Shapefiles: Polygon from the SLAR detection; Flighpath, Targets.
- Geotiff: SLAR Georeferenced images.

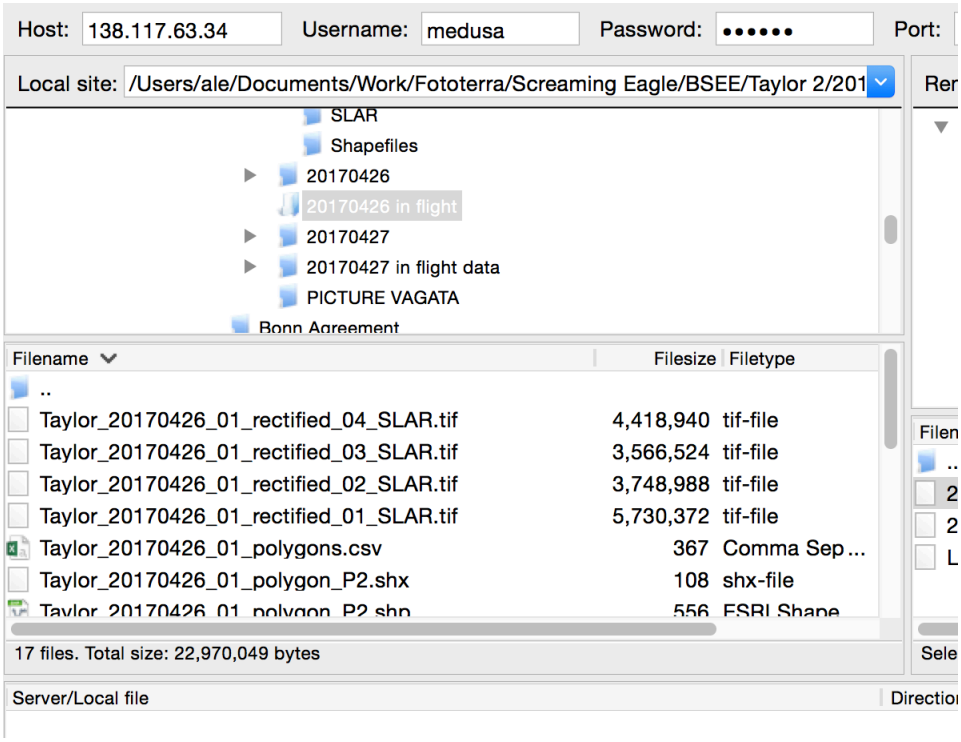

Fig.31 – Files transmitted during the mission

Conclusion: also during Mission#3 Poseidon successfully located the slick and defined the synoptic characteristics with the SLAR, creating also a navigation reference for the successive low altitude passes. During the low altitude passes the near range sensors gave positive confirmation of the nature of the slick and determined type of oil, thickness, relative thickness distribution and hot spot localization. Operators were able to analyze the spill scene during the flight in real time determining information as area, dimension, center coordinate, defining georeferenced targets and imageries. Files generated during the mission were sent via MBR microwave antenna to ground to test the antenna and data communication performances. Results were successful.

3.6 Metocean Conditions and Dynamic of the Spill

The opportunity to fly 3 consecutive missions in 3 days gave an interesting perspective also on the dynamic behavior of the spill related to the metocean conditions.

3.6.1 Metocean Analysis Methodology

Between April 25th and 27th, during the test over Taylor Energy site, a set of Metocean data (Sea Surface Temperature - SST; Wind and Surface Current Data) were acquired to understand the environmental conditions in the region of interest, and possibly relate the dynamic behavior of the spill to the environmental conditions.

SST data has been acquired from the Advanced Very High Resolution Radiometer (AVHRR) sensor onboard NOAA satellites and available in .tif format at http://coastwatch.noaa.gov/-cwn/search/interface.html and has been georeferenced for later Interpretation by Fototerra technicians.

Two types of wind data were used, those obtained from the Advanced Scatterometer (ASCAT) sensor on board the MetOp-B satellite, obtained from the website ftp://podaac-ftp.jpl.nasa.gov/allData/ascat-/preview/L2/metop_b/coastal_opt/2016/. When these data were not available because the passage of the satellite orbit did not coincide with the position of the the area of interest, wind data were obtained from in situ stations from oil platforms and buoys linked to the National Data Buoy Center - NDBC at http://www.ndbc.noaa.gov/. In the case of wind data obtained by buoys, the maps were generated from the tables with the surface wind hour averages available for download.

For ocean surface current information, data obtained from the NOAA HF Radar National Server were used. HF Radar is used to remotely measure ocean surface currents on the website http://hfradar.ndbc.noaa.gov/ and it is considered a very important data for predicting the trajectory of oil leakage at sea and an optimized flight plan. In our case, the HF data used were on average between 45 and 50 NM (83.3 to 92.6 km) from the area of interest, however, the surface circulation

pattern in this region of the Gulf of Mexico was very close to the current patterns conditions found near the Taylor area.

3.6.2 Metocean Conditions April 25th 2017

- Mission Start: 16:30Z (11:30 CST)
- Mission End: 19:15Z (14:15 CST)
- SST: between 20-23 °C;
- Wind:
- Current:

3.6.3 Metocean Conditions April 26th 2017

- Mission Start: 16:35Z (11:35 CST)
- Mission End: 18:40Z (13:40 CST)
- SST: between 22-25 °C;
- Wind: 200 @ 10-15 Kts
- Current: SE 25 cm/sec

3.6.4 Metocean Conditions April 26th 2017

- Mission Start: 22:45Z (17:45 CST)
- Mission End: 01:35Z (20:35 CST)
- SST: between 22-25 °C;
- Wind: Wind: 250 @ 10 Kts
- Current: SE 25 cm/sec
- Current: SE 25 cm/sec

3.6.5 Dynamic Behavior of the Spill

The following table summarizes the position and configuration of the slick between the 25th and the 27th of April.

Collection	Centroid LAT	Centroid LON	Area [Square NM]	Dimensions [NM]
Mission#1	28°55'43" N	088°55'14" W	13.1	3.86 x 7.11
Mission#2	28°58'03" N	088°57'21" W	2.64	1.23 x 3.59
Mission#3	29°35'24" N	090°19'21" W	7.51	2.01 x 4.58

Table 1 – Slick position and geometry during the 3 Missions



Fig.45 – Slick evolution during the 3 Mission

3.7 Thickness Map and Volume Calculation

The information collected during the flights allow to have a good estimate of the volume of the spilled oil in the area.

3.7.1 Volume Estimation Methodology

Among other capabilities, POSEIDON Sensors allow for real time Absolute Oil Thickness and quantitative Volume estimation, Hot-Spots identification and determination of oil as recoverable and non-recoverable, and accurate Post Spill Analysis for NRDA (Natural Resources Damage Assessment). Absolute Oil Thickness is measured by the Microwave Radiometer (MWR) that measures the absolute thickness in the 50µm - 3mm range and by the Laser Fluorosensor (LFS) that measures absolute thickness in the 0.1µm – 20µm range depending on the type of oil.

IR/UV sensor complements the information with Relative Thickness Mapping: Ultraviolet Line Scanner UV is sensitive from 0.01µm, Infrared Line Scanner IR is sensitive from 2µm.

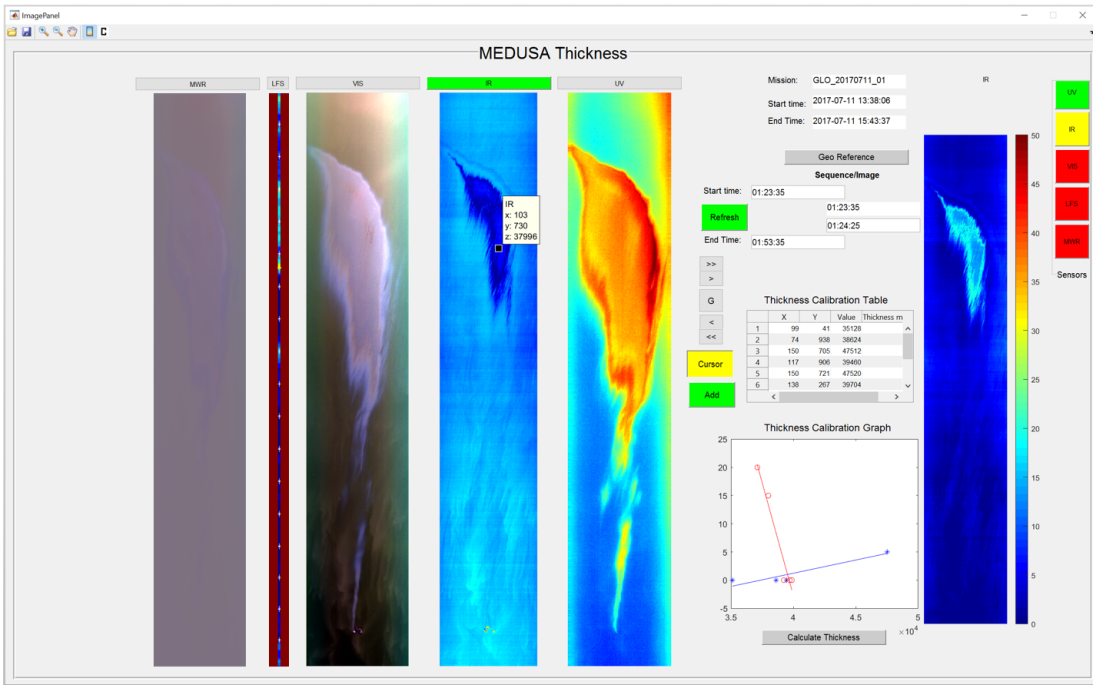

Fig.46 – Graphical User Interface (GUI) of the module for thickness calculation.

The fusion of the information from MWR, LFS, IR/UV allows to build accurate Thickness Maps in the 0.01µm to 3mm range. Fig.46 shows the interface of the module for thickness calculation integrated in the Mission Control Software.

The Thickness Map, and the area of the polygons that enclose the spill, or the patches of the spill, determined with the Far or Near Range Sensors allows the quantification of the Volume of the spill. Typical accuracy is 70-90% depending on the environmental conditions. The methodology for the estimate of the volume follows three steps:

- Synoptic Overview: the far range SLAR acquisition allows to determine the overall extent of the spill and to plan the next steps for near range analysis.
- To build a 'Thickness Map' the overall spill area is overflown in parallel patterns with overlaps to ensure the complete coverage of the area. Flight Lines are 2,000ft apart. In case of small and medium spills the standard flight altitude is 1,000ft that allows for coverage swath of 2,000ft. In case of extended spills the altitude can increase to 3,000ft to guarantee a wider sensor swath of 1NM. In case of spills with exceptional dimensions, other techniques can be put in place to ensure wider coverage without increase excessively the flight time.
- Scan rate of the sensors is 20Hz that means that the sensors can acquire thickness information each 4.5 meters at a cruise speed of 180 Kts.

3.7.2 Volume Estimation – April 25th

The 25th of April the spill structure had a predominant NW-SE direction, determined possibly by the wind/current configuration. The structure was delimited by a polygon of approximately 3.86x7.11 NM with a coverage of 48% and a resultant area of the surface target of 13.1 square nautical miles. Based on the LFS and IR/UV data a thickness map has been built, Fig.47 below.

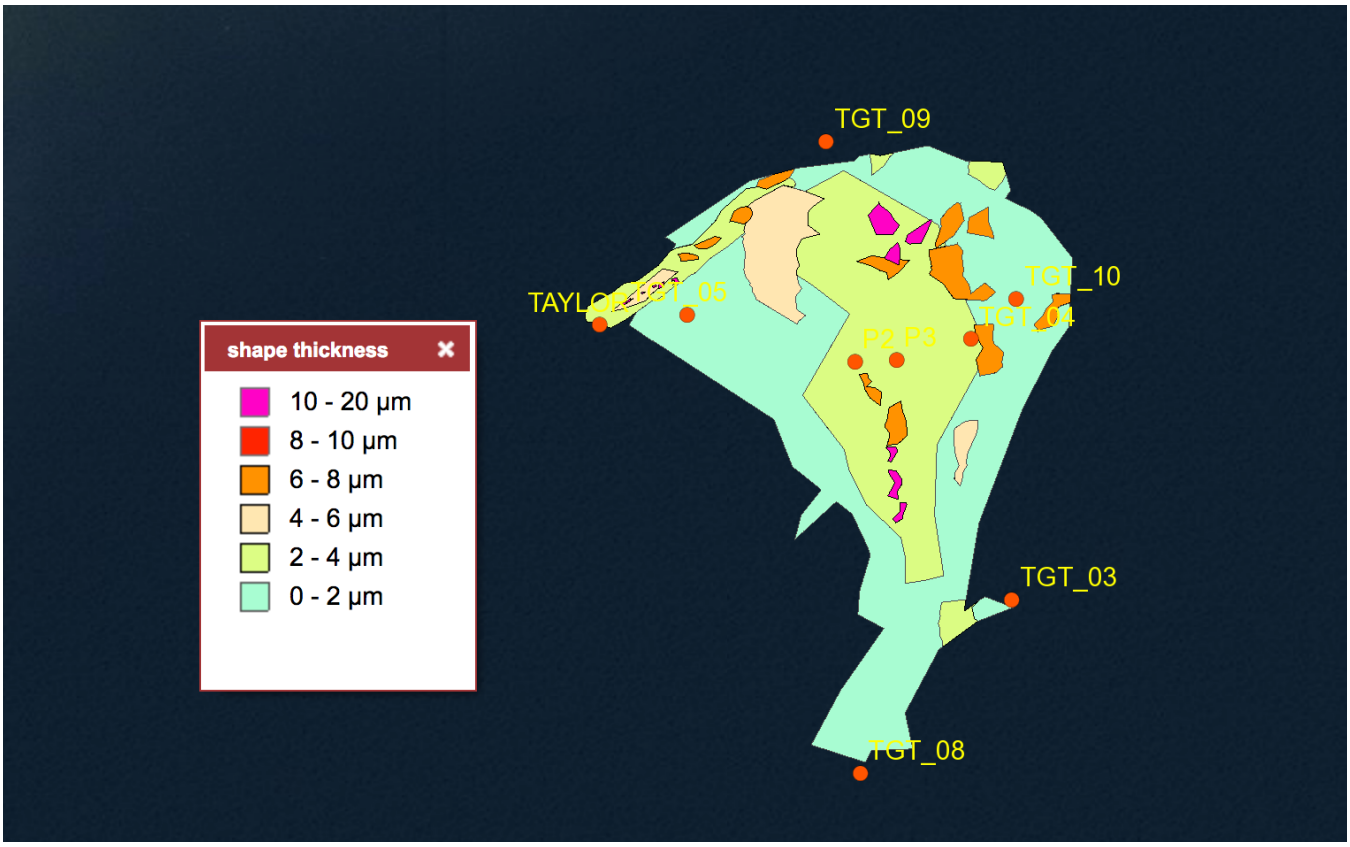

Fig.47 – Thickness Map

The map has been originated with data acquired with the IR/UV and the LFS that measured the absolute thickness with a scan frequency of 20Hz (thickness point every 4.5 meters).

It shows a thin sheen of about 2 µm, quite uniform in the overall spill area, and a limited area (less than 5% of the total) with a higher concentration of oil, and a thickness peak of about 5µm. This pattern was confirmed by the signature of all the sensors, IR, UV, VIS, LFS.

Based on the area of the polygon and the thickness distribution, during the first mission of the 25th of April the maximum estimated volume was **49.426 m^3** equivalent to **13,006 Gal**.

3.7.3 Volume Estimation – April 26th

During the mission the 26th of April the spill structure was different from the previous day, with a smaller size, a predominant SW-NE direction, determined possibly by the wind/current

configuration. The area was delimited by a polygon of approximately 1.23x3.59NM with a coverage of 60% and a resultant area of the surface target of 2.64 square nautical miles.

Based on the LFS and IR/UV data a thickness map has been built, Fig.48 below.

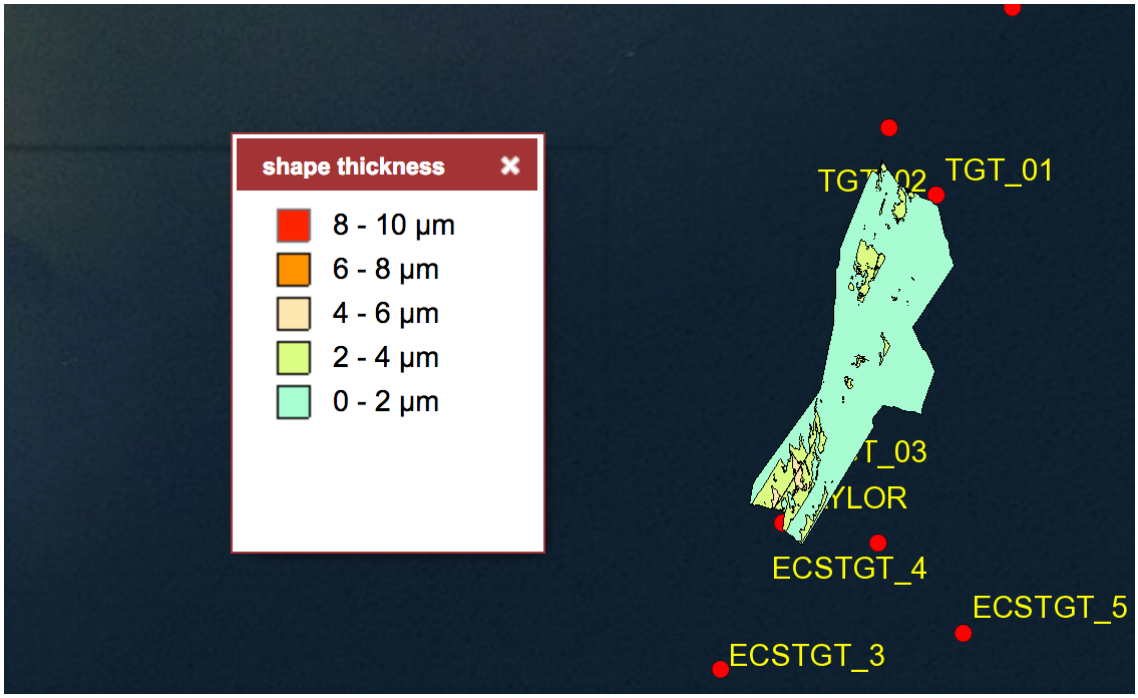

Fig.48 – Thickness Map

The map has been originated with data acquired with the IR/UV and the LFS that measured the absolute thickness with a scan frequency of 20Hz (thickness point every 4.5 meters).

It shows a thin sheen of about 2 µm, quite uniform in the overall spill area, and a limited area (about 5% of the total) with a higher concentration of oil, and a thickness of about 5µm. This pattern was confirmed by the signature of all the sensors, IR, UV, VIS, LFS.

Based on the area of the polygon and the thickness distribution, during the mission of the 26th of April the estimated volume was **19.100 m^3** equivalent to **5,026 Gal**.

4 Conclusions

Between the 25th and the 27th of April 2017 tests were promoted by BSEE and NOAA at the former Taylor Platform Site in order to assess and better understand the capabilities of remote sensing tools and other ways of collecting data, in an effort to enhance the ability to detect and measure oil spills offshore. Fototerra was invited to take part of the project with the airborne remote sensing platform Poseidon. The general objective of the open water test in Taylor, in line with the BSEE / NOAA goals, was to present the capabilities of the Poseidon platform in a real oil spill scenario and acquire data for surface oil detection and characterization, and show how the information and the methodologies can be effectively used in future oil spill responses, in permanent coastal surveillance, and natural damage assessment.

All the missions flown provided particularly significant results, the sensors were imaging the spill consistently providing the operators with detailed information of the spill on the far range and near range environments. Poseidon was capable to provide synoptic information of the overall spill as well as detailed spill analysis. The integrated navigation system, data processing and communication system complemented the sensor capabilities, making the operations extremely effective and efficient and showing how the platform will be effective in a real spill response.

Data were collected and processed in flight to obtain the following information: Synoptic overview and overall aerial extend of the spill, area of the spill, center coordinates of the oil spill, oil distribution map, oil type classification, oil thickness, indication of hotspots when present, and dynamic properties of the spill (e.g., drift and spreading of the oil on the sea surface).

The above-mentioned information was made available in real-time during the flight. During real operations, this capacity enables the operator to continuously report to the Incident Command Center and to the Responders to support the decision-making process with real-time data and so to dramatically improve the oil recovery process. This Document describes basic physical principles of the sensors and reports the first results of the data collections as well as the combination with metocean data that improve also the prediction of dynamic behavior of the spill.

Attachment J. Fototerra MC20 August 2017 Report

Fototerra

Taylor Energy Site 3rd Campaign - Offshore Oil Spill Remote Sensing Test

Report

Rev.1 – Sep 12th 2017

A.Vagata / T.Hengstermann

Fototerra Aerial Survey LLC

10435 Pladdawa Ln
Richmond, TX 77407

"The findings and opinions expressed in this report are solely those of the authors and do not necessarily reflect the views and policies of the Bureau of Safety and Environmental Enforcement, nor does mention of the trade names or commercial products constitute endorsement or recommendation for use."

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1 Executive Summary

Fototerra is taking part of a series of tests coordinated by BSEE and NOAA to support the Deepwater Horizon spill ongoing lessons learned with the aim to provide control and validation for surface oiling characterization efforts and to establish spatial and airborne data libraries necessary to use these techniques for future response and damage assessment. To advance the understanding for oil spill preparedness, BSEE and NOAA organized open water data collection experiments from multiple sensors and platforms. Aim of these experiments is to demonstrate how each sensor detects oil in the same physical and environmental conditions.

The open water collection took place the 16th of August 2017 in the area of the former Taylor Energy's production platform on Mississippi Canyon 20-A. The platform and its pipelines were destroyed in 2004, when Hurricane Ivan crossed the area. Since then, plumes of oil and gas are found seeping from the sea floor in the vicinity of both the well casings and the downed platform and oil has been spotted leaking at the site ever since. Fototerra participates in this event with the Poseidon platform equipped with its multi-sensors system. POSEIDON is an integrated system built on three blocks: multi-sensor platform, real time analysis and high-speed high-capacity communication. Capabilities include: detection of surface films (oil and pollutants); mapping of relative thickness; oil and pollutants type classification; measurement of absolute thickness and volume; determination of position, area, drift and spreading of the spill; preservation of evidence and real time data communication and mission coordination.

2 Introduction

The test campaign coordinated by BSEE and NOAA is composed of 3 Phases. Phase#1 - Controlled Experiment at Ohmsett, Phase#2 – Open Water testing at Taylor Energy site and Phase#3 - Operational Tools Algorithms and Training. Fototerra was involved in Phase#1 and Phase#2:

Phase#1 - Controlled experiment at Ohmsett Test Tank.

Between the 10th and the 21st of July 2016 Fototerra performed two series of tests: a bridge-mounted test in Ohmsett with Laser Fluorosensor (LFS) and Microwave Radiometer (MWR) and an overflight test with the entire suite of sensors. The LFS determined clearly the classification of the oil and the MWR determined with precision the thickness of the oil. The overflights, despite the challenging contained environment of the 200m by 20m test tank, provided very good results and the sensors from Medusa were imaging the area of the tank consistently. Results from Phase#1 were presented previously in a dedicated Report.

Phase#2 - Open Water testing at Taylor Energy site.

Between the 14th and the 18th of November 2016 (1st Offshore Campaign), between the 25th and the 27th of April 2017 (2nd Offshore Campaign) and the 16th of August 2017 (3rd Offshore Campaign) Fototerra performed data acquisition with the full suite of sensors including SLAR, in daytime and nighttime conditions at the Taylor Energy Site in the Gulf of Mexico, about 90NM southeast of New Orleans. Data were collected and processed to obtain the following information: identification of the target, synoptic overview and overall aerial extend of the spill, area, center coordinates of the oil spill, oil distribution map, oil type classification, oil thickness, indication of hotspots when present, and dynamic properties of the spill (e.g., drift and spreading of the oil on the sea surface).

The above-mentioned information was made available in real-time during the flight. During real operations, this capacity enables the operator to continuously report to the Incident Command Center supporting the decision-making process with real-time data and so to greatly improve the oil recovery process. This report aims to show chronology and the preliminary results of the 3rd Offshore Campaign.

3 Chronology and Preliminary Results

3.1 General Objective

The general objective of the open water test in Taylor, in line with the BSEE / NOAA goals, was to present the capabilities of the Poseidon platform in a real oil spill scenario and acquire data for surface oil detection and characterization, and show how the information acquired and the methodologies adopted can be used in future oil spill responses, in permanent coastal surveillance and natural damage assessment.

3.2 Specific Objective

Fototerra's specific objective was to perform planned overflights over the Taylor Energy platform site the 16th of August 2017 per the following schedule set up by BSEE and NOAA and based on satellite acquisition times.

08/16/2017 Collections

- 08/16 – Radarsat-2 7:30 am
- 08/16 – WV2 11:30 am
- 08/16 – Poseidon 7:30 am
- 08/16 – Poseidon 11:30 am

3.3 Poseidon Technology

For the open water test in Taylor, Fototerra utilized the full Poseidon platform.

Poseidon platform is built on three blocks: multisensor environment, real time data processing and communication.

POSEIDON's integrated multisensor platform is divided into far-range detection and near-range analysis. Far-range detection is based on the use of a real aperture radar system SLAR (side-looking airborne radar), which covers swaths of several tens of nautical miles (NM). Targets detected by the radar are then investigated on site using near-range sensors. Near-range analysis of oil spills includes visualization, quantification and classification of the type of oil. Near-range detection sensors

include: IR/UV (infrared ultraviolet) scanner, VIS (visual line) scanner, EO/IR (electro-optical infrared), MWR (microwave radiometer), LFS (laser fluorosensor). For SAR (Search and Rescue) support the POSEIDON is equipped with: direction finder and AIS. The platform is completed by a mission control system for real-time data processing and analysis and communication systems—broadband radio, satellite, satellite phone, VHF.

Side Looking Airborne Radar (SLAR) is a X-band microwave radar. Flying at an altitude between 1,000 and 6,000 ft., SLAR has a cross-track swath between 35 and 50 NM. Oil spill detection by radar is based on the principle that oil spills and biogenic slicks or specific hydrodynamic effects may result in a reduction of the radar backscatter signal due to the dampening of surface wave structures. SLAR is an all-weather sensor: Microwaves can penetrate clouds, fog, drizzle and rain. SLAR allows POSEIDON to cover more than 7,500 square nautical miles per hour.

Infrared Ultraviolet (IR/UV) imaging device is a standard instrument for near-range monitoring of oil spills and has shown its reliability, stability and operability over decades. At the near-range operational altitude of about 1,000 ft the swath width is between 2,000 and 3,000 ft. Films of crude oil in water can be detected in thermal IR because oil has a lower integral emissivity than the surrounding water in the spectral region, and oil can be heated up through absorption of sunlight if there is enough thickness. Minimum detectable oil thickness in the thermal IR starts from 2 μm; hotspots that are generated through absorption of sunlight appear in the thickness range up to 500 μm. UV remote sensing of oil is based on the fact that the air/oil interface of the oil film has about twice the integral near UV reflectance of the water. The UV can detect very thin sheens of oil; the minimum detectable thickness amounts to 0.01 μm. The combined IR/UV device shows the area of large and intermediate film thickness, as well as the total extent of the oil spill.

Visual Line Scanner (VIS) is used for acquisition of highly resolved georeferenced RGB (Red Green Blue) images. The RGB line scanner combines high mapping and georeferencing accuracy with the acquisition of color information that allows volume estimations based on oil appearance codes. The Microwave Radiometer (MWR) is a passive microwave remote sensor used to map oil layers exceeding a thickness of 50 μm. Oil spills appear as a brighter object in the microwave region relative

to the oil-free surface. The MWR allows determination of the absolute thickness of the oil spill and, therefore, the volume of the spill. In addition, the difference of sensitivity between MWR and IR/UV allows determination of the hotspots of the spill where the bulk of the oil is concentrated. This feature is greatly important for the responders. MWR is an all-weather sensor. At the near-range operational altitude, the swath width is about 2,000 ft.

The Laser Fluorosensor (LFS) is based on a high-power UV laser that sends short pulses toward the water surface. The laser-induced fluorescence and backscatter are received by a telescope and separate spectrally into a number of monochromatic signals. The detected discrete emission spectrum is used to estimate the oil class and classify the oil and to evaluate the absolute thickness of thin slicks in the range of 1 – 20 μm. The system has a pre-existing library of substances used to compare the actual detection.

Electro Optical Infrared (EO/IR) is an airborne observation system with HD sensors and HD video outputs. It is equipped with RGB and NIR (near-infrared) optics, multispectral zoom laser range finders, illuminators and pointers (red or NIR). The device delivers color and NIR images that allow situational awareness in all conditions day and night in critical SAR operations, navigation in challenging conditions, and clear images of the scene.

The mission control system computer provides sensor management, online visualization, real-time sensor fusion, data analysis and data storage in a central multimission unit. All operations are facilitated by an ergonomic graphical user interface (GUI). In contrast to traditional systems, which mainly perform visualization and storage of non-georeferenced sensor images, the system allows real-time data fusion, georeferencing and analysis of multisensor oil spill data.

3.4 Methodology

The methodology used during each flight follows the standard procedure that Fototerra adopts for an actual response operation, that includes: Step#1: Synoptic overview of the spill, Step#2: spill approach and Near Range Analysis, and Step#3: Data Processing and Data Communication.

Step#1: Poseidon approaches the Spill Area at an altitude of 3,000ft, scanning the area with the SLAR. At that altitude, the Swath is about 50NM and the total area scanned is about 7,500 square nautical

miles, the SLAR is a microwave real aperture radar effective in all weather, night and day conditions. The EO/IR sensor is also a good support on this phase giving the operator a night and day vision of the scene. During every operation Poseidon monitors possible marine and aviation distress frequencies with the Direction Finder, and ship traffic with the AIS (Automatic Information System). After the identification, the target is analyzed and georeferenced, to allow for an immediate localization on the navigation map and successive detailed analysis with the near range sensors. In this stage a polygon is designed around the target and information as area, coverage, overall dimensions and coordinates of the spill are determined. As the aircraft approaches the spill for the overflights with the near range sensors, the operator records the video the overall spill with the EO/IR to have a visual, or thermal at night, overview of the spill.

Step#2: Based on the far range overall images of the spill, the operator determines the best approach to be used for the following low level overflights in order to make the best detailed analysis of the spill. When the flight pattern is determined, the aircraft overflies the spill at an altitude of 1,000ft operating all the near range sensor that at that altitude have a swath of about 2,000ft. Near range sensors include: IR, UV, VIS, MWR, LFS. EO/IR and Direction Finder at this stage are still operational giving the operator support where necessary.

3.5 Chronology

Fototerra Mission Base for the Test Campaign has been the Houma-Terrebonne airport (KHUM), located about 100NM NW of the Taylor location. Flight from KHUM to Taylor location required about 35’ at 185KT of cruise airspeed. Every flight required to file a special DVFR (Defensive Visual Flight Rules) Flight Plan because the vicinity of Taylor to the ADIZ (Air Defense Interception Zone) that requires to follow special FAA rules. Extensive Helicopter and Aircraft Traffic Areas in the GoM required special attention, continuous contact with ATC (Air Traffic Control) and careful monitoring of local common traffic frequencies.

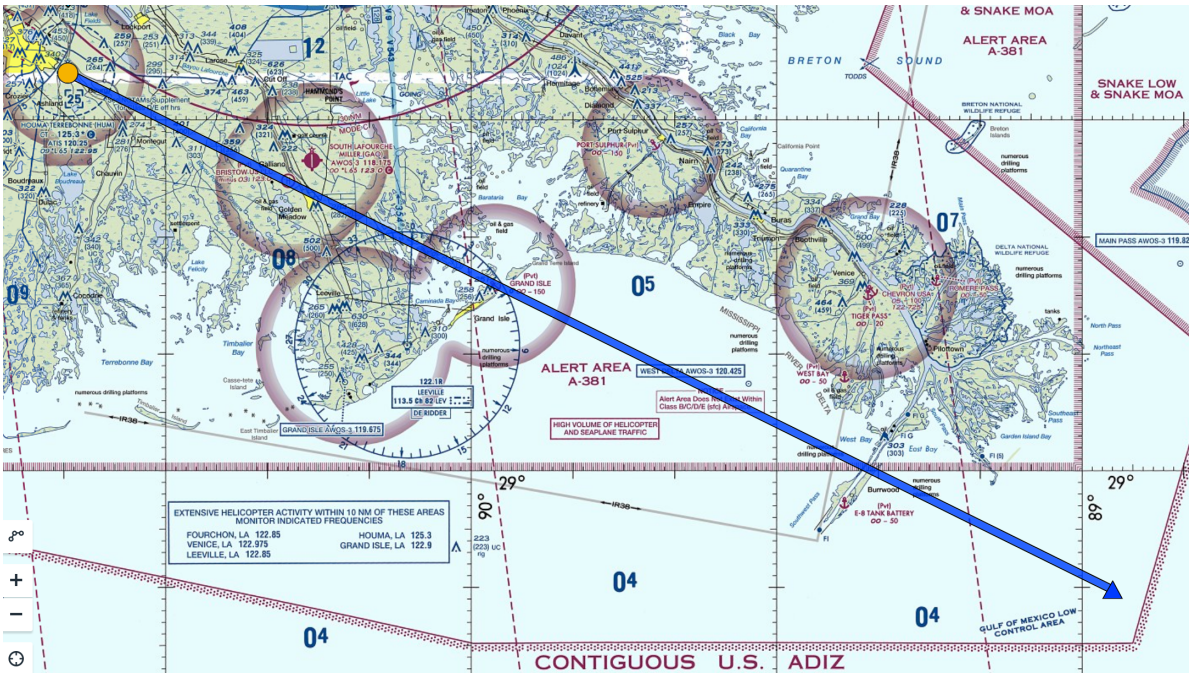

Fig.1 - Flight route from Houma-Terrebonne (KHUM) Airport to Taylor Energy site location.

The chronology of the flights (Mission IN – Mission OUT) has been the following:

August 16th - 1st Collection

Mission Start: 12:30Z (07:30 CST)

Mission End: 15:05Z (10:05 CST)

Mission Duration: 3h 05'

August 16th – 2nd Collection

Mission Start: 17:30Z (12:30 CST)

Mission End: 19:40Z (14:40 CST)

Mission Duration: 2h 10'

3.5.1 Mission#1 – August 16th 1st Collection

In the morning of August 16th EMB-110 Poseidon left Houma-Terrebonne airport at 07:30 CST. Poseidon approached the Taylor area with a SE track at 3,000 ft and about 185KT of cruise speed.

Step#1 - Synoptic Overview: the SLAR immediately detected a structure with strongly reduced backscatter that was identified as a surface target. The structure was delimited by a polygon of approximately 1.5x10 NM with a coverage of 46% and a resultant area of the surface target of 6.56 square nautical miles. Polygon was centered on the following coordinates: N 29°01'11" W 088°52'39". The following figures show the SLAR images, the georeferenced polygon, and the resultant SLAR georeferenced image with and without flight track (Fig.2 to Fig.6).

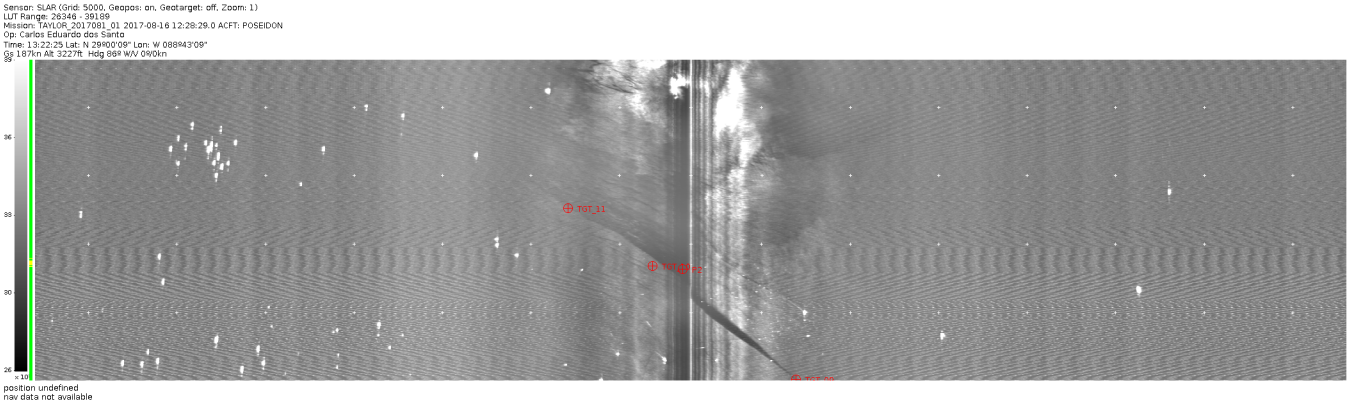

Fig.2 - SLAR images of the spill: NW to SE approach

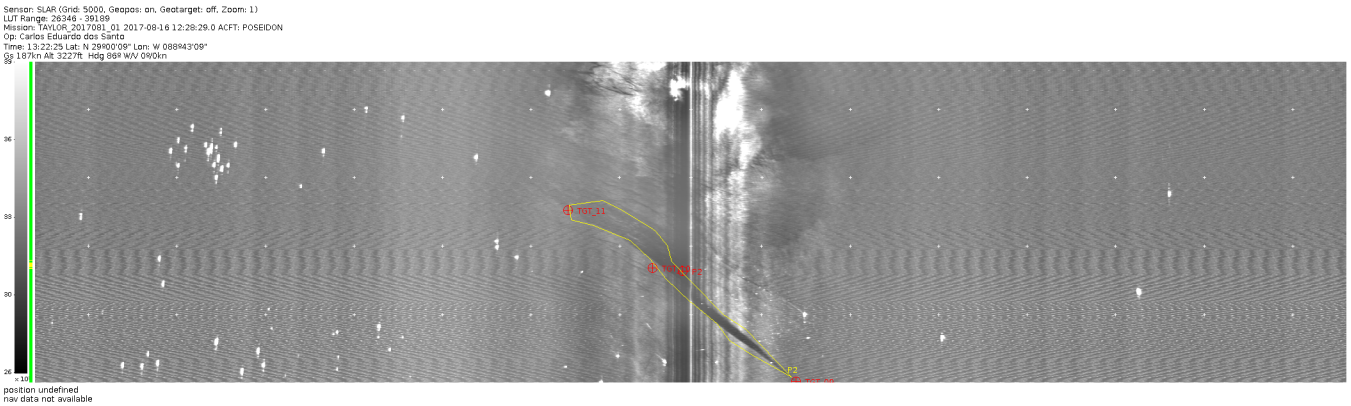

Fig.3 - SLAR images of the spill with polygon: NW to SE approach

During the same mission one more oil slick was identified with the SLAR about 55NM NW of Taylor, of about 0.4 square nautical miles, (Fig.4).

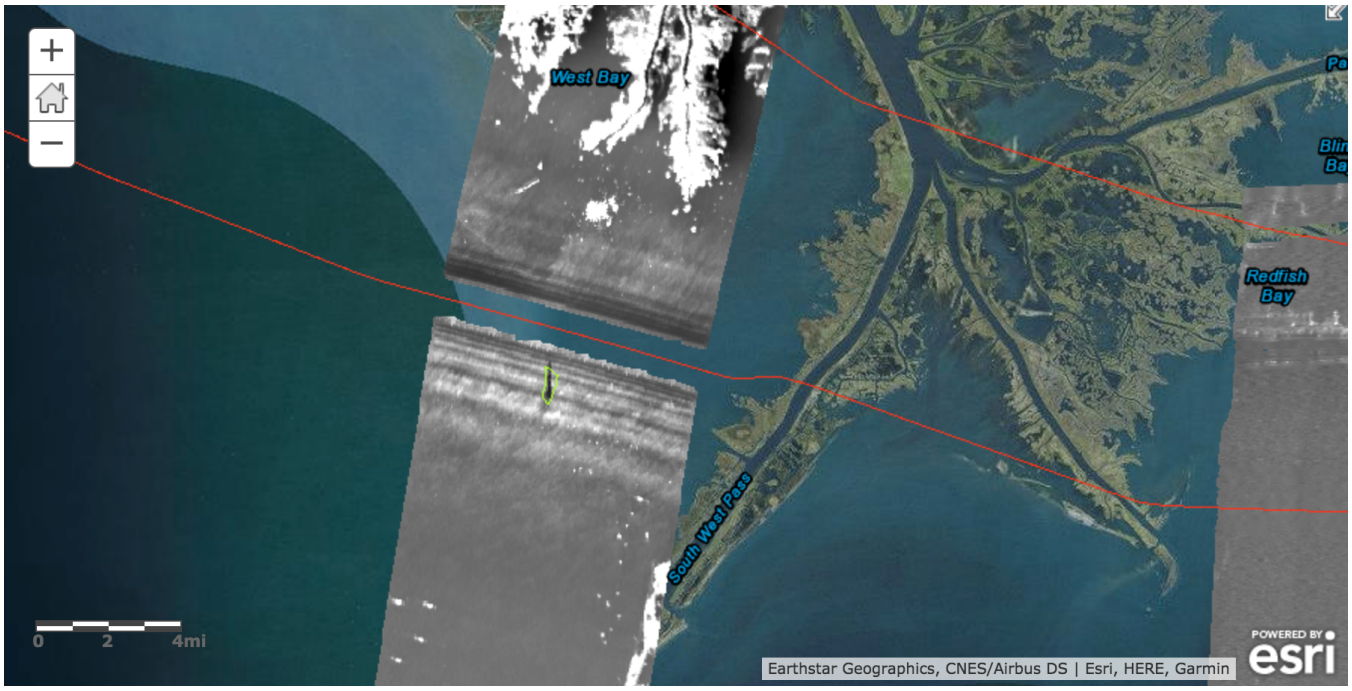

Fig.4 - SLAR images of a 'mystery spill' encountered during the mission

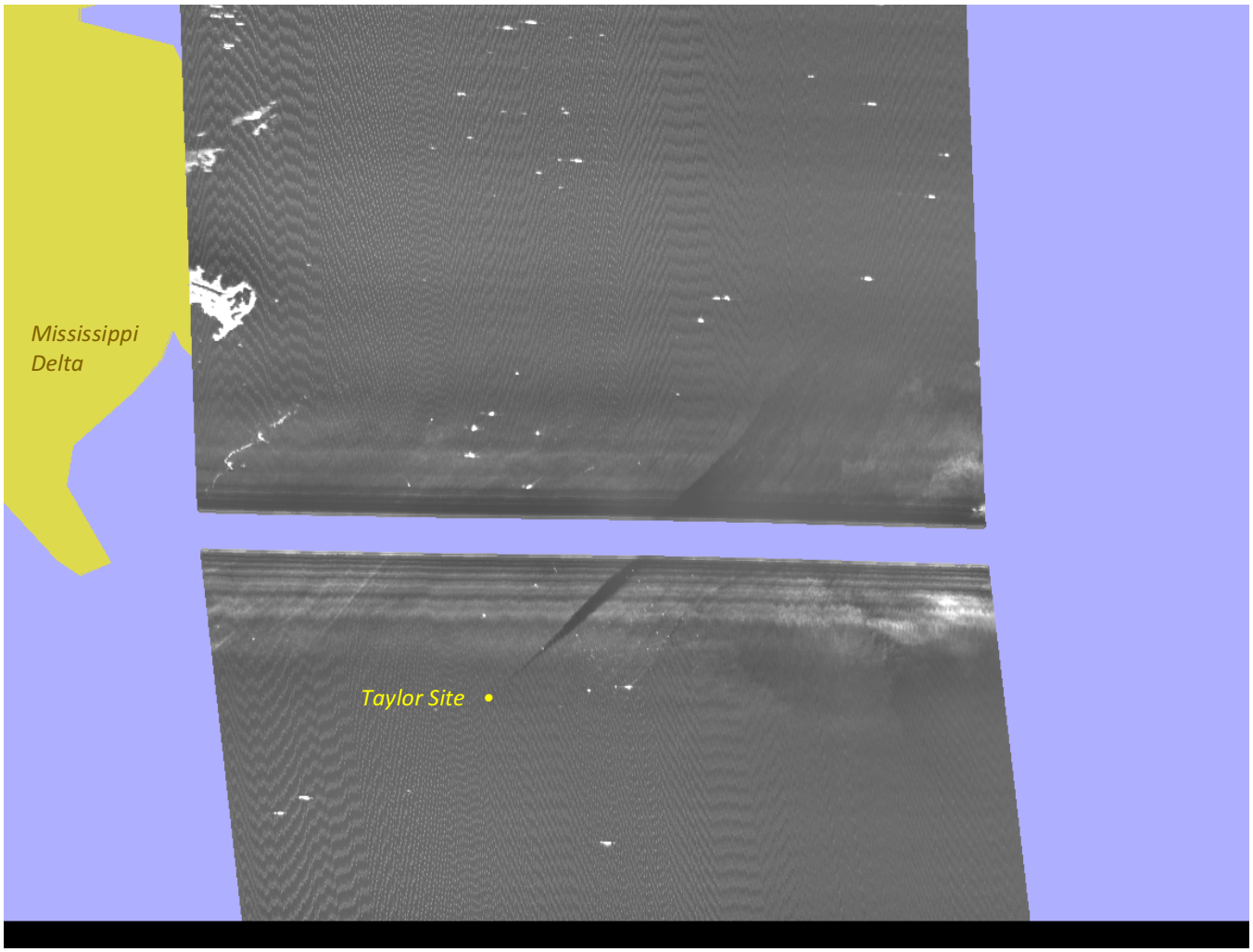

Fig.5 - SLAR georeferenced image

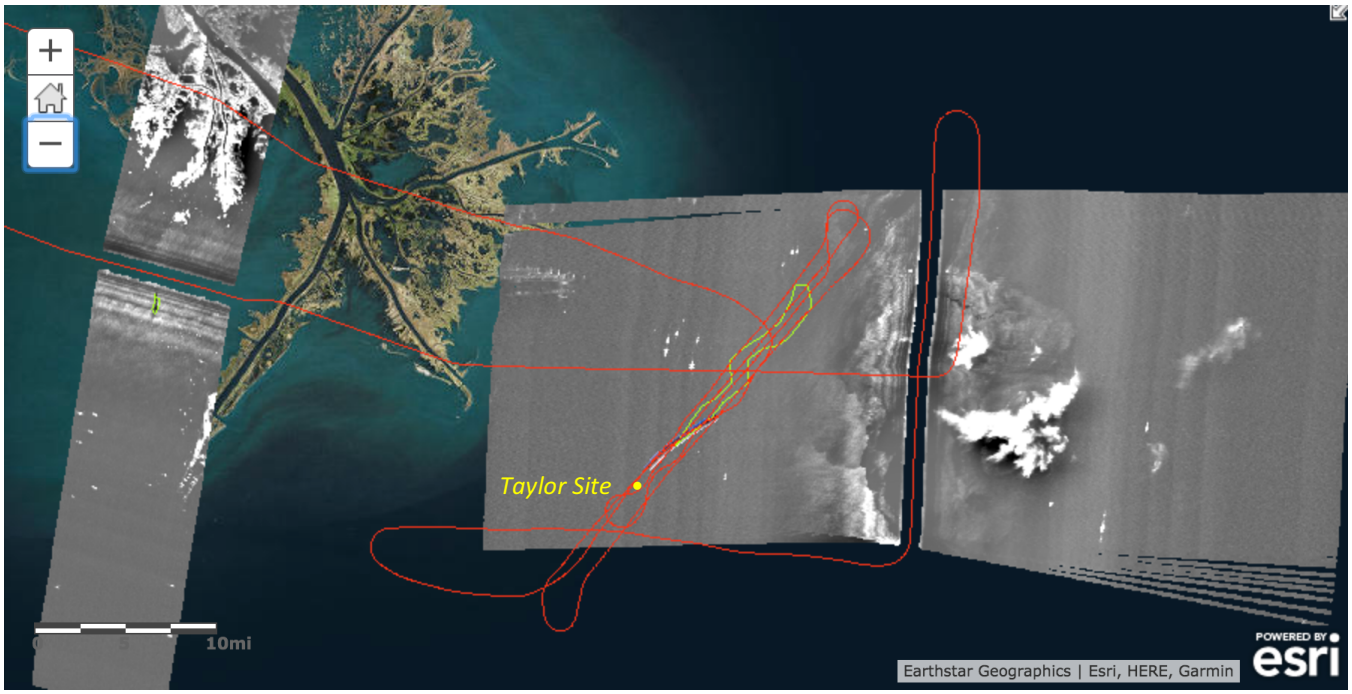

Fig.6 - SLAR georeferenced image with flight track and polygon.

After the detection, localization and georeferencing of the target Poseidon started the approach to the spill to perform the near range analysis, the slick showed a match with the SLAR image. The slick had an appearance sheen to metallic, with the direction along the prevalent wind (Fig.7 and Fig.8).

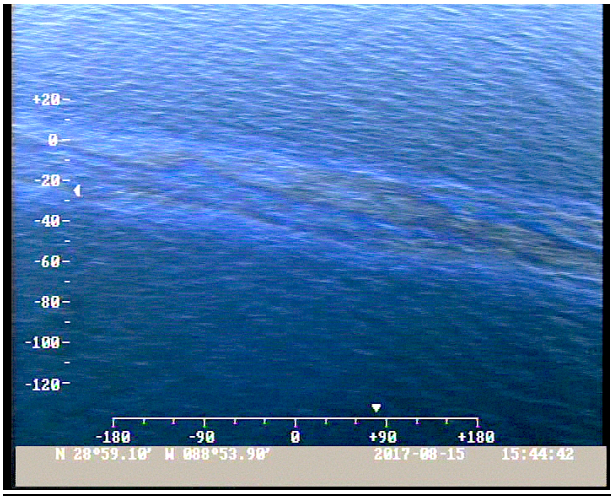

Fig.7 –Spill appearance.



Fig.8 – Overview of the spill.

Step#2: spill approach and Near Range Analysis.

At an altitude of 1,000ft Poseidon was directed over the slick to overfly it in parallel patterns to obtain a complete coverage and analyze the slick features with the near range sensors. Purpose of the Near Range analysis is to confirm the nature of the spill, oil or other substances, evaluate and map the thickness to estimate the volume, and determine the hot spots, areas where the oil is concentrated.

Fig.9 below shows the parallel pattern flown to insure maximum coverage.

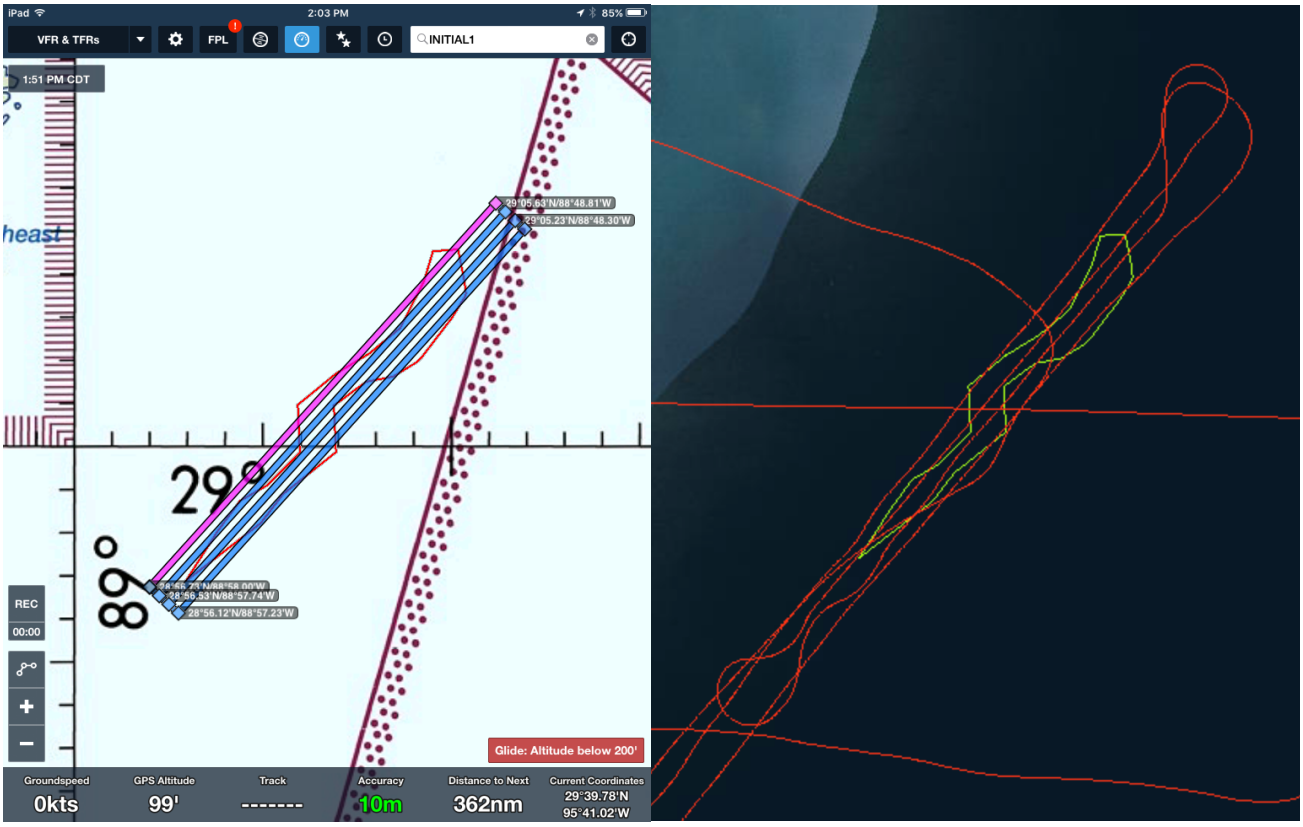

Fig.9 – Parallel Pattern flown to acquire near range images.

Fig.10 and Fig.11 below show the 'waterfall' images taken from the sensors, including IR, UV, VIS, IR/UV fusion over Taylor waypoint. In the 'waterfall' display the length of the image is about 1.1 NM at 180 KT of cruise speed, and the width is equivalent to the swath of the sensor, about 2,000 ft.

The response in the IR and UV bands was decisive to qualify mineral oil. The MWR response, suggested that the slick was very thin, less than 50µm, the IR showed an area of high relative thickness. VIS showed the appearance of the slick as a sheen with some rainbow structure.

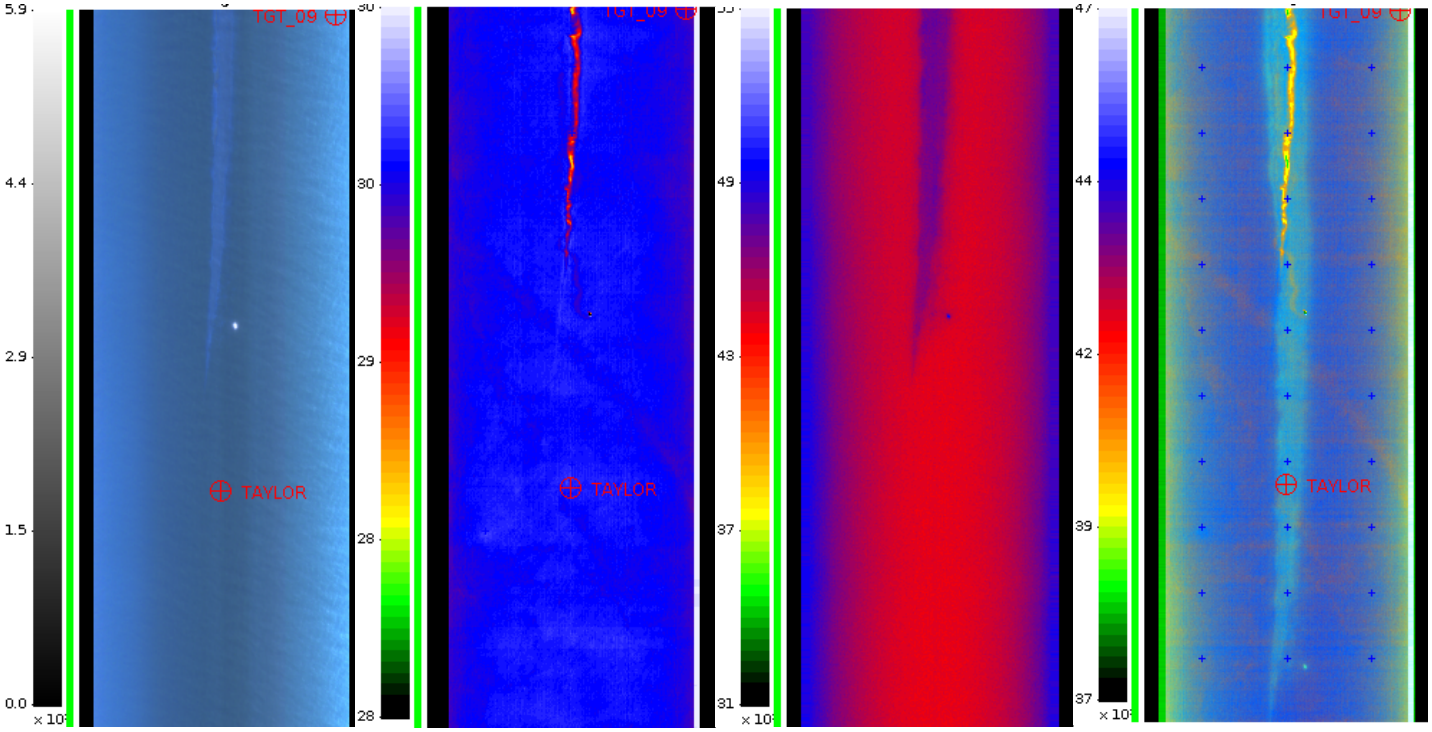

Fig.10 – Taylor waypoint, VIS, IR, UV, FUSION IR/UV images.

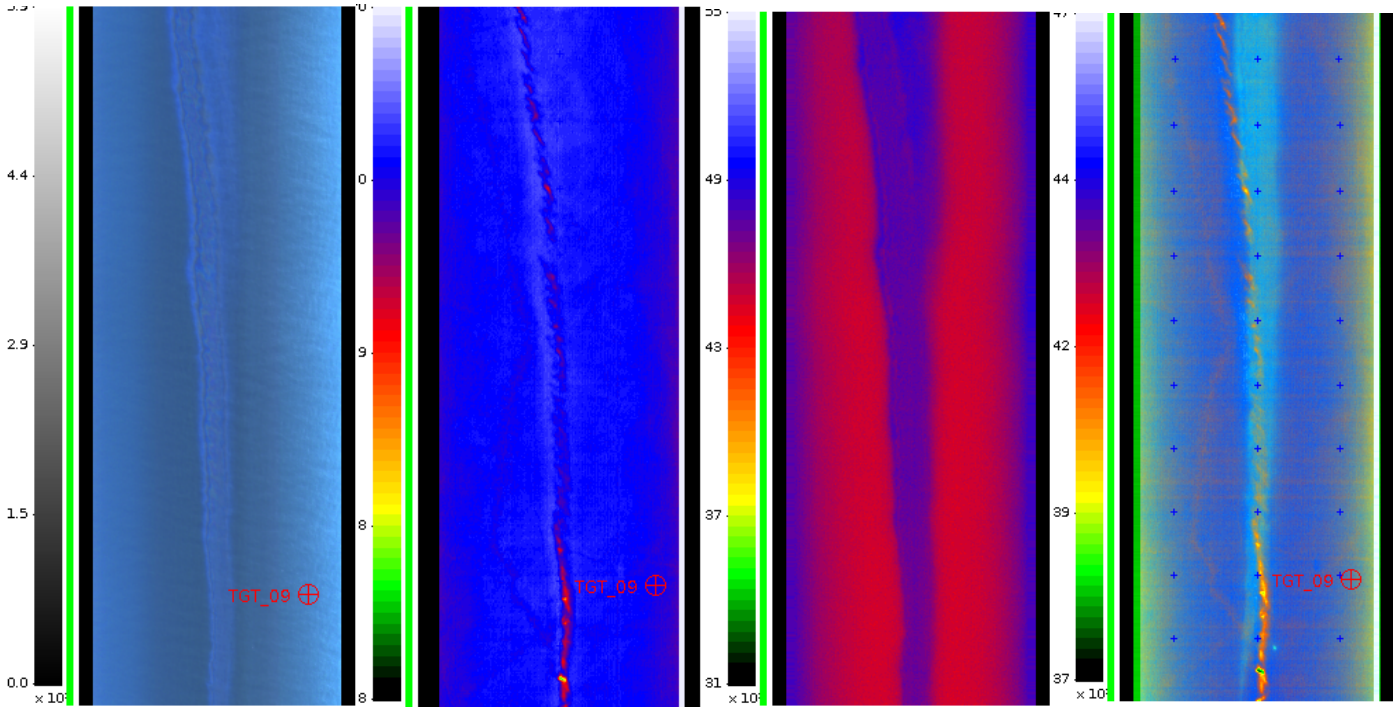

Fig.11 – Target_09, VIS, IR, UV, FUSION IR/UV images

Near Range images can be georeferenced, and a 'mosaic' composition of the scene can be made. Fig.12 below show an example of georeferenced IR images.

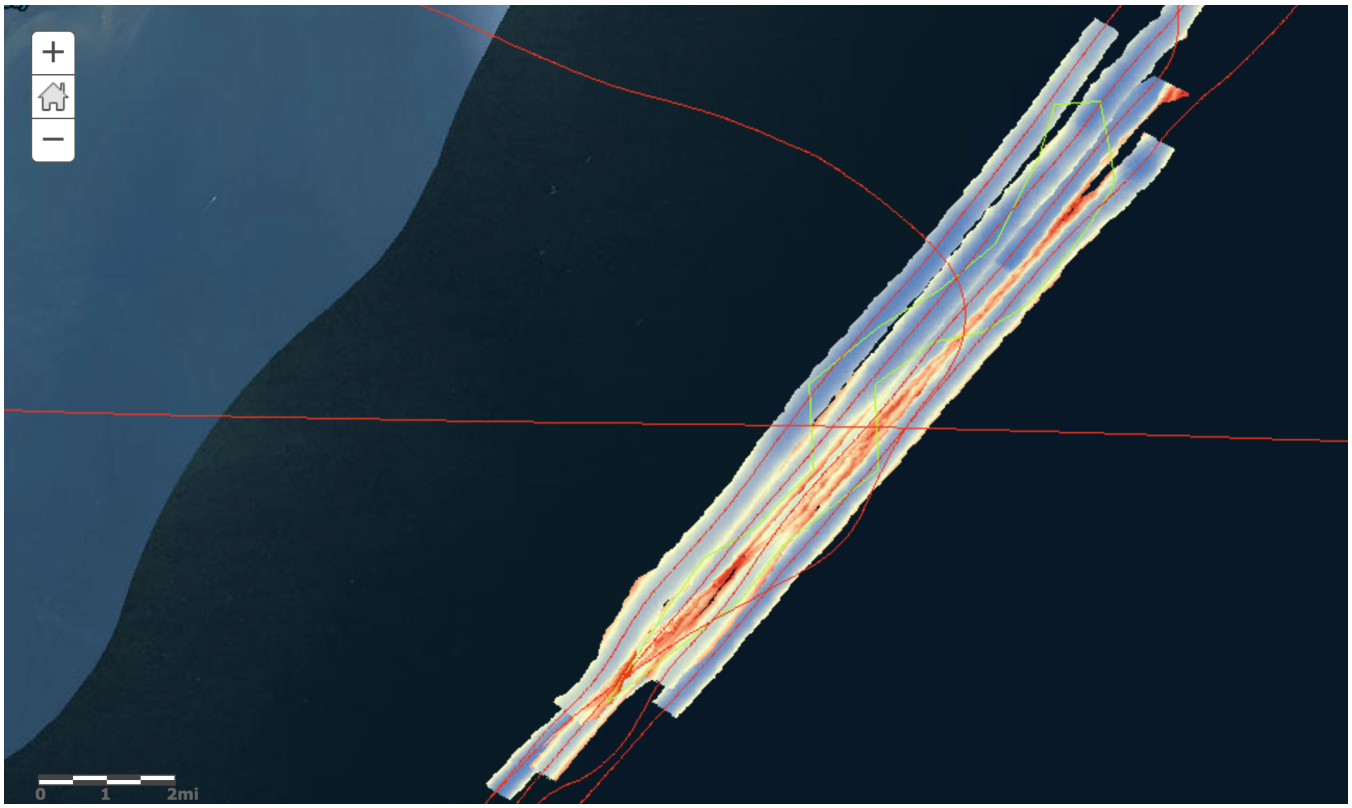

Fig.12 –UV georeferenced image.

Fig.13 to 16 show the area around the Taylor site. The IR image shows few spots where the oil is thicker in proximity of the former platform site. UV and VIS show the extent of the sheen that appears very thin. Classification of the oil from the LFS in proximity of the Taylor site position was 'Very Light Crude' consistent with a fresh spill. The overall sheen was very thin; the max thickness measured by the LFS was in the order of 4.5µm.

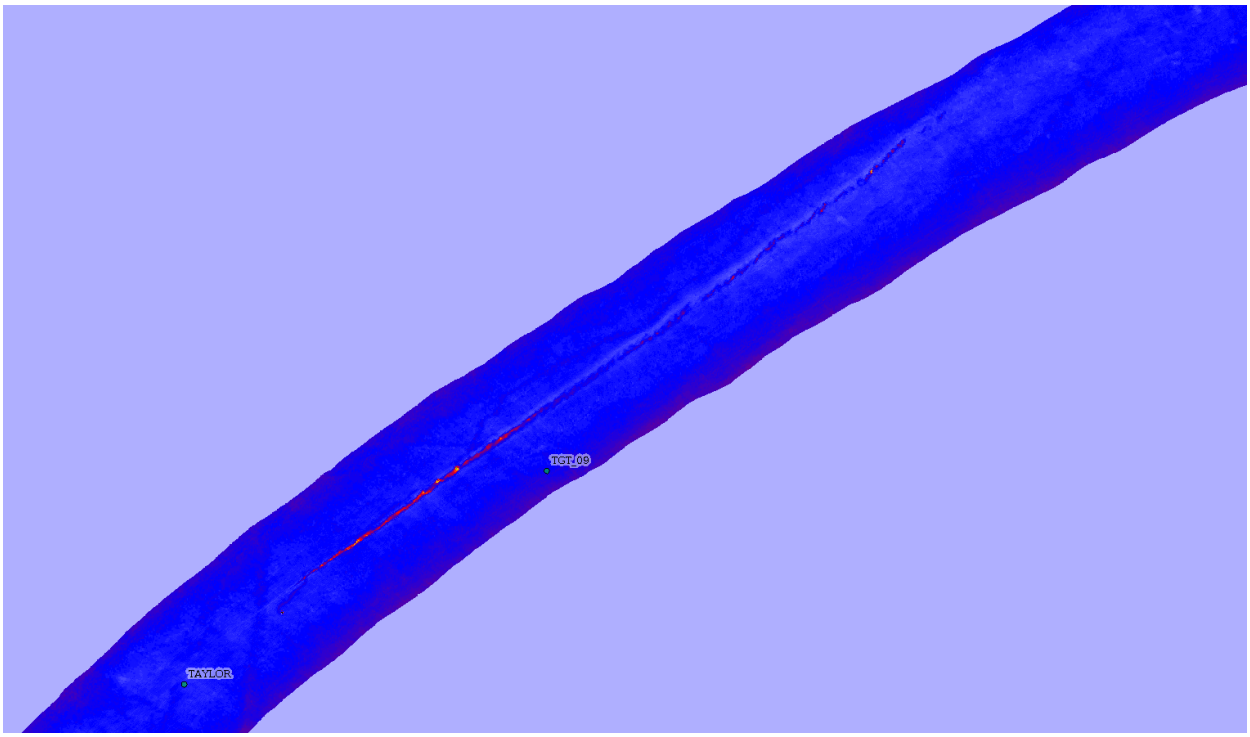

Fig.13 – IR georeferenced image.

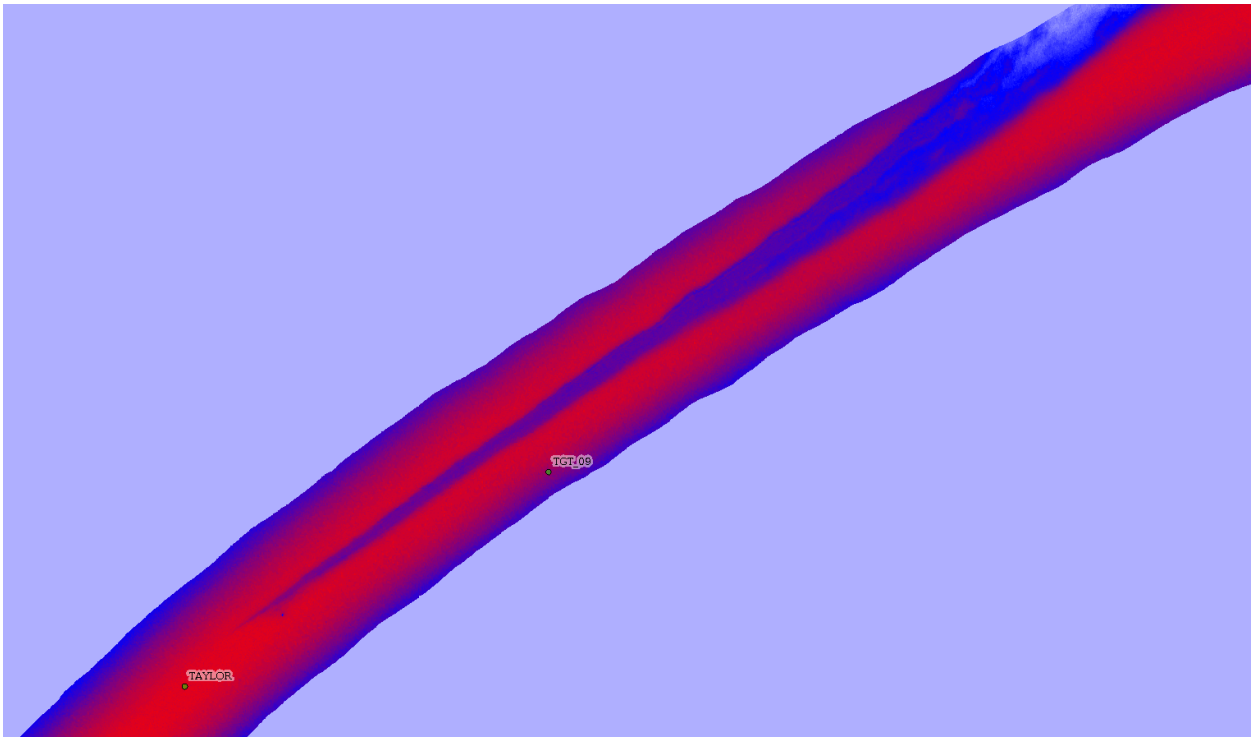

Fig.14 - UV georeferenced image.

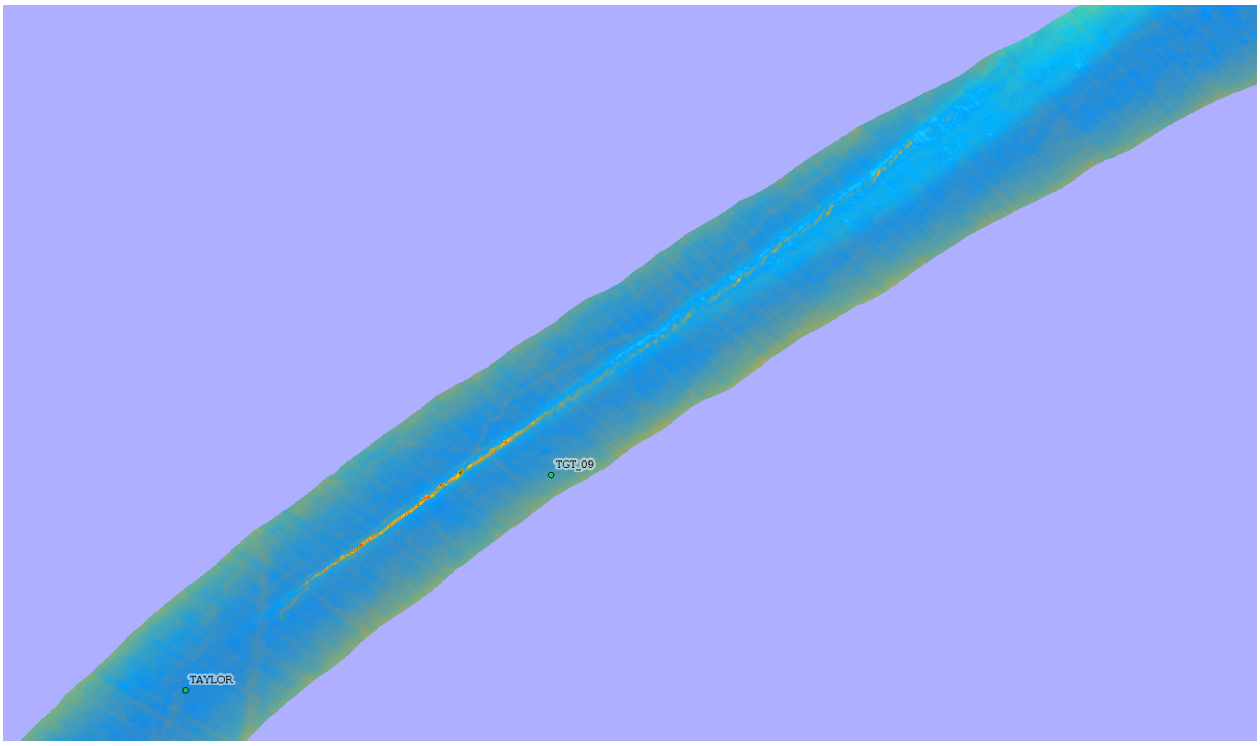

Fig.15 – IR/UV Fusion georeferenced image.

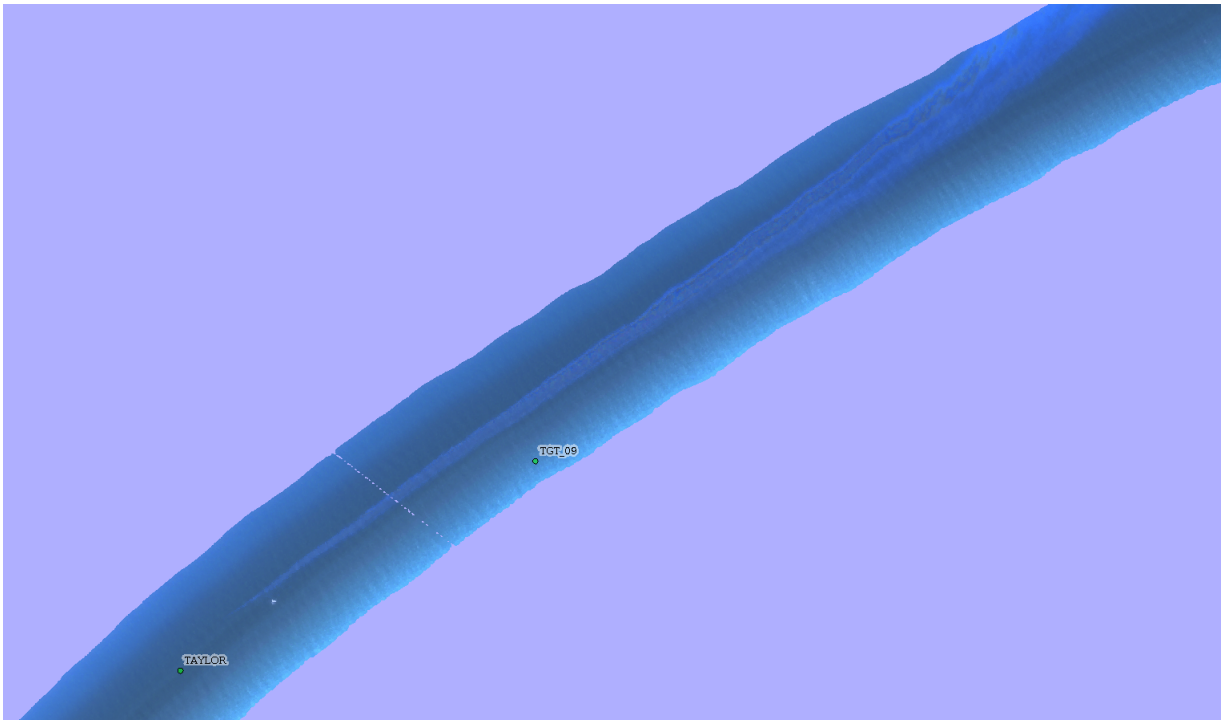

Fig.16 – VIS georeferenced image.

Conclusion: during Mission#1 Poseidon successfully located the slick and defined the synoptic characteristics with the SLAR, creating also a navigation reference for the successive low altitude passes. During the low altitude passes the near range sensors gave positive confirmation of the nature of the slick and determined relative thickness distribution and hot spot localization. Operators could analyze the spill scene during the flight in real time determining information as area, dimension, center coordinate, defining georeferenced targets and imageries. Data were processed in real time during the flight. Results were considered successful.

3.5.2 Mission#2 – August 16th 2nd Collection

For Mission#2 Poseidon left Houma-Terrebonne airport at 12:30 CST.

As the previous mission, Poseidon approached the Taylor area with a SE track at 3,000 ft and about 185KT of cruise speed.

Step#1 - Synoptic Overview: at the time of the 2nd mission the wind speed in the area was between 0-2 Kts and the sea surface appeared particularly flat with very low capillary waves activity. Under these circumstances the radar backscatter was extremely low and, the target found in the Taylor area extremely weak. The structure was different from the previous flight, much elongated, with a predominant SW-NE direction, determined possibly by the wind/current configuration. The area was delimited by a polygon of approximately 1.96x16.67NM with a coverage of 12% and a resultant area of the surface target of 3.76 square nautical miles. Polygon was centered on the following coordinates: N 29°00'31" W 088°49'19". The following figures show the SLAR images, the georeferenced polygon and the resultant SLAR georeferenced image with and without flight track (Fig.17 to Fig.19).

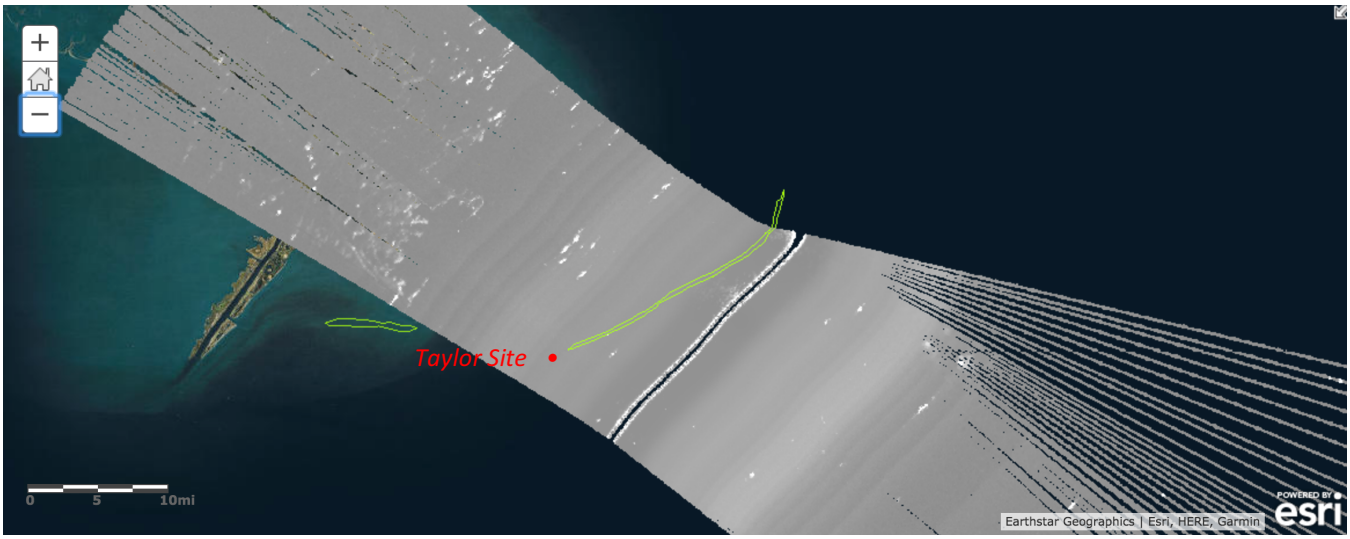

Fig.17 - SLAR georeferenced image with polygon.

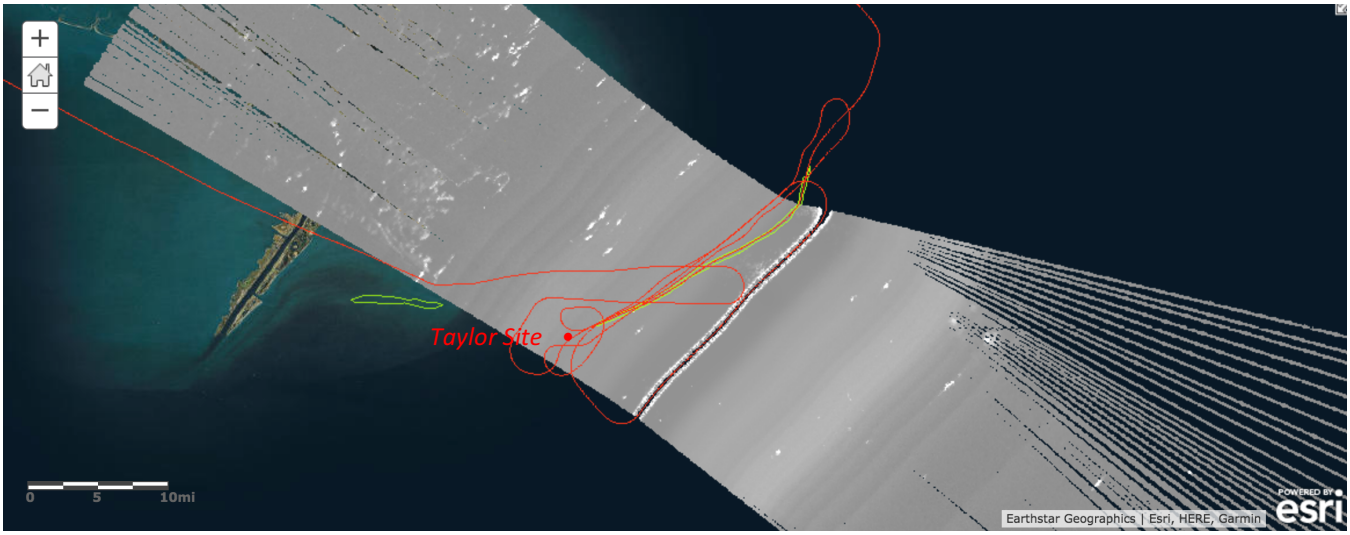

Fig.18 - SLAR georeferenced image with flight track and polygon.

During the same mission two more oil slick was identified with the SLAR. The first in the Grand Isle area, the second in the Mississippi Delta area (Fig.19).

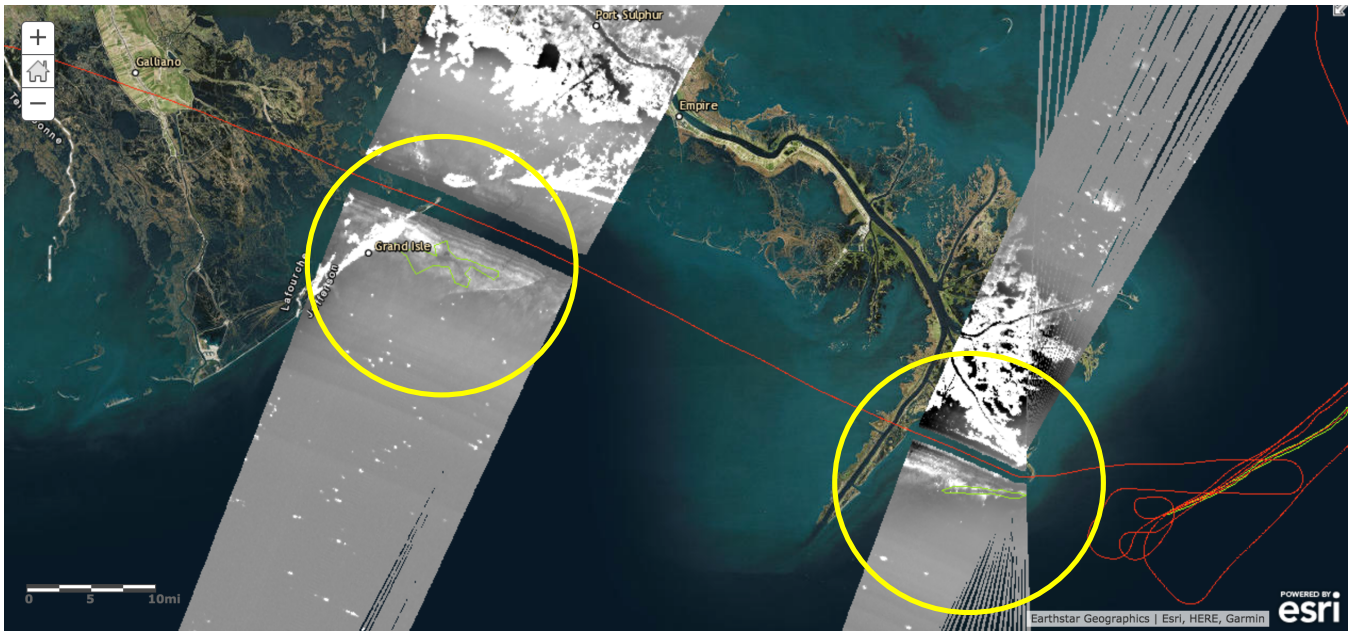

Fig.19 - SLAR images of two 'mystery spills' encountered during the mission

After the detection, localization and georeferencing of the target Poseidon started the approach to the spill to perform the near range analysis, the slick showed a match with the SLAR image. The slick had an appearance sheen to metallic, with the direction along the prevalent wind (Fig.20 and Fig.21).



Fig.20 – Oil appearance in the Taylor site area.

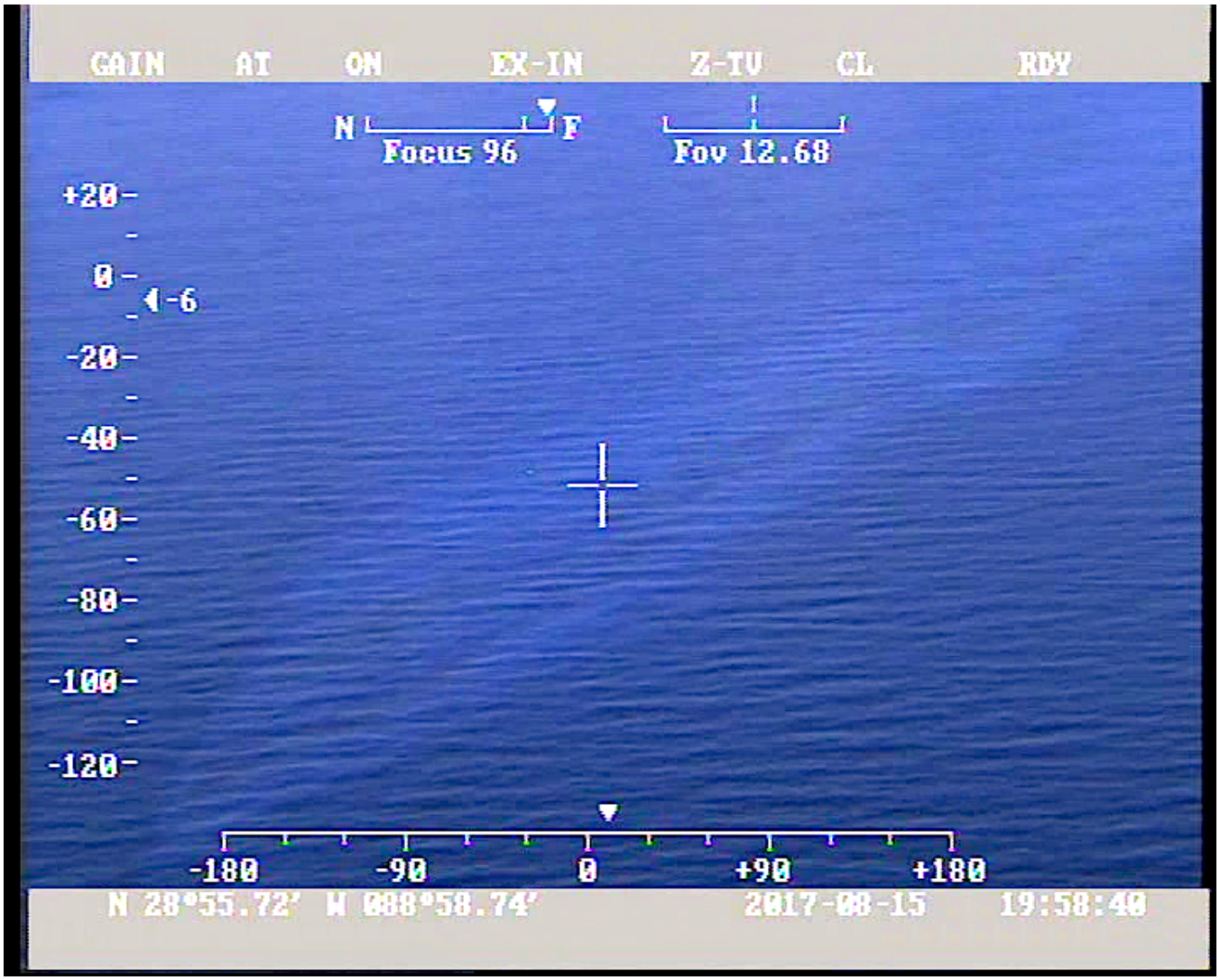

Fig.21 – Overview of the spill.

Step#2: spill approach and Near Range Analysis.

At an altitude of 1,000ft Poseidon was directed over the slick to overfly it in parallel patterns to obtain a complete coverage and analyze the slick features with the near range sensors. Purpose of the Near Range analysis is to confirm the nature of the spill, oil or other substances, evaluate and map the thickness to estimate the volume, and determine the hot spots, areas where the oil is concentrated.

Fig.22 below shows the parallel pattern flown to insure maximum coverage.

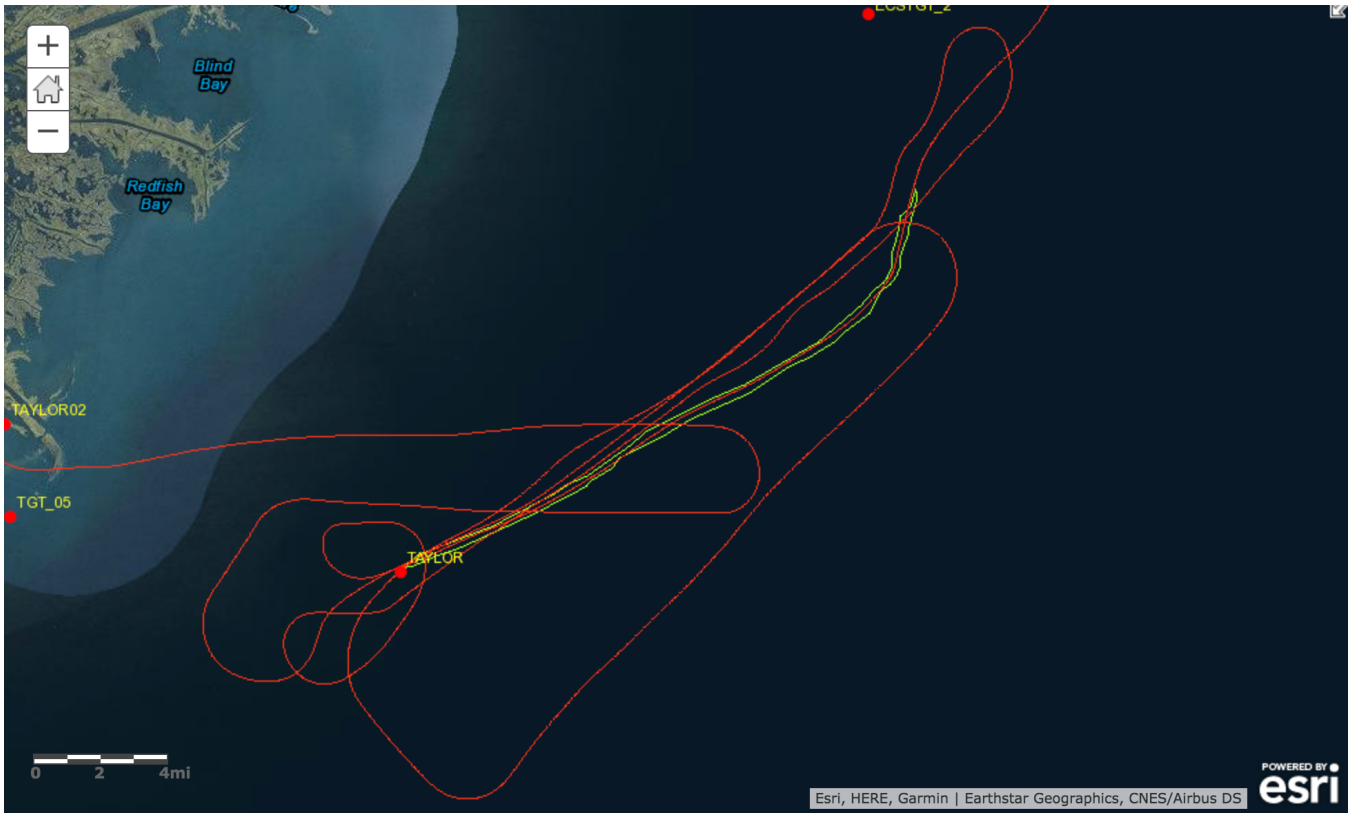

Fig.22 – Parallel Pattern flown to acquire near range images.

Similarly to the previous flight the response in the IR and UV bands was decisive to qualify mineral oil. The MWR response, suggested that the slick was extremely thin, the IR showed very few and scattered areas of high relative thickness. VIS showed the appearance of the slick as a sheen with some rainbow structure. The thickness measured over the slick never exceeded 5µm, 90% of the sheen was less than 2µm.

Fig.23 to 30 show the area around the Taylor site. The IR image shows few spots where the oil is thicker in proximity of the former platform site. UV and VIS show the extent of the sheen that appears very thin and elongated. Classification of the oil from the LFS in proximity of the Taylor site position was 'Very

Light Crude' consistent with a fresh spill. The overall sheen was very thin; the max thickness measured by the LFS was in the order of 4.5µm.

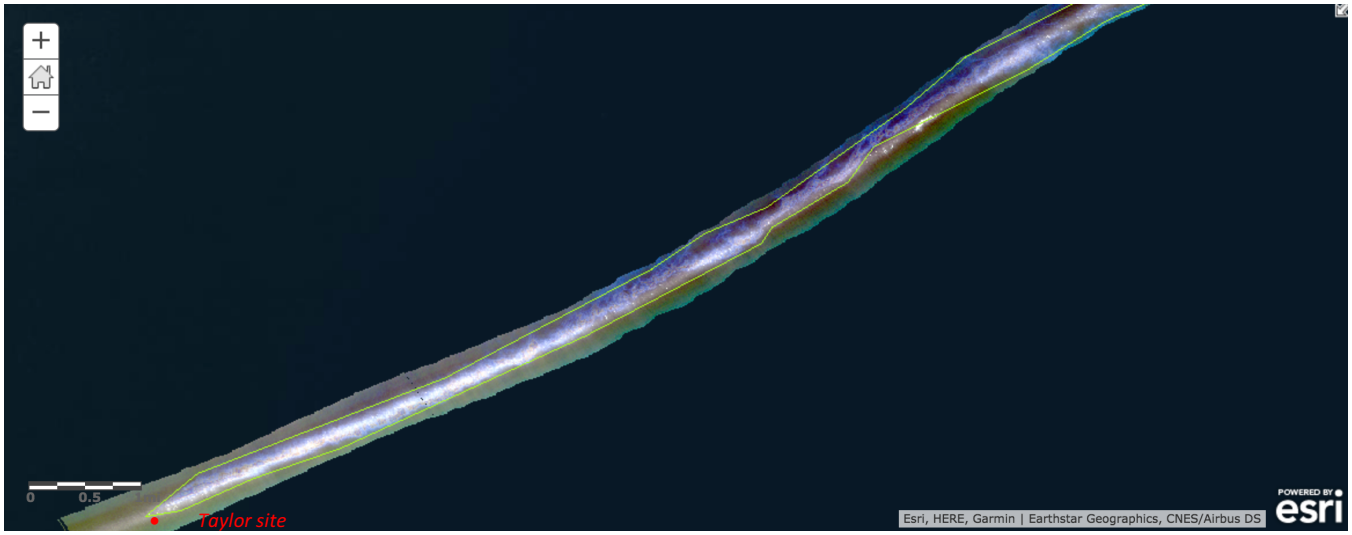

Fig.23 – VIS georeferenced image (1/2).

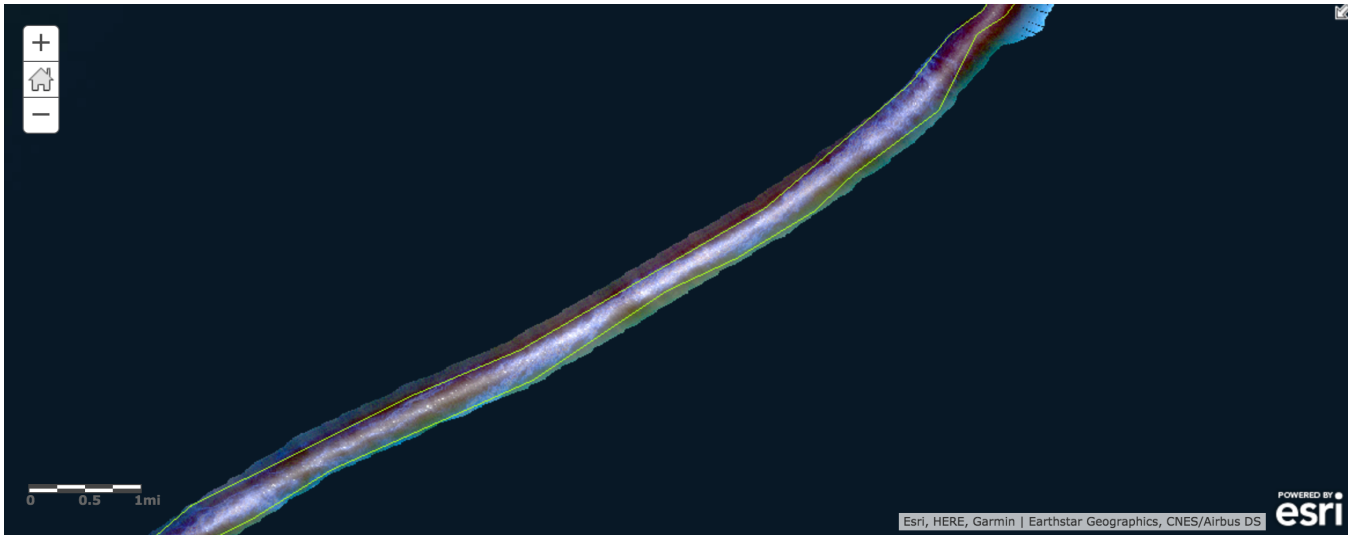

Fig.24 – VIS georeferenced image (2/2).

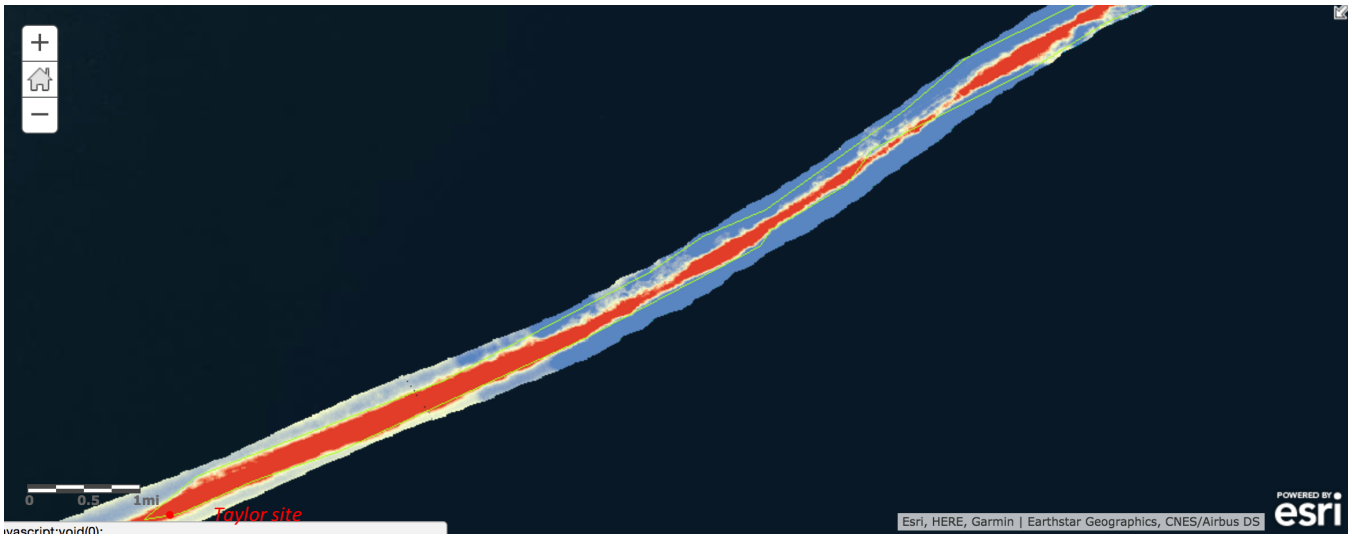

Fig.25 - UV georeferenced image (1/2).

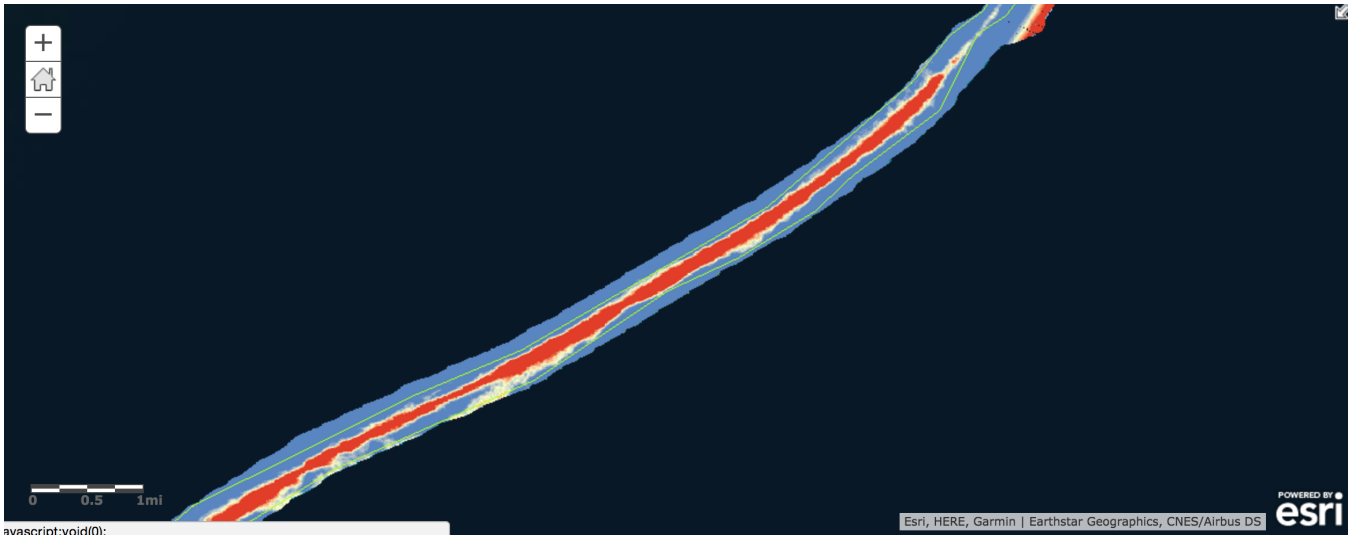

Fig.26 – UV georeferenced image (2/2).

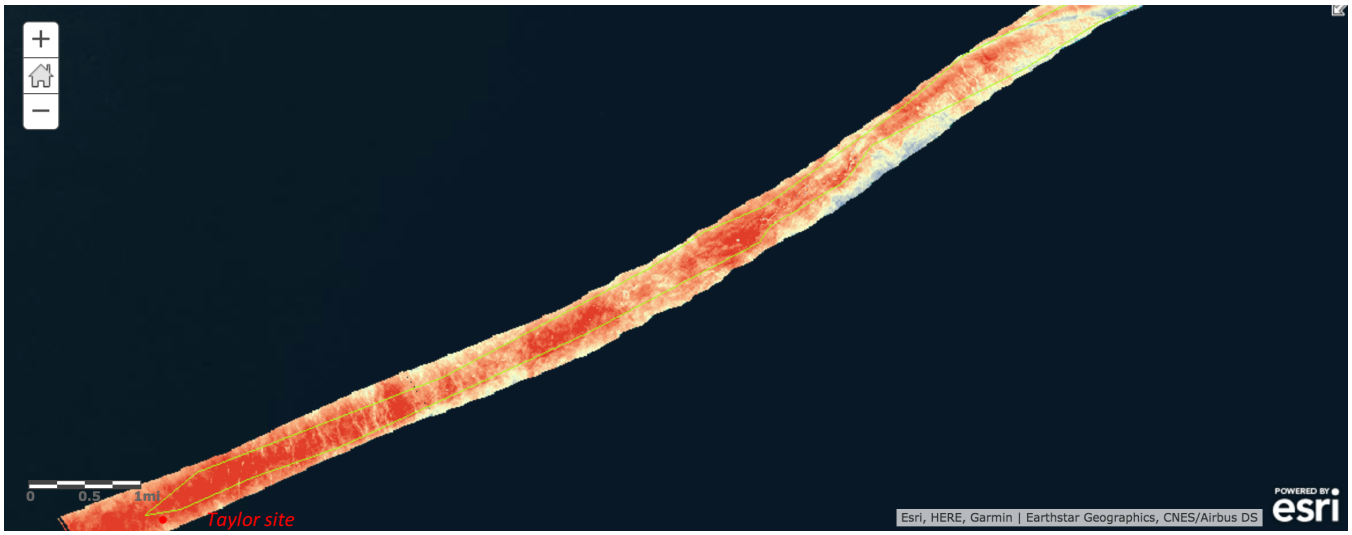

Fig.27 – IR georeferenced image (1/2).

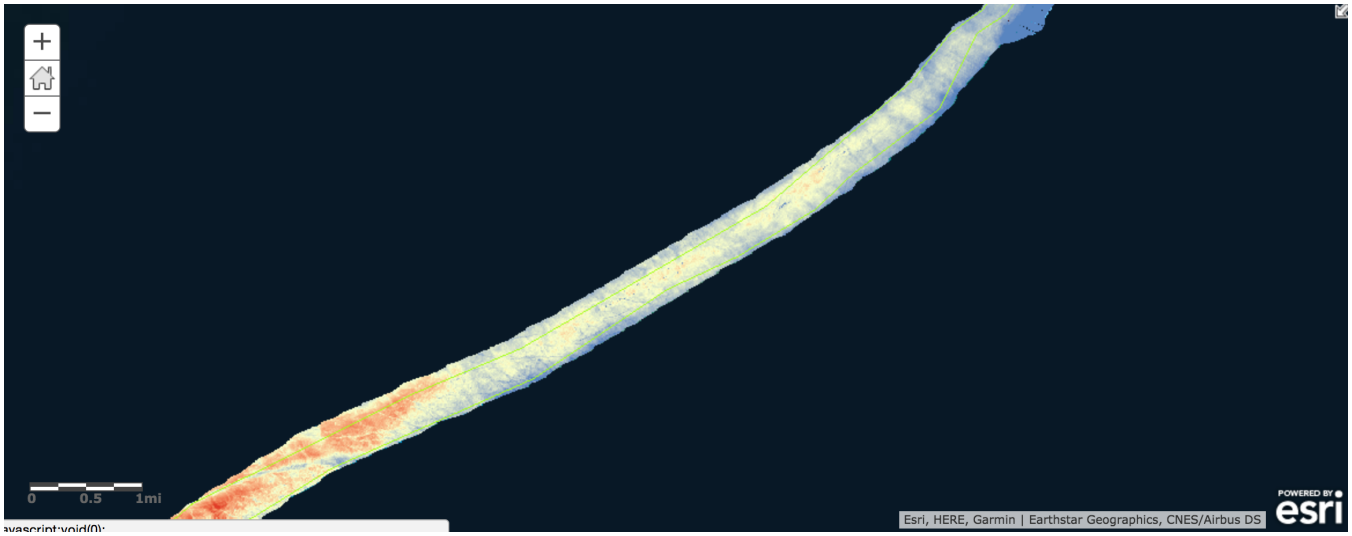

Fig.28 – IR georeferenced image (2/2).

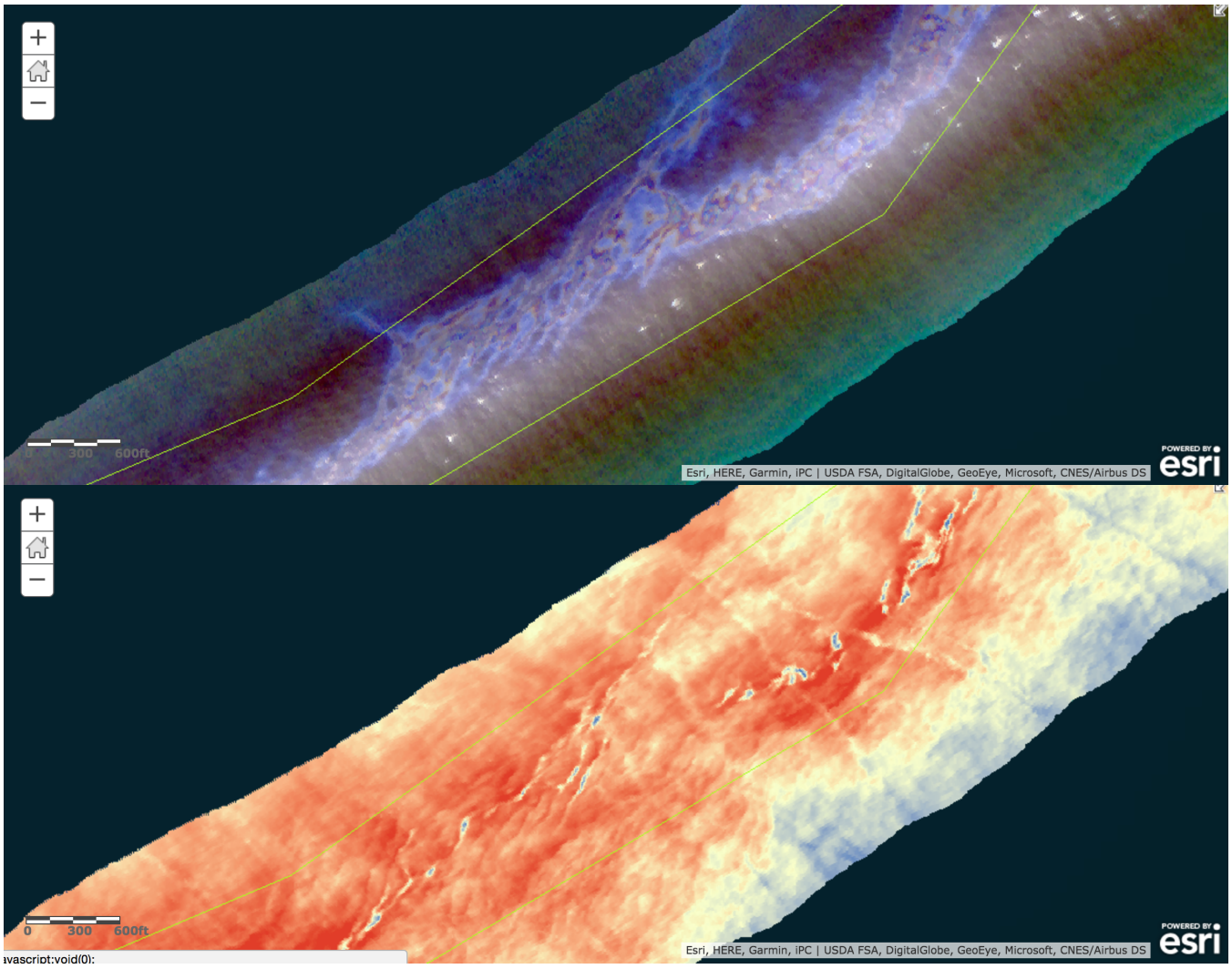

Fig.29 – Oil sheen in the VIS and IR sensors. Few scattered hot-spots appear in the IR image.

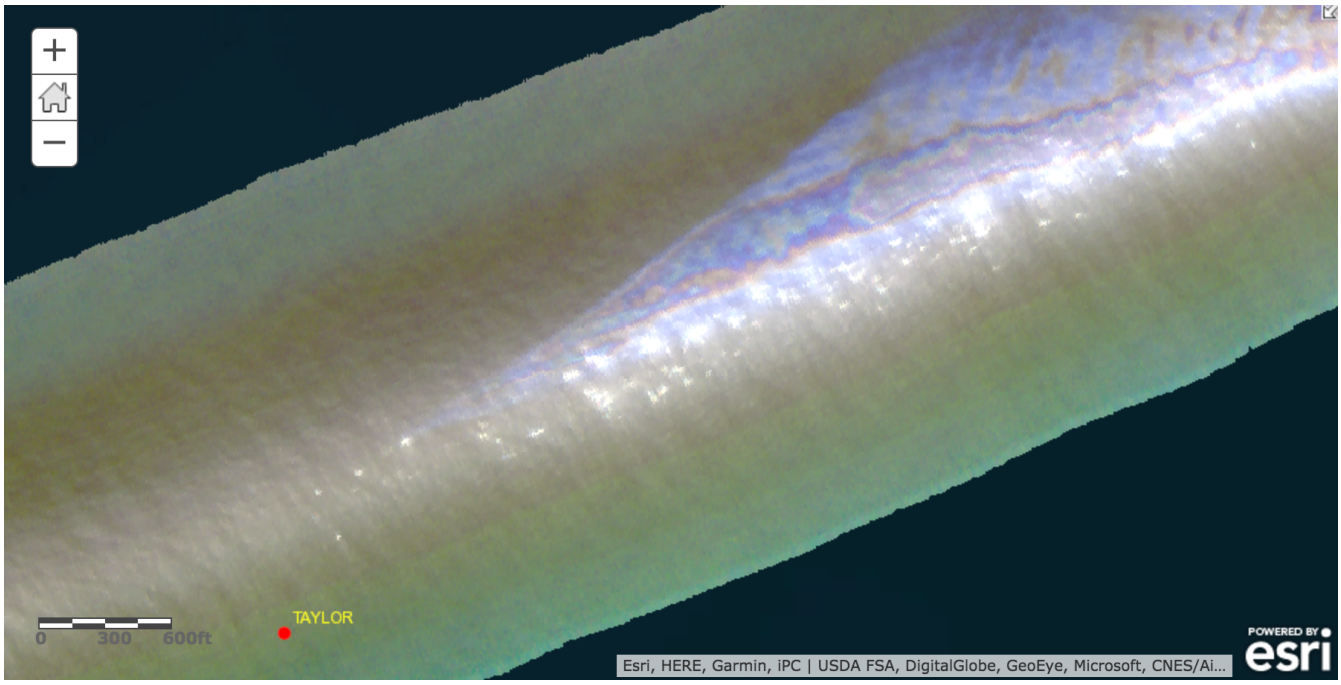

Fig.30 – Onset of the oil sheen in proximity of the Taylor site.

Conclusion: during Mission#2 Poseidon successfully located the slick and defined the synoptic characteristics with the SLAR, creating also a navigation reference for the successive low altitude passes. During the low altitude passes the near range sensors gave positive confirmation of the nature of the slick and determined relative thickness distribution and hot spot localization. Operators could analyze the spill scene during the flight in real time determining information as area, dimension, center coordinate, defining georeferenced targets and imageries. Data were processed in real time during the flight. Results were considered successful.

3.6 Thickness map and Volume Calculation

The information collected during the flights allow to have a good estimate of the volume of the spilled oil in the area.

3.6.1 Volume Estimation Methodology

Among other capabilities, POSEIDON Sensors allow for real time Absolute Oil Thickness and quantitative Volume estimation, Hot-Spots identification and determination of oil as recoverable and non-recoverable, and accurate Post Spill Analysis for NRDA (Natural Resources Damage Assessment). Absolute Oil Thickness is measured by the Microwave Radiometer (MWR) that measures the absolute thickness in the 50µm - 3mm range and by the Laser Fluorosensor (LFS) that measures absolute thickness in the 0.1µm – 20µm range depending on the type of oil.

IR/UV sensor complements the information with Relative Thickness Mapping: Ultraviolet Line Scanner UV is sensitive from 0.01µm, Infrared Line Scanner IR is sensitive from 2µm.

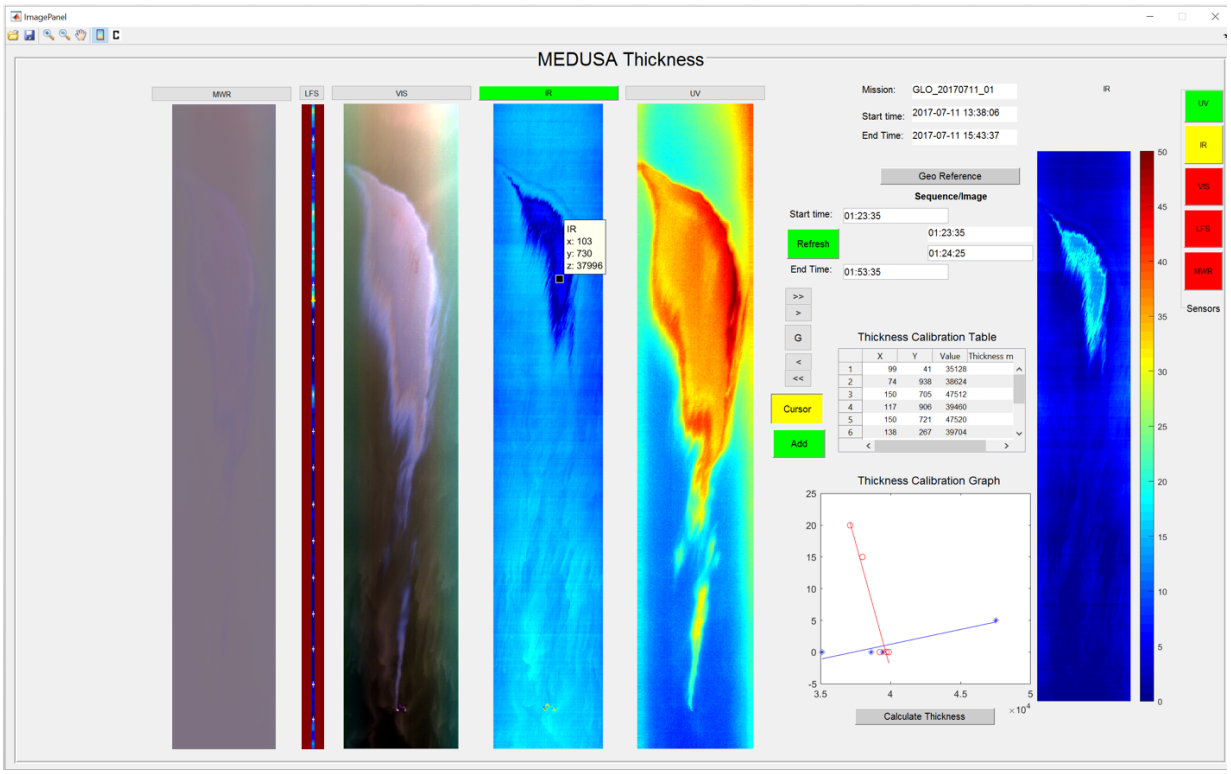

Fig.31 – Graphical User Interface (GUI) of the module for thickness calculation.

The fusion of the information from MWR, LFS, IR/UV allows to build accurate Thickness Maps in the 0.01µm to 3mm range. Fig.31 shows the interface of the module for thickness calculation integrated in the Mission Control Software.

The Thickness Map, and the area of the polygons that enclose the spill, or the patches of the spill, determined with the Far or Near Range Sensors allows the quantification of the Volume of the spill. Typical accuracy is 70-90% depending on the environmental conditions. The methodology for the estimate of the volume follows three steps:

- Synoptic Overview: the far range SLAR acquisition allows to determine the overall extent of the spill and to plan the next steps for near range analysis.
- To build a 'Thickness Map' the overall spill area is overflown in parallel patterns with overlaps to ensure the complete coverage of the area. Flight Lines are 2,000ft apart. In case of small and medium spills the standard flight altitude is 1,000ft that allows for coverage swath of 2,000ft. In case of extended spills the altitude can increase to 3,000ft to guarantee a wider sensor swath of 1NM. In case of spills with exceptional dimensions, other techniques can be put in place to ensure wider coverage without increase excessively the flight time.
- Scan rate of the sensors is 20Hz that means that the sensors can acquire thickness information each 4.5 meters at a cruise speed of 180 Kts.

3.6.2 Volume Estimation – August 16th 1st Collection

The 16th of August the spill structure had a predominant SW-NE direction, determined possibly by the wind/current configuration. The structure was delimited by a polygon of approximately 1.5x10 NM with a coverage of 46% and a resultant area of the surface target of 6.56 square nautical miles. Based on the LFS and IR/UV data a thickness map has been built, Fig.32 below.

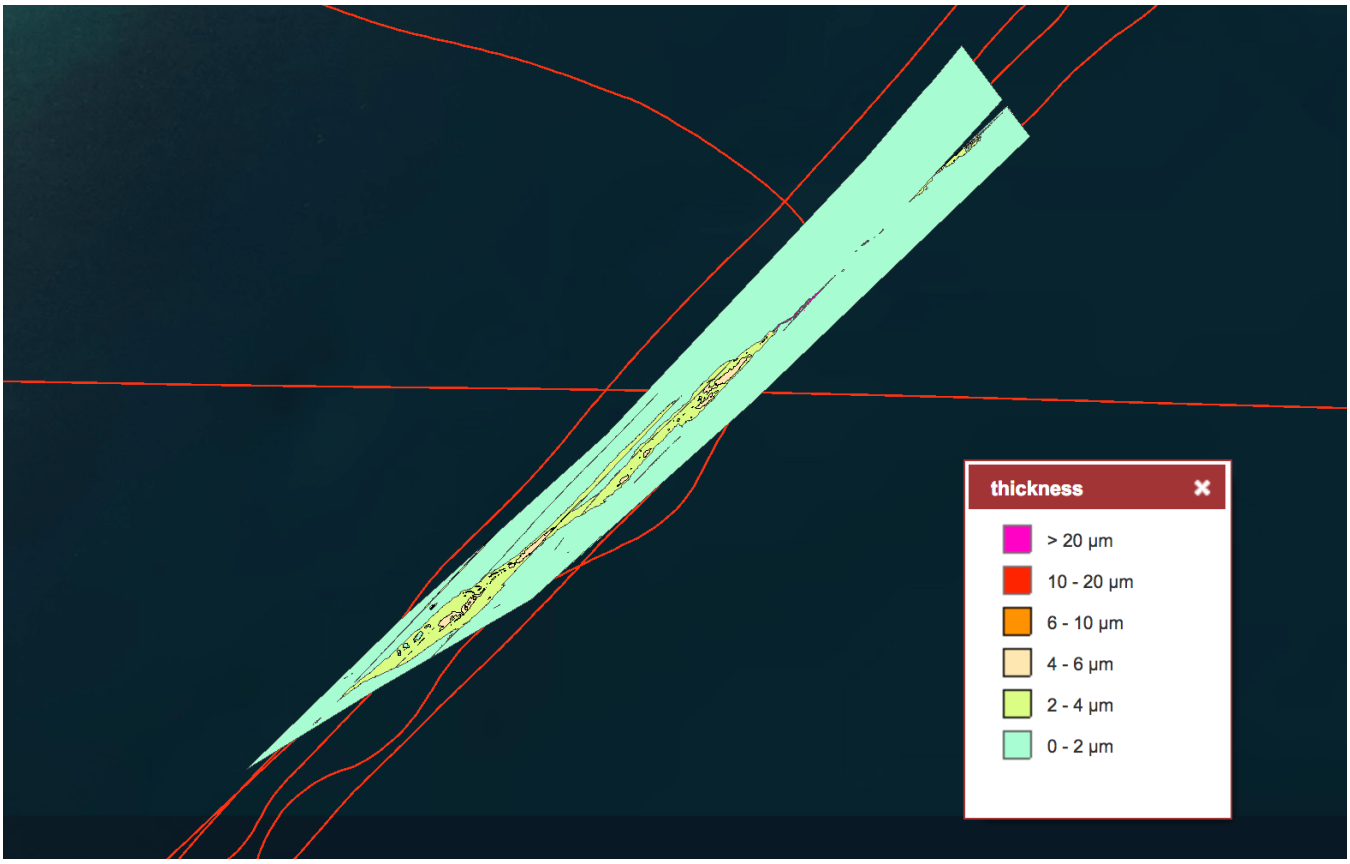

Fig.32 – Thickness Map

The map has been originated with data acquired with the IR/UV and the LFS that measured the absolute thickness with a scan frequency of 20Hz (thickness point every 4.5 meters).

It shows a thin sheen of less than 1 µm, quite uniform in the overall spill area, and a limited area (less than 5% of the total) with a higher concentration of oil, and a thickness peak of about 5µm. This pattern was confirmed by the signature of all the sensors, IR, UV, VIS, LFS.

Based on the area of the polygon and the thickness distribution, during the first mission of the 16th of August the estimated volume was **13.750 m^3** equivalent to **3,632 Gal**.

3.6.3 Volume Estimation – August 16th 2nd Collection

During the second mission the 16th of August the spill structure was much elongated still with a predominant SW-NE direction. The area was delimited by a polygon of approximately 1.96x16.67NM with a coverage of 12% and a resultant area of the surface target of 3.76 square nautical miles.

Based on the LFS and IR/UV data a thickness map has been built, Fig.33 below.



Fig.33 – Thickness Map

The map has been originated with data acquired with the IR/UV and the LFS that measured the absolute thickness with a scan frequency of 20Hz (thickness point every 4.5 meters).

It shows a thin sheen of less than 1 µm, quite uniform in the overall spill area, and a limited area (about 1% of the total) with a higher concentration of oil, and a thickness peak of about 5µm. This pattern was confirmed by the signature of all the sensors, IR, UV, VIS, LFS.

Based on the area of the polygon and the thickness distribution, during the mission of the 16th of August the estimated volume was **8.517 m^3** equivalent to **2,250 Gal**.

4 Conclusions

The 16th of August the third test campaign were promoted by BSEE and NOAA at the former Taylor Platform Site in order to assess and better understand the capabilities of remote sensing tools and other ways of collecting data, in an effort to enhance the ability to detect and measure oil spills offshore. Fototerra was invited to take part of the test with the airborne remote sensing platform Poseidon. The general objective of the open water test in Taylor, in line with the BSEE / NOAA goals, was to present the capabilities of the Poseidon platform in a real oil spill scenario and acquire data for surface oil detection and characterization, and show how the information and the methodologies can be effectively used in future oil spill responses, in permanent coastal surveillance, and natural damage assessment.

All the missions flown provided significant results, the sensors were imaging the spill consistently providing the operators with detailed information of the spill on the far range and near range environments. Poseidon was capable to provide synoptic information of the overall spill as well as detailed spill analysis. The integrated navigation system, data processing and communication system complemented the sensor capabilities, making the operations extremely effective and efficient and showing how the platform will be effective in a real spill response.

Data were collected and processed in flight to obtain the following information: Synoptic overview and overall aerial extend of the spill, area of the spill, center coordinates of the oil spill, oil distribution map, oil type classification, oil thickness, indication of hotspots when present, and dynamic properties of the spill (e.g., drift and spreading of the oil on the sea surface).

The above-mentioned information was made available in real-time during the flight. During real operations, this capacity enables the operator to continuously report to the Incident Command Center and to the Responders to support the decision-making process with real-time data and so to dramatically improve the oil recovery process. This Document describes basic physical principles of the sensors and reports the first results of the data collections as well as the combination with metocean data that improve also the prediction of dynamic behavior of the spill.

Attachment K. November 2016 MC20 Sampling and Analysis Plan

Taylor Energy Spill Site Sampling 2016
Project-Specific Sampling and Analysis Plan

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"The findings and opinions expressed in this report are solely those of the authors and do not necessarily reflect the views and policies of the Bureau of Safety and Environmental Enforcement, nor does mention of the trade names or commercial products constitute endorsement or recommendation for use."

October 17, 2016

1. Introduction and Purpose

In September 2004, Taylor Energy's Mississippi Canyon 20-A production platform was destroyed in a hurricane. Oil continues to leak from the Taylor Energy site into the Gulf of Mexico, creating a continuous slick where oil observation and analysis methods can be tested and verified. For this synoptic sampling study, we propose the following data collections at the Taylor Energy oil slick: site characterization, oil sheen/slick thickness measurements, bulk oil sample collection, targeted discrete water sampling based on real-time fluorescence measurements, fluorescence monitoring, air sampling (semi-volatile and volatile organic compounds, SVOCs and VOCs), and ultraviolet (UV) and visible light attenuation measurements.

All data collection and sampling activities will occur at or near the former Mississippi Canyon 20-A production platform site located approximately 12 miles south of the mouth of the Mississippi River. Data collection and sampling activities will occur during multiple sampling trips that coincide with relatively calm water and weather conditions; satellite coverage windows; and availability of aircraft, boats, and personnel.

The purpose of this Sampling and Analysis Plan (SAP) is to provide sampling objectives and proposed data and sample collection methods. Protocols for sample collection and handling are provided in a series of Standard Operating Procedures (SOPs) attached herein. Only the on-water field sampling activities are described in this work plan.

1.1 Objectives

Work described in this plan is being conducted to fulfill two main objectives:

1. ***Rapid surface slick characterization***: Collect oil thickness measurements, water samples, and other data at approximately the same time and in the same locations that aerial satellite data are collected.

2. ***Targeted environmental sampling***: Collect oil samples air samples at multiple heights, water samples at multiple depths, and oil thickness measurements, at locations with observed surface oil. When possible, sampling will target areas where fluorescence and/or field observations show that oil slicks and dispersed oil are present.

2. Field Activities Associated with Each Sampling Objective

This section provides a detailed summary of each sampling objective and associated goals. Data and sample collection methods are further described in subsequent sections of this work plan and attached SOPs.

2.1 Objective #1: Rapid Surface Slick Characterization

A team of researchers on a boat will conduct surface slick characterization activities, including water and oil sampling and thickness measurements at the same time and in the same locations where low-altitude aircraft and overhead satellites are collecting remote sensing data. This sampling objective requires careful coordination between the sampling boat, aircraft overflights, and satellite coverage. Because ground crews have no control over the timing of satellite passes, field activities will be planned according to available windows in satellite coverage.

A schedule of the satellite overpass times will be developed before each trip. Our goal is to complete aircraft overflights and boat-based slick characterization as close as reasonably possible to the time when a satellite is acquiring data.

Prior to and during a satellite overpass, a low-altitude aircraft will fly over the slick to determine the optimal sampling locations for the boat. Spotters on the aircraft will guide the boat to sampling locations using an aviation handheld radio with aircraft communications channels or a satellite phone.

Boat-based oil thickness measurements will be made using dip plates, 3M sorbent pads, and the WaterMapping sampler. The boat will also deploy a Turner Designs Cyclops 7 fluorometer at each sampling location at a single depth to log fluorescence data during oil thickness sampling. Bulk oil samples may also be collected for chemical analysis to aid in the interpretation of sorbent pad data. Water samples near the surface may also be collected. Additional information on these sampling methods is provided below and in the attached method-specific SOPs.

2.2 Objective #2: Targeted Environmental Sampling

We aim to collect targeted surface oil, water, and air samples in areas with observed oil slicks. We are most interested in sampling areas with high levels of oil contamination. In addition, one background site will be sampled during each sampling trip. When possible, spotters in low-flying aircraft will guide the boat to sampling sites with substantial oil slick contamination. If spotters in overhead aircraft are not available, sampling sites will be located by starting at the location of the former platform site, as determination by global position system (GPS) coordinates, and radiating outward until the boat intersects an oil slick. Sampling sites may also be located using an unmanned aircraft system (UAS) with a high-resolution camera, operated from the boat.

Table 1 provides a summary of environmental sampling activities that may be conducted at background and oil-contaminated sampling sites. Depending on site conditions and availability, we will conduct any or all of these sampling activities. If possible, fluorescence monitoring data will be used to direct water sampling. We have designed a system where water can be pumped from four different sampling depths concurrently with fluorescence monitoring. This allows us to immediately initiate water sampling when fluorescence anomalies are observed.

Table 1. Environmental sampling activities that may be conducted at background and targeted sampling locations

Sampling activity	
Site characterization	Water chemistry sampling
Fluorescence monitoring	Air chemistry sampling
Oil sheen/slick thickness measurements	UV attenuation – radiometer
Bulk oil chemistry sampling	Visible light attenuation – Secchi disk

Targeted air sampling may also be conducted to characterize occurrence and concentrations of volatile or aerosolized compounds at various heights above observable oil emulsions and slick. We will target areas with high levels of observable oil accumulations and deploy a floating air sampling buoy. The air sampling buoy has the capability of simultaneously collecting air samples at three set heights of approximately 0.1 m, 0.5 m, and 1.0 m above the water surface.

Oil thickness measurements will be taken using dip plates, 3M sorbent pads, and/or the WaterMapping sampler. Along with the oil thickness measurements, a bulk oil sample will also be collected from each site, if sufficient oil is present. Other observational data may include UV and visible light attenuation, which would be measured using a Biospherical radiometer and a Secchi disk, respectively. Additional information on each of the targeted sampling methods is provided below and in the attached method-specific SOPs.

2.3 Development of Fluorescence Monitoring Methods

An additional goal of the sampling is to develop procedures for the use of fluorescence monitoring to identify areas with dispersed oil in the water column. During the first trip, we will attempt to develop a method for using the Turner Designs Cyclops 7 fluorometer to detect oil and/or oil constituents in water. We will collect fluorescence measurements at a background site and other uncontaminated sampling sites to establish the typical background fluorescence signal. At a site with visible surface oil, we will then conduct transects in and out of the visible oil slick, in areas with varying degrees of observable oil, collecting fluorescence measurements at different depths near the surface. We anticipate seeing anomalies such as spikes in fluorescence when the fluorometer encounters oil droplets. If fluorescence anomalies are observed at a site, targeted environmental sampling (Objective #2) will be initiated. Additional information on operating the fluorometer and documenting environmental conditions is provided below and in the attached method-specific SOPs.

3. Sampling Procedures

This section describes the procedures that will be followed when conducting field activities associated with the two primary sampling objectives. This includes a description of how we will plan and prioritize sampling. We also provide detailed information on how each sampling activity will be conducted and how many samples will be collected. Sampling methods will reference respective SOPs that we provide at the end of this work plan. Materials and equipment needed for each step in the procedures are also provided in the SOPs.

3.1 Planning and Prioritization

For each sampling trip, we will conduct sample collection activities over two or more consecutive days, leaving from Boothville-Venice, LA. Boat-based field crews will stay overnight at the Port Eads Marina and Lodges in Port Eads, LA. Port Eads is approximately 20 miles down the Mississippi River from Boothville-Venice and is only accessible by boat. There are few supplies at Port Eads; therefore, field crews will leave Venice with all of the critical sampling equipment and supplies for the entire sampling trip.

Sampling trips will coincide with at least one satellite overpass. Sampling activities will be planned around the satellite coverage window(s), with Objective #1 activities being prioritized during times with overhead satellites. We plan to conduct targeted sampling activities (except air sampling) at up to three slick sites per day, depending on time available. Targeted sampling activities will also occur at one background site per sampling trip. Background sites will be selected in the field and occur in areas that are at least a few miles from the former Mississippi Canyon 20-A production platform and do not have any visible oil or elevated fluorescence readings. Air sampling will be conducted at one oil-contaminated site per day and one

background site per trip. Additional time will be spent developing the method for real-time detection of oil in the water column using fluorescence monitoring.

When available, spotters on an airplane will help locate sites with oil slicks during sampling activities. The boat-based field crew will be in direct communication with the spotters on the aircraft. Boat-to-aircraft communication will primarily be made using an aviation handheld radio tuned to 123.45 MHz. We will also have a marine radio and a satellite phone as backup communication devices. Spotter aircraft will not be available during the entire time that boat-based sampling activities are being conducted. Therefore, the field team leader will prioritize sampling objectives based on information obtained from the spotter aircraft when available.

3.2 Site Characterization

Site characterization activities will occur at every site for each of the two sampling objectives. Upon arrival at the site, site characterization data will be collected according to the Site Characterization SOP (SOP 1). The site characterization data will include GPS track-log coordinates to capture the route taken during sampling, GPS waypoints to document specific locations where samples and observational data are collected, time and date of each sampling activity, fluorescence monitoring logs and point data to detect dispersed oil, and observational data that includes degree of observed sea-surface oiling. Wind speed and direction, air temperature, humidity, weather conditions, sea state observations, and other site attributes may also be documented. Field data will be recorded in the Site Characterization and Oil Thickness Data Sheet provided with SOP 1.

Site characterization activities will include digital photographs and video recordings. Digital photographs and videos will be used to document site conditions, the degree of oiling, the appearance of surface oil at sampling locations, and fluorescence monitoring data and anomalies. Field crews will make every effort to link GPS and fluorometer logs, observations of surface slick conditions, and sea-state conditions. This includes syncing the time and date on GPS and fluorometer devices with digital cameras, video recorders, and other data recording devices. This will facilitate data analyses and enable field crews to review digital media with respect to fluorescence monitoring and track logs.

3.3 Fluorescence Monitoring

Fluorescence monitoring data at a fixed depth may be collected as the boat traverses around a sampling site. This will allow a rapid characterization of the spatial extent of hydrocarbons at the site without conducting more time-intensive water sampling. The depth for deployment of the fluorometer during these transects will be determined during the method development activities conducted during the first trip. As the boat traverses a site, we will mark waypoints when the fluorometer enters and exits the slick oil. Each waypoint number and a description of that waypoint will be recorded on the Fluorescence Transect Data Sheet (see SOP 7). We will discontinue fluorometer use if it interferes with other sampling activities during rapid slick characterization (Objective #1).

During the targeted environmental sampling (Objective #2), fluorescence monitoring will be conducted at each site to help target contaminated areas for water sampling. To conduct targeted water sampling with fluorescence monitoring, the fluorometer and water sample tubing will be deployed together. The fluorometer will be deployed at a fixed depth, while four separate lines of

tubing will be deployed at the four water sampling depths. See Section 3.5 for additional details on water sampling. With the fluorometer set to logging mode and the peristaltic pump turned on so that water samples can be collected quickly, the boat will slowly traverse in and out of the slick area at a site. We will mark waypoints when the fluorometer enters and exits the slick oil. Each waypoint number and a description of that waypoint will be recorded on the Fluorescence with Water Sampling Data Sheet (see SOP 6). We will also record the start and end time of each transect. A detailed protocol for the collection of fluorescence transect data can be found in the Fluorescence Transect Data Sheet (SOP 7).

If a spike or anomaly in the fluorescence signal is observed, the boat will stop and water samples will be collected. This will mark the end of the transect. It may require several transects in and out of the area to determine if an anomaly is observed. To help establish background noise, a fluorescence transect at a background site will need to be collected prior to sampling at the oil-contaminated site. Additional transects throughout the day may be collected as the vessel traverses from site to site.

Once a location for water sampling has been determined, a fluorescence profile at the same location will also be conducted at the same time that water samples are being collected (see SOP 7). Fluorescence profiles may be collected at additional sites at the discretion of the field team leader.

3.4 Oil Sampling

Oil thickness measurements will be collected at all sites. These measurements will include sampling three to five areas of oil slick or sheen using 3M sorbent pads (T 151 pads), dip plates, and/or the WaterMapping sampler. For each sampling site, we will target areas of slick that represent the range of different thicknesses at the site. At sites with heavy emulsions, bulk oil samples may be collected for chemical analysis and oil-to-water ratio determination. Collection of oil slick or sheen by sorbent pads will be based on methods described by SINTEF (Daling and Leirvik, 2002). The measurement of oil thickness by dip plates is based on a method described by Svejkovsky and Muskat (2006), while the WaterMapping sampler is an oil cylinder collection and inspection technique that Oscar Garcia of WaterMapping LLC recently developed. Detailed protocols of the sorbent pad, dip plate, and WaterMapping sampler oil thickness measurements are provided in the Sorbent Pad Sampling SOP (SOP 2), the Dip Plate Oil Thickness SOP (SOP 4), and the WaterMapping Sampler Oil Thickness SOP (SOP 5), respectively. Bulk oil will be collected according the protocols described in the Bulk Oil Sampling SOP (SOP 3). All bulk oil and sorbent pad samples will be sent to ALS Environmental for analysis. See Table 2 for a summary of the surface oil samples to be collected at each site.

Table 2. Number of oil samples collected or measurements made at control and oiled sites

Site	Oil – slick or sheen (PAH/TPH)	Oil – bulk (PAH/TPH)	Oil – bulk (oil-to-water)	Oil thickness estimate (dip plate)	Oil thickness estimate (WaterMapping sampler)
Control sites	1–2	0	0	0	0
Oiled sites	3–5	0–1	0–1	3–5	3–5

PAH: polycyclic aromatic hydrocarbon.
TPH: total petroleum hydrocarbon.

3.5 Targeted Water Sampling

We plan to collect water samples at up to three sites per day and one background site per trip as part of the targeted environmental sampling objective. At each site, we plan to collect discrete water column grab samples at up to four depths below the slick at approximately 0.1 m, 0.5 m, 1.0 m, and 3.0 m, unless real-time fluorescence data indicate alternate depths should be sampled. Discrete water samples will be collected using high-purity tubing and a peristaltic pump. At each sampling depth, we will collect a 250-mL whole water sample. Details on the water sample collection methods are provided in SOP 6. Table 3 provides a sample matrix for all analytical chemistry samples.

Table 3. Taylor Energy analytical samples

Site	Whole water (PAH)	Whole water (TPH)	Oil slick (pad; PAH)	Oil slick (pad; TPH)	Bulk oil (PAH/TPH)	Air (PAH)	Air (VOC)
Site 1	1	4	1	3	1	3	3
Site 2	1	4	1	3	1	3	3
Site 3	1	4	1	3	1	3	3
Site 4	1	4	1	3	0	0	0
Site 5	1	4	1	3	0	0	0
Site 6	1	4	1	3	0	0	0
Background site	1	1	1	1	0	3	3

At the discretion of the field team leader, water samples may be collected without concurrent fluorescence data. Collection of water samples without fluorescence data may be necessary if a water sample needs to be collected rapidly while a satellite is passing overhead (Objective #1).

To reduce analytical costs, we will employ a tiered approach to sample analysis. First, we will analyze samples from the two shallowest depths at all sites. If the results suggest that PAHs are present at a greater depth, we will subsequently analyze the samples collected from deeper in the water column. For all extracted samples, the analytical laboratory will perform a PAH/TPH co-extraction so that either or both analyses can be conducted. The whole water samples closest to the surface will be analyzed for PAHs using U.S. Environmental Protection Agency (EPA Method 8270) with selected ion monitoring (SIM) and for TPHs using EPA Method 8015C. The three deeper samples will be analyzed for TPHs only to reduce analytical costs (Table 3) provides the anticipated chemical analyses of those samples.

3.6 Targeted Air Sampling

Because air sampling is very time-intensive, we plan to collect air samples from at most one oil-contaminated site per day and one background site per trip. The air samples will be collected from a site where water samples are also being collected, as a part of the targeted environmental sampling objective (Objective #2). Researchers on the vessel will collect air samples at three heights (approximately 0.1 m, 0.5 m, and 1.0 m) above the oil slick to analyze for PAHs and for VOCs, including benzene, toluene, ethylbenzene, and xylenes (BTEX). ALS Environmental in Salt Lake City, UT, will analyze the air samples. We propose to collect VOC air samples using helium diffusion samplers (HDSs) that will be provided by the analytical laboratory. For the PAH analysis, we propose using active air pumping through XAD-2 resin sorbent tubes. See SOP 8 for details on air sampling and Table 3 for the sample matrix.

3.7 UV and Visible Light Attenuation Sampling

UV and visible light attenuation will be determined at each site using a Biospherical radiometer and a Secchi disk, respectively, according to methods provided in SOP 9.

3.8 Photographic Documentation of Site

Site characterization and sampling will be documented using video and photographs according to guidelines in the Video and Photograph Documentation SOP (SOP 10). All videos and photograph information, including associated date, time, and GPS coordinates, will be recorded on the Video Documentation or Photograph Documentation Data Sheets, respectively.

3.9 Sample Labeling, Handling, and Storage

Samples will be labeled according to the Labeling Field Samples SOP (SOP 11), and maintained under chain of custody (COC) as described in the Sample Chain of Custody SOP (SOP 12). After collection, samples will be packaged and shipped to the ALS Environmental analytical laboratory following the Sample Handling and Shipping SOP (SOP 13).

3.10 Sampling Equipment Decontamination

Any sample processing equipment used to collect multiple samples will be decontaminated as described in the Equipment Decontamination in the Field SOP (SOP 14).

References

Daling, P.S. and F. Leirvik. 2002. BONNEX 2002, June 17th–19th: Oil Film Thickness Measurements and Pictures Taken from Sampling Boats – Data Report. SINTEF report # STF66 F02084.

Svejkovsky, J. and J. Muskat. 2006. Real-Time Detection of Oil Slick Thickness Patterns with a Portable Multispectral Sensor. Minerals Management Service, Final Report for Project #0105CT39144.

SOP 1: Site Characterization

This SOP will be used for collection of site characterization data. At each site, atmospheric site characterization data will be collected including air temperature, humidity, wind speed, wind direction, and a general description of weather conditions and sea state. In addition, GPS track data will log the GPS coordinates of the site and marked waypoints will be used to identify the location of specific sampling activities.

Materials and Equipment

Table 1.1 lists the materials and equipment required to complete the procedures described in this SOP.

Table 1.1. Materials and equipment required for the Site Characterization SOP

Anemometer multimeter	Note cards	Site Characterization and Oil Thickness Data Sheet
Permanent markers, pens, and pencils	GPS unit (with current time and date)	

Site Characterization Procedure

1. Fill out the initial GPS coordinates of the location and general site information for the site on the Site Characterization and Oil Thickness Data Sheet. Record the site identification (ID), name of individual(s) collecting samples, and sampling date on the data sheet.

    a. *Site ID assignments*. Start sampling sites with site ID-01 and number each site sequentially.

2. Collect air temperature, humidity, and wind speed using an Extech EN100 anemometer multimeter following manufacturer instructions. Record data on the Site Characterization and Oil Thickness Data Sheet.

3. Record general site description characteristics, including weather conditions and sea state, on the Site Characterization and Oil Thickness Data Sheet.

Site Characterization and Oil Thickness Data Sheet

Site Characterization and Oil Thickness

Site ID:	Date:	Sampler(s):

Site Characterization

Air Temp (°C)	Humidity (%)	Wind Speed (knots)	Sea State*	General Weather Conditions**

Sorbent Pads

#	Time (24h)	Waypoint #	Sample #	Slick Description	Photo #s	Notes
1						
2						
3						
4						
5						

Dip Plates

#	Time (24h)	Waypoint #	Dip Plate #	Plate wt (g)	Plate + oil wt (g)	Slick Description
1						
	Notes/Photo #s					
2						
	Notes/Photo #s					
3						
	Notes/Photo #s					
4						
	Notes/Photo #s					
5						
	Notes/Photo #s					

WaterMapping

#	Time (24h)	Waypoint #	Sample #	Slick Description	Photo #s	Notes
1						
2						
3						

Bulk Oil Collection

#	Time (24h)	Waypoint #	Sample #	Slick Description	Notes
1					
2					

* Example **sea states**: Calm, Swells (approx. wave height ft), Chop, Foam, Whitecaps
** Example **weather conditions**: Sunny, Partly Cloudy (% coverage), Rainy, Stormy, Gusty

SOP 2: Sorbent Pad Sampling

This SOP will be used to collect oil slick or oil sheen samples for chemical analysis. At each site, three to five oil slick or sheen samples will be collected using decontaminated 3M T151 sorbent pads. Note that not all samples may be collected at each site.

Materials and Equipment

Table 2.1 lists the materials and equipment required to complete the procedures described in this SOP.

Table 2.1. Materials and equipment required for the Sorbent Pad Sampling SOP

Certified, pre-cleaned 16-oz sample containers with labels	Nitrile gloves (powderless)	Permanent markers, pens, and pencils
Pad sampling buoy with grab pole	Decontaminated 3M T151 sorbent pads (8.5" x 9.5")	Ziploc baggies, bubble wrap, cooler with ice
Five-gallon buckets	Paper towels	Clear packaging tape
Large metal tongs	Digital camera (with current time and date)	Methylene chloride
Site Characterization and Oil Thickness Data Sheet (SOP 1)	Photograph Documentation Data Sheet (SOP 10)	

Sorbent Pad Sampling Procedure

Before arriving at site:

1. Decontaminate 3M sorbent pads by rinsing with methylene chloride, then let dry overnight in a chemical fume hood. Store decontaminated pads in individual, re-sealable plastic bags until use.

Upon arrival at the site:

1. Obtain a Site Characterization and Oil Thickness Data Sheet (SOP 1) and ensure that the site ID and sampling date are recorded on the data sheet
2. Ensure all sampling and sample processing equipment are decontaminated as described in the Equipment Decontamination in the Field SOP (SOP 14).

Follow the steps below to collect the sample:

1. Put on a new pair of powderless nitrile gloves.
2. Obtain new, pre-labeled 16-oz glass jar sample containers needed for sample collection at the site. Sample container labels will be filled out as described in the Labeling Field Samples SOP (SOP 11).
3. Obtain new, decontaminated sorbent pad. Attach sorbent pad to sorbent pad sampling buoy.

4. Collect the oil slick or sheen off the surface of the water from three separate areas at the sample site. If the site contains areas of distinctly different oil thicknesses, try to target areas that represent the range of different thicknesses observed at the site.

    a. Before each oil sample is collected, mark a waypoint on the GPS device to record the GPS coordinates of the sampling location.
    b. Take one or more photographs of the area being sampled to visually capture the oil slick or sheen. In addition, photograph the target area. Ensure that the date and time on the camera are accurate so the photographs can be linked with data from the GPS device.
    c. Place the sorbent pad buoy with attached sorbent pad onto the slick using a grab pole. Allow to sit on the surface for 30 seconds[1] to permit adsorption of oil onto the pad (Figure 2.1). Pull the pad off the water using the grab pole and carefully bring aboard. Using large metal tongs to grab the pad, fold oiled pad with oiled side inward, and transfer to a pre-cleaned jar for analysis. (*Note: As several sorbent pad buoys will be available, designate separate buoys for sites with thicker emulsions versus sites with only thin sheens to minimize cross-contamination between sites*.)

Figure 2.1. Sampling an oil slick using a sorbent pad buoy with sorbent pad.



5. On the Site Characterization and Oil Thickness Data Sheet, record sample time, waypoint number, sample number, a description of the slick area sampled, and the photograph number(s). If necessary, note any other sample characteristics. After collection, tighten the cap of each sample container and thoroughly dry with a clean paper towel. Check that the sample label is properly and completely filled out, and that all samples are recorded on the proper data sheet. Wrap clear tape around the entire circumference of each sample bottle so that it completely covers the label.

6. Store the sorbent pad samples in a cooler with wet ice until sent to the analytical laboratory. Ensure that no ice or water contact the samples when in the cooler by placing samples in separate Ziploc bags. See the Sample Handling and Shipping SOP (SOP 13) for procedures on how to ship samples.

7. Record all photograph information on the Photograph Documentation Data Sheet following guidelines provided in the Video and Photograph Documentation SOP (SOP 10).

1. The field team leader may adjust oil sampling according to conditions. If the pads placed on a slick are unable to adsorb all the oil, discard the sample, and move to a new area with similar slick characteristics. In the new slick area, use an alternative method (e.g., dip plates, the WaterMapping sampler) to estimate oil slick thickness.

8. Decontaminate non-disposable sampling equipment and sample processing tools prior to sampling the next site, following the Equipment Decontamination in the Field SOP (SOP 14).

9. Once the sampling is complete at a site, photograph all data sheets. This will serve as a backup for hardcopy documents until all data sheets can be scanned and archived.

SOP 3: Bulk Oil Sampling

This SOP will be used to collect oil slick or oil sheen samples for chemical analysis. At sites with heavy oil emulsions, a bulk oil sample from the site will be collected.

Materials and Equipment

Table 3.1 lists the materials and equipment required to complete the procedures described in this SOP.

Table 3.1. Materials and equipment required for the Bulk Oil Sampling SOP

Certified, pre-cleaned 4-oz sample containers with labels	Nitrile gloves (powderless)	Decontaminated glass jars to use as secondary containers
Permanent markers, pens, and pencils	Digital camera (with current time and date)	Ziploc baggies, bubble wrap, cooler with ice
Five-gallon buckets	Dip plates	Clear packaging tape
Paper towels	Sampling pole	Plastic pipette
Site Characterization and Oil Thickness Data Sheet (SOP 1)	Photograph Documentation Data Sheet (SOP 10)	

Bulk Oil Sampling Procedure

Upon arrival at the site:

1. Obtain a Site Characterization and Oil Thickness Data Sheet (SOP 1) and ensure that the site ID and sampling date are recorded on the data sheet
2. Ensure all sampling and sample processing equipment are decontaminated as described in the Equipment Decontamination in the Field SOP (SOP 14).

Follow the steps below to collect the sample:

1. Put on a new pair of powderless nitrile gloves.
2. Obtain new, pre-labeled 4-oz glass jar sample containers needed for sample collection at the site. Sample container labels will be filled out as described in the Labeling Field Samples SOP (SOP 11).
3. If thicker oil emulsion patches exist at the site, collect bulk oil from the surface using one of three methods:
    a. Use a pre-cleaned, 4-oz glass sampling jar attached to a sampling pole. During collection, take care to minimize the transfer of ocean water. This method is best when large areas of thick emulsion are present.
    b. Use a plastic bucket to collect a “bucket-cast” to capture larger mousse/emulsion samples, and then skim the oil from the bucket and transfer to a pre-cleaned, 4-oz sampling glass jar. Use a plastic pipette to remove excess ocean water. Repeat bucket casts until enough oil is collected so that the jar is at least ¼ full.
    c. Use a dip plate to pull small patches of oil emulsion from the ocean surface, and scrape into a pre-cleaned, 4-oz glass sampling jar. Repeat until enough oil is collected so that the

jar is at least ¼ full. See the Dip Plate Oil Thickness SOP (SOP 4) for additional details on this method.

4. On the Site Characterization and Oil Thickness Data Sheet, record sample time, waypoint number, sample number, and a description of the slick area sampled. After collection, tighten the cap of each sample container and thoroughly dry with a clean paper towel. Check that the sample label is properly and completely filled out, and that all samples are recorded on the proper data sheet. Wrap clear tape around the entire circumference of each sample bottle so that it completely covers the label.
5. Store the bulk oil samples in a cooler with wet ice until sent to the analytical laboratory. Ensure that no ice or water contact the samples when in the cooler by placing samples in separate Ziploc bags. See the Sample Handling and Shipping SOP (SOP 13) for procedures on how to ship samples.
6. Record all photograph information on the Photograph Documentation Data Sheet following guidelines provided in the Video and Photograph Documentation SOP (SOP 10).
7. Decontaminate non-disposable sampling equipment and sample processing tools prior to sampling the next site, following the Equipment Decontamination in the Field SOP (SOP 14).
8. Once the sampling is complete at a site, photograph all data sheets. This will serve as a backup for hardcopy documents until all data sheets can be scanned and archived.

SOP 4: Dip Plate Oil Thickness

This SOP will be used to collect oil slick or oil sheen for gravimetric estimation of slick thickness. At each site, three to five oil slick or sheen samples will be collected for gravimetric estimation of slick thickness. Note that only sites with some emulsion can be sampled using this method. Thinner oil sheens can only be sampled using the sorbent pads and the WaterMapping sampler.

Materials and Equipment

Table 4.1 lists the materials and equipment required to complete the procedures described in this SOP.

Table 4.1. Materials and equipment required for the Dip Plate Oil Thickness SOP

Sampling grab pole	Plexiglas plates with rope attachment	One-gallon re-sealable plastic bags
Portable balance	Paper towels	Metric tape measure
Rubber spatulas	Digital camera (with current time and date)	Permanent markers, pens, and pencils
Nitrile gloves (powderless)	Site Characterization and Oil Thickness Data Sheet (SOP 1)	Photograph Documentation Data Sheet (SOP 10)

Dip Plate Oil Thickness Procedure

Before arriving at site:

1. Wipe Plexiglas dip plates with paper towel to ensure the plate is clean and dry.
2. Mark the plate at 15 cm from the bottom with a permanent marker.
3. Label and weigh up to 50 1-gallon re-sealable plastic bags with designated Plexiglas dip plate. All measurements with the balance should be done on a stable surface on the shore.

Upon arrival at the site:

1. Ensure that the site ID and sampling date are recorded on the Site Characterization and Oil Thickness Data Sheet (SOP 1).
2. Ensure that all sampling and sample processing equipment are decontaminated as described in the Equipment Decontamination in the Field SOP (SOP 14).

Follow the steps below to collect the sample:

1. Put on a new pair of powderless nitrile gloves.
2. Obtain a decontaminated Plexiglas plate from its 1-gallon plastic bag. Record the plate number on the appropriate data sheet.
3. At each site, select three to five separate sampling locations to collect oil slick or sheen off the surface of the water. If the site contains areas of distinctly different oil thicknesses, target areas that represent the thickest and thinnest thicknesses, as well as areas with an oil thickness that is most representative of the site.

a. Before each oil sample is collected, mark a waypoint to record the GPS coordinates of the sampling location
b. Take several photographs of the area being sampled to visually capture the oil slick or sheen.

4. Before collection starts, record the sample time, the waypoint number, and photograph image numbers on the Site Characterization and Oil Thickness Data Sheet (SOP 1). Also provide a general description of the slick (e.g., thick emulsion, thin emulsion, patchy emulsion, sheen). If necessary, note any other characteristics of the slick in the Notes column (e.g., vegetation present).

5. To sample the oil slick, slowly lower the Plexiglas plate in the vertical position into the water to where the plate is marked, and then slowly pull it out of the water. See Figure 4.1 for photographs illustrating this procedure. If the oil slick is not adhering to the plate, discard the current plate and repeat with a new plate.

Figure 4.1. Collecting an oil slick using Plexiglas plates to estimate slick thickness.



6. To minimize loss of oil from the plate, quickly place plate into the appropriate plastic bag. If using pre-weighed dip plates and re-sealable plastic bags, wipe any excess moisture from bag, seal, and store in a cool, dry place (e.g., empty cooler) until back on the shore where each dip plate can be re-weighed.

7. Attempt to lower dip plate to the pre-measured line. If the dip collection is lower or higher than the pre-measured line, measure the actual sampling depth from the plate (while in its plastic bag), and record on the appropriate data sheet. Oil can then be transferred to a sample jar to serve as a bulk oil sample (see Bulk Oil Sampling SOP 3), or can be discarded.

8. Ensure that all photograph information has been recorded on the Photograph Documentation Data Sheet following guidelines provided in the Video and Photograph Documentation SOP (SOP 10).

9. Decontaminate all non-disposable sampling equipment and sample processing tools prior to sampling the next site, following the Equipment Decontamination in the Field SOP (SOP 14).

SOP 5: WaterMapping Sampler Oil Thickness

This SOP will be used to measure oil slick thickness using the WaterMapping sampler. At each site, the WaterMapping sampler will collect three to five oil slick or sheen samples for slick thickness measurement by.

Materials and Equipment

Table 5.1 lists the materials and equipment required to complete the procedures described in this SOP.

Table 5.1. Materials and equipment required for the WaterMapping Sampler Oil Thickness SOP

Sampling grab pole	WaterMapping sampler	Nitrile gloves (powderless)
Large sorbent pads or plastic sheet	Paper towels and cleaning wipes	Digital camera (with current time and date)
Permanent markers, pens, and pencils	Plastic sample collection tubes	Special photograph box (to standardize photographs)
Site Characterization and Oil Thickness Data Sheet (SOP 1) and Photograph Documentation Data Sheet (SOP 10)	Tub O' Towels wipes	GoPro camera (with current time and date)

WaterMapping Sampler Oil Thickness Procedure

Before arriving at site:

1. Wipe several plastic sample collection tubes with Tub O' Towels wipes on the inside and the outside of the tube, which will minimize oil sticking to the sides of the tube
2. Label each tube with a sample number starting with 01
3. Clean and prepare the WaterMapping sampler.

Upon arrival at the site:

1. Ensure that the site ID and sampling date are recorded on the Site Characterization and Oil Thickness Data Sheet (SOP 1).
2. Put on a new pair of powderless nitrile gloves.
3. Obtain a clean and labeled plastic tube. Write the tube number on the appropriate data sheet. Insert the sampling tube into the WaterMapping sampler.
4. At each site, select three to five separate areas to collect oil slick or sheen off the water surface. If the site contains areas of distinctly different oil thicknesses, target areas that represent the thickest and thinnest thicknesses, as well as areas with an oil thickness that is most representative of the site.
5. Before each oil sample is collected, take several photographs of the area being sampled to visually capture the oil slick or sheen.
6. Before collection starts, record the site ID, the sample collection date, the sample time, and GPS coordinates or waypoint number on the data sheet. Also provide a general description of

the slick (e.g., thick emulsion, thin emulsion, patchy emulsion, sheen). If necessary, note any other characteristics of the slick in the Notes column (e.g., vegetation present).

7. To sample the oil slick, slowly lower the sampler into the water. Allow water with the slick to pass through the sampling tube for a few seconds, using visual observations or the video from the onboard GoPro, if available, to determine when best to collect the sample.
8. Using a remote control, collect the sample by closing the two end caps.
9. Using a grab pole, gently pull the sampler off the water and place on large sorbent pads or plastic sheeting, which will minimize oil contamination to the deck of the vessel.
10. Store sample tubes in the vertical position in a cool, dark place.
11. Back on shore, photograph each sample tube to determine height of the oil in the sample tube, which can be used to determine volume of the oil sample collected. Use a photography box to standardize each photograph taken. Ensure all tubes have remained in a vertical position for sufficient time to allow all oil to settle before the picture is taken.
12. Ensure that all photograph information has been recorded on the Photograph Documentation Data Sheet following guidelines provided in the Video and Photograph Documentation SOP (SOP 10).
13. Clean sampler with paper towels and cleaning wipes before setting up for the next sample collection.

SOP 6: Water Sampling

This SOP will be used to collect surface and near surface water samples for chemical analysis. For Objective #1, a simple grab sample will be collected near the ocean surface. At each site where water samples are collected for Objective #2, the samples will be collected at up to four depths below the oil slick, using a 4-channel peristaltic pump so that all four depths can be collected simultaneously. At each depth, a 250 mL whole water sample will be collected for potential PAH and/or TPH analysis. Note that not all samples may be collected at each site.

Materials and Equipment

Table 6.1 lists the materials and equipment required to complete the procedures described in this SOP.

Table 6.1. Materials and equipment required for the Water Sampling SOP

Certified, pre-cleaned 250-mL amber glass sample containers with labels	Nitrile gloves (powderless)	Waste bucket
Peristaltic pump (4-channel) with polyethylene tubing marked at target depths	Permanent markers, pens, and pencils	Ziploc baggies, bubble wrap, cooler with ice
Clear packaging tape	Multi-colored electrical tape	Tape measure
Three-inch polyvinyl chloride (PVC) pipe with cap	Paper towels	Fluorescence with Water Sampling Data Sheet
Digital camera (with current time and date)		

Water Sampling Procedure

Sample Collection Precautions

To minimize the effects of the boat's presence on the water sampling results, the following methods will be employed[2]:

1. Always enter the sampling site traveling in up current, so that any oil dispersed by the boat will move away from the sampling site. Then, travel at an angle to the current for the last few hundred feet to ensure the boat does not drift back through the slick area it had just disturbed.
2. Deploy the sample tubing on the up current side of the boat and as far from the boat hull as possible. A sampling boom may be used to extend tubing away from the boat.
3. If engines are running, ensure that all work is being conducted upwind of any exhaust. If possible, turn off the engines and drift during sampling.
4. Maintain situational awareness, and discontinue sampling if warranted.

2. The ability to employ many of these methods will be dependent on having a vessel with the appropriate equipment.

To minimize cross-contamination during sampling for Objective #2, the following methods will be employed:

1. Always deploy polyethylene tubing in clean water or, if necessary, use a large diameter-PVC tube with a cap so that tubing can be deployed without encountering the slick oil. Remove the cap after the PVC pipe and tubing are in the water. The PVC tubing with the cap can be suspended from the boom that rotates, allowing one field person to deploy the PVC tubing into the water, remove the cap, and then deploy the water sample tubing along the side of the boat. The boom should be rotated so that the sampling occurs away from the boat.
2. At each site, use dedicated tubing for all samples.
3. Before sample collection, flush the sample tubing with at least 1 L of water.
4. Segregate dirty and clean work areas. Lay out clean substrates, such as sorbent pads, tarps, or paper towels, to work on and replace frequently.

Sample Collection Methods

Upon arrival at the site:

1. Obtain a Fluorescence with Water Sampling Data Sheet and ensure that the site ID and sampling date are recorded on the appropriate lines
2. Ensure that all sampling and sample processing equipment are decontaminated as described in the Equipment Decontamination in the Field SOP (SOP 14).

Follow the steps below to collect the sample:

1. Put on a new pair of powderless nitrile gloves.
2. Obtain new, pre-labeled 250-mL amber glass sample containers for the site. Organize so that the sample containers are easy to find during sample collection activities.
    a. Sample container labels will be filled out as described in the Labeling Field Samples SOP (SOP 11).
3. To collect samples at multiple depths, prepare four lengths of fresh, uncontaminated tubing for deployment. The length of each will depend on the boat and boom; prepare a 2-m, 2.5-m, 3-m, and 5-m length of tubing for each site unless the field team leader suggests alternate lengths:
    a. Mark the four target depths on the tubing with electrical tape, using a different color to mark the target depths, and mark above and below the target depth every 0.1 meter up to one meter on either side of the target depth using black electrical tape. Then, align the target depth markings of each length of tubing and tape the four tubes together so each is at its respective depth. The tubing can then be lowered into the water until the water's surface intersects the colored electrical tape representing the desired target depth.
    b. The initial four target sampling depths will be 0.1 m, 0.5 m, 1 m, and 3 m; however, if fluorescence spectroscopy data indicate deeper depths should be sampled, they will be adjusted accordingly. (*Note: If the boat is rolling significantly, surface tubing may need*

to be deployed to deeper depths to avoid pulling the tubing out of the water and through the slick.)

c. Tether a tubing weight to each tubing end to minimize the pull from currents. If possible, extend the tubing away from the boat using an extension device.

4. Deploy tubing into the water

   a. To minimize contamination of sample tubing, deploy the tubing through clean water before the boat enters the oil slick site or, if necessary, deploy it through a PVC pipe with a cap to protect the ends of the tubing as it enters the water. Once in the water, remove the cap by tapping the cap edge with the sampling pole.

5. Collect water samples from each of four specified depths. Water samples will be collected using a peristaltic pump as described below. Before the start of collection, first flush the sample tubing with approximately 1 L of water, allowing the water to go into a waste bucket. Then place a 250-mL amber glass, pre-cleaned sample bottle under the sample tubing and collect a whole water sample for PAH/TPH. Ensure the bottles are completely full so there is minimal headspace when capped.

6. During the sample collection, mark a waypoint to record GPS coordinates of the sampling location.

7. On the Fluorescence with Water Sampling Data Sheet, add sample time, waypoint number, sample number, sample depth, and a description of the slick. If necessary, note any other sample characteristics.

8. After collection, tighten the cap of each sample container and thoroughly dry with a clean paper towel. Check that the sample label is properly and completely filled out, and that all samples are recorded on the proper data sheet. Wrap clear tape around the entire circumference of each sample bottle so that it completely covers the label.

9. Store water samples upright in a cooler with wet ice until sending to the analytical laboratory.

10. Decontaminate non-disposable sampling equipment and sample processing tools prior to sampling the next site, following the Equipment Decontamination in the Field SOP (SOP 14).

11. Once sampling is complete at a site, photograph all data sheets. This will serve as a backup for hardcopy documents until all data sheets can be scanned and archived.

Fluorescence with Water Sampling Data Sheet

Fluorescence with Water Sampling

Site ID:	Date:	Sampler(s):

Water Samples

#	Time (24h)	Waypoint #	Sample #	Slick Description	Depth (m)	Notes
1						
2						
3						
4						

Fluorescence Profile

#	Descending/ Ascending	Start Time	End Time	Waypoint #	Profile Depth (m)	Notes
1	Descending					
	Ascending					
2	Descending					
	Ascending					
3	Descending					
	Ascending					
4	Descending					
	Ascending					
5	Descending					
	Ascending					

Fluorescence Transect

#	Start Time	End Time	Depth (m)	Notes

WP #	Waypoint Description	Fluor. (mV)	WP #	Waypoint Description	Fluor. (mV)

SOP 7: Fluorescence

This SOP will be used to collect real-time fluorescence transect and profile data.

Materials and Equipment

Table 7.1 lists the materials and equipment required to complete the procedures described in this SOP.

Table 7.1. Materials and equipment required for the Fluorescence SOP

Turner Designs Cyclops 7 fluorometer	Nitrile gloves (powderless)	Laptop computer with DataBank software
3 " PVC with cap	Sampling pole	Boom
Fluorescence with Water Sampling Data Sheet (SOP 6)	Fluorescence Transect Data Sheet	Permanent markers, pens, and pencils

General Site Documentation

Real-time fluorescence data will be collected to help target areas for water sampling. In addition, as water samples are being collected for Objective #2, the fluorometer will be slowly lowered from the surface to the deepest depth sampled to capture a fluorescence profile of the water column at the time of water sampling. Fluorescence profiles may be collected at additional sites at the discretion of the field team leader. Additional transects throughout the day may be collected as the vessel traverses from site to site.

Turner Designs Cyclops 7 Fluorometer

Before arriving at site:

1. Fully charge the laptop the night before
2. Synchronize time on the laptop to the time on the GPS device using the DataBank software
3. Set the logging interval to take a reading every 10 seconds using the DataBank software.

Collecting a Fluorescence Profile

Before arriving at the site:

1. To minimize contamination of the fluorometer, deploy the fluorometer through clean water before the boat enters the oil slick site or, if necessary, deploy it through a PVC pipe with a cap to protect the ends of the tubing as it enters the water. Once in the water, remove the cap by tapping the cap edge with the sampling pole.
2. *Press* the **Power** button to turn on the fluorometer.
3. Allow the fluorometer to warm up for 1–2 minutes

Upon arrival at the site:

1. Fluorescence profiles will be collected at the same time and location as water sampling for Objective #2.
2. As the water samples are being collected, take a descending and an ascending fluorescence profile.
3. To collect a profile, first initiate logging mode, if not already logging. To initiate the logging mode, hold the **Store** button. Once the logging mode has begun, the display will read "LOGGING MODE ENTERED."
4. Slowly lower the fluorometer from the surface to the deepest depth sampled. Record the time at the start and end of the profile, the depth of the profile, and that it was a descending profile on the Fluorescence with Water Sampling Data Sheet. Then slowly raise the fluorometer back to the surface, avoiding pulling the sensor out the water through the slick oil. Again, note the time at start and end of profile, depth of the profile, and that it was an ascending profile on the Fluorescence with Water Sampling Data Sheet (SOP 6).
5. End the logging mode by pressing the **Power** button.

Collecting a Fluorescence Transect

Before arriving at the site:

1. To minimize contamination of the fluorometer, deploy the fluorometer through clean water before the boat enters the oil slick site or, if necessary, deploy it through a PVC pipe with a cap to protect the ends of the tubing as it enters the water. Once in the water, remove the cap by tapping the cap edge with the sampling pole.
2. The depth of deployment may change depending on field results and at the discretion of the field team leader, but as a default, deploy the fluorometer to 0.5 m.
3. Press the **Power** button to turn on the laptop.
4. Allow the fluorometer to warm up for 1–2 minutes.
5. Press the **Select** button to increment through the parameter groups (1–16). To organize transects, use a new parameter group for each transect and profile. Stop on your parameter of choice to select. Each parameter group used should be uncalibrated.

Upon arrival at the site:

1. Assess extent of the slick at the site. Discuss with the boat captain how the area should be traversed for sampling. If possible, the transect should traverse areas that are both up current and down current of the slick area, and should enter and exit the slick multiple times.
2. Initiate the logging mode, if not already logging. To initiate the logging mode, hold the **Store** button. Once the logging mode has begun, the display will read "LOGGING MODE ENTERED."

3. Begin to traverse the slick area. As the boat moves around the site, mark waypoints when the fluorometer enters and exits the slick oil. Record fluorescence readings at each waypoint. When out of the slick area, note if the boat is up current or down current of the slick. Record each waypoint number and a description of that waypoint on the Fluorescence Transect Data Sheet (if conducting a transect without water sampling) or on the Fluorescence with Water Sampling Data Sheet (SOP 6; if conducting a transect for targeted water sampling).
4. If a spike or anomaly in the fluorescence signal is observed, press the **Store** button to store the current reading displayed.
5. Mark a new waypoint and record the observed fluorescence reading. Press the **Recall** button if you need to display the last record stored.
6. If conducting the transect for targeted water sampling, stop the boat and collect a set of water samples according to the Water Sampling SOP (SOP 6). Otherwise, continue fluorescence monitoring until the planned transect is complete.
7. Once the transect is complete, press the **Power** button to end the logging mode.

Fluorescence Transect Data Sheet

Fluorescence Transect

Site ID:	Date:	Sampler(s):

Fluorescence Transect

#	Start Time	End Time	Depth (m)	Site Description	Notes

WP #	Waypoint Description	Fluor. (mV)	WP #	Waypoint Description	Fluor. (mV)

SOP 8: Air Sampling

This SOP will be used to collect air samples for chemical analysis. At each site, air samples will be collected at three heights above the oil slick (< 0.1 m, 0.5 m, and 1.0 m). At each height, air samples will be collected for both PAH and VOC analysis. The VOC air samples will be collected using HDSs that will collect an integrated air sample over a period of 15 minutes. The PAH air samples will be collected using XAD-2 resin sorbent tubes through which air will be pumped at 1 L/minute.

Materials and Equipment

Table 8.1 lists the materials and equipment required to complete the procedures described in this SOP.

Table 8.1. Materials and equipment required for the Air Sampling SOP

Pre-prepared HDSs from ALS	Pre-prepared XAD resin tubes from ALS in envelope	Air sampling buoy
Permanent markers, pens, and pencils	Air pumps with Tygon tubing from ALS	Ziploc baggies, bubble wrap, cooler with ice
Rotameter for pump calibration	Nitrile gloves (powderless)	Clear packaging tape
Aluminum foil	Secondary timer	Paper towels
Air Sampling Data Sheet	GPS unit (with current time and date)	COC seals and forms
Ropes	Sampling poles	

Air Sample Collection Procedure

Sample Preparation Methods

1. Before arriving at the site, prepare three HDSs and three XAD-2 resin sampler air pumps for sampling. Preparation instructions are as follows:

Preparation of HDSs

1. For the HDSs, attach a pressure gauge to the top of the sampler to check pressure to verify the sampler is still charged with helium. If the sampler is charged with 7–8 psi, the sampler is ready to sample. Do not use the sampler if it is not pressurized. See Figure 8.1 for an example of an HDS with a gauge that shows 7–8 psi.

2. If the HDS is ready, record its bar code on the Air Sampling Data Sheet.

    a. **Do not** put a sample label directly onto the HDS as it may interfere with sample analysis. Instead, after sampling is complete, the HDSs will be wrapped in aluminum foil, and the sample label can be applied to the aluminum foil wrap.

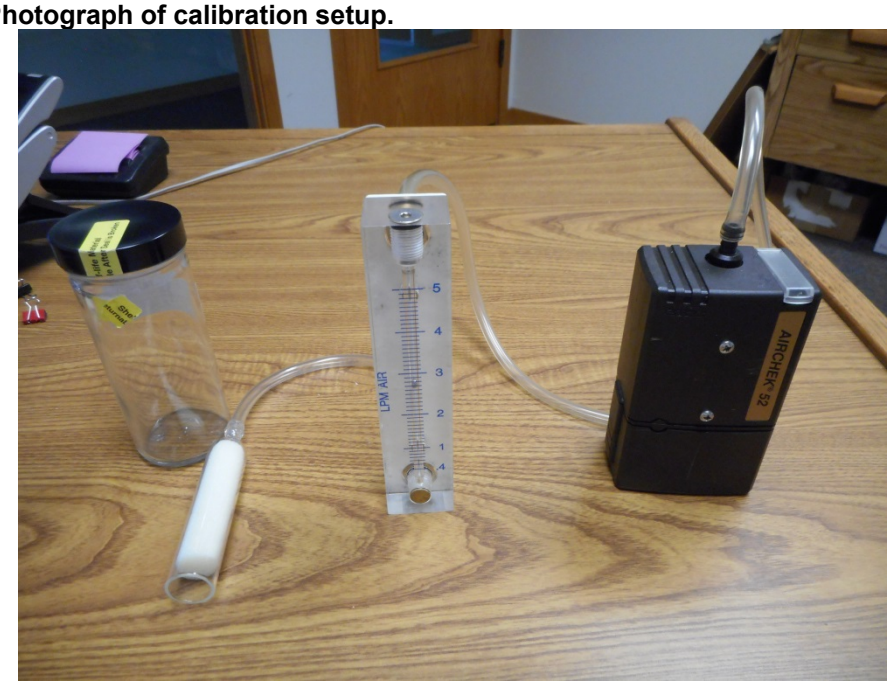
Figure 8.1. HDS with pressure gauge to check that the sampler is still charged with helium and with stem removed.



Calibration of XAD Resin Tube Air Pumps

1. Ensure all pumps are fully charged the night before sampling begins.
2. For the XAD resin tube sampling, the flow rate of each air pump needs to be calibrated prior to and after every use.
3. To calibrate, connect the "calibration XAD resin tube" to the sample tubing and pump to be used. It is important to calibrate the pump using the same tubing and tubing length that will be used during sampling; for each height, the pump needs to be calibrated with the specific tubing for that height. Then connect the other end of the sample tubing to the bottom of the rotameter. Finally, using a short section of tubing, connect the pump to the top of the rotameter. See Figure 8.2 for a picture of the calibration set up.
4. Set the rotameter on a flat surface and turn on the air pump. Allow the pump to stabilize for 5 minutes. Then, read the flow rate of the pump from the middle of the silver ball in the rotameter.
5. Adjust air flow for the pump so that it is at 1 L/minute using the small adjustment screw by the pump on/off button.
6. Record the air flow for each pump on the Air Sampling Data Sheet, as the initial air flow for the sampler.
7. Calibration should be checked before and after sampling with the difference between the flow rates not to exceed +/- 5%. The average of the initial and final flow rate will be used to calculate the final air volume.
8. Once the pump has been calibrated, remove the calibration tube from the tubing connected to the pump.

Figure 8.2. Photograph of calibration setup.



Sample Collection Methods

Follow the steps below to collect air samples:

1. Put on a new pair of powderless nitrile gloves.
2. Prepare the air sampling buoy for deployment by attaching ropes to the eyehooks on the bottom of the buoy. Ensure the ropes are not tangled. Determine what area will be best for air sampling based on wind direction and slick area.
3. Obtain three new XAD resin tube samplers. Remove stoppers from each end of the XAD resin tubes. Place these two items back into an envelope to be used when the sampling is completed. Record the barcode for each XAD resin sampler on the Air Sampling Data Sheet (the barcode will be on the side of the tube).
4. Load the HDS and XAD resin tube samplers into the air sampling buoy, ensuring that the samplers and air pumps are well-secured to the buoy and the air tubing is well-attached to the pump and tube.
5. Start the air pumps to the XAD resin tubes first, and start a stopwatch, which will serve as a backup to the time recorded by the pump.
6. Once the air pumps are started, initiate sampling of HDSs by unscrewing the HDS tops. See Figure 8.1. To expedite this process, have a different person unscrew each HDS.
7. To avoid misplacing tops, place each top in individual plastic bags labeled by height. Keep plastic bags on the clipboard with the Air Sampling Data Sheet.

8. Deploy the air sampling buoy onto the slick area as soon as possible after initiation of HDS sampling. See Figure 8.3 for photographs of an air sampling buoy with XAD resin and HDSs.
9. The air sampling buoy will be deployed for at least 1 hour. Watch the buoy at all times when out on the water.
10. Once the sampling is complete, pull the air sampling buoy out of the water using ropes and grab poles.
11. Before turning off the air pumps to the XAD resin samplers, record the time displayed on the small liquid crystal display (LCD) screen on the air pump. Stop the stopwatch, and check that the time on the pump matches the time on the stopwatch. Then turn off the air pumps and screw on the tops to the HDSs to cease sampling of both samplers.
12. Collect XAD-2 sorbent tubes from the air sampling buoys, wrap in aluminum foil, and return to its respective envelope with sample ID information, and place in Ziploc bag to protect from moisture.
13. Recalibrate the air sample pumps using the steps above to determine any changes in air flow rate during sampling. Record the final air flow rate from the pump on the Air Sampling Data Sheet.
14. Place HDS and XAD resin tube samples in a cooler with wet ice until shipped to analytical laboratory.
15. Decontaminate non-disposable sampling equipment and sample processing tools prior to sampling the next site, following the Equipment Decontamination in the Field SOP (SOP 14).

Figure 8.3. Photographs of air sampling buoy: side view of buoy on water (top left), top view of buoy (bottom left), top view of air sampling pumps (top right), and top view of air sampling pumps for XAD-2 samplers (bottom right).



Air Sampling Data Sheet

Air Sampling

Site ID:	Date:	Sampler(s):
Slick Description:		

HDS Air Samples

#	Time (24h)	Waypoint #	Sample # (bar code)	Sample Height (m)	Initial Pressure	Sampling Time (min)
1						
	Notes					
2						
	Notes					
3						
	Notes					

XAD Air Samples

#	Time (24h)	Waypoint #	Sample # (bar code)	Sample Height (m)	Initial Pump Rate (L/min)	Final Pump Rate (L/min)	Sampling Time (min)
1							
	Notes						
2							
	Notes						
3							
	Notes						

SOP 9: UV and Visible Light Attenuation

Water turbidity/visible light attenuation data will be collected using a Secchi disk and UV light attenuation data will be collected with a Biospherical radiometer. This SOP describes how to collect visible light attenuation data using a Secchi disk and UV light attenuation measurements with a Biospherical radiometer.

Materials and Equipment

Table 9.1 lists the materials and equipment required to complete the procedures described in this SOP.

Table 9.1. Materials and equipment required for the UV and Visible Light Attenuation SOP

Biospherical radiometer with computer	Nitrile gloves (powderless)	Sorbent pad or soap
Secchi disk with calibrated rope and weight	Metal clips	UV and Visible Profile Data Sheet
Permanent markers, pens, and pencils	Digital camera (with current time and date)	

UV Light Attenuation Data Collection Methods

1. Connect the radiometer cable to our powersource/translator (a small deckbox), which is connected to a laptop running PROFILER software.
2. Turn on the BioSpherical radiometer, and press Record on the PROFILER screen.
3. Clear an area of slick oil using a sorbent pad or soap.
4. Slowly lower the meter down through the cleared area. Just before the sensor is dropped below the water surface, cover the sensor with the data sheet for a few seconds. This will provide a clear indication in the datalog of when the profile measurements have started.
5. Lower the radiometer until the UV light has been fully attenuated, and then slowly pull back up. A depth sensor on the instrument will capture the depth.
6. Press Stop on the PROFILER screen to stop recording the data.
7. Record the site ID, date and time of the UV profile, and any notes on the UV and Visible Light Attenuation Data Sheet.

Secchi Disk Data Collection Methods

In an area of slick that has not been disturbed by other activities, take three Secchi disk measurements following the methods below.

1. Obtain a 20-cm Secchi disk with attached lead weight and calibrated rope.
2. Move to the side of the boat that is in the shade so measurements are not disturbed by sun glare or, if necessary, block the sun with your body to reduce glare. Remove sunglasses during measurement so they do not interfere with your ability to see the disk.
3. Attach end of the Secchi disk rope to the boat to avoid losing equipment if dropped.

4. Clear an area of slick oil using sorbent pads, and lower the Secchi disk through the cleared area into the water.
5. Slowly shift the Secchi disk from the cleared area to an area with the slick or sheen. Try to minimize slick disturbance and keep the disk under the slick while taking Secchi depth measurements.
6. Take photograph(s) of slick area being measured by Secchi disk.
7. Lower the disk down until no longer visible. Make a note of the depth by reading the depth off the calibrated line. If this is not visible, then make a note of the depth by placing a metal clip on the calibrated line that lines up with the top of the boat's railing.
8. Record the site ID, date, and time of the Secchi disk profile, and any notes on the UV and Visible Light Attenuation Data Sheet.

UV and Visible Light Attenuation Data Sheet

UV and Visible Light Attenuation Data Sheet

Date: _____ **Time Start:** _____ **Time End:** _____ **Field Recorder:** _____

Site ID: _____ **GPS (Lat/Long):** _____

Sampling Crew Names/Affiliations: _____

UV Profile Filename: _____

Secchi Disk and UV Radiation Attenuation Measurements							
Secchi Depth 1 (m)		**UV Attenuation Drop 1**		**UV Attenuation Drop 2**		**UV Attenuation Drop 3**	
Secchi Depth 2 (m)		**UV-A (surface)**		**UV-A (surface)**		**UV-A (surface)**	
Secchi Depth 3 (m)		**UV-A (at depth)**		**UV-A (at depth)**		**UV-A (at depth)**	
Mean Depth (m)		**Depth of Drop (m)**		**Depth of Drop (m)**		**Depth of Drop (m)**	

Notes/Weather Conditions:

Water Quality Measurements	
Depth of WQ Measurement	
Water Temperature	
Salinity	

SOP 10: Video and Photograph Documentation

This SOP lists the required materials and describes standard methods for collecting and documenting photographs taken as a part of field data collection activities.

Materials and Equipment

Table 10.1 lists the materials and equipment required to complete the procedures described in this SOP.

Table 10.1. Materials and equipment required for the Video and Photograph Documentation SOP

Digital camera with memory card programmed with correct date and time according to GPS unit	GoPro Hero 4 with extra batteries and accessories
GPS unit	Permanent markers, pens, and pencils
Photograph Documentation Data Sheet and Video Documentation Data Sheet	

Procedures

Included as part of this SOP is a video and photograph documentation checklist. This checklist is merely a guide for the photographer/videographer and does not represent all possible photographs or videos that could be taken during a sampling trip.

When videos or photographs are taken, follow these steps:

Step 1. Fill in the information at the top of the Video Documentation and Photograph Documentation Data Sheets for videos and photographs, respectively. This information is used to identify the location and document equipment and personnel involved in data collection efforts.

- Photographer/videographer
  - Name of the field member taking the photographs
- Photographer/videographer affiliation
- Date (when location was visited)
- Site ID
- Camera ID
  - Unique identifier to track which camera was used
  - Example: serial number or brief description
- Memory card ID
  - Unique identifier to track which memory card was used
  - Example: serial number or brief description
- Photograph-specific comments
  - General description of location and/or activities related to photographs on log; can call out specific photographs of interest in this space.

Note that the time each video/photograph is taken will be recorded by the camera on the video/photograph itself. Ensure that the camera is set to the correct time and date before any photograph or video is taken.

Step 2. Turn on the GPS tracking log (if the GPS unit has this capability), mark a waypoint to identify the location, and photograph the display screen (time, coordinates, and waypoint number should be visible in the photograph). Record this picture as the first photograph on the data sheet.

Step 3. Take photographs or videos.

Photographs: For each photograph or group of photographs of the same subject, record a waypoint in the GPS unit, the photograph image number, and a general description of the photograph on the Photograph Documentation Data Sheet.

Videos: For each video or group of videos of the same subject, record a waypoint in the GPS unit and the video file number. In addition, record the start time and end time of the captured video and a general description of the video on the Video Documentation Data Sheet.

Video and Photograph Documentation Checklist

Use this checklist as a guide for video and photograph documentation to be completed at each site. This checklist is merely a guide, and does not represent all videos or photographs that may potentially be taking during sampling.

- ❑ First photograph for each site should be of the GPS unit marking the location of the sampling site that the following photographs will be taken from. If multiple cameras are used, each camera should photograph the GPS unit.
- ❑ Ensure that the time and date are correct on all cameras used.
- ❑ Photograph each area sampled with sorbent pads, dip plates, and WaterMapping sampler.
- ❑ Photograph each area where Secchi disk measurements are taken.
- ❑ Take video and/or photographs of area during fluorescence transects.
- ❑ Take video and/or photographs to capture general site characteristics.
- ❑ Once sampling is complete at each site, photograph the GPS unit to capture the GPS coordinates at the end of the sampling.
- ❑ Using a designated camera, photograph all data sheets from the completed site to serve as a backup copy.

Photograph Documentation Data Sheet

Photograph Documentation

Photographer name	
Photographer affiliation	
Camera ID	
Memory Card ID	
Video Specific Comments (optional) *Call attention to any specific photos of high value or photos that are data themselves.*	

Photo Number	Date	Start Time	Site ID	Description

Video Documentation Data Sheet

Video Documentation

Videographer name	
Videographer affiliation	
Camera ID	
Memory Card ID	
Video Specific Comments (optional) *Call attention to any specific photos of high value or photos that are data themselves.*	

Video Number	Date	Start Time	Site ID	Description

SOP 11: Labeling Field Samples

This SOP details how field samples will be labeled.

Materials and Equipment

Table 11.1 lists the materials and equipment required to complete the procedures described in this SOP.

Table 11.1. Materials and equipment required for the Labeling Field Samples SOP

Sample containers	Clear packing tape	Fine-point permanent markers
Sample container labels		

Field Sample Labeling Procedure

1. Fill out the required information on sample labels prior to affixing labels to the sample containers

   All sample labels will contain the following information, written legibly in permanent ink:

   - Sample ID (details provided below)
   - Container number for a given sample ID (example: 1 of 3, 2 of 3, and 3 of 3)
   - Date and time of sample collection (military or 24-hour time format)
   - Sample collector's name

2. Attach the completed sample labels to the sampling containers

3. All sample labels will be covered with clear packing tape that completely encircles the sample container to prevent smearing or physical damage to the label.

Sample ID Designations

Each sample will receive a unique alphanumeric designation as the Sample ID. The following format will be used:

GridID-Date-Y####-XX##-##

First segment: GridID represents location of the sample collection. On this sampling trip, all GridIDs will be "Taylor" to indicate that the sampling is occurring around the Taylor Energy spill site.

Second segment (Y####): sampling date. This five-digit date code includes a letter to represent the year, with 2016 = A. Following the year letter code are four digits for the month and day, including zeroes. Do not use slashes or dashes between digits. For example, the data code for October 10, 2016 would be A1010.

Third segment (XX##): matrix and site ID. This four-digit code is made of two two-digit sections where the first two digits represent the matrix. The matrix codes are for this trip can be found in Table 11.2. The second two digits are the site ID. The site ID 01 will be reserved for the background site sampled during each trip. Oil contaminated sampling sites will start with 02 and increase sequentially.

Table 11.2. Sample media designation codes

Sample media	Matrix code
Oil – Pad	OP
Oil – Bulk	OL
Whole Water – PAH	WW
Air – VOC	AV
Air – PAH	AP

Fourth segment (##): sequential number. The final segment of the sample ID will consist of a unique, sequential number. Because multiple samples will be collected by different team members simultaneously, each sample type will have their own group of unique sample numbers to avoid assigning the same unique number to multiple samples. The groups will be as follows: oil samples will start at 01 and get numbered sequentially up to 50, water samples will start with 51 and get numbered sequentially up to 80, and air samples will start with 81 and get numbered sequentially up to 99 (Table 11.3).

Table 11.3. Unique sample number groups for each sample type

Sample type	Unique sample numbers
Oil	01–50
Water	51–80
Air	81–99

Example sample IDs: the sample ID for a bulk oil sample taken at Site 04, which was the 10th oil sample collected at that site on October 10, 2016, would be Taylor-A1010-OL04-10.

Note that if multiple containers are filled with sample media from a single sampling point for the same analysis, the sample ID will be identical for all containers. The sample label will also be similar except that each container will have a different container number that references the total number of containers that were filled (e.g., 1 of 4, 2 of 4). This labeling scheme will be used regardless of sample container type and analyses.

SOP 12: Sample Chain of Custody

This SOP describes sample COC requirements and procedures. All collected samples will be maintained under strict COC, which is the documentation of a sample's history from the time of collection through sample analysis to final disposal. COC forms will be used to document sample COC, relinquish samples, request analyses when relinquishing samples to an analytical laboratory, and transfer samples to long-term storage.

The individual who prepares and labels a sample is responsible for the care and custody of all samples in his/her possession, until they are officially relinquished using COC forms. Samples can be relinquished by sending to analytical laboratories, personally handing off to the intended recipient (individual or laboratory), or storing in a secure location. A sample is considered to be appropriately in the custody of the sampler only in the following situations:

- The sample is in the individual's possession or within eyesight of the individual.
- The sample is in a sealed container that cannot be tampered with or opened without breaking the seal.
- The sample is in a designated secure area, cold storage room, locked refrigerator, or similar storage area with limited access. Access can be controlled using keyed locks, sign in/out sheets, and/or video monitoring.
- The sample is in a shipping cooler, envelope, or box that is tamper-resistant, properly prepared for shipping, and secured using custody seal tape.

COC Forms

1. Obtain enough new COC forms for all the samples being shipped to the analytical laboratory or transferred to storage
    a. Note that COC forms usually only have enough entries for 10–20 samples
2. Record the following contact information on each COC form:
    a. Project name (Taylor Energy)
    b. Project Manager (Heather Forth, Abt Associates)
    c. Sampler contact information (current street and email address, cell phone number, and fax number)
    d. Sampler signature
    e. Special instructions/comments (if samples were pulled from storage and being sent to the analytical laboratory, specific storage conditions)
3. Record the following sample information on respective COC forms:
    a. Sample ID (unique for each sample, see SOP 11, the Labeling Field Samples SOP)
    b. Date and time of sample collection (information should be found on the respective, completed data sheets)
    c. Sample matrix (e.g., whole water, bulk oil)

   d. Number of sample containers sharing the same, respective sample ID
   e. Analysis required for each sample (usually indicated using check boxes; check all that apply)

4. Record the following COC information at the bottom of the COC form:

   a. Printed name and signature of individual relinquishing custody
   b. Date and time when samples were relinquished from custody (this will be the last entry made before making copies of the completed COC form and sealing in the cooler or securing with stored samples)

5. Photograph of filled out hardcopy COC forms to serve as a backup record.

Relinquishing Samples

1. Completely fill out the COC form, as described above
2. If sending to an analytical laboratory, notify the laboratory of the shipment and ship samples as described in the Sample Handling and Shipping SOP (SOP 13).

SOP 13: Sample Handling and Shipping

This SOP describes how to handle and ship samples for chemical analysis while maintaining established COC requirements as described in the Sample Chain of Custody SOP (SOP 12). It also provides sample hold times for the different sample matrix types.

Materials and Equipment

Table 13.1 lists the materials and equipment required to complete the procedures described in this SOP.

Table 13.1. Materials and equipment required for the Sample Handling and Shipping SOP

1-gallon Ziploc bags	Bubble wrap	Digital camera
Paper towels	Clear packaging tape	FedEx domestic shipping air bills
COC seals or evidence tape	Cooler(s) with ice or cold packs	Plastic bottles of any size ranging from 30 mL to 250 mL filled with cold tap water (temperature blank)
COC forms		

Sample Handling and Shipping Methods

1. Ensure all samples are shipped within the prescribed sample hold times listed in Table 13.2. Handling and hold time recommendations are based on guidelines from the analytical laboratory.

Table 13.2. Recommended storage conditions and hold times for environmental samples. Maximum hold time refers to the required length of time from sample collection to organic analysis extraction that is allowable before sample integrity may be jeopardized.

Sample type	Storage conditions	Maximum hold times
Water TPH/PAH samples	On ice at approximately 4°C	Seven days if not acid preserved Fourteen days if acid preserved
Bulk oil/product sample	Short-term: on ice at approximately 4°C Long-term (> 1 week): Standard refrigerator at approximately 4°C	None
Oiled filters/pads/nets	Store frozen at -20°C	None
Air PAH samples	On ice at approximately 4°C	Thirty days
Air VOC samples	Room temperature	Thirty days

2. Obtain enough COC forms and coolers to contain all of the samples that are being shipped.
    a. Note that COC forms usually only have enough entries for 10–20 samples
    b. Samples listed on a single COC form will not be split between coolers
    c. More than one COC form can be used for each cooler.
3. Fill out COC form according to the Sample Chain of Custody SOP (SOP 12).

4. Pack the cooler.

    a. Place a layer of bubble wrap and paper towels in the bottom of the cooler.
    b. Wrap samples in bubble wrap and pack so that they are not directly touching each other or hard objects such as ice packs.
    c. All samples should be upright in cooler. Do not pack samples on their sides.
    d. Pack samples with enough ice to keep cooled to approximately 4°C until received by the laboratory. Ice will be in gel packs, water frozen in excess sample bottles, and/or ice cubes within multiple re-sealable plastic bags to prevent water or ice from touching sample bottles.
    e. If not already in the cooler from the analytical laboratory, a temperature blank bottle will be included in each cooler. Make the temperature blank by adding cold water to a capped 30- to 250-mL Falcon tube or plastic bottle, and clearly label it "Temperature Blank." The analytical laboratory will measure the temperature in this bottle as representative of the temperature of the sample bottles.

5. Confirm that each cooler only contains samples that are listed on the COC form(s) in that cooler.

6. Once all sample and analysis information is recorded on each COC form, the person relinquishing custody of the samples to the laboratory will sign and date the COC form(s).

7. Seal the original COC form(s) in a plastic re-sealable bag and tape the bag to the underside of the cooler lid (or the inside of the cooler).

8. For each cooler, sign and date at least two COC seals (small stickers or tape with a line for a signature and date) or sections of evidence tape for each shipping container.

9. Place signed COC seals or evidence tape on opposite corners of the cooler across the seam between the cooler lid and the main body of the cooler (Figure 13.1). Seals must be arranged so that the cooler cannot be opened without disturbing the seals.

10. Place clear packing tape over the COC seals or evidence tape.

11. Seal the cooler by taping around the seam between the lid and body of the cooler and around the entire cooler (Figure 13.2).

12. Deliver cooler(s) to a FedEx location or have FedEx pick up the cooler(s). Do not leave the cooler(s) at an unattended FedEx drop-off location. Samples will be shipped as soon as possible following collection in order to provide ample time to perform extractions within the appropriate holding time. Avoid shipping samples over weekends.

13. All water and oil analytical samples will be sent to ALS Environmental in Kelso, Washington, for analysis. All air samples will be sent to ALS Environmental in Salt Lake City, Utah. Below are instructions for filling out the FedEx air bill including the appropriate FedEx code to use for all shipments and the shipping address for ALS Environmental.

    a. Sender's Account Number: 2931-9475-0
    b. Internal Reference: 21272-0400
    c. Recipient:

For water and oil samples:
ALS Environmental, 1317 South 13th Avenue, Kelso, WA 98626
(Telephone: 800-695-7222)

For air samples:
ALS Environmental, 960 W. LeVoy Drive, Salt Lake City, UT 84123
(Telephone: 801-266-7700)

d. Express Package Service: check "FedEx Standard Overnight"
e. Packaging: check "Other"
f. Special Handling: leave blank, but check "No" for *Does this shipment contain dangerous goods?*
g. Payment: check "Sender"
h. Residential Delivery Signature Options: check "No Signature Required."

Figure 13.1. Placement of signed COC seals (green) on the outside of shipping coolers.

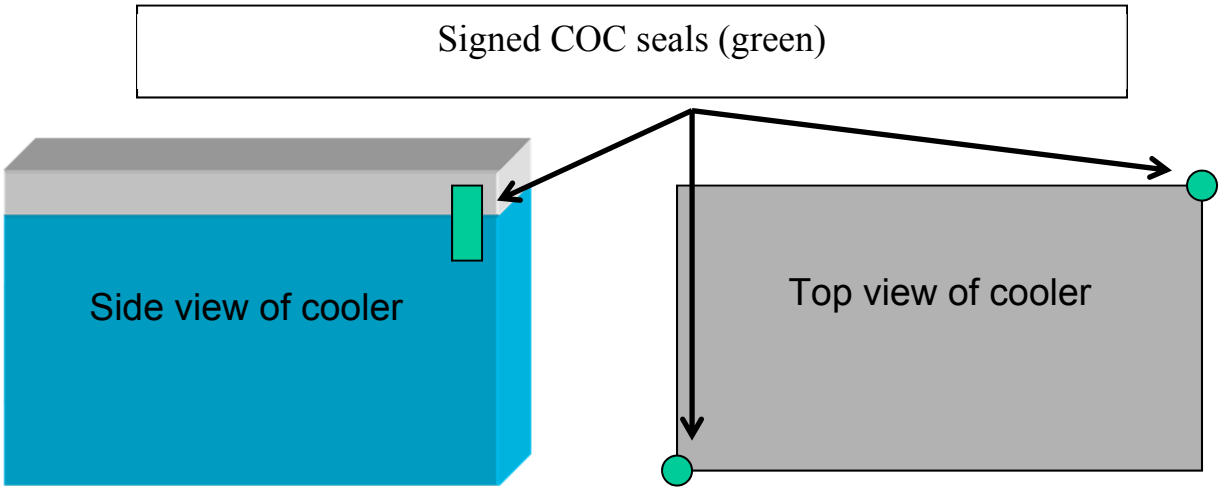
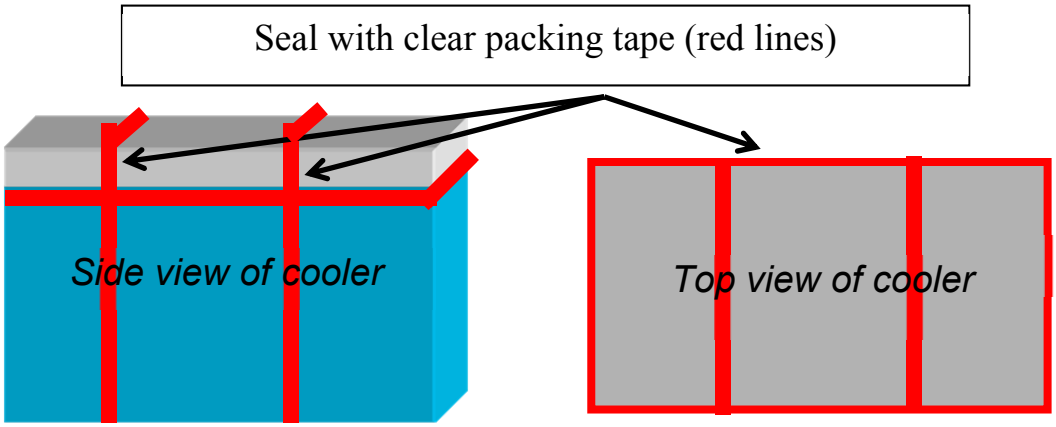


Figure 13.2. Placement of clear packing tape (red line) on shipping coolers.



SOP 14: Equipment Decontamination in the Field

Sampling and sample processing equipment will be decontaminated before use according to methods described in this SOP. Decontamination procedures follow recommendations for equipment decontamination described in U.S. EPA (2001).

Materials and Equipment

Table 14.1 lists the materials and equipment required to complete the procedures described in this SOP.

Table 14.1. Materials and equipment required for the Equipment Decontamination in the Field SOP

Nitrile gloves	Five gallon buckets with lids	Uncolored plastic bags
Alconox powder soap	Tap water	Paper towels
Scrub brushes	Deionized (DI) or distilled water	Activated carbon
Simple Green	Metal colander	Metal bowl
Rubbermaid tubs	Laboratory-grade ethanol	

General Equipment Decontamination Methods

1. Determine what equipment needs decontamination.
    a. In general, this includes any equipment that is re-used and involved in the collection of water and sorbent pad analytical samples. These are the samples that are most sensitive to cross-contamination.
    b. Decontamination will be performed before collecting and processing samples from a site, unless the equipment is new and certified pre-cleaned.
2. Put on disposable nitrile gloves before starting.
3. Wash equipment thoroughly with phosphate-free detergent (Alconox or Simple Green) using a scrub brush to remove any attached particles.
    a. All rinsate should be collected in a five-gallon bucket and poured through activated carbon to remove oil contamination before discarding in the ocean or down the drain.
4. Rinse with copious quantities of tap water.
5. Rinse with copious quantities of DI or distilled water.
6. Shake off excess water.
7. Laboratory-grade ethanol may be available to help remove persistent oil or to decontaminate specific sample handling equipment such as glass secondary containers, metal forceps or tweezers, and metal clips. Do not use ethanol on sensitive equipment, such as the fluorometer and the radiometer. See manufacturer's instructions for guidelines.
    a. Capture all ethanol in a metal bowl for proper disposal; do not reuse
    b. Allow ethanol on sampling equipment to air dry prior to being used.

8. If not using decontaminated sampling equipment right after decontamination, wrap equipment in clean paper towels or aluminum foil and, if possible, store in uncolored plastic bags.

Reference

U.S. EPA. 2001. *Methods for Collection, Storage and Manipulation of Sediments for Chemical and Toxicological Analyses: Technical Manual*. EPA-823-B-01-002. U.S. Environmental Protection Agency, Office of Water, Washington, DC. October.

Attachment L. April 2017 MC20 Sampling and Analysis Plan

Taylor Energy Spill Site Sampling 2017
Project-Specific Sampling and Analysis Plan

Submitted to:

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"The findings and opinions expressed in this report are solely those of the authors and do not necessarily reflect the views and policies of the Bureau of Safety and Environmental Enforcement, nor does mention of the trade names or commercial products constitute endorsement or recommendation for use."

April 18, 2017

1. Introduction and Purpose

In September 2004, Taylor Energy's Mississippi Canyon 20-A production platform was destroyed in a hurricane. Oil continues to leak from the Taylor Energy site into the Gulf of Mexico, creating a continuous slick where oil observation and analysis methods can be tested and verified. For this synoptic sampling study, we propose the following data collections at the Taylor Energy oil slick: site characterization, oil sheen/slick thickness measurements, bulk oil sample collection, targeted discrete water sampling based on real-time fluorescence measurements, fluorescence monitoring, air monitoring [volatile organic compounds (VOCs)], and ultraviolet (UV) and visible light attenuation measurements.

All data collection and sampling activities will occur at or near the former Mississippi Canyon 20-A production platform site located approximately 12 miles south of the mouth of the Mississippi River. Data collection and sampling activities will occur during multiple sampling trips that coincide with relatively calm water and weather conditions; satellite coverage windows; and availability of aircraft, boats, and personnel.

The purpose of this Sampling and Analysis Plan (SAP) is to provide sampling objectives, and proposed data and sample collection methods. Protocols for sample collection and handling are provided in a series of Standard Operating Procedures (SOPs) attached herein. Only the on-water field sampling activities are described in this work plan.

1.1 Objectives

Work described in this plan is being conducted to fulfill two main objectives:

1. ***Rapid surface slick characterization***: Collect oil thickness measurements and other data at approximately the same time and in the same locations that aerial and satellite data are collected at locations with observed surface oil.

2. ***Targeted environmental sampling***: Collect oil samples, water samples at multiple depths, and oil thickness measurements at locations with observed surface oil. When possible, sampling will target areas where fluorescence and/or field observations show that oil slicks and dispersed oil are present. In addition, continuous air monitoring data will be collected at each site and throughout the day.

2. Field Activities Associated with Each Sampling Objective

This section provides a detailed summary of each sampling objective and associated goals. Data and sample collection methods are further described in subsequent sections of this SAP and attached SOPs.

2.1 Objective #1: Rapid Surface Slick Characterization

A team of researchers on a boat will conduct surface slick characterization activities at the same time and in the same locations where low-altitude aircraft and overhead satellites are collecting remote sensing data. This sampling objective requires careful coordination between the sampling boat, aircraft overflights, and satellite coverage. Because ground crews have no control over the timing of satellite passes, field activities will be planned according to available windows in satellite coverage.

A schedule of the satellite overpass times will be developed before each trip. Our goal is to complete aircraft overflights and boat-based slick characterization as close as reasonably possible to the time when a satellite is acquiring data.

Prior to and during a satellite overpass, a low-altitude aircraft will fly over the slick to determine the optimal sampling locations for the boat. Spotters on the aircraft will guide the boat to sampling locations using an aviation handheld radio with aircraft communications channels or a satellite phone.

Boat-based oil thickness measurements will be made using dip plates, sorbent pads, and the WaterMapping sampler. The crew will also deploy a Turner Designs Cyclops 7 fluorometer at each sampling location at a single depth (generally 1 m) to log fluorescence data during oil thickness sampling. Bulk oil samples may also be collected for chemical analysis to aid in the interpretation of sorbent pad data. Additional information on these sampling methods is provided below and in the attached method-specific SOPs.

2.2 Objective #2: Targeted Environmental Sampling

We aim to collect targeted surface oil and water samples in areas with observed oil slicks. We are most interested in sampling areas with high levels of oil contamination. In addition, at least one background site will be sampled during each sampling trip. When possible, spotters in low-flying aircraft will guide the boat to sampling sites with substantial oil slick contamination. If spotters in overhead aircraft are not available, sampling sites will be located by starting at the location of the former platform site, as determination by global position system (GPS) coordinates, and radiating outward until the boat intersects an oil slick. Sampling sites may also be located using an unmanned aircraft system (UAS) with a high-resolution camera, operated from the boat.

Table 1 provides a summary of environmental sampling activities that may be conducted at background and oil-contaminated sampling sites. Depending on site conditions and availability, we will conduct any or all of these sampling activities.

Table 1. Environmental sampling activities that may be conducted at background and targeted sampling locations

Sampling activity	
Site characterization	Water chemistry sampling
Fluorescence monitoring	Air monitoring
Oil sheen/slick thickness measurements	UV attenuation – radiometer
Bulk oil chemistry sampling	Visible light attenuation – Secchi disk

At sites with visible surface oil, we will conduct fluorescence transects in and out of the visible oil slick, targeting areas with varying degrees of observable oil at the site. If possible, fluorescence monitoring data from these transects will be used to direct water sampling. We designed a system where water can be pumped from four different sampling depths concurrently with fluorescence monitoring, which will allow us to immediately initiate water sampling when fluorescence anomalies are observed. We will then collect fluorescence profiles alongside the collection of water samples so that fluorescence intensity can be calibrated using the measured total petroleum hydrocarbon (TPH) concentrations of the water samples. Throughout the trip, we

may also collect a few large-volume water samples to pair fluorescence measurements with 250-mL water samples analyzed for TPH.

Oil thickness measurements will be taken using dip plates, sorbent pads, and/or the WaterMapping sampler. Along with the oil thickness measurements, a bulk oil sample will also be collected from each site, if sufficient oil is present. Other observational data may include UV and visible light attenuation, which would be measured using a Biospherical radiometer (UV and visible light) and a Secchi disk (visible light). Additional information on each of the targeted sampling methods is provided below and in the attached method-specific SOPs.

At the beginning of each day, we will mount an UltraRAE VOC air monitor to the side of the boat (at a fixed height to be determined onsite). The monitor will log VOC concentrations at 1-minute intervals throughout the day. Timestamps from the air monitor will be synchronized with the GPS device so that the VOC concentrations from the air monitor can be linked to the GPS data. In addition, spot readings will be recorded throughout the day as backup to the instrument data logging (SOP 1).

3. Sampling Procedures

This section describes the procedures that will be followed when conducting field activities associated with the two primary sampling objectives. This includes a description of how we will plan and prioritize sampling. We also provide detailed information on how each sampling activity will be conducted and how many samples will be collected. Sampling methods will reference respective SOPs that we provide at the end of this SAP. Materials and equipment needed for each step in the procedures are also provided in the SOPs.

3.1 Planning and Prioritization

For each sampling trip, we will conduct sample collection activities over two or more consecutive days, leaving from Boothville-Venice, LA. Boat-based field crews will stay overnight at the Port Eads Marina and Lodges in Port Eads, LA. Port Eads is approximately 20 miles down the Mississippi River from Boothville-Venice and is only accessible by boat. There are few supplies at Port Eads; therefore, field crews will leave Venice with all of the critical sampling equipment and supplies for the entire sampling trip.

Sampling trips will coincide with at least one satellite overpass. Sampling activities will be planned around the satellite coverage window(s), with Objective #1 activities being prioritized during times with overhead satellites. We plan to conduct targeted sampling activities at up to three slick sites per day, depending on time available. Targeted sampling activities will also occur at one or more background sites per sampling trip. Background sites will be selected in the field and occur in areas that are at least a few miles from the former Mississippi Canyon 20-A production platform and do not have any visible oil or elevated fluorescence readings.

When available, spotters on an airplane will help locate sites with oil slicks during sampling activities. The boat-based field crew will be in direct communication with the spotters on the aircraft. Boat-to-aircraft communication will primarily be made using an aviation handheld radio tuned to 123.45 MHz. We will also have a marine radio and a satellite phone as backup communication devices. Spotter aircraft will not be available during the entire time that boat-

based sampling activities are being conducted. Therefore, the field team leader will prioritize sampling objectives based on information obtained from the spotter aircraft when available.

3.2 Site Characterization

Site characterization activities will occur at every site for each of the two sampling objectives. Upon arrival at the site, site characterization data will be collected according to the Site Characterization SOP (SOP 1). The site characterization data will include GPS track-log coordinates to capture the route taken during sampling, GPS waypoints to document specific locations where samples and observational data are collected, time and date of each sampling activity, fluorescence monitoring logs and point data to detect dispersed oil, and observational data that includes degree of observed sea-surface oiling. Wind speed and direction, air temperature, humidity, weather conditions, sea state observations, and other site attributes may also be documented. Field data will be recorded in the Site Characterization and Oil Thickness Data Sheet provided with SOP 2.

Site characterization activities will include digital photographs and video recordings. Digital photographs and videos will be used to document site conditions, the degree of oiling, the appearance of surface oil at sampling locations, and fluorescence monitoring data and anomalies. Field crews will make every effort to link GPS and fluorometer logs, observations of surface slick conditions, and sea-state conditions. This includes syncing the time and date on GPS and fluorometer devices with digital cameras, video recorders, and other data recording devices. This will facilitate data analyses and enable field crews to review digital media with respect to fluorescence monitoring and track logs.

To provide a more continuous record of the environmental conditions throughout each sampling day, wind speed and direction, air temperature, weather conditions, sea-state observations, air VOC concentrations, and other environmental attributes will also be documented semi-regularly throughout the day. These data will be recorded in the Site Characterization Log provided with SOP 1.

3.3 Fluorescence Monitoring

Fluorescence monitoring data at a fixed depth may be collected as the boat traverses around a sampling site. This will allow a rapid characterization of the spatial extent of hydrocarbons at the site without conducting more time-intensive water sampling. Generally, for fluorescence transects, we will deploy the fluorometer to a depth of 1 m; however, this depth may be adjusted based on site-specific conditions. The depth for deployment of the fluorometer during these transects will be determined by the field team leader. As the boat traverses a site, we will mark waypoints when the fluorometer enters and exits the slick oil. Each waypoint number and a description of that waypoint will be recorded on the Fluorescence Transect/Profile Data Sheet (see SOP 7). We will discontinue fluorometer use if it interferes with other sampling activities during rapid slick characterization (Objective #1).

During the targeted environmental sampling (Objective #2), fluorescence monitoring will be conducted at each site to help target contaminated areas for water sampling. To conduct targeted water sampling with fluorescence monitoring, the fluorometer and water sample tubing will be deployed together. The fluorometer will be deployed at a fixed depth, while four separate lines of tubing will be deployed at the four water sampling depths. See Section 3.5 for additional details

on water sampling. With the fluorometer set to logging mode and the peristaltic pump turned on so that water samples can be collected quickly, the boat will slowly traverse or drift the slick area at a site. We will mark waypoints when the fluorometer enters and exits the slick oil. Each waypoint number and a description of that waypoint will be recorded on the Fluorescence Water Sampling Data Sheet (see SOP 6). We will also record the start and end time of each transect. A detailed protocol for the collection of fluorescence transect data can be found in the Fluorescence Transect/Profile Data Sheet (SOP 7).

If a spike or anomaly in the fluorescence signal is observed, the boat will stop and water samples will be collected. This will mark the end of the transect. It may require several transects in and out of the area to determine if an anomaly is observed. To help establish site-specific background fluorescence, the fluorescence transect(s) at each site should also include measurements that are several meters outside of the surface slick oil area. In addition, fluorescence transects at one or more background sites will also be collected. Additional transects throughout the day may be collected as the vessel traverses from site to site.

Once a location for water sampling has been determined, a fluorescence profile at the same location will be conducted at the same time that water samples are being collected (see SOP 7). Fluorescence profiles may be collected at additional sites at the discretion of the field team leader.

3.4 Oil Sampling

Oil thickness measurements will be collected at all sites. These measurements will include sampling three to five areas of oil slick or sheen using sorbent pads (3M T151 pads), dip plates, and/or the WaterMapping sampler. For each sampling site, we will target areas of slick that represent the range of different thicknesses at the site. At sites with heavy emulsions, bulk oil samples may be collected for chemical analysis and oil-to-water ratio determination. The collection of oil slick or sheen by sorbent pads will be based on methods described by SINTEF (Daling and Leirvik, 2002). The measurement of oil thickness by dip plates is based on a method described by Svejkovsky and Muskat (2006), while the WaterMapping sampler is an oil cylinder collection and inspection technique that Oscar Garcia of WaterMapping LLC recently developed. Detailed protocols of the sorbent pad, dip plate, and WaterMapping sampler oil thickness measurements are provided in the Sorbent Pad Sampling SOP (SOP 2), the Dip Plate Oil Thickness SOP (SOP 4), and the WaterMapping Sampler Oil Thickness SOP (SOP 5), respectively. Bulk oil will be collected according the protocols described in the Bulk Oil Sampling SOP (SOP 3). All bulk oil and sorbent pad samples will be sent to ALS Environmental for analysis. See Table 2 for a summary of the surface oil samples to be collected at each site.

Table 2. Number of oil samples collected or measurements made at control and oiled sites

Site	Oil – slick or sheen (sorbent pad)	Oil – bulk (PAH/TPH)	Oil – bulk (oil-to-water)	Oil thickness estimate (dip plate)	Oil thickness estimate (WaterMapping sampler)
Control sites	1–2	0	0	0	0
Oiled sites	3–5	0–1	0–1	3–5	3–5

PAH: polycyclic aromatic hydrocarbon.

3.5 Targeted Water Sampling

We plan to collect water samples at up to three sites per day and one background site per trip as part of the targeted environmental sampling objective. At each site, we plan to collect discrete water column grab samples at up to four depths below the slick at approximately 0.1 m, 0.5 m, 1.0 m, and 3.0 m, unless field conditions such as wave height or real-time fluorescence data indicate alternate depths should be targeted. Discrete water samples will be collected using high-purity tubing and a peristaltic pump. At each sampling depth, we will collect a 250-mL whole water sample. Details on the water sample collection methods are provided in the Water Sampling SOP (SOP 6). Table 3 provides a sample matrix for all analytical chemistry samples.

Table 3. Taylor Energy analytical samples

Site	Bulk Oil PAH	Bulk Oil TPH	Oil Slick (pad) PAH	Oil Slick (pad) TPH	Whole Water TPH
Day 1	1	2	0	12	8
Day 2	1	2	0	12	8
Day 3	1	2	0	12	8
Day 4	1	2	0	12	8
Total	4	8	0	48	32

To reduce analytical costs, we will employ a tiered approach to sample analysis. First, we will analyze samples from the two shallowest depths at all sites. If the results suggest that oil is present at a greater depth, we will subsequently analyze the deeper samples collected in the water column. The whole water samples closest to the surface will be analyzed for PAHs using U.S. Environmental Protection Agency (EPA Method 8270) with selected ion monitoring (SIM) and for TPHs using EPA Method 8015C. The three deeper samples will be analyzed for TPHs only to reduce analytical costs. Table 3 provides the anticipated chemical analyses of those samples.

3.6 Air Monitoring

Using an UltraRAE 3000 portable air monitor, we will continuously monitor the VOC concentrations in the air. The UltraRAE air monitor will be turned on upon arrival at the first site at the start of the day, and will collect VOC concentrations continuously, at 1-minute intervals throughout the day.

3.7 UV and Visible Light Attenuation Sampling

UV and visible light attenuation will be determined at each site using a Biospherical radiometer (UV and visible light) and a Secchi disk (visible light), according to methods provided in SOP 9. These measurements will be taken concurrently or nearly concurrently so that the results can be used to correlate Secchi disk data to UV attenuation data for interpretation of historical and future Secchi disk data with regards to UV attenuation.

3.8 Photographic Documentation of Site

Site characterization and sampling will be documented using video and photographs according to guidelines in the Video and Photograph Documentation SOP (SOP 10). Photographs will be georeferenced to a GPS device using synchronized timestamps. If the photograph or video is

associated with a specific sampling activity, that photograph number or video filename will be recorded on the respective data sheet next to that activity.

3.9 Sample Labeling, Handling, and Storage

Samples will be labeled according to the Labeling Field Samples SOP (SOP 11), and maintained under chain of custody (COC) as described in the Sample Chain of Custody SOP (SOP 12). After collection, samples will be packaged and shipped to the ALS Environmental analytical laboratory following the Sample Handling and Shipping SOP (SOP 13).

3.10 Sampling Equipment Decontamination

Any sample processing equipment used to collect multiple samples will be decontaminated as described in the Equipment Decontamination in the Field SOP (SOP 14).

References

Daling, P.S. and F. Leirvik. 2002. BONNEX 2002, June 17th–19th: Oil Film Thickness Measurements and Pictures Taken from Sampling Boats – Data Report. SINTEF report # STF66 F02084.

Svejkovsky, J. and J. Muskat. 2006. Real-Time Detection of Oil Slick Thickness Patterns with a Portable Multispectral Sensor. Minerals Management Service, Final Report for Project #0105CT39144.

SOP 1: Site Characterization

This SOP will be used for collection of site characterization data. Since conditions can change during sampling at individual sites, characterization data such as wind speed, wind direction, VOC air concentrations, weather conditions, and sea state will be collected semi-regularly throughout the day. In addition, GPS track data will log the GPS coordinates of the site and marked waypoints will be used to identify the location of specific sampling activities.

Materials and Equipment

Table 1.1 lists the materials and equipment required to complete the procedures described in this SOP.

Table 1.1. Materials and equipment required for the Site Characterization SOP

Anemometer multimeter	VOC air monitor (spot checks)	Site Characterization Log
Permanent markers, pens, and pencils	GPS unit (with current time and date)	

Site Characterization Procedure

1. Throughout the day, collect air temperature, wind speed, and wind direction data using an Extech EN100 anemometer multimeter following manufacturer instructions. Note time and collect a waypoint # for each data collection event. Record all data on the Site Characterization Log.
2. In addition, record general site description characteristics, including weather conditions and sea state, for each data collection event on the Site Characterization Log.
3. Finally, as a spot check, record the VOC concentration from the air monitor for each data collection event.

Site Characterization Log

Site Characterization Log

Date	Sampler(s):

Site Characterization

Time	WP #	Wind Speed (knots)	Wind Direction	VOCs (ppm)	Air Temp (°C)	Sea State*	General Weather Conditions**

* Example **sea states**: Calm, Swells (approx. wave height ft), Chop, Foam, Whitecaps

** Example **weather conditions**: Sunny, Partly Cloudy (% coverage), Rainy, Stormy, Gusty

SOP 2: Sorbent Pad Sampling

This SOP will be used to collect oil slick or oil sheen samples for chemical analysis. At each site, three to five oil slick or sheen samples will be collected using decontaminated 3M T151 sorbent pads. Note that not all samples may be collected at each site.

Materials and Equipment

Table 2.1 lists the materials and equipment required to complete the procedures described in this SOP.

Table 2.1. Materials and equipment required for the Sorbent Pad Sampling SOP

Certified, pre-cleaned 16-oz sample containers with labels	Nitrile gloves (powderless)	Permanent markers, pens, and pencils
Pad sampling buoy with grab pole	Decontaminated 3M T151 sorbent pads (8.5" x 9.5")	Ziploc baggies, bubble wrap, cooler with ice
Five-gallon buckets	Paper towels	Clear packaging tape
Large metal tongs	Digital camera (with current time and date)	Methylene chloride
Site Characterization and Oil Thickness Data Sheet		

Sorbent Pad Sampling Procedure

Before arriving at site:

1. Decontaminate the sorbent pads by rinsing with methylene chloride, then let dry overnight in a chemical fume hood. Store decontaminated pads in individual, re-sealable plastic bags until use.

Upon arrival at the site:

1. Obtain a Site Characterization and Oil Thickness Data Sheet (SOP 2) and ensure that the site identification (ID) and sampling date are recorded on the data sheet.
2. Ensure all sampling and sample processing equipment are decontaminated as described in the Equipment Decontamination in the Field SOP (SOP 14).

Follow the steps below to collect the sample:

1. Put on a new pair of powderless nitrile gloves.
2. Obtain new, pre-labeled 16-oz glass jar sample containers needed for sample collection at the site. Sample container labels will be filled out as described in the Labeling Field Samples SOP (SOP 11).
3. Obtain a new, decontaminated sorbent pad. Attach the sorbent pad to the sorbent pad sampling buoy.
4. Collect the oil slick or sheen off the surface of the water from three separate areas at the sample site. If the site contains areas of distinctly different oil thicknesses, try to target areas that represent the range of different thicknesses observed at the site.

a. Before each oil sample is collected, mark a waypoint on the GPS device to record the GPS coordinates of the sampling location.
b. Take one or more photographs of the area being sampled to visually capture the oil slick or sheen. In addition, photograph the target area. Ensure that the date and time on the camera are accurate so the photographs can be linked with data from the GPS device.
c. Place the sorbent pad buoy with the attached sorbent pad onto the slick using a grab pole. Allow to sit on the surface for 30 seconds[1] to permit adsorption of oil onto the pad (Figure 2.1). Pull the pad off the water using the grab pole and carefully bring aboard. Using large metal tongs to grab the pad, fold oiled pad with the oiled side inward, and transfer to a pre-cleaned jar for analysis. (*Note: As several sorbent pad buoys will be available, designate separate buoys for sites with thicker emulsions versus sites with only thin sheens to minimize cross-contamination between sites*.)

Figure 2.1. Sampling an oil slick using a sorbent pad buoy with sorbent pad.



5. On the Site Characterization and Oil Thickness Data Sheet (SOP 2), record sample time, waypoint number, sample number, a description of the slick area sampled, and the photograph number(s).Make note of any unusual or noteworthy sample characteristics. After collection, tighten the cap of each sample container and thoroughly dry with a clean paper towel. Check that the sample label is properly and completely filled out, and that all samples are recorded on the proper data sheet. Wrap clear tape around the entire circumference of each sample bottle so that it completely covers the label.

6. Store the sorbent pad samples in a cooler with wet ice until sent to the analytical laboratory. Ensure that no ice or water contact the samples when in the cooler by placing the samples in separate Ziploc bags. See the Sample Handling and Shipping SOP (SOP 13) for procedures on how to ship samples.

7. Decontaminate non-disposable sampling equipment and sample processing tools prior to sampling the next site, following the Equipment Decontamination in the Field SOP (SOP 14).

8. Once the sampling is complete at a site, photograph all data sheets. This will serve as a backup for hardcopy documents until all data sheets can be scanned and archived.

1. The field team leader may adjust oil sampling according to conditions. If the pads placed on a slick are unable to adsorb all the oil, discard the sample, and move to a new area with similar slick characteristics. In the new slick area, use an alternative method (e.g., dip plates, the WaterMapping sampler) to estimate oil slick thickness.

Site Characterization and Oil Thickness Data Sheet

Site Characterization and Oil Thickness

Site ID:	Date:	Sampler(s):

Site Characterization

Air Temp (°C)	Wind Speed (knots)	Wind Direction	Sea State*	General Weather Conditions**

Sorbent Pads

#	Time (24h)	Waypoint #	Sample #	Slick Description	Photo #s	Notes
1						
2						
3						
4						
5						

Dip Plates

#	Time (24h)	Waypoint #	Dip Plate #	Plate wt (g)	Plate + oil wt (g)	Slick Description
1						
	Notes/Photo #s					
2						
	Notes/Photo #s					
3						
	Notes/Photo #s					
4						
	Notes/Photo #s					
5						
	Notes/Photo #s					

WaterMapping

#	Time (24h)	Waypoint #	Sample #	Slick Description	Photo #s	Notes
1						
2						
3						
4						

Bulk Oil Collection

#	Time (24h)	Waypoint #	Sample #	Slick Description	Notes
1					

* Example **sea states**: Calm, Swells (approx. wave height ft), Chop, Foam, Whitecaps

** Example **weather conditions**: Sunny, Partly Cloudy (% coverage), Rainy, Stormy, Gusty

SOP 3: Bulk Oil Sampling

This SOP will be used to collect oil slick or oil sheen samples for chemical analysis. At sites with heavy oil emulsions, a bulk oil sample from the site will be collected.

Materials and Equipment

Table 3.1 lists the materials and equipment required to complete the procedures described in this SOP.

Table 3.1. Materials and equipment required for the Bulk Oil Sampling SOP

Certified, pre-cleaned 16-oz and 4-oz sample containers with labels	Nitrile gloves (powderless)	Decontaminated glass jars to use as secondary containers
Permanent markers, pens, and pencils	Digital camera (with current time and date)	Ziploc baggies, bubble wrap, cooler with ice
Five-gallon buckets	Dip plates	Clear packaging tape
Paper towels	Sampling pole	Plastic pipette
Site Characterization and Oil Thickness Data Sheet (SOP 2)		

Bulk Oil Sampling Procedure

Upon arrival at the site:

1. Obtain a Site Characterization and Oil Thickness Data Sheet (SOP 2) and ensure that the site ID and sampling date are recorded on the data sheet.

2. Ensure all sampling and sample processing equipment are decontaminated as described in the Equipment Decontamination in the Field SOP (SOP 14).

Follow the steps below to collect the sample:

1. Put on a new pair of powderless nitrile gloves.

2. Obtain new, pre-labeled 16-oz glass jar sample containers needed for sample collection at the site. Sample container labels will be filled out as described in the Labeling Field Samples SOP (SOP 11).

3. If thicker oil emulsion patches exist at the site, collect bulk oil from the surface using one of three methods:

    a. Use a pre-cleaned, 4-oz glass sampling jar attached to a sampling pole. During collection, take care to minimize the transfer of ocean water. This method is best when large areas of thick emulsion are present.
    b. Use a plastic bucket to collect a “bucket-cast” to capture larger mousse/emulsion samples, and then skim the oil from the bucket and transfer to a pre-cleaned, 16-oz sampling glass jar. Use a plastic pipette to remove excess ocean water. Repeat bucket casts until enough oil is collected so that the jar is at least ¼ full (or a minimum of 15 mL of bulk oil).
    c. Use a dip plate to pull small patches of oil emulsion from the ocean surface, and scrape into a pre-cleaned, 16-oz glass sampling jar. Repeat until enough oil is collected so that

the jar is at least ¼ full (or a minimum of 15 mL of bulk oil). See the Dip Plate Oil Thickness SOP (SOP 4) for additional details on this method.

4. On the Site Characterization and Oil Thickness Data Sheet (SOP 2), record sample time, waypoint number, sample number, and a description of the slick area sampled. After collection, tighten the cap of each sample container and thoroughly dry with a clean paper towel. Check that the sample label is properly and completely filled out, and that all samples are recorded on the proper data sheet. Wrap clear tape around the entire circumference of each sample bottle so that it completely covers the label.

5. Store the bulk oil samples in a cooler with wet ice until sent to the analytical laboratory. Ensure that no ice or water contact the samples when in the cooler by placing the samples in separate Ziploc bags. See the Sample Handling and Shipping SOP (SOP 13) for procedures on how to ship samples.

6. Decontaminate non-disposable sampling equipment and sample processing tools prior to sampling the next site, following the Equipment Decontamination in the Field SOP (SOP 14).

7. Once the sampling is complete at a site, photograph all data sheets. This will serve as a backup for hardcopy documents until all data sheets can be scanned and archived.

SOP 4: Dip Plate Oil Thickness

This SOP will be used to collect oil slick or oil sheen for gravimetric estimation of slick thickness. At each site, three to five oil slick or sheen samples will be collected for gravimetric estimation of slick thickness. Note that only sites with some emulsion can be sampled using this method. Thinner oil sheens can only be sampled using the sorbent pads and the WaterMapping sampler.

Materials and Equipment

Table 4.1 lists the materials and equipment required to complete the procedures described in this SOP.

Table 4.1. Materials and equipment required for the Dip Plate Oil Thickness SOP

Sampling grab pole	Plexiglas plates	One-gallon re-sealable plastic bags
Portable balance	Paper towels	Metric tape measure
Rubber spatulas	Digital camera (with current time and date)	Permanent markers, pens, and pencils
Nitrile gloves (powderless)	Site Characterization and Oil Thickness Data Sheet (SOP 2)	Carabiners and clips

Dip Plate Oil Thickness Procedure

Before arriving at site:

1. Wipe Plexiglas dip plates with a paper towel to ensure the plate is clean and dry.
2. Label and weigh up to 50 1-gallon re-sealable plastic bags with designated Plexiglas dip plate. All measurements with the balance should be done on a stable surface on the shore.

Upon arrival at the site:

1. Ensure that the site ID and sampling date are recorded on the Site Characterization and Oil Thickness Data Sheet (SOP 2).
2. Ensure that all sampling and sample processing equipment are decontaminated as described in the Equipment Decontamination in the Field SOP (SOP 14).

Follow the steps below to collect the sample:

1. Put on a new pair of powderless nitrile gloves.
2. Obtain a decontaminated Plexiglas plate from its 1-gallon plastic bag. Record the plate number on the appropriate data sheet.
3. At each site, select three to five separate sampling locations to collect oil slick or sheen off the surface of the water. If the site contains areas of distinctly different oil thicknesses, target areas that represent the thickest and thinnest thicknesses, as well as areas with an oil thickness that is most representative of the site.

a. Before each oil sample is collected, mark a waypoint to record the GPS coordinates of the sampling location
b. Take several photographs of the area being sampled to visually capture the oil slick or sheen.

4. Before collection starts, record the sample time, the waypoint number, and photograph image numbers on the Site Characterization and Oil Thickness Data Sheet (SOP 2). Also provide a general description of the slick (e.g., thick emulsion, thin emulsion, patchy emulsion, sheen). If necessary, note any other characteristics of the slick in the Notes column (e.g., vegetation present).

5. To sample the oil slick, slowly lower the Plexiglas plate vertically into the water until it is fully dipped in the water, and then slowly pull it out of the water. See Figure 4.1 for photographs illustrating this procedure. If the oil slick is not adhering to the plate, the plate gets wet before it is dipped into the oil, or other issues arise during sampling, discard the current plate and repeat the procedures with a new plate.

Figure 4.1. Collecting an oil slick using Plexiglas plates to estimate slick thickness.



6. Allow the water to drip off of the plate, and then place the plate into the appropriate plastic bag. If using pre-weighed dip plates and re-sealable plastic bags, wipe any excess moisture from bag; seal the bag; and store in a cool, dry place (e.g., empty cooler) until back on the shore when each dip plate will be re-weighed.

7. Decontaminate all non-disposable sampling equipment and sample processing tools prior to sampling the next site, following the Equipment Decontamination in the Field SOP (SOP 14).

SOP 5: WaterMapping Sampler Oil Thickness

This SOP will be used to measure oil slick thickness using the WaterMapping sampler. At each site, the WaterMapping sampler will collect three to five oil slick or sheen samples for slick thickness estimates.

Materials and Equipment

Table 5.1 lists the materials and equipment required to complete the procedures described in this SOP.

Table 5.1. Materials and equipment required for the WaterMapping Sampler Oil Thickness SOP

Sampling grab pole	WaterMapping sampler	Nitrile gloves (powderless)
Large sorbent pads or plastic sheet	Paper towels and cleaning wipes	Digital camera (with current time and date)
Permanent markers, pens, and pencils	Plastic sample collection tubes	Special photograph box (to standardize photographs)
Site Characterization and Oil Thickness Data Sheet (SOP 2)	Tub O' Towels wipes	GoPro camera (with current time and date)

WaterMapping Sampler Oil Thickness Procedure

Before arriving at site:

1. Wipe several plastic sample collection tubes with Tub O' Towels wipes on the inside and the outside of the tube, which will minimize oil sticking to the sides of the tube
2. Label each tube with a sample number starting with WM01
3. Clean and prepare the WaterMapping sampler.

Upon arrival at the site:

1. Ensure that the site ID and sampling date are recorded on the Site Characterization and Oil Thickness Data Sheet (SOP 2).
2. Put on a new pair of powderless nitrile gloves.
3. Obtain a clean and labeled plastic tube. Write the tube number on the appropriate data sheet. Insert the sampling tube into the WaterMapping sampler.
4. At each site, select three to five separate areas to collect oil slick or sheen off the water surface. If the site contains areas of distinctly different oil thicknesses, target areas that represent the thickest and thinnest thicknesses, as well as areas with an oil thickness that is most representative of the site.
5. Before each oil sample is collected, take several photographs of the area being sampled to visually capture the oil slick or sheen.
6. Before collection starts, record the site ID, the sample collection date, the sample time, and GPS coordinates or waypoint number on the data sheet. Also provide a general description of

the slick (e.g., thick emulsion, thin emulsion, patchy emulsion, sheen). If necessary, note any other characteristics of the slick in the Notes column (e.g., vegetation present).

7. To sample the oil slick, slowly lower the sampler into the water. Allow water with the slick to pass through the sampling tube for a few seconds, using visual observations or the video from the onboard GoPro, if available, to determine when best to collect the sample.
8. Using a remote control, collect the sample by closing the bottom end caps.
9. Using a grab pole, gently pull the sampler off the water and place on large sorbent pads or plastic sheeting, which will minimize oil contamination to the deck of the vessel.
10. Store sample tubes in the vertical position in a cool, dark place.
11. Back on shore, photograph each sample tube to determine height of the oil in the sample tube, which can be used to determine volume of the oil sample collected. Use a photography box to standardize each photograph taken. Ensure all tubes have remained in a vertical position for a sufficient time to allow all oil to settle before the photograph is taken.
12. Clean the sampler with paper towels and cleaning wipes before setting up for the next sample collection.

SOP 6: Water Sampling

This SOP will be used to collect surface and near surface water samples for chemical analysis. At each site, water samples will be collected at up to four depths below the oil slick, using a 4-channel peristaltic pump so that all four depths can be collected simultaneously. At each depth, a 250-mL whole water sample will be collected for TPH analysis. Note that not all samples may be collected at each site.

Materials and Equipment

Table 6.1 lists the materials and equipment required to complete the procedures described in this SOP.

Table 6.1. Materials and equipment required for the Water Sampling SOP

Certified, pre-cleaned 250-mL amber glass sample containers with labels	Nitrile gloves (powderless)	Waste bucket
Peristaltic pump (4-channel) with polyethylene tubing marked at target depths	Permanent markers, pens, and pencils	Ziploc baggies, bubble wrap, cooler with ice
Clear packaging tape	Multi-colored electrical tape	Tape measure
Three-inch polyvinyl chloride (PVC) pipe with cap	Paper towels	Water Sampling Data Sheet
Digital camera (with current time and date)		

Water Sampling Procedure

Sample Collection Precautions

To minimize the effects of the boat's presence on the water sampling results, the following methods will be employed[2]:

1. Always enter the sampling site traveling up current, so that any oil dispersed by the boat will move away from the sampling site. Then, travel at an angle to the current for the last few hundred feet to ensure the boat does not drift back through the slick area it had just disturbed.
2. Deploy the sample tubing on the up current side of the boat and as far from the boat hull as possible. A sampling boom may be used to extend tubing away from the boat.
3. If engines are running, ensure that all work is being conducted upwind of any exhaust. If possible, turn off the engines and drift during sampling.
4. Maintain situational awareness, and discontinue sampling if warranted.
5. At each site, use dedicated tubing for all samples.

2. The ability to employ many of these methods will be dependent on having a vessel with the appropriate equipment.

6. Before sample collection, flush the sample tubing with at least 1 L of water.

7. Segregate dirty and clean work areas. Lay out clean substrates, such as sorbent pads, tarps, or paper towels, to work on and replace frequently.

Sample Collection Methods

Upon arrival at the site:

1. Obtain a Water Sampling Data Sheet (SOP 6) and ensure that the site ID and sampling date are recorded on the appropriate lines

2. Ensure that all sampling and sample processing equipment are decontaminated as described in the Equipment Decontamination in the Field SOP (SOP 14).

Follow the steps below to collect the sample:

1. Put on a new pair of powderless nitrile gloves.

2. Obtain new, pre-labeled 250-mL amber glass sample containers for the site. Organize so that the sample containers are easy to locate during sample collection activities.

    a. Sample container labels will be filled out as described in the Labeling Field Samples SOP (SOP 11).

3. To collect samples at multiple depths, prepare four lengths of fresh, uncontaminated tubing for deployment. The length of each will depend on the boat and boom; prepare a 2-m, 2.5-m, 3-m, and 5-m length of tubing for each site unless the field team leader suggests alternate lengths.

    a. Mark the four target depths on the tubing with electrical tape, using a different color to mark each target depths, and mark above and below each target depth every 0.1 meter up to 1.0 meter on either side of the target depth using black electrical tape. Then, align the target depth markings of each length of tubing and tape the four tubes together so each is at its respective depth. The tubing can then be lowered into the water until the water's surface intersects the colored electrical tape representing the desired target depth.
    b. The initial four target sampling depths will be 0.1 m, 0.5 m, 1 m, and 3 m; however, if fluorescence spectroscopy data indicate deeper depths should be sampled, the depths will be adjusted accordingly. (*Note: If the boat is rolling significantly, surface tubing may need to be deployed to deeper depths to avoid pulling the tubing out of the water and through the slick.*)
    c. Tether a tubing weight to each tubing end to minimize the pull from currents. If possible, extend the tubing away from the boat using an extension device.

4. Deploy the tubing into the water.

    a. To minimize contamination of the sample tubing, deploy the tubing through clean water before the boat enters the oil slick site, use a paddle or spray of water to move the slick out of the way or, if necessary, deploy it through a PVC pipe with a cap to protect the ends of the tubing as it enters the water. Once in the water, remove the cap by tapping the cap edge with the sampling pole.

5. Collect water samples from each of four specified depths. Water samples will be collected using a peristaltic pump as described below. Before the start of collection, first flush the sample tubing with approximately 1 L of water, allowing the water to go into a waste bucket. Then place a 250-mL amber glass, pre-cleaned sample bottle under the sample tubing and collect a whole water sample for PAH/TPH. Ensure the bottles are completely full so there is minimal headspace when capped.
6. During the sample collection, mark a waypoint to record GPS coordinates of the sampling location.
7. On the Water Sampling Data Sheet (SOP 6), add sample time, waypoint number, sample number, sample depth, and a description of the slick. Make note of any unusual or noteworthy sample characteristics.
8. After collection, tighten the cap of each sample container and thoroughly dry with a clean paper towel. Check that the sample label is properly and completely filled out, and that all samples are recorded on the proper data sheet. Wrap clear tape around the entire circumference of each sample bottle so that it completely covers the label.
9. Store water samples upright in a cooler with wet ice until sending to the analytical laboratory.
10. Decontaminate non-disposable sampling equipment and sample processing tools prior to sampling the next site, following the Equipment Decontamination in the Field SOP (SOP 14).
11. Once sampling is complete at a site, photograph all data sheets. This will serve as a backup for hardcopy documents until all data sheets can be scanned and archived.

Collection of Large-Volume Water Sample for Paired Fluorescence and TPH Chemistry

1. After the water profile samples have been collected, collect a large-volume water sample from any or all depths.
2. Submerge fluorometer into the discrete sample, allow the meter to stabilize, and record the fluorescence measurement.
3. Pour 250 mL of this large-volume water sample into a 250-mL sample bottle for TPH analysis.

Sonde Multimeter Water Quality Collection Methods

The sonde multimeter will be used to collect water column profiles of the following water quality parameters: temperature, salinity, turbidity, and depth.

1. Turn on the handheld meter and check the time, date, and data storage settings (handheld logging). Check the external battery connection and charge.
2. Take the cover cup off the sonde multimeter and check that all sensors are clear of any oil or debris.
3. Recheck the cable connections and ensure the rope is secured.

4. Test communications between the handheld meter and the sonde multimeter.
5. Attach the metallic end cover to the sonde multimeter.
6. Set the pressure values to zero.
7. Clear a small area of slick using sorbent pads, or add a small amount of Simple Green to the water to create an "oil-free" point of entrance for the sonde multimeter.
8. Lower the sonde through the oil-free point to start the profile.
9. If collecting single depth data alongside UV measurements (see SOP 9), position sonde at the desired depth (0.5 m), and record time, waypoint, depth, and real-time values from the sonde multimeter on the UV and Visible Light Profile Data Sheet (SOP 9). If collecting a water quality profile, position the sonde as close to the surface as possible. Then, start the profile recording time, waypoint, depth, and real-time values from the sonde multimeter every 0.5 m on the Water Sampling Data Sheet (SOP 6).
10. Check the real-time profile plots on the handheld meter and the recorded data for anomalous readings to verify the sonde multimeter is working properly.
11. Continue lowering the sonde multimeter until it reaches a depth of 5 m.
12. Finish the profile by slowly raising the sonde multimeter through the water column (i.e., down – up cast).
13. Once complete, submerge the sonde multimeter into a bucket with clean water and Simple Green to clean before the next profile.

Water Sampling Data Sheet

Water Sampling

Site ID:	Date:	Sampler(s):

Water Samples

Time (24h)	Start WP #	End WP #	Slick Description

#	Sample #	Depth (m)	Fluor Spot Readings (mv)	Notes
1				
2				
3				
4				

Fluorescence Profile (Continuous)

1	Start Time	Start WP	Start Depth (m)	Start Record #	Fluor (mV)	Notes
	End Time	End WP	End Depth (m)	End Record #	Fluor (mV)	Notes
2	Start Time	Start WP	Start Depth (m)	Start Record #	Fluor (mV)	Notes
	End Time	End WP	End Depth (m)	End Record #	Fluor (mV)	Notes
3	Start Time	Start WP	Start Depth (m)	Start Record #	Fluor (mV)	Notes
	End Time	End WP	End Depth (m)	End Record #	Fluor (mV)	Notes
4	Start Time	Start WP	Start Depth (m)	Start Record #	Fluor (mV)	Notes
	End Time	End WP	End Depth (m)	End Record #	Fluor (mV)	Notes

Water Quality Profile

Time	WP	Depth (m)	Temp (°C)	Salinity	Turbidity	

SOP 7: Fluorescence

This SOP will be used to collect real-time fluorescence transect and profile data.

Materials and Equipment

Table 7.1 lists the materials and equipment required to complete the procedures described in this SOP.

Table 7.1. Materials and equipment required for the Fluorescence SOP

Turner Designs Cyclops 7 fluorometer	Nitrile gloves (powderless)	Laptop computer with DataBank software
3“ PVC with cap	Sampling pole	Boom
Water Sampling Data Sheet (SOP 6)	Fluorescence Transect/Profile Data Sheet	Permanent markers, pens, and pencils

General Site Documentation

Real-time fluorescence data will be collected to help target areas for water sampling. In addition, as water samples are being collected for Objective #2, the fluorometer will be slowly lowered from the surface to the deepest depth sampled to capture a fluorescence profile of the water column at the time of water sampling. Fluorescence profiles may be collected at additional sites at the discretion of the field team leader. Additional transects throughout the day may be collected as the vessel traverses from site to site.

Turner Designs Cyclops 7 Fluorometer

Before arriving at site:

1. Fully charge the laptop the night before
2. Synchronize time on the laptop to the time on the GPS device using the DataBank software
3. Set the logging interval to take a reading every 10 seconds using the DataBank software.

Collecting a Fluorescence Profile

Before arriving at the site:

1. To minimize contamination of the fluorometer, deploy the fluorometer through clean water before the boat enters the oil slick site, use a spray of water or paddle to move the slick out of the way or, if necessary, deploy it through a PVC pipe with a cap to protect the ends of the tubing as it enters the water. Once in the water, remove the cap by tapping the cap edge with the sampling pole.
2. *Press* the **Power** button to turn on the fluorometer.
3. Allow the fluorometer to warm up for 1–2 minutes.

Upon arrival at the site:

1. Fluorescence profiles will be collected at the same time and location as water sampling for Objective #2.
2. As the water samples are being collected, take a continuous, descending fluorescence profile and a continuous, ascending fluorescence profile.
3. To collect a continuous fluorescence profile, position the fluorometer at the surface, start the datalogging function, and then slowly lower the fluorometer to the desired depth (matching the deepest depth water samples are being collected, if possible). Record the times, data record numbers (displayed in upper right-hand corner of the datalogger when the fluorometer is in the logging mode), and depths at the beginning and end of the fluorescence profile.
4. To collect a continuous, ascending fluorescence profile, turn off the fluorescence log. This will provide a clear separation between the data for the two profiles. Once datalogging is re-initiated, starting at depth, slowly raise the fluorometer until it is just below the surface. Again, record times, data record numbers (displayed in upper right-hand corner of the datalogger when the fluorometer is logging), and depths at the beginning and end of the fluorescence profile. Stop logging once the profile is complete.

   Note: to initiate the logging mode, hold the **Store** button. Once the logging mode has begun, the display will read "LOGGING MODE ENTERED." End the logging mode by pressing the **Power** button.
5. In addition to continuous profiles, fluorescence profiles may also be conducted by collecting measurements for 1 minute each at 3–5 discrete depths. While these profiles provide a richer dataset for each depth, they take significantly longer than the water sampling, and thus should be performed after the continuous profiles are completed.

Collecting a Fluorescence Transect

Before arriving at the site:

1. To minimize contamination of the fluorometer, deploy the fluorometer through clean water before the boat enters the oil slick site, use a spray of water or paddle to move the slick out of the way or, if necessary, deploy it through a PVC pipe with a cap to protect the ends of the tubing as it enters the water. Once in the water, remove the cap by tapping the cap edge with the sampling pole.
2. The depth of deployment may change depending on field results and at the discretion of the field team leader, but as a default, deploy the fluorometer to 1 m.
3. Press the **Power** button to turn on the DataBank datalogger.
4. Allow the fluorometer to warm up for 1–2 minutes.

Upon arrival at the site:

1. Assess the extent of the slick at the site. Discuss with the boat captain how the area should be traversed for sampling. If possible, the transect should traverse areas that are both up current and down current of the slick area, and should enter and exit the slick multiple times.

2. Initiate the logging mode, if not already logging. To initiate the logging mode, hold the **Store** button. Once the logging mode has begun, the display will read "LOGGING MODE ENTERED."

3. Begin to traverse the slick area. As the boat moves around the site, mark waypoints when the fluorometer enters and exits the slick oil. Record fluorescence readings at each waypoint. When out of the slick area, note if the boat is up current or down current of the slick. Record each waypoint number and a description of that waypoint on the Fluorescence Transect/Profile Data Sheet.

4. If a spike or anomaly in the fluorescence signal is observed, press the **Store** button to store the current reading displayed.

5. Mark a new waypoint and record the observed fluorescence reading. Press the **Recall** button if you need to display the last record stored.

6. If conducting the transect for targeted water sampling, stop the boat and collect a set of water samples according to the Water Sampling SOP (SOP 6). Otherwise, continue the fluorescence monitoring until the planned transect is complete.

7. Once the transect is complete, press the **Power** button to end the logging mode.

Fluorescence Transect/Profile Data Sheet

Fluorescence Transect/Profile

Site ID:	Date:	Sampler(s):

Fluorescence Transect

#	Start Time	End Time	Depth (m)	Site Description	Notes

Time	WP #	Waypoint Description	Fluor. (mV)	Time	WP#	Waypoint Description	Fluor. (mV)

SOP 8: Air Monitoring

This SOP will be used to conduct air sample monitoring using the UltraRAE 3000. The UltraRAE air monitor will be turned on upon arrival at the first site at the start of the day, and will collect VOC concentrations continuously, at 1-minute intervals throughout the day.

Materials and Equipment

Table 8.1 lists the materials and equipment required to complete the procedures described in this SOP.

Table 8.1. Materials and equipment required for the Air Sampling SOP

UltraRAE 3000 air monitor	PVC mount to attach monitor to boat	Site Characterization Log (SOP 1)

Air Monitor Procedure

Monitor Preparation

1. Mount the UltraRAE air monitor to the deck boat using a large PVC tube capped at one end and zip ties. Note the height of the monitor from the water's surface.
2. Ensure the monitor has an attached pre-filter to prevent excess water from entering the sensor.

Continuous Air Monitoring

1. Upon arrival at the first contaminated site of the day, turn on the monitor. A loud beep will sound to indicate the monitor is working properly.
2. Place the monitor in the mount.
3. The monitor will begin logging at 1-minute intervals as soon as it has warmed up.
4. At semi-regular intervals, record VOC concentrations from the air monitor. Include additional spot checks at times when the air monitor alarm is going off (which indicates concentrations of 2 ppm or higher are being detected).
5. At the end of the day, turn the air monitor off.
6. Download the data from the air monitor at the end of each day according to manufacturer instructions.

SOP 9: UV and Visible Light Attenuation

Water turbidity/visible light attenuation data will be collected using a Secchi disk and UV light attenuation data will be collected with a Biospherical radiometer. This SOP describes how to collect visible light attenuation data using a Secchi disk and UV light attenuation measurements with a Biospherical radiometer.

Materials and Equipment

Table 9.1 lists the materials and equipment required to complete the procedures described in this SOP.

Table 9.1. Materials and equipment required for the UV and Visible Light Attenuation SOP

Biospherical radiometer with computer	Nitrile gloves (powderless)	Spray bottle with soap or water
Secchi disk with rope and weight	Metal clips	UV and Visible Light Profile Data Sheet
Permanent markers, pens, and pencils	Digital camera (with current time and date)	

UV Light Attenuation Data Collection Methods

1. Connect the radiometer cable to the powersource/translator (a small deckbox), which is connected to a laptop running the PROFILER software.
2. Turn on the BioSpherical radiometer, and press **Record** on the PROFILER screen.
3. Clear an area of the slick oil using a small spray of Simple Green soap or water from a spray bottle or a paddle to physically move the slick from an area.
4. Slowly lower the meter into the cleared area. Just before the sensor is lowered below the water surface, cover the sensor with the data sheet for a few seconds. This will provide a clear indication in the datalog of when the profile measurements have started.
5. Lower the radiometer until the UV light has been fully attenuated, and then slowly raise it back up. Since the depth sensor may not work properly due to the protective cover used to keep oil from contaminating the light sensor, the time, waypoint #, depth, and associated UV intensity should be recorded at several depths along the profile.
6. Press **Stop** on the PROFILER screen to stop recording the data.
7. Record the site ID, date, and time of the UV profile, and any notes on the UV and Visible Light Attenuation Data Sheet.

Secchi Disk Data Collection Methods

In an area of slick that has not been disturbed by other activities, take three Secchi disk measurements following the methods below.

1. Obtain a 20-cm Secchi disk with an attached lead weight and calibrated rope.

2. Move to the side of the boat that is in the shade so that measurements are not disturbed by sun glare or, if necessary, block the sun with your body to reduce glare. Remove sunglasses during measurement so they do not interfere with your ability to see the disk.
3. Attach the end of the Secchi disk rope to the boat to avoid losing equipment if dropped.
4. Clear an area of the slick oil using a small spray of Simple Green soap or water from a spray bottle or a paddle to physically move the slick from an area.
5. Lower the Secchi disk through the cleared area into the water.
6. Slowly shift the Secchi disk from the cleared area to an area with the slick or sheen. Try to minimize any slick disturbance and keep the disk under the slick while taking Secchi depth measurements.
7. Take photograph(s) of the slick area being measured by the Secchi disk.
8. Lower the disk into the water until no longer visible. Make a note of the depth by reading the depth off the calibrated line. Then raise the disk until it is visible again and make a note of this depth. The Secchi disk depth is the average of these two readings. If the depth on the calibrated line is not visible during either measurement, make a note of the depth by placing a metal clip on the calibrated line that lines up with the top of the boat's railing.
9. Record the site ID, date, and time of the Secchi disk profile, and any notes on the UV and Visible Light Profile Data Sheet.

UV Light Attenuation Transect

1. Connect the radiometer cable to the powersource/translator (a small deckbox), which is connected to a laptop running the PROFILER software.
2. Turn on the BioSpherical radiometer, and press **Record** on the PROFILER screen.
3. Clear an area of slick oil using a small spray of Simple Green soap or water from a spray bottle or a paddle to physically move the slick from an area.
4. Slowly lower the meter through the cleared area. Just before the sensor is lowered below the water surface, cover the sensor with the data sheet for a few seconds. This will provide a clear indication in the datalog of when the profile measurements have started.
5. Adjust the meter to a fixed depth of 0.5 m (depth may be modified in the field based on site-specific conditions).
6. Begin to slowly traverse the slick site. As the boat moves around the site, mark waypoints when the fluorometer enters and exits slick oil of different thicknesses. Record the UV intensity readings at each waypoint. Record each waypoint number and a description of that waypoint on the UV Attenuation Transect Data Sheet.
7. If possible, conduct slick thickness measurements alongside the UV attenuation transect so that the slick thickness can be related to UV attenuation.
8. Once the transect is complete, press the **Power** button to end the logging mode.

UV and Visible Light Profile Data Sheet

UV and Visible Light Profile

Site ID:	Date	Sampler(s):

Water Quality Measurements

Time	WP#	Depth (m)	Water Temp (°C)	Salinity	Turbidity

Secchi Disk Measurements

#	Time	WP #	Slick Description	Secchi Depth (m)	Photo #s	Notes
1						
2						
3						

UV Profile 1 (Filename):

Time	WP #	Depth (m)	UV-A	Time	WP #	Depth (m)	UV-A

UV Profile 2 (Filename):

Time	WP #	Depth (m)	UV-A	Time	WP #	Depth (m)	UV-A

UV Profile 3 (Filename):

Time	WP #	Depth (m)	UV-A	Time	WP #	Depth (m)	UV-A

UV Attenuation Transect Data Sheet

UV Attenuation Transect

Site ID:	Date:	Sampler(s):

Fluorescence Transect

#	Start Time	End Time	Depth (m)	Site Description	Notes

Time	WP #	Waypoint Description	UV-A	Time	WP#	Waypoint Description	UV-A

SOP 10: Video and Photograph Documentation

This SOP lists the required materials and describes standard methods for collecting and documenting photographs taken as a part of field data collection activities.

Materials and Equipment

Table 10.1 lists the materials and equipment required to complete the procedures described in this SOP.

Table 10.1. Materials and equipment required for the Video and Photograph Documentation SOP

Digital camera with memory card programmed with correct date and time according to the GPS unit	GoPro Hero 4 with extra batteries and accessories
GPS unit	Permanent markers, pens, and pencils

Procedures

Below is a video and photograph documentation checklist. This checklist is merely a guide for the photographer/videographer and does not represent all possible photographs or videos that could be taken during a sampling trip.

1. The time each video/photograph is taken will be recorded by the camera on the video/photograph itself. Ensure that the camera is set to the correct time and date before any photograph or video is taken.
2. Turn on the GPS tracking log, mark a waypoint to identify the location, and photograph the display screen (time, coordinates, and waypoint number should be visible in the photograph). Record this picture as the first photograph on the data sheet.
3. Take photographs or videos.

Video and Photograph Documentation Checklist

Use this checklist as a guide for video and photograph documentation to be completed at each site. This checklist is merely a guide, and does not represent all videos or photographs that may potentially be taking during sampling.

- ❑ First photograph for each site should be of the GPS unit marking the location of the sampling site that the following photographs will be taken from. If multiple cameras are used, each camera should photograph the GPS unit.
- ❑ Ensure that the time and date are correct on all cameras used.
- ❑ Photograph each area sampled with sorbent pads, dip plates, and the WaterMapping sampler.
- ❑ Photograph each area where Secchi disk measurements are taken.
- ❑ Take video and/or photographs of the area during fluorescence transects.
- ❑ Take video and/or photographs to capture general site characteristics.
- ❑ Once sampling is complete at each site, photograph the GPS unit to capture the GPS coordinates at the end of the sampling.
- ❑ Using a designated camera, photograph all data sheets from the completed site to serve as a backup copy.

SOP 11: Labeling Field Samples

This SOP details how field samples will be labeled.

Materials and Equipment

Table 11.1 lists the materials and equipment required to complete the procedures described in this SOP.

Table 11.1. Materials and equipment required for the Labeling Field Samples SOP

Sample containers	Clear packing tape	Fine-point permanent markers
Sample container labels		

Field Sample Labeling Procedure

1. Fill out the required information on sample labels prior to affixing the labels to the sample containers

   All sample labels will contain the following information, written legibly in permanent ink:

   - Sample ID (details provided below)
   - Container number for a given sample ID (example: 1 of 3, 2 of 3, and 3 of 3)
   - Date and time of sample collection (military or 24-hour time format)
   - Sample collector's name

2. Attach the completed sample labels to the sampling containers

3. All sample labels will be covered with clear packing tape that completely encircles the sample container to prevent smearing or physical damage to the label.

Sample ID Designations

Each sample will receive a unique alphanumeric designation as the Sample ID. The following format will be used:

GridID-Y####-XX##-##

First segment: GridID represents location of the sample collection. On this sampling trip, all GridIDs will be "Taylor" to indicate that the sampling is occurring around the Taylor Energy spill site.

Second segment (Y####): sampling date. This five-digit date code includes a letter to represent the year, with 2017 = B. Following the year letter code are four digits for the month and day, including zeroes. Do not use slashes or dashes between digits. For example, the data code for October 10, 2017 would be B1010.

Third segment (XX##): matrix and site ID. This four-digit code is made of two, two-digit sections where the first two digits represent the matrix. The matrix codes for this trip can be found in Table 11.2. The second two digits are the site ID. Sampling sites will start with 01 and increase sequentially.

Table 11.2. Sample media designation codes

Sample media	Matrix code
Oil – pad	OP
Oil – bulk	OL
Whole water – PAH	WW
Air – VOC	AV
Air – PAH	AP

Fourth segment (##): sequential number. The final segment of the sample ID will consist of a unique, sequential number. Because multiple samples will be collected by different team members simultaneously, each sample type will start with 01 and increase sequentially.

Example sample IDs: the sample ID for a bulk oil sample taken at Site 04, which was the 10th oil sample collected at that site on October 10, 2017, would be Taylor-B1010-OL04-10.

Note that if multiple containers are filled with sample media from a single sampling point for the same analysis, the sample ID will be identical for all containers. The sample label will also be similar except that each container will have a different container number that references the total number of containers that were filled (e.g., 1 of 4, 2 of 4). This labeling scheme will be used regardless of sample container type and analyses.

SOP 12: Sample Chain of Custody

This SOP describes sample COC requirements and procedures. All collected samples will be maintained under strict COC, which is the documentation of a sample's history from the time of collection through sample analysis to final disposal. COC forms will be used to document sample COC, relinquish samples, request analyses when relinquishing samples to an analytical laboratory, and transfer samples to long-term storage.

The individual who prepares and labels a sample is responsible for the care and custody of all samples in his/her possession, until they are officially relinquished using COC forms. Samples can be relinquished by sending to analytical laboratories, personally handing off to the intended recipient (individual or laboratory), or storing in a secure location. A sample is considered to be appropriately in the custody of the sampler only in the following situations:

- The sample is in the individual's possession or within eyesight of the individual.
- The sample is in a sealed container that cannot be tampered with or opened without breaking the seal.
- The sample is in a designated secure area, cold storage room, locked refrigerator, or similar storage area with limited access. Access can be controlled using keyed locks, sign in/out sheets, and/or video monitoring.
- The sample is in a shipping cooler, envelope, or box that is tamper-resistant, properly prepared for shipping, and secured using custody seal tape.

COC Forms

1. Obtain enough new COC forms for all samples being shipped to the analytical laboratory or transferred to storage
    a. Note that COC forms usually only have enough entries for 10–20 samples
2. Record the following contact information on each COC form:
    a. Project name (Taylor Energy)
    b. Project Manager (Heather Forth, Abt Associates)
    c. Sampler contact information (current street and email address, cell phone number, and fax number)
    d. Sampler signature
    e. Special instructions/comments (if samples were pulled from storage and being sent to the analytical laboratory, specific storage conditions)
3. Record the following sample information on respective COC forms:
    a. Sample ID (unique for each sample, see SOP 11, the Labeling Field Samples SOP)
    b. Date and time of sample collection (information should be found on the respective, completed data sheets)
    c. Sample matrix (e.g., whole water, bulk oil)

   d. Number of sample containers sharing the same, respective sample ID
   e. Analysis required for each sample (usually indicated using check boxes; check all that apply)

4. Record the following COC information at the bottom of the COC form:

   a. Printed name and signature of individual relinquishing custody
   b. Date and time when samples were relinquished from custody (this will be the last entry made before making copies of the completed COC form and sealing in the cooler or securing with stored samples)

5. Photograph of filled out hardcopy COC forms to serve as a backup record.

Relinquishing Samples

1. Completely fill out the COC form, as described above

2. If sending to an analytical laboratory, notify the laboratory of the shipment and ship samples as described in the Sample Handling and Shipping SOP (SOP 13).

SOP 13: Sample Handling and Shipping

This SOP describes how to handle and ship samples for chemical analysis while maintaining established COC requirements as described in the Sample Chain of Custody SOP (SOP 12). It also provides sample hold times for the different sample matrix types.

Materials and Equipment

Table 13.1 lists the materials and equipment required to complete the procedures described in this SOP.

Table 13.1. Materials and equipment required for the Sample Handling and Shipping SOP

1-gallon Ziploc bags	Bubble wrap	Digital camera
Paper towels	Clear packaging tape	FedEx domestic shipping air bills
COC seals or evidence tape	Cooler(s) with ice or cold packs	Plastic bottles of any size ranging from 30 mL to 250 mL filled with cold tap water (temperature blank)
COC forms		

Sample Handling and Shipping Methods

1. Ensure all samples are shipped within the prescribed sample hold times listed in Table 13.2. Handling and hold time recommendations are based on guidelines from the analytical laboratory.

Table 13.2. Recommended storage conditions and hold times for environmental samples.
Maximum hold time refers to the required length of time from sample collection to organic analysis extraction that is allowable before sample integrity may be jeopardized.

Sample type	Storage conditions	Maximum hold times
Water TPH/PAH samples	On ice at approximately 4°C	Seven days if not acid preserved Fourteen days if acid preserved
Bulk oil/product sample	Short-term: on ice at approximately 4°C Long-term (> 1 week): standard refrigerator at approximately 4°C	None
Oiled filters/pads/nets	Store frozen at -20°C	None
Air PAH samples	On ice at approximately 4°C	Thirty days
Air VOC samples	Room temperature	Thirty days

2. Obtain enough COC forms and coolers to contain all samples that are being shipped.
    a. Note that COC forms usually only have enough entries for 10–20 samples
    b. Samples listed on a single COC form will not be split between coolers
    c. More than one COC form can be used for each cooler.
3. Fill out COC form according to the Sample Chain of Custody SOP (SOP 12).
4. Pack the cooler:
    a. Place a layer of bubble wrap and paper towels in the bottom of the cooler.
    b. Wrap samples in bubble wrap and pack so that they are not directly touching each other or hard objects such as ice packs.
    c. All samples should be upright in cooler. Do not pack samples on their sides.

d. Pack samples with enough ice to keep cooled to approximately 4°C until received by the laboratory. Ice will be in gel packs, water frozen in excess sample bottles, and/or ice cubes within multiple re-sealable plastic bags to prevent water or ice from touching sample bottles.
e. If not already in the cooler from the analytical laboratory, a temperature blank bottle will be included in each cooler. Make the temperature blank by adding cold water to a capped 30- to 250-mL Falcon tube or plastic bottle, and clearly label it "Temperature Blank." The analytical laboratory will measure the temperature in this bottle as representative of the temperature of the sample bottles.

5. Confirm that each cooler only contains samples that are listed on the COC form(s) in that cooler.

6. Once all sample and analysis information is recorded on each COC form, the person relinquishing custody of the samples to the laboratory will sign and date the COC form(s).

7. Seal the original COC form(s) in a plastic re-sealable bag and tape the bag to the underside of the cooler lid (or the inside of the cooler).

8. For each cooler, sign and date at least two COC seals (small stickers or tape with a line for a signature and date) or sections of evidence tape for each shipping container.

9. Place signed COC seals or evidence tape on opposite corners of the cooler across the seam between the cooler lid and the main body of the cooler (Figure 13.1). Seals must be arranged so that the cooler cannot be opened without disturbing the seals.

10. Place clear packing tape over the COC seals or evidence tape.

11. Seal the cooler by taping around the seam between the lid and body of the cooler and around the entire cooler (Figure 13.2).

12. Deliver cooler(s) to a FedEx location or have FedEx pick up the cooler(s). Do not leave the cooler(s) at an unattended FedEx drop-off location. Samples will be shipped as soon as possible following collection in order to provide ample time to perform extractions within the appropriate holding time. Avoid shipping samples over weekends.

13. All water and oil analytical samples will be sent to ALS Environmental in Kelso, Washington, for analysis. All air samples will be sent to ALS Environmental in Salt Lake City, Utah. Below are instructions for filling out the FedEx air bill, including the appropriate FedEx code to use for all shipments and the shipping address for ALS Environmental.

    a. Sender's Account Number: 2931-9475-0
    b. Internal Reference: 21272-0400
    c. Recipient:

    <u>For water and oil samples</u>:
    ALS Environmental, 1317 South 13th Avenue, Kelso, WA 98626
    (Telephone: 800-695-7222)

d. Express Package Service: check "FedEx Standard Overnight"
e. Packaging: check "Other"
f. Special Handling: leave blank, but check "No" for *Does this shipment contain dangerous goods?*
g. Payment: check "Sender"
h. Residential Delivery Signature Options: check "No Signature Required."

Figure 13.1. Placement of signed COC seals (green) on the outside of shipping coolers.

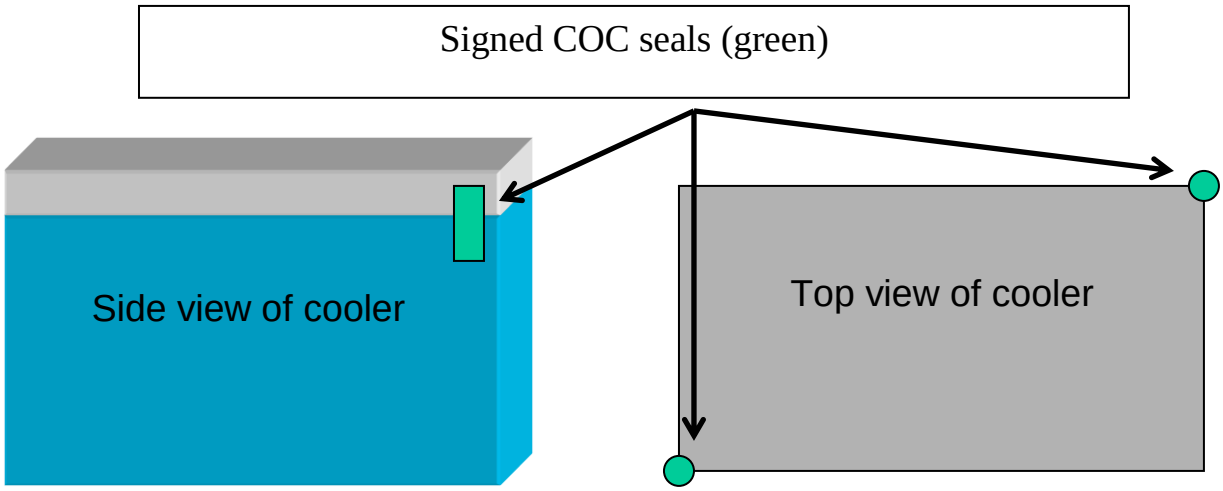
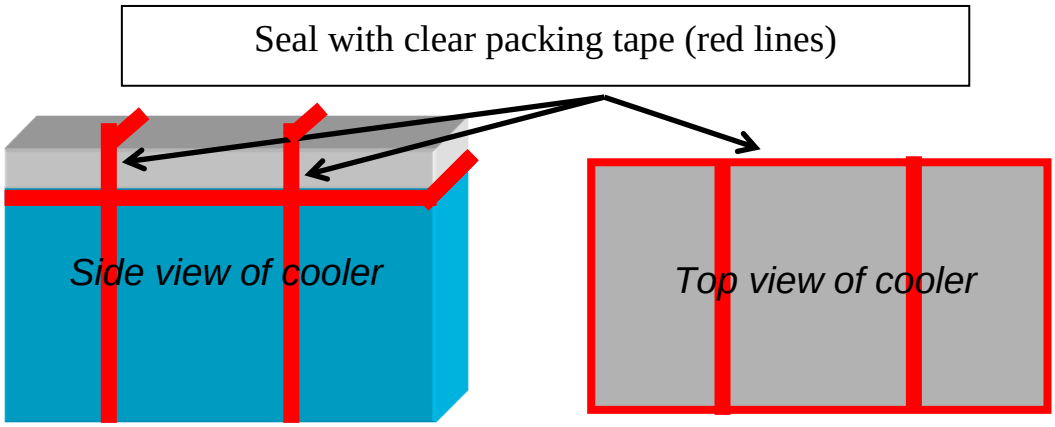


Figure 13.2. Placement of clear packing tape (red line) on shipping coolers.



SOP 14: Equipment Decontamination in the Field

Sampling and sample processing equipment will be decontaminated before use according to methods described in this SOP. Decontamination procedures follow recommendations for equipment decontamination described in U.S. EPA (2001).

Materials and Equipment

Table 14.1 lists the materials and equipment required to complete the procedures described in this SOP.

Table 14.1. Materials and equipment required for the Equipment Decontamination in the Field SOP

Nitrile gloves	Five-gallon buckets with lids	Uncolored plastic bags
Alconox powder soap	Tap water	Paper towels
Scrub brushes	Deionized (DI) or distilled water	Activated carbon
Simple Green or Alconox detergent	Metal colander	Metal bowl
Rubbermaid tubs		

General Equipment Decontamination Methods

1. Determine what equipment needs decontamination:
    a. In general, this includes any equipment that is re-used and involved in the collection of water and sorbent pad analytical samples. These are the samples that are most sensitive to cross-contamination.
    b. Decontamination will be performed before collecting and processing samples from a site, unless the equipment is new and certified pre-cleaned.
2. Put on disposable nitrile gloves before starting.
3. Wash equipment thoroughly with phosphate-free detergent (Alconox or Simple Green) using a scrub brush to remove any attached particles.
    a. All rinsate should be collected in a five-gallon bucket and poured through activated carbon to remove oil contamination before discarding the water in the ocean or down a drain.
4. Rinse with copious quantities of tap water.
5. Rinse with copious quantities of DI or distilled water.
6. Shake off excess water.
7. If not using decontaminated sampling equipment right after decontamination, wrap equipment in clean paper towels or aluminum foil and, if possible, store in uncolored plastic bags.

Reference

U.S. EPA. 2001. *Methods for Collection, Storage and Manipulation of Sediments for Chemical and Toxicological Analyses: Technical Manual*. EPA-823-B-01-002. U.S. Environmental Protection Agency, Office of Water, Washington, DC. October.

Attachment M. August 2017 MC20 Sampling and Analysis Plan

Taylor Energy Spill Site Sampling Summer 2017
Project-Specific Sampling and Analysis Plan

Submitted to:

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August 7, 2017

1. Introduction and Purpose

In September 2004, Taylor Energy's Mississippi Canyon 20-A production platform was destroyed in a hurricane. Oil continues to leak from the Taylor Energy site into the Gulf of Mexico, creating a continuous slick where oil observation and analysis methods can be tested and verified. For this synoptic sampling study, we propose the following data collections at the Taylor Energy oil slick: site characterization, oil sheen/slick thickness measurements, bulk oil sample collection, targeted discrete water sampling based on real-time fluorescence measurements, fluorescence monitoring, air monitoring [volatile organic compounds (VOCs)], and solar radiation intensity measurements.

All data collection and sampling activities will occur at or near the former Mississippi Canyon 20-A production platform site located approximately 12 miles south of the mouth of the Mississippi River. Data collection and sampling activities will occur during multiple sampling trips that coincide with relatively calm water and weather conditions; satellite coverage windows; and availability of aircraft, boats, and personnel.

The purpose of this Sampling and Analysis Plan (SAP) is to provide sampling objectives, and proposed data and sample collection methods. Protocols for sample collection and handling are provided in a series of Standard Operating Procedures (SOPs) attached herein. Only the on-water field sampling activities are described in this work plan.

1.1 Objectives

Work described in this plan is being conducted to fulfill two main objectives:

1. ***Rapid surface slick characterization***: Collect oil thickness measurements and other data at approximately the same time and in the same locations that aerial and satellite data are collected at locations with observed surface oil.

2. ***Targeted environmental sampling***: Collect oil samples, water samples at multiple depths, and oil thickness measurements at locations with observed surface oil. When possible, sampling will target areas where fluorescence and/or field observations show that oil slicks and dispersed oil are present. In addition, continuous air monitoring data will be collected at each site and throughout the day.

2. Field Activities Associated with Each Sampling Objective

This section provides a detailed summary of each sampling objective and associated goals. Data and sample collection methods are further described in subsequent sections of this SAP and attached SOPs.

2.1 Objective #1: Rapid Surface Slick Characterization

A team of researchers on a boat will conduct surface slick characterization activities at the same time and in the same locations where low-altitude aircraft and overhead satellites are collecting remote sensing data. This sampling objective requires careful coordination between the sampling boat, aircraft overflights, and satellite coverage. Because ground crews have no control over the timing of satellite passes, field activities will be planned according to available windows in satellite coverage.

A schedule of the satellite overpass times will be developed before each trip. Our goal is to complete aircraft overflights and boat-based slick characterization as close as reasonably possible to the time when a satellite is acquiring data.

Prior to and during a satellite overpass, a low-altitude aircraft will fly over the slick to determine the optimal sampling locations for the boat. Spotters on the aircraft will guide the boat to sampling locations using an aviation handheld radio with aircraft communications channels or a satellite phone.

Boat-based oil thickness measurements will be made using dip plates, sorbent pads, and the WaterMapping sampler. The crew will also deploy a Turner Designs Cyclops 7 fluorometer at each sampling location at a single depth (generally 1 m) to log fluorescence data during oil thickness sampling. Additionally, the crew may deploy an autonomous underwater vehicle (AUV), the Remote Environmental Monitoring UnitS (REMUS) 100, to measure subsurface fluorescence and other water quality parameters during oil thickness sampling. Bulk oil samples may also be collected for chemical analysis to aid in the interpretation of sorbent pad data. Additional information on these sampling methods is provided below and in the attached method-specific SOPs.

2.2 Objective #2: Targeted Environmental Sampling

We aim to collect targeted surface oil and water samples in areas with observed oil slicks. We are most interested in sampling areas with high levels of oil contamination. In addition, at least one background site will be sampled during each sampling trip. When possible, spotters in low-flying aircraft will guide the boat to sampling sites with substantial oil slick contamination. If spotters in overhead aircraft are not available, sampling sites will be located by starting at the location of the former platform site, as determination by global position system (GPS) coordinates, and radiating outward until the boat intersects an oil slick. Sampling sites may also be located using an unmanned aircraft system (UAS) with a high-resolution camera, operated from the boat.

Table 1 provides a summary of environmental sampling activities that may be conducted at background and oil-contaminated sampling sites. Depending on site conditions and availability, we will conduct any or all of these sampling activities.

Table 1. Environmental sampling activities that may be conducted at background and targeted sampling locations

Sampling activity	
Site characterization	Water chemistry sampling
Fluorescence monitoring	Air monitoring
Oil sheen/slick thickness measurements	Subsurface site characterization
Bulk oil chemistry sampling	Solar radiation intensity
Bulk oil sampling for onshore or laboratory toxicity testing	Water sampling for onshore or laboratory toxicity testing

At sites with visible surface oil, we will conduct fluorescence transects in and out of the visible oil slick, targeting areas with varying degrees of observable oil at the site. If possible, fluorescence monitoring data from these transects will be used to direct water sampling. We designed a system where water can be pumped from four different sampling depths concurrently

with fluorescence monitoring, which will allow us to immediately initiate water sampling when fluorescence anomalies are observed. We will then collect fluorescence profiles alongside the collection of water samples so that fluorescence intensity can be calibrated using the measured total petroleum hydrocarbon (TPH) concentrations of the water samples. Throughout the trip, we may also collect a few large-volume water samples to pair fluorescence measurements with 250-mL water samples analyzed for TPH.

Oil thickness measurements will be taken using dip plates, sorbent pads, and/or the WaterMapping sampler. Along with the oil thickness measurements, a bulk oil sample will also be collected from each site, if sufficient oil is present. Other observational data may include solar radiation intensity, which would be measured using a HOBO Pendant Temperature/Light Data Logger. Additional information on each of the targeted sampling methods is provided below and in the attached method-specific SOPs.

The crew will also deploy the REMUS 100 to collect subsurface site characterization data. The REMUS 100 will collect fluorescence data, depth measurements, water quality measurements, water current velocities, and side scan sonar imagery. Additional information on the REMUS 100 is provided below.

At the beginning of each day, we will mount an UltraRAE VOC air monitor to the side of the boat (at a fixed height to be determined onsite). The monitor will log VOC concentrations at 1-minute intervals throughout the day. Timestamps from the air monitor will be synchronized with the GPS device so that the VOC concentrations from the air monitor can be linked to the GPS data. In addition, spot readings will be recorded throughout the day as backup to the instrument data logging (SOP 1).

3. Sampling Procedures

This section describes the procedures that will be followed when conducting field activities associated with the two primary sampling objectives. This includes a description of how we will plan and prioritize sampling. We also provide detailed information on how each sampling activity will be conducted and how many samples will be collected. Sampling methods will reference respective SOPs that we provide at the end of this SAP. Materials and equipment needed for each step in the procedures are also provided in the SOPs.

3.1 Planning and Prioritization

For each sampling trip, we will conduct sample collection activities over two or more consecutive days, leaving from Boothville-Venice, LA. Boat-based field crews will stay overnight at the Port Eads Marina and Lodges in Port Eads, LA. Port Eads is approximately 20 miles down the Mississippi River from Boothville-Venice and is only accessible by boat. There are few supplies at Port Eads; therefore, field crews will leave Venice with all of the critical sampling equipment and supplies for the entire sampling trip.

Sampling trips typically will coincide with at least one satellite overpass and will be planned around the satellite coverage window(s), with Objective #1 activities being prioritized during times with overhead satellites. We plan to conduct targeted sampling activities at up to three slick sites per day, depending on time available. Targeted sampling activities will also occur at one or more background sites per sampling trip. Background sites will be selected in the

field and occur in areas that are at least a few miles from the former Mississippi Canyon 20-A production platform and do not have any visible oil or elevated fluorescence readings.

When available, spotters on an airplane will help locate sites with oil slicks during sampling activities. The boat-based field crew will be in direct communication with the spotters on the aircraft. Boat-to-aircraft communication will primarily be made using an aviation handheld radio tuned to 123.45 MHz. We will also have a marine radio and a satellite phone as backup communication devices. Spotter aircraft will not be available during the entire time that boat-based sampling activities are being conducted. Therefore, the field team leader will prioritize sampling objectives based on information obtained from the spotter aircraft when available.

3.2 Site Characterization

Site characterization activities will occur at every site for each of the two sampling objectives. Upon arrival at the site, site characterization data will be collected according to the Site Characterization SOP (SOP 1). The site characterization data will include GPS track-log coordinates to capture the route taken during sampling, GPS waypoints to document specific locations where samples and observational data are collected, time and date of each sampling activity, fluorescence monitoring logs and point data to detect dispersed oil, and observational data that includes degree of observed sea-surface oiling. Wind speed and direction, air temperature, humidity, weather conditions, sea state observations, and other site attributes may also be documented. Field data will be recorded in the Site Characterization and Oil Thickness Data Sheet provided with SOP 2.

Site characterization activities will include digital photographs and video recordings. Digital photographs and videos will be used to document site conditions, the degree of oiling, the appearance of surface oil at sampling locations, and fluorescence monitoring data and anomalies. Field crews will make every effort to link GPS and fluorometer logs, observations of surface slick conditions, and sea-state conditions. This includes syncing the time and date on GPS and fluorometer devices with digital cameras, video recorders, and other data recording devices. This will facilitate data analyses and enable field crews to review digital media with respect to fluorescence monitoring and track logs.

To provide a more continuous record of the environmental conditions throughout each sampling day, wind speed and direction, air temperature, weather conditions, sea-state observations, air VOC concentrations, and other environmental attributes will also be documented semi-regularly throughout the day. These data will be recorded in the Site Characterization Log provided with SOP 1.

3.3 Fluorescence Monitoring

Fluorescence monitoring data at a fixed depth may be collected as the boat traverses around a sampling site. This will allow a rapid characterization of the spatial extent of hydrocarbons at the site without conducting more time-intensive water sampling. Generally, for fluorescence transects, we will deploy the fluorometer to a depth of 1 m; however, this depth may be adjusted based on site-specific conditions. The depth for deployment of the fluorometer during these transects will be determined by the field team leader. As the boat traverses a site, we will mark waypoints when the fluorometer enters and exits the slick oil. Each waypoint number and a description of that waypoint will be recorded on the Fluorescence Transect/Profile Data Sheet

(see SOP 7). We will discontinue fluorometer use if it interferes with other sampling activities during rapid slick characterization (Objective #1).

During the targeted environmental sampling (Objective #2), fluorescence monitoring will be conducted at each site to help target contaminated areas for water sampling. To conduct targeted water sampling with fluorescence monitoring, the fluorometer and water sample tubing will be deployed together. The fluorometer will be deployed at a fixed depth, while four separate lines of tubing will be deployed at the four water sampling depths. See Section 3.5 for additional details on water sampling. With the fluorometer set to logging mode and the peristaltic pump turned on so that water samples can be collected quickly, the boat will slowly traverse or drift the slick area at a site. We will mark waypoints when the fluorometer enters and exits the slick oil. Each waypoint number and a description of that waypoint will be recorded on the Fluorescence Water Sampling Data Sheet (see SOP 6). We will also record the start and end time of each transect. A detailed protocol for the collection of fluorescence transect data can be found in the Fluorescence Transect/Profile Data Sheet (SOP 7).

If a spike or anomaly in the fluorescence signal is observed, the boat will stop and water samples will be collected. This will mark the end of the transect. It may require several transects in and out of the area to determine if an anomaly is observed. To help establish site-specific background fluorescence, the fluorescence transect(s) at each site should also include measurements that are several meters outside of the surface slick oil area. In addition, fluorescence transects at one or more background sites will also be collected. Additional transects throughout the day may be collected as the vessel traverses from site to site.

Once a location for water sampling has been determined, a fluorescence profile at the same location will be conducted at the same time that water samples are being collected (see SOP 7). Fluorescence profiles may be collected at additional sites at the discretion of the field team leader.

3.4 Oil Sampling

Oil thickness measurements will be collected at all sites. These measurements will include sampling three to five areas of oil slick or sheen using sorbent pads (3M T151 pads), dip plates, and/or the WaterMapping sampler. For each sampling site, we will target areas of slick that represent the range of different thicknesses at the site. At sites with heavy emulsions, bulk oil samples may be collected for chemical analysis and oil-to-water ratio determination. The collection of oil slick or sheen by sorbent pads will be based on methods described by SINTEF (Daling and Leirvik, 2002). The measurement of oil thickness by dip plates is based on a method described by Svejkovsky and Muskat (2006), while the WaterMapping sampler is an oil cylinder collection and inspection technique that Oscar Garcia of WaterMapping LLC recently developed. Detailed protocols of the sorbent pad, dip plate, and WaterMapping sampler oil thickness measurements are provided in the Sorbent Pad Sampling SOP (SOP 2), the Dip Plate Oil Thickness SOP (SOP 4), and the WaterMapping Sampler Oil Thickness SOP (SOP 5), respectively. Bulk oil will be collected using dip plates or a propriety oil scooper cloth developed by the Korean Institute of Science and Technology according the protocols described in the Bulk Oil Sampling SOP (SOP 3). All bulk oil (with the exception of bulk oil collected opportunistically for onshore or laboratory toxicity testing) and sorbent pad samples will be sent

to ALS Environmental for analysis. See Table 2 for a summary of the surface oil samples to be collected at each site.

Table 2. Number of oil samples collected or measurements made at control and oiled sites

Site	Oil – slick or sheen (sorbent pad)	Oil – bulk (PAH/TPH)	Oil – bulk (oil-to-water)	Oil thickness estimate (dip plate)	Oil thickness estimate (WaterMapping sampler)
Control sites	1–2	0	0	0	0
Oiled sites	3–5	0–2	0–1	3–5	3–5

PAH: polycyclic aromatic hydrocarbon.

3.5 Targeted Water Sampling

We plan to collect water samples at up to three sites per day and one background site per trip as part of the targeted environmental sampling objective. At each site, we plan to collect discrete water column grab samples at up to four depths below the slick at approximately 0.1 m, 0.5 m, 1.0 m, and 3.0 m, unless field conditions such as wave height or real-time fluorescence data indicate alternate depths should be targeted. Discrete water samples will be collected using high-purity tubing and a peristaltic pump. At each sampling depth, we will collect a 250-mL whole water sample. At some sites, we may opportunistically collect water samples for onshore or laboratory toxicity testing. Details on the water sample collection methods are provided in the Water Sampling SOP (SOP 6). Table 3 provides a sample matrix for all analytical chemistry samples.

Table 3. Taylor Energy potential analytical samples (maximum)

Site	Bulk oil PAH	Bulk oil TPH	Oil slick (pad) PAH	Oil slick (pad) TPH	Whole water TPH
Day 1	1	2	0	12	8
Day 2	1	2	0	12	8
Day 3	1	2	0	12	8
Total	3	6	0	36	24

To reduce analytical costs, we will employ a tiered approach to sample analysis. First, we will analyze samples from the two shallowest depths at all sites. If the results suggest that oil is present at a greater depth, we will subsequently analyze the deeper samples collected in the water column. The whole water samples closest to the surface will be analyzed for PAHs using U.S. Environmental Protection Agency (EPA Method 8270) with selected ion monitoring (SIM) and for TPHs using EPA Method 8015C. The three deeper samples will be analyzed for TPHs only to reduce analytical costs. Table 3 provides the anticipated chemical analyses of those samples.

3.6 Air Monitoring

Using an UltraRAE 3000 portable air monitor, we will continuously monitor the VOC concentrations in the air. The UltraRAE air monitor will be turned on upon arrival at the first site at the start of the day, and will collect VOC concentrations continuously, at 1-minute intervals throughout the day.

3.7 Subsurface Site Characterization

We will collect subsurface site characterization data using the REMUS 100 (SOP 15). The REMUS 100 is an AUV designed for operation in water depths to 100 meters. Crew members may deploy the REMUS 100 at each site depending on conditions. The REMUS 100 will collect fluorescence data, depth measurements, water quality measurements, water current velocities, and side scan sonar imagery.[1]

3.8 Solar Radiation Intensity Measurements

We will use a HOBO Pendant Temperature/Light Data Logger to measure solar radiation intensity at each site. The HOBO logger will be calibrated and deployed according to the manufacturer's guidelines and SOP 9.

3.9 Water and Bulk Oil Sampling for Onshore or Laboratory Toxicity Tests

Water and bulk oil will be collected opportunistically for onshore or laboratory toxicity testing. These samples will be collected following the same protocols described in Sections 3.4 and 3.5 above (SOP 3 Bulk Oil and SOP 6 Water).

3.10 Photographic Documentation of Site

Site characterization and sampling will be documented using video and photographs according to guidelines in the Video and Photograph Documentation SOP (SOP 10). Photographs will be georeferenced to a GPS device using synchronized timestamps. If the photograph or video is associated with a specific sampling activity, that photograph number or video filename will be recorded on the respective data sheet next to that activity.

3.11 Sample Labeling, Handling, and Storage

Samples will be labeled according to the Labeling Field Samples SOP (SOP 11), and maintained under chain of custody (COC) as described in the Sample Chain of Custody SOP (SOP 12). After collection, samples will be packaged and shipped to the ALS Environmental analytical laboratory following the Sample Handling and Shipping SOP (SOP 13).

3.12 Sampling Equipment Decontamination

Any sample processing equipment used to collect multiple samples will be decontaminated as described in the Equipment Decontamination in the Field SOP (SOP 14).

References

Daling, P.S. and F. Leirvik. 2002. BONNEX 2002, June 17th–19th: Oil Film Thickness Measurements and Pictures Taken from Sampling Boats – Data Report. SINTEF report # STF66 F02084.

Svejkovsky, J. and J. Muskat. 2006. Real-Time Detection of Oil Slick Thickness Patterns with a Portable Multispectral Sensor. Minerals Management Service, Final Report for Project #0105CT39144.

1. See http://www.whoi.edu/main/remus100 for more information.

SOP 1: Site Characterization

This SOP will be used for collection of site characterization data. Since conditions can change during sampling at individual sites, characterization data such as wind speed, wind direction, VOC air concentrations, weather conditions, and sea state will be collected semi-regularly throughout the day. In addition, GPS track data will log the GPS coordinates of the site and marked waypoints will be used to identify the location of specific sampling activities.

Materials and Equipment

Table 1.1 lists the materials and equipment required to complete the procedures described in this SOP.

Table 1.1. Materials and equipment required for the Site Characterization SOP

Anemometer multimeter	VOC air monitor (spot checks)	Site Characterization Log
Permanent markers, pens, and pencils	GPS unit (with current time and date)	

Site Characterization Procedure

1. Throughout the day, collect air temperature, wind speed, and wind direction data using an Extech EN100 anemometer multimeter following manufacturer instructions. Note time and collect a waypoint # for each data collection event. Record all data on the Site Characterization Log.
2. In addition, record general site description characteristics, including weather conditions and sea state, for each data collection event on the Site Characterization Log.
3. Finally, as a spot check, record the VOC concentration from the air monitor for each data collection event.

Site Characterization Log

Site Characterization Log

Date	Sampler(s):

Site Characterization

Time	WP #	Wind Speed (knots)	Wind Direction	VOCs (ppm)	Air Temp (°C)	Sea State*	General Weather Conditions**

* Example **sea states**: Calm, Swells (approx. wave height ft), Chop, Foam, Whitecaps

** Example **weather conditions**: Sunny, Partly Cloudy (% coverage), Rainy, Stormy, Gusty

SOP 2: Sorbent Pad Sampling

This SOP will be used to collect oil slick or oil sheen samples for chemical analysis. At each site, three to five oil slick or sheen samples will be collected using decontaminated 3M T151 sorbent pads. Note that not all samples may be collected at each site.

Materials and Equipment

Table 2.1 lists the materials and equipment required to complete the procedures described in this SOP.

Table 2.1. Materials and equipment required for the Sorbent Pad Sampling SOP

Certified, pre-cleaned 16-oz sample containers with labels	Nitrile gloves (powderless)	Permanent markers, pens, and pencils
Pad sampling buoy with grab pole	Decontaminated 3M T151 sorbent pads (8.5" x 9.5")	Ziploc baggies, bubble wrap, cooler with ice
Five-gallon buckets	Paper towels	Clear packaging tape
Large metal tongs	Digital camera (with current time and date)	Methylene chloride
Site Characterization and Oil Thickness Data Sheet		

Sorbent Pad Sampling Procedure

Before arriving at site:

1. Decontaminate the sorbent pads by rinsing with methylene chloride, then let dry overnight in a chemical fume hood. Store decontaminated pads in individual, re-sealable plastic bags until use.

Upon arrival at the site:

1. Obtain a Site Characterization and Oil Thickness Data Sheet (SOP 2) and ensure that the site identification (ID) and sampling date are recorded on the data sheet.
2. Ensure all sampling and sample processing equipment are decontaminated as described in the Equipment Decontamination in the Field SOP (SOP 14).

Follow the steps below to collect the sample:

1. Put on a new pair of powderless nitrile gloves.
2. Obtain new, pre-labeled 16-oz glass jar sample containers needed for sample collection at the site. Sample container labels will be filled out as described in the Labeling Field Samples SOP (SOP 11).
3. Obtain a new, decontaminated sorbent pad. Attach the sorbent pad to the sorbent pad sampling buoy.
4. Collect the oil slick or sheen off the surface of the water from three separate areas at the sample site. If the site contains areas of distinctly different oil thicknesses, try to target areas that represent the range of different thicknesses observed at the site.

a. Before each oil sample is collected, mark a waypoint on the GPS device to record the GPS coordinates of the sampling location.
b. Take one or more photographs of the area being sampled to visually capture the oil slick or sheen. In addition, photograph the target area. Ensure that the date and time on the camera are accurate so the photographs can be linked with data from the GPS device.
c. Place the sorbent pad buoy with the attached sorbent pad onto the slick using a grab pole. Allow to sit on the surface for 30 seconds[2] to permit adsorption of oil onto the pad (Figure 2.1). Pull the pad off the water using the grab pole and carefully bring aboard. Using large metal tongs to grab the pad, fold oiled pad with the oiled side inward, and transfer to a pre-cleaned jar for analysis. (*Note: As several sorbent pad buoys will be available, designate separate buoys for sites with thicker emulsions versus sites with only thin sheens to minimize cross-contamination between sites*.)

Figure 2.1. Sampling an oil slick using a sorbent pad buoy with sorbent pad.



5. On the Site Characterization and Oil Thickness Data Sheet (SOP 2), record sample time, waypoint number, sample number, a description of the slick area sampled, and the photograph number(s).Make note of any unusual or noteworthy sample characteristics. After collection, tighten the cap of each sample container and thoroughly dry with a clean paper towel. Check that the sample label is properly and completely filled out, and that all samples are recorded on the proper data sheet. Wrap clear tape around the entire circumference of each sample bottle so that it completely covers the label.

6. Store the sorbent pad samples in a cooler with wet ice until sent to the analytical laboratory. Ensure that no ice or water contact the samples when in the cooler by placing the samples in separate Ziploc bags. See the Sample Handling and Shipping SOP (SOP 13) for procedures on how to ship samples.

7. Decontaminate non-disposable sampling equipment and sample processing tools prior to sampling the next site, following the Equipment Decontamination in the Field SOP (SOP 14).

8. Once the sampling is complete at a site, photograph all data sheets. This will serve as a backup for hardcopy documents until all data sheets can be scanned and archived.

2. The field team leader may adjust oil sampling according to conditions. If the pads placed on a slick are unable to adsorb all the oil, discard the sample, and move to a new area with similar slick characteristics. In the new slick area, use an alternative method (e.g., dip plates, the WaterMapping sampler) to estimate oil slick thickness.

Site Characterization and Oil Thickness Data Sheet

Site Characterization and Oil Thickness

Site ID:	Date:	Sampler(s):

Site Characterization

Air Temp (°C)	Wind Speed (knots)	Wind Direction	Sea State*	General Weather Conditions**

Sorbent Pads

#	Time (24h)	Waypoint #	Sample #	Slick Description	Photo #s	Notes
1						
2						
3						
4						
5						

Dip Plates

#	Time (24h)	Waypoint #	Dip Plate #	Plate wt (g)	Plate + oil wt (g)	Slick Description
1						
	Notes/Photo #s					
2						
	Notes/Photo #s					
3						
	Notes/Photo #s					
4						
	Notes/Photo #s					
5						
	Notes/Photo #s					

WaterMapping

#	Time (24h)	Waypoint #	Sample #	Slick Description	Photo #s	Notes
1						
2						
3						
4						

Bulk Oil Collection

#	Time (24h)	Waypoint #	Sample #	Slick Description	Notes
1					

* Example **sea states**: Calm, Swells (approx. wave height ft), Chop, Foam, Whitecaps

** Example **weather conditions**: Sunny, Partly Cloudy (% coverage), Rainy, Stormy, Gusty

SOP 3: Bulk Oil Sampling

This SOP will be used to collect oil slick or oil sheen samples for chemical analysis. At sites with heavy oil emulsions, a bulk oil sample from the site will be collected for chemical analysis or for use in onshore or laboratory toxicity testing.

Materials and Equipment

Table 3.1 lists the materials and equipment required to complete the procedures described in this SOP.

Table 3.1. Materials and equipment required for the Bulk Oil Sampling SOP

Certified, pre-cleaned 16-oz and 4-oz sample containers with labels	Nitrile gloves (powderless)	Decontaminated glass jars to use as secondary containers
Permanent markers, pens, and pencils	Digital camera (with current time and date)	Ziploc baggies, bubble wrap, cooler with ice
Five-gallon buckets	Dip plates	Clear packaging tape
Paper towels	Sampling pole	Plastic pipette
Site Characterization and Oil Thickness Data Sheet (SOP 2)	Oil scooper cloth	

Bulk Oil Sampling Procedure

Upon arrival at the site:

1. Obtain a Site Characterization and Oil Thickness Data Sheet (SOP 2) and ensure that the site ID and sampling date are recorded on the data sheet.
2. Ensure all sampling and sample processing equipment are decontaminated as described in the Equipment Decontamination in the Field SOP (SOP 14).

Follow the steps below to collect the sample:

1. Put on a new pair of powderless nitrile gloves.
2. Obtain new, pre-labeled 16-oz glass jar sample containers needed for sample collection at the site. Sample container labels will be filled out as described in the Labeling Field Samples SOP (SOP 11).
3. If thicker oil emulsion patches exist at the site, collect bulk oil from the surface using one of four methods:
    a. Use a pre-cleaned, 4-oz glass sampling jar attached to a sampling pole. During collection, take care to minimize the transfer of ocean water. This method is best when large areas of thick emulsion are present.
    b. Use a plastic bucket to collect a “bucket-cast” to capture larger mousse/emulsion samples, and then skim the oil from the bucket and transfer to a pre-cleaned, 16-oz sampling glass jar. Use a plastic pipette to remove excess ocean water. Repeat bucket casts until enough oil is collected so that the jar is at least ¼ full (or a minimum of 15 mL of bulk oil).

c. Use a dip plate to pull small patches of oil emulsion from the ocean surface, and scrape into a pre-cleaned, 16-oz glass sampling jar. Repeat until enough oil is collected so that the jar is at least ¼ full (or a minimum of 15 mL of bulk oil). See the Dip Plate Oil Thickness SOP (SOP 4) for additional details on this method.
d. Use a propriety oil scooper cloth (developed by the Korean Institute of Science and Technology) attached to a sampling pole to capture mousse/emulsion samples. Transfer oil and pour into a pre-cleaned, 16-oz glass sampling jar.

4. On the Site Characterization and Oil Thickness Data Sheet (SOP 2), record sample time, waypoint number, sample number, and a description of the slick area sampled. After collection, tighten the cap of each sample container and thoroughly dry with a clean paper towel. Check that the sample label is properly and completely filled out, and that all samples are recorded on the proper data sheet. Wrap clear tape around the entire circumference of each sample bottle so that it completely covers the label.

5. Store the bulk oil samples in a cooler with wet ice until sent to the analytical laboratory. Ensure that no ice or water contact the samples when in the cooler by placing the samples in separate Ziploc bags. See the Sample Handling and Shipping SOP (SOP 13) for procedures on how to ship samples.

6. Decontaminate non-disposable sampling equipment and sample processing tools prior to sampling the next site, following the Equipment Decontamination in the Field SOP (SOP 14).

7. Once the sampling is complete at a site, photograph all data sheets. This will serve as a backup for hardcopy documents until all data sheets can be scanned and archived.

SOP 4: Dip Plate Oil Thickness

This SOP will be used to collect oil slick or oil sheen for gravimetric estimation of slick thickness. At each site, three to five oil slick or sheen samples will be collected for gravimetric estimation of slick thickness. Note that only sites with some emulsion can be sampled using this method. Thinner oil sheens can only be sampled using the sorbent pads and the WaterMapping sampler.

Materials and Equipment

Table 4.1 lists the materials and equipment required to complete the procedures described in this SOP.

Table 4.1. Materials and equipment required for the Dip Plate Oil Thickness SOP

Sampling grab pole	Plexiglas plates	One-gallon re-sealable plastic bags
Portable balance	Paper towels	Metric tape measure
Rubber spatulas	Digital camera (with current time and date)	Permanent markers, pens, and pencils
Nitrile gloves (powderless)	Site Characterization and Oil Thickness Data Sheet (SOP 2)	Carabiners and clips

Dip Plate Oil Thickness Procedure

Before arriving at site:

1. Wipe Plexiglas dip plates with a paper towel to ensure the plate is clean and dry.
2. Label and weigh up to 50 1-gallon re-sealable plastic bags with designated Plexiglas dip plate. All measurements with the balance should be done on a stable surface on the shore.

Upon arrival at the site:

1. Ensure that the site ID and sampling date are recorded on the Site Characterization and Oil Thickness Data Sheet (SOP 2).
2. Ensure that all sampling and sample processing equipment are decontaminated as described in the Equipment Decontamination in the Field SOP (SOP 14).

Follow the steps below to collect the sample:

1. Put on a new pair of powderless nitrile gloves.
2. Obtain a decontaminated Plexiglas plate from its 1-gallon plastic bag. Record the plate number on the appropriate data sheet.
3. At each site, select three to five separate sampling locations to collect oil slick or sheen off the surface of the water. If the site contains areas of distinctly different oil thicknesses, target areas that represent the thickest and thinnest thicknesses, as well as areas with an oil thickness that is most representative of the site.

a. Before each oil sample is collected, mark a waypoint to record the GPS coordinates of the sampling location
b. Take several photographs of the area being sampled to visually capture the oil slick or sheen.

4. Before collection starts, record the sample time, the waypoint number, and photograph image numbers on the Site Characterization and Oil Thickness Data Sheet (SOP 2). Also provide a general description of the slick (e.g., thick emulsion, thin emulsion, patchy emulsion, sheen). If necessary, note any other characteristics of the slick in the Notes column (e.g., vegetation present).

5. To sample the oil slick, slowly lower the Plexiglas plate vertically into the water until it is fully dipped in the water, and then slowly pull it out of the water. See Figure 4.1 for photographs illustrating this procedure. If the oil slick is not adhering to the plate, the plate gets wet before it is dipped into the oil, or other issues arise during sampling, discard the current plate and repeat the procedures with a new plate.

Figure 4.1. Collecting an oil slick using Plexiglas plates to estimate slick thickness.



6. Allow the water to drip off of the plate, and then place the plate into the appropriate plastic bag. If using pre-weighed dip plates and re-sealable plastic bags, wipe any excess moisture from bag; seal the bag; and store in a cool, dry place (e.g., empty cooler) until back on the shore when each dip plate will be re-weighed.

7. Decontaminate all non-disposable sampling equipment and sample processing tools prior to sampling the next site, following the Equipment Decontamination in the Field SOP (SOP 14).

SOP 5: WaterMapping Sampler Oil Thickness

This SOP will be used to measure oil slick thickness using the WaterMapping sampler. At each site, the WaterMapping sampler will collect three to five oil slick or sheen samples for slick thickness estimates.

Materials and Equipment

Table 5.1 lists the materials and equipment required to complete the procedures described in this SOP.

Table 5.1. Materials and equipment required for the WaterMapping Sampler Oil Thickness SOP

Sampling grab pole	WaterMapping sampler	Nitrile gloves (powderless)
Large sorbent pads or plastic sheet	Paper towels and cleaning wipes	Digital camera (with current time and date)
Permanent markers, pens, and pencils	Plastic sample collection tubes	Special photograph box (to standardize photographs)
Site Characterization and Oil Thickness Data Sheet (SOP 2)	Tub O' Towels wipes	GoPro camera (with current time and date)

WaterMapping Sampler Oil Thickness Procedure

Before arriving at site:

1. Wipe several plastic sample collection tubes with Tub O' Towels wipes on the inside and the outside of the tube, which will minimize oil sticking to the sides of the tube
2. Label each tube with a sample number starting with WM01
3. Clean and prepare the WaterMapping sampler.

Upon arrival at the site:

1. Ensure that the site ID and sampling date are recorded on the Site Characterization and Oil Thickness Data Sheet (SOP 2).
2. Put on a new pair of powderless nitrile gloves.
3. Obtain a clean and labeled plastic tube. Write the tube number on the appropriate data sheet. Insert the sampling tube into the WaterMapping sampler.
4. At each site, select three to five separate areas to collect oil slick or sheen off the water surface. If the site contains areas of distinctly different oil thicknesses, target areas that represent the thickest and thinnest thicknesses, as well as areas with an oil thickness that is most representative of the site.
5. Before each oil sample is collected, take several photographs of the area being sampled to visually capture the oil slick or sheen.
6. Before collection starts, record the site ID, the sample collection date, the sample time, and GPS coordinates or waypoint number on the data sheet. Also provide a general description of

the slick (e.g., thick emulsion, thin emulsion, patchy emulsion, sheen). If necessary, note any other characteristics of the slick in the Notes column (e.g., vegetation present).

7. To sample the oil slick, slowly lower the sampler into the water. Allow water with the slick to pass through the sampling tube for a few seconds, using visual observations or the video from the onboard GoPro, if available, to determine when best to collect the sample.
8. Using a remote control, collect the sample by closing the bottom end caps.
9. Using a grab pole, gently pull the sampler off the water and place on large sorbent pads or plastic sheeting, which will minimize oil contamination to the deck of the vessel.
10. Store sample tubes in the vertical position in a cool, dark place.
11. Back on shore, photograph each sample tube to determine height of the oil in the sample tube, which can be used to determine volume of the oil sample collected. Use a photography box to standardize each photograph taken. Ensure all tubes have remained in a vertical position for a sufficient time to allow all oil to settle before the photograph is taken.
12. Clean the sampler with paper towels and cleaning wipes before setting up for the next sample collection.

SOP 6: Water Sampling

This SOP will be used to collect surface and near surface water samples for chemical analysis or onshore or laboratory toxicity testing. At each site, water samples will be collected at up to four depths below the oil slick, using a 4-channel peristaltic pump so that all four depths can be collected simultaneously. At each depth, a 250-mL whole water sample will be collected for TPH analysis. At some sites, bulk water samples will be collected for onshore or laboratory toxicity testing. Note that not all samples may be collected at each site.

Materials and Equipment

Table 6.1 lists the materials and equipment required to complete the procedures described in this SOP.

Table 6.1. Materials and equipment required for the Water Sampling SOP

Certified, pre-cleaned 250-mL amber glass sample containers with labels	Nitrile gloves (powderless)	Waste bucket
Peristaltic pump (4-channel) with polyethylene tubing marked at target depths	Permanent markers, pens, and pencils	Ziploc baggies, bubble wrap, cooler with ice
Clear packaging tape	Multi-colored electrical tape	Tape measure
Three-inch polyvinyl chloride (PVC) pipe with cap	Paper towels	Water Sampling Data Sheet
Digital camera (with current time and date)	Pre-cleaned 4-L amber glass jug	

Water Sampling Procedure

Sample Collection Precautions

To minimize the effects of the boat's presence on the water sampling results, the following methods will be employed[3]:

1. Always enter the sampling site traveling up current, so that any oil dispersed by the boat will move away from the sampling site. Then, travel at an angle to the current for the last few hundred feet to ensure the boat does not drift back through the slick area it had just disturbed.
2. Deploy the sample tubing on the up current side of the boat and as far from the boat hull as possible. A sampling boom may be used to extend tubing away from the boat.
3. If engines are running, ensure that all work is being conducted upwind of any exhaust. If possible, turn off the engines and drift during sampling.
4. Maintain situational awareness, and discontinue sampling if warranted.
5. At each site, use dedicated tubing for all samples.

3. The ability to employ many of these methods will be dependent on having a vessel with the appropriate equipment.

6. Before sample collection, flush the sample tubing with at least 1 L of water.

7. Segregate dirty and clean work areas. Lay out clean substrates, such as sorbent pads, tarps, or paper towels, to work on and replace frequently.

Sample Collection Methods

Upon arrival at the site:

1. Obtain a Water Sampling Data Sheet (SOP 6) and ensure that the site ID and sampling date are recorded on the appropriate lines

2. Ensure that all sampling and sample processing equipment are decontaminated as described in the Equipment Decontamination in the Field SOP (SOP 14).

Follow the steps below to collect the sample:

1. Put on a new pair of powderless nitrile gloves.

2. Obtain new, pre-labeled 250-mL amber glass sample containers for the site. Organize so that the sample containers are easy to locate during sample collection activities.

    a. Sample container labels will be filled out as described in the Labeling Field Samples SOP (SOP 11).

3. To collect samples at multiple depths, prepare four lengths of fresh, uncontaminated tubing for deployment. The length of each will depend on the boat and boom; prepare a 2-m, 2.5-m, 3-m, and 5-m length of tubing for each site unless the field team leader suggests alternate lengths.

    a. Mark the four target depths on the tubing with electrical tape, using a different color to mark each target depths, and mark above and below each target depth every 0.1 meter up to 1.0 meter on either side of the target depth using black electrical tape. Then, align the target depth markings of each length of tubing and tape the four tubes together so each is at its respective depth. The tubing can then be lowered into the water until the water's surface intersects the colored electrical tape representing the desired target depth.
    b. The initial four target sampling depths will be 0.1 m, 0.5 m, 1 m, and 3 m; however, if fluorescence spectroscopy data indicate deeper depths should be sampled, the depths will be adjusted accordingly. (*Note: If the boat is rolling significantly, surface tubing may need to be deployed to deeper depths to avoid pulling the tubing out of the water and through the slick.*)
    c. Tether a tubing weight to each tubing end to minimize the pull from currents. If possible, extend the tubing away from the boat using an extension device.

4. Deploy the tubing into the water.

    a. To minimize contamination of the sample tubing, deploy the tubing through clean water before the boat enters the oil slick site, use a paddle or spray of water to move the slick out of the way or, if necessary, deploy it through a PVC pipe with a cap to protect the ends of the tubing as it enters the water. Once in the water, remove the cap by tapping the cap edge with the sampling pole.

5. Collect water samples from each of four specified depths. Water samples will be collected using a peristaltic pump as described below. Before the start of collection, first flush the sample tubing with approximately 1 L of water, allowing the water to go into a waste bucket. Then place a 250-mL amber glass, pre-cleaned sample bottle under the sample tubing and collect a whole water sample for PAH/TPH. Ensure the bottles are completely full so there is minimal headspace when capped.

6. During the sample collection, mark a waypoint to record GPS coordinates of the sampling location.

7. On the Water Sampling Data Sheet (SOP 6), add sample time, waypoint number, sample number, sample depth, and a description of the slick. Make note of any unusual or noteworthy sample characteristics.

8. After collection, tighten the cap of each sample container and thoroughly dry with a clean paper towel. Check that the sample label is properly and completely filled out, and that all samples are recorded on the proper data sheet. Wrap clear tape around the entire circumference of each sample bottle so that it completely covers the label.

9. Store water samples upright in a cooler with wet ice until sending to the analytical laboratory.

10. Decontaminate non-disposable sampling equipment and sample processing tools prior to sampling the next site, following the Equipment Decontamination in the Field SOP (SOP 14).

11. Once sampling is complete at a site, photograph all data sheets. This will serve as a backup for hardcopy documents until all data sheets can be scanned and archived.

Collection of Large-Volume Water Sample for Paired Fluorescence and TPH Chemistry

1. After the water profile samples have been collected, collect a large-volume water sample from any or all depths.

2. Submerge fluorometer into the discrete sample, allow the meter to stabilize, and record the fluorescence measurement.

3. Pour 250 mL of this large-volume water sample into a 250-mL sample bottle for TPH analysis.

Collection of Large-Volume Water Sample for Onshore or Laboratory Toxicity Testing

1. After the water profile samples have been collected, a large-volume water sample may be collected from any depth.

2. Water samples will be collected using a peristaltic pump or small submersible pump.

3. Place a pre-cleaned 4-L amber jug under the sample tubing and collect a whole water sample for onshore or laboratory toxicity testing. Ensure the bottles are completely full so there is minimal headspace when capped.

Sonde Multimeter Water Quality Collection Methods

The sonde multimeter (YSI EXO1) will be used to collect water column profiles of the following water quality parameters: temperature, salinity, turbidity, and depth.

1. Turn on the handheld meter and check the time, date, and data storage settings (handheld logging). Check the external battery connection and charge.
2. Take the cover cup off the sonde multimeter and check that all sensors are clear of any oil or debris.
3. Recheck the cable connections and ensure the rope is secured.
4. Test communications between the handheld meter and the sonde multimeter.
5. Attach the metallic end cover to the sonde multimeter.
6. Set the pressure values to zero.
7. Clear a small area of slick using sorbent pads, or add a small amount of Simple Green to the water to create an "oil-free" point of entrance for the sonde multimeter.
8. Lower the sonde through the oil-free point to start the profile.
9. If collecting a water quality profile, position the sonde as close to the surface as possible. Then, start the profile recording time, waypoint, depth, and real-time values from the sonde multimeter every 0.5 m on the Water Sampling Data Sheet (SOP 6).
10. Check the real-time profile plots on the handheld meter and the recorded data for anomalous readings to verify the sonde multimeter is working properly.
11. Continue lowering the sonde multimeter until it reaches a depth of 5 m.
12. Finish the profile by slowly raising the sonde multimeter through the water column (i.e., down – up cast).
13. Once complete, submerge the sonde multimeter into a bucket with clean water and Simple Green to clean before the next profile.

Water Sampling Data Sheet

Water Sampling

Site ID:	Date:	Sampler(s):

Water Samples

Time (24h)	Start WP #	End WP #	Slick Description

#	Sample #	Depth (m)	Fluor Spot Readings (mv)	Notes
1				
2				
3				
4				

Fluorescence Profile (Continuous)

1	Start Time	Start WP	Start Depth (m)	Start Record #	Fluor (mV)	Notes
	End Time	End WP	End Depth (m)	End Record #	Fluor (mV)	Notes
2	Start Time	Start WP	Start Depth (m)	Start Record #	Fluor (mV)	Notes
	End Time	End WP	End Depth (m)	End Record #	Fluor (mV)	Notes
3	Start Time	Start WP	Start Depth (m)	Start Record #	Fluor (mV)	Notes
	End Time	End WP	End Depth (m)	End Record #	Fluor (mV)	Notes
4	Start Time	Start WP	Start Depth (m)	Start Record #	Fluor (mV)	Notes
	End Time	End WP	End Depth (m)	End Record #	Fluor (mV)	Notes

Water Quality Profile

Time	WP	Depth (m)	Temp (°C)	Salinity	Turbidity	Notes

SOP 7: Fluorescence

This SOP will be used to collect real-time fluorescence transect and profile data.

Materials and Equipment

Table 7.1 lists the materials and equipment required to complete the procedures described in this SOP.

Table 7.1. Materials and equipment required for the Fluorescence SOP

Turner Designs Cyclops 7 fluorometer	Nitrile gloves (powderless)	Laptop computer with DataBank software
3“ PVC with cap	Sampling pole	Boom
Water Sampling Data Sheet (SOP 6)	Fluorescence Transect/Profile Data Sheet	Permanent markers, pens, and pencils

General Site Documentation

Real-time fluorescence data will be collected to help target areas for water sampling. In addition, as water samples are being collected for Objective #2, the fluorometer will be slowly lowered from the surface to the deepest depth sampled to capture a fluorescence profile of the water column at the time of water sampling. Fluorescence profiles may be collected at additional sites at the discretion of the field team leader. Additional transects throughout the day may be collected as the vessel traverses from site to site.

Turner Designs Cyclops 7 Fluorometer

Before arriving at site:

1. Fully charge the laptop the night before
2. Synchronize time on the laptop to the time on the GPS device using the DataBank software
3. Set the logging interval to take a reading every 10 seconds using the DataBank software.

Collecting a Fluorescence Profile

Before arriving at the site:

1. To minimize contamination of the fluorometer, deploy the fluorometer through clean water before the boat enters the oil slick site, use a spray of water or paddle to move the slick out of the way or, if necessary, deploy it through a PVC pipe with a cap to protect the ends of the tubing as it enters the water. Once in the water, remove the cap by tapping the cap edge with the sampling pole.
2. *Press* the **Power** button to turn on the fluorometer.
3. Allow the fluorometer to warm up for 1–2 minutes.

Upon arrival at the site:

1. Fluorescence profiles will be collected at the same time and location as water sampling for Objective #2.

2. As the water samples are being collected, take a continuous, descending fluorescence profile and a continuous, ascending fluorescence profile.

3. To collect a continuous fluorescence profile, position the fluorometer at the surface, start the datalogging function, and then slowly lower the fluorometer to the desired depth (matching the deepest depth water samples are being collected, if possible). Record the times, data record numbers (displayed in upper right-hand corner of the datalogger when the fluorometer is in the logging mode), and depths at the beginning and end of the fluorescence profile.

4. To collect a continuous, ascending fluorescence profile, turn off the fluorescence log. This will provide a clear separation between the data for the two profiles. Once datalogging is re-initiated, starting at depth, slowly raise the fluorometer until it is just below the surface. Again, record times, data record numbers (displayed in upper right-hand corner of the datalogger when the fluorometer is logging), and depths at the beginning and end of the fluorescence profile. Stop logging once the profile is complete.

   Note: to initiate the logging mode, hold the **Store** button. Once the logging mode has begun, the display will read "LOGGING MODE ENTERED." End the logging mode by pressing the **Power** button.

5. In addition to continuous profiles, fluorescence profiles may also be conducted by collecting measurements for 1 minute each at 3–5 discrete depths. While these profiles provide a richer dataset for each depth, they take significantly longer than the water sampling, and thus should be performed after the continuous profiles are completed.

Collecting a Fluorescence Transect

Before arriving at the site:

1. To minimize contamination of the fluorometer, deploy the fluorometer through clean water before the boat enters the oil slick site, use a spray of water or paddle to move the slick out of the way or, if necessary, deploy it through a PVC pipe with a cap to protect the ends of the tubing as it enters the water. Once in the water, remove the cap by tapping the cap edge with the sampling pole.

2. The depth of deployment may change depending on field results and at the discretion of the field team leader, but as a default, deploy the fluorometer to 1 m.

3. Press the **Power** button to turn on the DataBank datalogger.

4. Allow the fluorometer to warm up for 1–2 minutes.

Upon arrival at the site:

1. Assess the extent of the slick at the site. Discuss with the boat captain how the area should be traversed for sampling. If possible, the transect should traverse areas that are both up current and down current of the slick area, and should enter and exit the slick multiple times.

2. Initiate the logging mode, if not already logging. To initiate the logging mode, hold the **Store** button. Once the logging mode has begun, the display will read "LOGGING MODE ENTERED."

3. Begin to traverse the slick area. As the boat moves around the site, mark waypoints when the fluorometer enters and exits the slick oil. Record fluorescence readings at each waypoint. When out of the slick area, note if the boat is up current or down current of the slick. Record each waypoint number and a description of that waypoint on the Fluorescence Transect/Profile Data Sheet.

4. If a spike or anomaly in the fluorescence signal is observed, press the **Store** button to store the current reading displayed.

5. Mark a new waypoint and record the observed fluorescence reading. Press the **Recall** button if you need to display the last record stored.

6. If conducting the transect for targeted water sampling, stop the boat and collect a set of water samples according to the Water Sampling SOP (SOP 6). Otherwise, continue the fluorescence monitoring until the planned transect is complete.

7. Once the transect is complete, press the **Power** button to end the logging mode.

Fluorescence Transect/Profile Data Sheet

Fluorescence Transect/Profile

Site ID:	Date:	Sampler(s):

Fluorescence Transect

#	Start Time	End Time	Depth (m)	Site Description	Notes

Time	WP #	Waypoint Description	Fluor. (mV)	Time	WP#	Waypoint Description	Fluor. (mV)

SOP 8: Air Monitoring

This SOP will be used to conduct air sample monitoring using the UltraRAE 3000. The UltraRAE air monitor will be turned on upon arrival at the first site at the start of the day, and will collect VOC concentrations continuously, at 1-minute intervals throughout the day.

Materials and Equipment

Table 8.1 lists the materials and equipment required to complete the procedures described in this SOP.

Table 8.1. Materials and equipment required for the Air Sampling SOP

UltraRAE 3000 air monitor	PVC mount to attach monitor to boat	Site Characterization Log (SOP 1)

Air Monitor Procedure

Monitor Preparation

1. Mount the UltraRAE air monitor to the deck boat using a large PVC tube capped at one end and zip ties. Note the height of the monitor from the water's surface.
2. Ensure the monitor has an attached pre-filter to prevent excess water from entering the sensor.

Continuous Air Monitoring

1. Upon arrival at the first contaminated site of the day, turn on the monitor. A loud beep will sound to indicate the monitor is working properly.
2. Place the monitor in the mount.
3. The monitor will begin logging at 1-minute intervals as soon as it has warmed up.
4. At semi-regular intervals, record VOC concentrations from the air monitor. Include additional spot checks at times when the air monitor alarm is going off (which indicates concentrations of 2 ppm or higher are being detected).
5. At the end of the day, turn the air monitor off.
6. Download the data from the air monitor at the end of each day according to manufacturer instructions.

SOP 9: Solar Radiation Intensity

This SOP describes required materials and standard methods for the use of the Onset HOBO Pendant Temperature/Light Data Logger.

Materials and Equipment

Onset HOBO Pendant Temperature/Light Data Logger with a waterproof shuttle case.[4]

Solar Radiation Intensity Measurements

1. Calibrate the logger according to manufacturer's instructions (available from the Onset website).
2. Attach the logger to a flat surface, ensuring that the sensor is pointing up.
3. Prior to deployment, trigger the logger to start recording (see manufacturer's instructions). The light on the front of the logger confirms that the logger is logging.
4. Deploy the logger. Ensure that the sensor is always pointing up.
5. At the end of selected sampling time, retrieve the logger.
6. Record site ID, date, and time of the logging event, and any additional notes on the Solar Radiation Intensity Log.
7. Repeat steps 4–6 at each selected site.

4. http://www.onsetcomp.com/products/data-loggers/ua-002-64.

Solar Radiation Intensity Log

Solar Radiation Intensity Log

Site ID:	Date:	Sampler(s):

Solar Radiation Logging

#	Start Time	End Time	Depth (m)	Site Description	Notes

Time	WP #	Waypoint Description	Time	WP#	Waypoint Description

SOP 10: Video and Photograph Documentation

This SOP lists the required materials and describes standard methods for collecting and documenting photographs taken as a part of field data collection activities.

Materials and Equipment

Table 10.1 lists the materials and equipment required to complete the procedures described in this SOP.

Table 10.1. Materials and equipment required for the Video and Photograph Documentation SOP

Digital camera with memory card programmed with correct date and time according to the GPS unit	GoPro Hero 4 with extra batteries and accessories
GPS unit	Permanent markers, pens, and pencils

Procedures

Below is a video and photograph documentation checklist. This checklist is merely a guide for the photographer/videographer and does not represent all possible photographs or videos that could be taken during a sampling trip.

1. The time each video/photograph is taken will be recorded by the camera on the video/photograph itself. Ensure that the camera is set to the correct time and date before any photograph or video is taken.
2. Turn on the GPS tracking log, mark a waypoint to identify the location, and photograph the display screen (time, coordinates, and waypoint number should be visible in the photograph). Record this picture as the first photograph on the data sheet.
3. Take photographs or videos.

Video and Photograph Documentation Checklist

Use this checklist as a guide for video and photograph documentation to be completed at each site. This checklist is merely a guide, and does not represent all videos or photographs that may potentially be taking during sampling.

- ❑ First photograph for each site should be of the GPS unit marking the location of the sampling site that the following photographs will be taken from. If multiple cameras are used, each camera should photograph the GPS unit.
- ❑ Ensure that the time and date are correct on all cameras used.
- ❑ Photograph each area sampled with sorbent pads, dip plates, and the WaterMapping sampler.
- ❑ Photograph each area where Secchi disk measurements are taken.
- ❑ Take video and/or photographs of the area during fluorescence transects.
- ❑ Take video and/or photographs to capture general site characteristics.
- ❑ Once sampling is complete at each site, photograph the GPS unit to capture the GPS coordinates at the end of the sampling.
- ❑ Using a designated camera, photograph all data sheets from the completed site to serve as a backup copy.

SOP 11: Labeling Field Samples

This SOP details how field samples will be labeled.

Materials and Equipment

Table 11.1 lists the materials and equipment required to complete the procedures described in this SOP.

Table 11.1. Materials and equipment required for the Labeling Field Samples SOP

Sample containers	Clear packing tape	Fine-point permanent markers
Sample container labels		

Field Sample Labeling Procedure

1. Fill out the required information on sample labels prior to affixing the labels to the sample containers

   All sample labels will contain the following information, written legibly in permanent ink:

   - Sample ID (details provided below)
   - Container number for a given sample ID (example: 1 of 3, 2 of 3, and 3 of 3)
   - Date and time of sample collection (military or 24-hour time format)
   - Sample collector's name

2. Attach the completed sample labels to the sampling containers

3. All sample labels will be covered with clear packing tape that completely encircles the sample container to prevent smearing or physical damage to the label.

Sample ID Designations

Each sample will receive a unique alphanumeric designation as the Sample ID. The following format will be used:

GridID-Y####-XX##-##

First segment: GridID represents location of the sample collection. On this sampling trip, all GridIDs will be "Taylor" to indicate that the sampling is occurring around the Taylor Energy spill site.

Second segment (Y####): sampling date. This five-digit date code includes a letter to represent the year, with 2017 = B. Following the year letter code are four digits for the month and day, including zeroes. Do not use slashes or dashes between digits. For example, the data code for October 10, 2017 would be B1010.

Third segment (XX##): matrix and site ID. This four-digit code is made of two, two-digit sections where the first two digits represent the matrix. The matrix codes for this trip can be found in Table 11.2. The second two digits are the site ID. Sampling sites will start with 01 and increase sequentially.

Table 11.2. Sample media designation codes

Sample media	Matrix code
Oil – pad	OP
Oil – bulk	OL
Whole water – PAH	WW
Air – VOC	AV
Air – PAH	AP

Fourth segment (##): sequential number. The final segment of the sample ID will consist of a unique, sequential number. Because multiple samples will be collected by different team members simultaneously, each sample type will start with 01 and increase sequentially.

Example sample IDs: the sample ID for a bulk oil sample taken at Site 04, which was the 10th oil sample collected at that site on October 10, 2017, would be Taylor-B1010-OL04-10.

Note that if multiple containers are filled with sample media from a single sampling point for the same analysis, the sample ID will be identical for all containers. The sample label will also be similar except that each container will have a different container number that references the total number of containers that were filled (e.g., 1 of 4, 2 of 4). This labeling scheme will be used regardless of sample container type and analyses.

SOP 12: Sample Chain of Custody

This SOP describes sample COC requirements and procedures. All collected samples will be maintained under strict COC, which is the documentation of a sample's history from the time of collection through sample analysis to final disposal. COC forms will be used to document sample COC, relinquish samples, request analyses when relinquishing samples to an analytical laboratory, and transfer samples to long-term storage.

The individual who prepares and labels a sample is responsible for the care and custody of all samples in his/her possession, until they are officially relinquished using COC forms. Samples can be relinquished by sending to analytical laboratories, personally handing off to the intended recipient (individual or laboratory), or storing in a secure location. A sample is considered to be appropriately in the custody of the sampler only in the following situations:

- The sample is in the individual's possession or within eyesight of the individual.
- The sample is in a sealed container that cannot be tampered with or opened without breaking the seal.
- The sample is in a designated secure area, cold storage room, locked refrigerator, or similar storage area with limited access. Access can be controlled using keyed locks, sign in/out sheets, and/or video monitoring.
- The sample is in a shipping cooler, envelope, or box that is tamper-resistant, properly prepared for shipping, and secured using custody seal tape.

COC Forms

1. Obtain enough new COC forms for all samples being shipped to the analytical laboratory or transferred to storage
    a. Note that COC forms usually only have enough entries for 10–20 samples
2. Record the following contact information on each COC form:
    a. Project name (Taylor Energy)
    b. Project Manager (Heather Forth, Abt Associates)
    c. Sampler contact information (current street and email address, cell phone number, and fax number)
    d. Sampler signature
    e. Special instructions/comments (if samples were pulled from storage and being sent to the analytical laboratory, specific storage conditions)
3. Record the following sample information on respective COC forms:
    a. Sample ID (unique for each sample, see SOP 11, the Labeling Field Samples SOP)
    b. Date and time of sample collection (information should be found on the respective, completed data sheets)
    c. Sample matrix (e.g., whole water, bulk oil)

   d. Number of sample containers sharing the same, respective sample ID
   e. Analysis required for each sample (usually indicated using check boxes; check all that apply)

4. Record the following COC information at the bottom of the COC form:

   a. Printed name and signature of individual relinquishing custody
   b. Date and time when samples were relinquished from custody (this will be the last entry made before making copies of the completed COC form and sealing in the cooler or securing with stored samples)

5. Photograph of filled out hardcopy COC forms to serve as a backup record.

Relinquishing Samples

1. Completely fill out the COC form, as described above

2. If sending to an analytical laboratory, notify the laboratory of the shipment and ship samples as described in the Sample Handling and Shipping SOP (SOP 13).

Chain of Custody Form

NRDA Chain of Custody Form: Taylor Sampling

COC Form _____ of _____

Check a box: ☐ Samples to ALS ☐ Samples to other lab _____ ☐ Samples analyzed on-site ☐ Samples stored on-site ☐ Data

Sampler/Shipper Information	Stratus Contact Information
Contact/Phone/Email:	Jeff Morris 303-381-8000 Jeff_Morriss@abtassoc.com
Affiliation:	

Incident Name: Taylor Energy Sampling ☐ These data require validation

Special Instructions:

ALS Contact Information	
Contact	Kelley Lovejoy
Address	1317 S. 13th Ave Kelso WA 98626
Phone	360-501-3350
ALS SR#:	

Sample ID	Sample collection Date	Sample collection Time	Matrix	Analyses requested: PAH/Alk (8270C SIM/PAH)	Total Extractable Hydrocarbons							# of containers	Comments
	mm/ddyyyy	*(24-hr local)*		*Enter x's in boxes below.*									

Relinquished by					Received by				
Date	Time	Signature	Printed Name/Org.		Date	Time		Signature	Printed Name/Org.

SOP 13: Sample Handling and Shipping

This SOP describes how to handle and ship samples for chemical analysis while maintaining established COC requirements as described in the Sample Chain of Custody SOP (SOP 12). It also provides sample hold times for the different sample matrix types.

Materials and Equipment

Table 13.1 lists the materials and equipment required to complete the procedures described in this SOP.

Table 13.1. Materials and equipment required for the Sample Handling and Shipping SOP

1-gallon Ziploc bags	Bubble wrap	Digital camera
Paper towels	Clear packaging tape	FedEx domestic shipping air bills
COC seals or evidence tape	Cooler(s) with ice or cold packs	Plastic bottles of any size ranging from 30 mL to 250 mL filled with cold tap water (temperature blank)
COC forms		

Sample Handling and Shipping Methods

1. Ensure all samples are shipped within the prescribed sample hold times listed in Table 13.2. Handling and hold time recommendations are based on guidelines from the analytical laboratory.

Table 13.2. Recommended storage conditions and hold times for environmental samples.
Maximum hold time refers to the required length of time from sample collection to organic analysis extraction that is allowable before sample integrity may be jeopardized.

Sample type	Storage conditions	Maximum hold times
Water TPH/PAH samples	On ice at approximately 4°C	Seven days if not acid preserved Fourteen days if acid preserved
Bulk oil/product sample	Short-term: on ice at approximately 4°C Long-term (> 1 week): standard refrigerator at approximately 4°C	None
Oiled filters/pads/nets	Store frozen at -20°C	None
Air PAH samples	On ice at approximately 4°C	Thirty days
Air VOC samples	Room temperature	Thirty days

2. Obtain enough COC forms and coolers to contain all samples that are being shipped.
    a. Note that COC forms usually only have enough entries for 10–20 samples
    b. Samples listed on a single COC form will not be split between coolers
    c. More than one COC form can be used for each cooler.
3. Fill out COC form according to the Sample Chain of Custody SOP (SOP 12).
4. Pack the cooler:
    a. Place a layer of bubble wrap and paper towels in the bottom of the cooler.
    b. Wrap samples in bubble wrap and pack so that they are not directly touching each other or hard objects such as ice packs.
    c. All samples should be upright in cooler. Do not pack samples on their sides.

d. Pack samples with enough ice to keep cooled to approximately 4°C until received by the laboratory. Ice will be in gel packs, water frozen in excess sample bottles, and/or ice cubes within multiple re-sealable plastic bags to prevent water or ice from touching sample bottles.
e. If not already in the cooler from the analytical laboratory, a temperature blank bottle will be included in each cooler. Make the temperature blank by adding cold water to a capped 30- to 250-mL Falcon tube or plastic bottle, and clearly label it "Temperature Blank." The analytical laboratory will measure the temperature in this bottle as representative of the temperature of the sample bottles.

5. Confirm that each cooler only contains samples that are listed on the COC form(s) in that cooler.

6. Once all sample and analysis information is recorded on each COC form, the person relinquishing custody of the samples to the laboratory will sign and date the COC form(s).

7. Seal the original COC form(s) in a plastic re-sealable bag and tape the bag to the underside of the cooler lid (or the inside of the cooler).

8. For each cooler, sign and date at least two COC seals (small stickers or tape with a line for a signature and date) or sections of evidence tape for each shipping container.

9. Place signed COC seals or evidence tape on opposite corners of the cooler across the seam between the cooler lid and the main body of the cooler (Figure 13.1). Seals must be arranged so that the cooler cannot be opened without disturbing the seals.

10. Place clear packing tape over the COC seals or evidence tape.

11. Seal the cooler by taping around the seam between the lid and body of the cooler and around the entire cooler (Figure 13.2).

12. Deliver cooler(s) to a FedEx location or have FedEx pick up the cooler(s). Do not leave the cooler(s) at an unattended FedEx drop-off location. Samples will be shipped as soon as possible following collection in order to provide ample time to perform extractions within the appropriate holding time. Avoid shipping samples over weekends.

13. All water and oil analytical samples will be sent to ALS Environmental in Kelso, Washington, for analysis. All air samples will be sent to ALS Environmental in Salt Lake City, Utah. Below are instructions for filling out the FedEx air bill, including the appropriate FedEx code to use for all shipments and the shipping address for ALS Environmental.

    a. Sender's Account Number: 2931-9475-0
    b. Internal Reference: 21272-0400
    c. Recipient:

    <u>For water and oil samples</u>:
    ALS Environmental, 1317 South 13th Avenue, Kelso, WA 98626
    (Telephone: 800-695-7222)

d. Express Package Service: check "FedEx Standard Overnight"
e. Packaging: check "Other"
f. Special Handling: leave blank, but check "No" for *Does this shipment contain dangerous goods?*
g. Payment: check "Sender"
h. Residential Delivery Signature Options: check "No Signature Required."

Figure 13.1. Placement of signed COC seals (green) on the outside of shipping coolers.

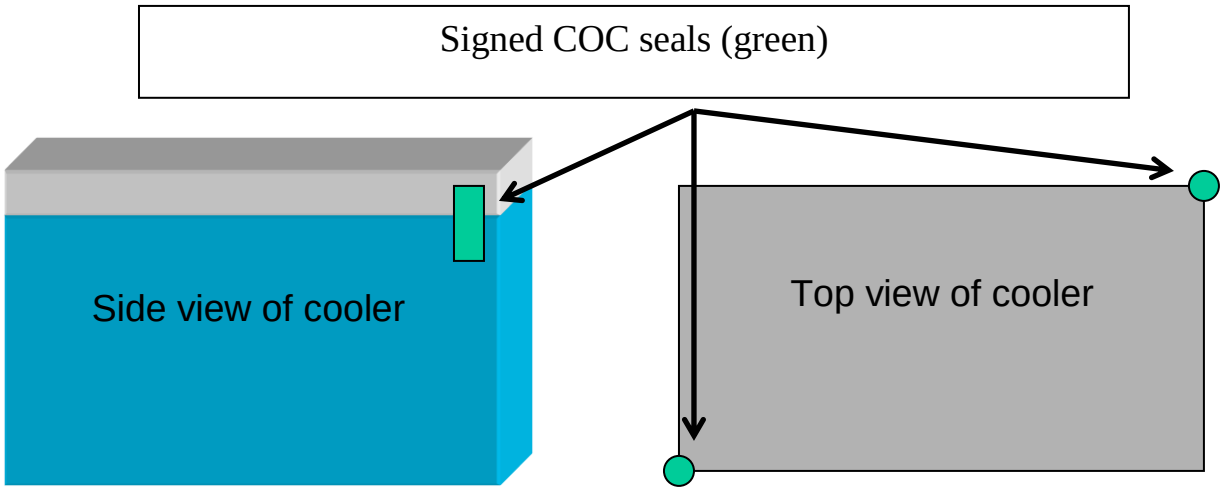
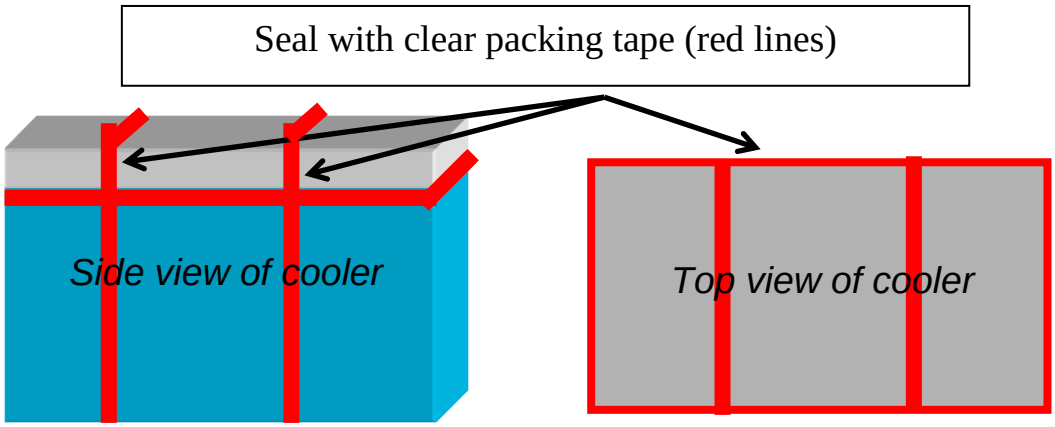


Figure 13.2. Placement of clear packing tape (red line) on shipping coolers.



SOP 14: Equipment Decontamination in the Field

Sampling and sample processing equipment will be decontaminated before use according to methods described in this SOP. Decontamination procedures follow recommendations for equipment decontamination described in U.S. EPA (2001).

Materials and Equipment

Table 14.1 lists the materials and equipment required to complete the procedures described in this SOP.

Table 14.1. Materials and equipment required for the Equipment Decontamination in the Field SOP

Nitrile gloves	Five-gallon buckets with lids	Uncolored plastic bags
Alconox powder soap	Tap water	Paper towels
Scrub brushes	Deionized (DI) or distilled water	Activated carbon
Simple Green or Alconox detergent	Metal colander	Metal bowl
Rubbermaid tubs		

General Equipment Decontamination Methods

1. Determine what equipment needs decontamination:
    a. In general, this includes any equipment that is re-used and involved in the collection of water and sorbent pad analytical samples. These are the samples that are most sensitive to cross-contamination.
    b. Decontamination will be performed before collecting and processing samples from a site, unless the equipment is new and certified pre-cleaned.
2. Put on disposable nitrile gloves before starting.
3. Wash equipment thoroughly with phosphate-free detergent (Alconox or Simple Green) using a scrub brush to remove any attached particles.
    a. All rinsate should be collected in a five-gallon bucket and poured through activated carbon to remove oil contamination before discarding the water in the ocean or down a drain.
4. Rinse with copious quantities of tap water.
5. Rinse with copious quantities of DI or distilled water.
6. Shake off excess water.
7. If not using decontaminated sampling equipment right after decontamination, wrap equipment in clean paper towels or aluminum foil and, if possible, store in uncolored plastic bags.

SOP 15: REMUS

This SOP describes required materials and standard methods for deployment and retrieval of the REMUS 100 AUV.

Materials and Equipment

The REMUS vehicle comes fully supported with all parts necessary for navigation; data collection and logging; acoustic navigation sources, floats, and weights; vehicle tracking unit; ruggedized laptop; and spare parts kit and cables.

Deployment

A minimum of two people will deploy and recover the REMUS 100.

Operation

The REMUS 100 will be operated by the designated and trained AUV operators from the Woods Hole Oceanographic Institution (WHOI) according to the WHOI SOPs.

Reference

U.S. EPA. 2001. *Methods for Collection, Storage and Manipulation of Sediments for Chemical and Toxicological Analyses: Technical Manual*. EPA-823-B-01-002. U.S. Environmental Protection Agency, Office of Water, Washington, DC. October.

Attachment N. REMUS 100 Data

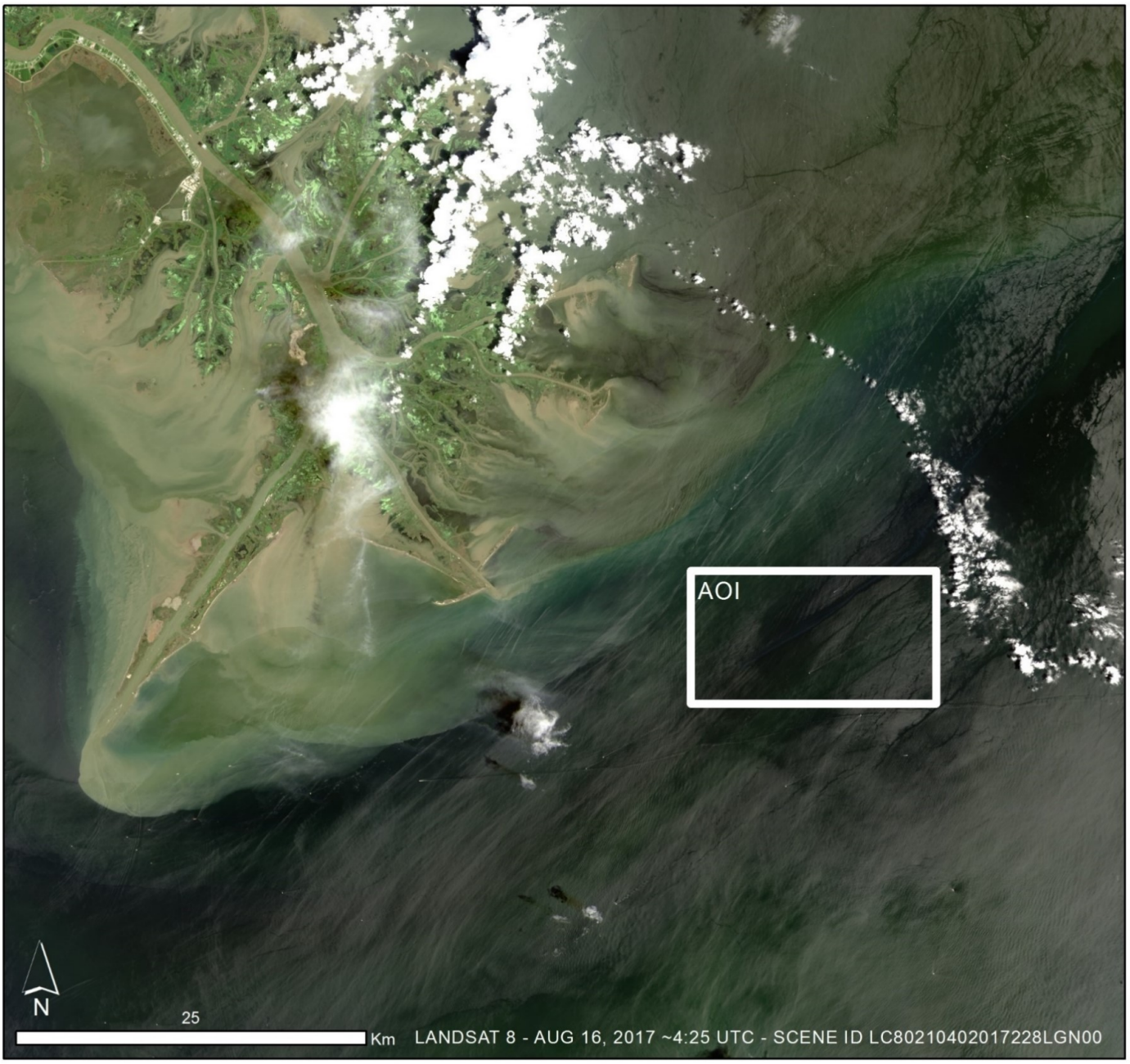
REMUS SEA OWL AND CTD MISSIONS
DATA OVERVIEW

AUGUST 15, 2017
AUGUST 16, 2017
AUGUST 17, 2017



"The findings and opinions expressed in this report are solely those of the authors and do not necessarily reflect the views and policies of the Bureau of Safety and Environmental Enforcement, nor does mention of the trade names or commercial products constitute endorsement or recommendation for use."

AREA OF INTEREST



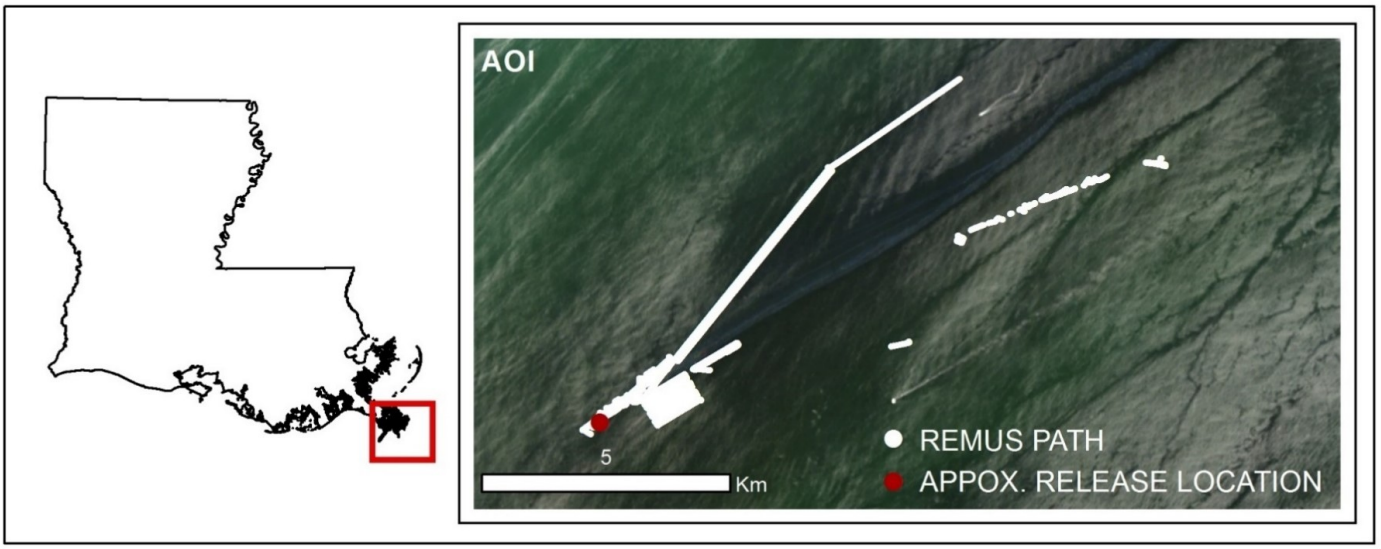


Figure 1 Area of interest

REMUS MISSIONS

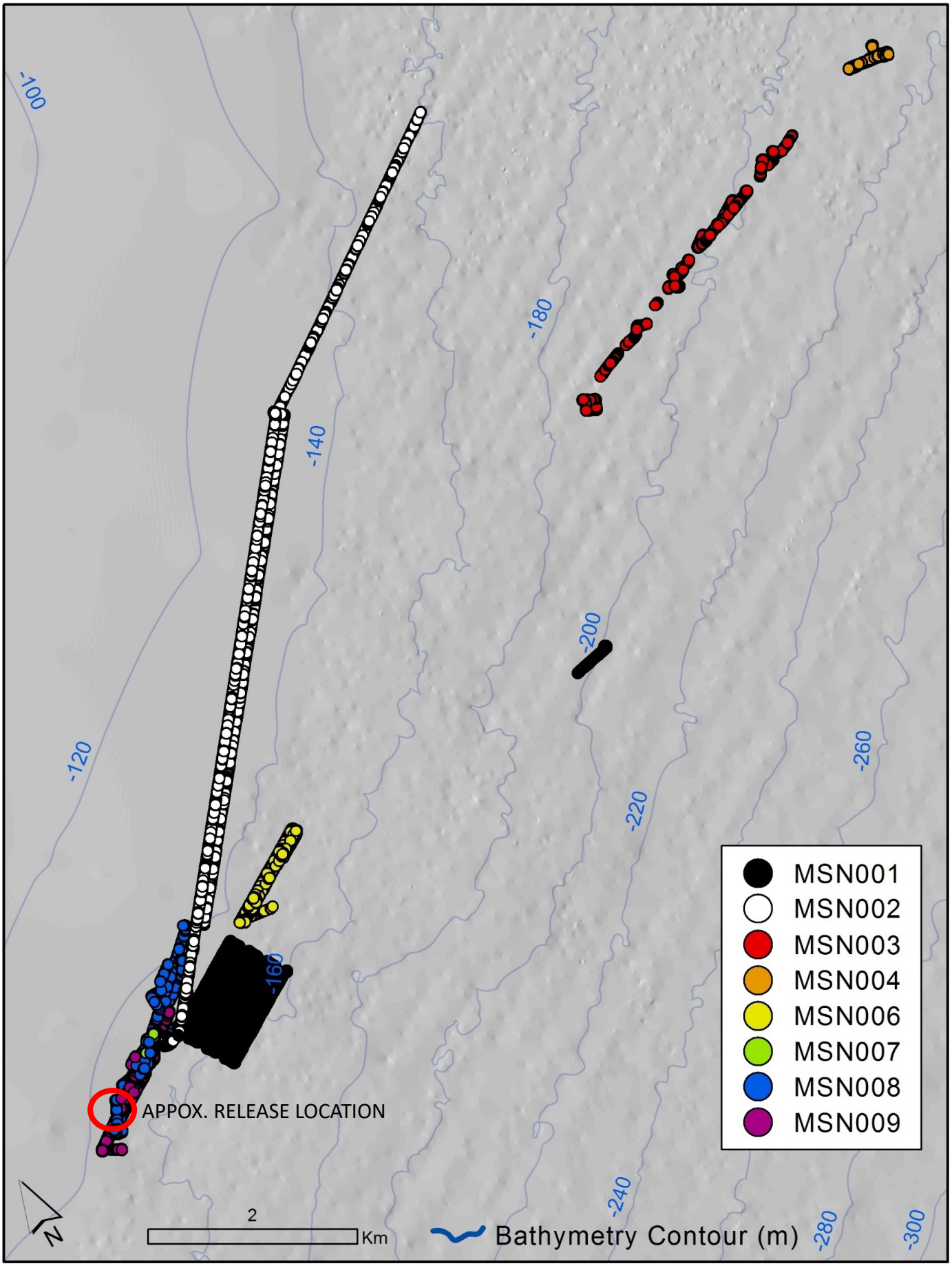


Figure 2 Data collection points for REMUS missions

MISSION DEPTHS

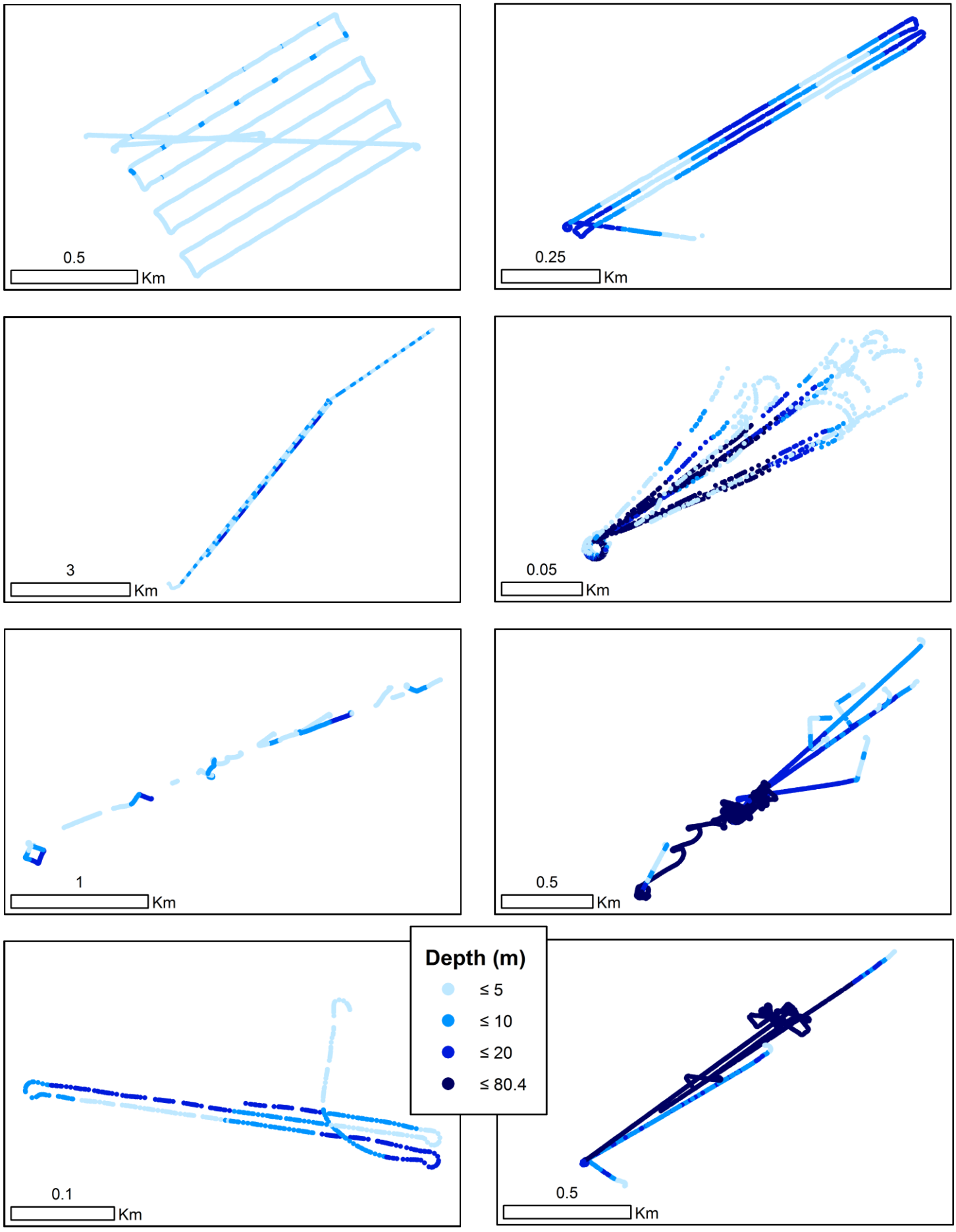


Figure 3 Mission depths

MISSION SUMMARY

Mission	Date	UTC Start Time	UTC Finish Time	# of Samples	Max Depth (m)	Mission Location (Blue)
MSN001	8/15/2017	9:24:29 PM	10:59:22 PM	3818	5.55	
MSN002	8/16/2017	2:28:14 PM	4:45:20 PM	5581	15.35	
MSN003	8/16/2017	6:37:09 PM	7:21:06 PM	1504	15.24	
MSN004	8/16/2017	7:34:26 PM	7:46:25 PM	496	15.48	
MSN006	8/16/2017	9:12:07 PM	9:46:26 PM	1386	15.4	
MSN007	8/17/2017	2:40:29 PM	3:26:45 PM	1815	63.97	
MSN008	8/17/2017	3:38:22 PM	4:35:19 PM	5031	73.72	
MSN009	8/17/2017	6:21:54 PM	7:16:02 PM	2187	80.84	

Table 1 Mission summaries

TEMPERATURE: ALL MISSIONS

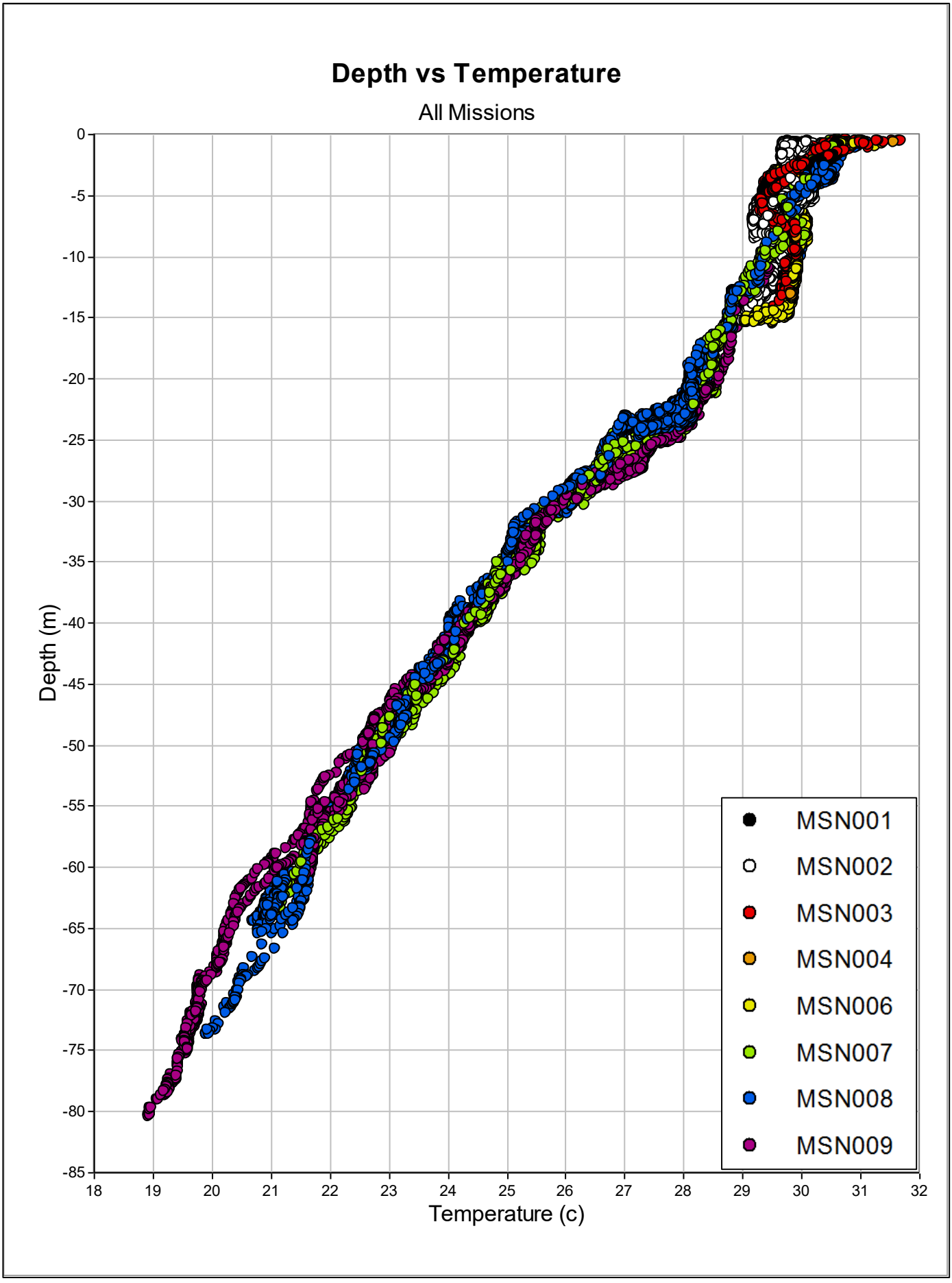


Figure 4 Temperature scatterplot—all missions

TEMPERATURE: MISSIONS 1-4

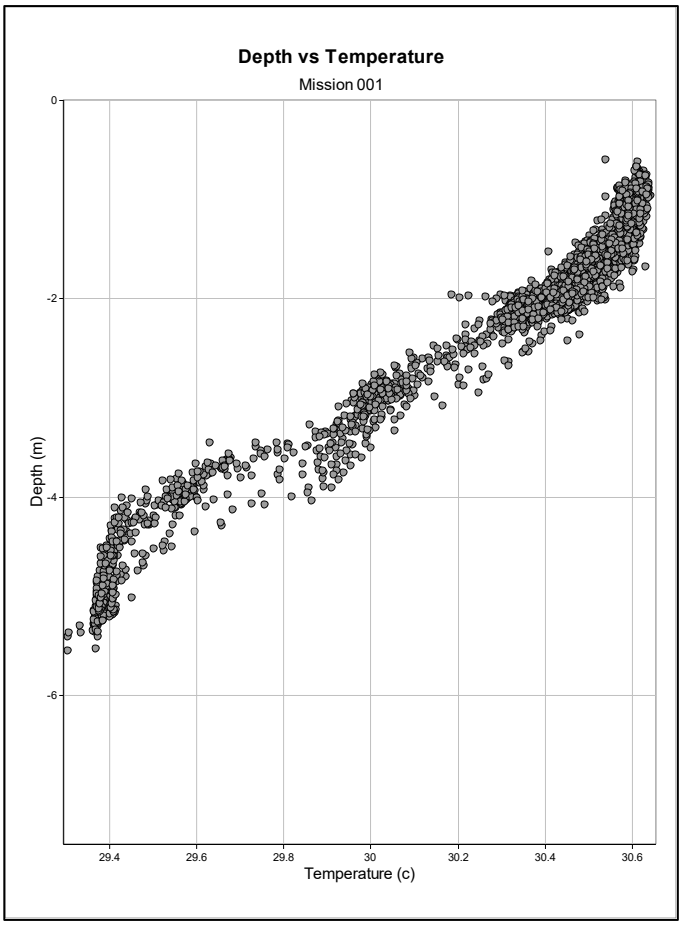


Figure 5 Temperature scatterplot—MSN 1

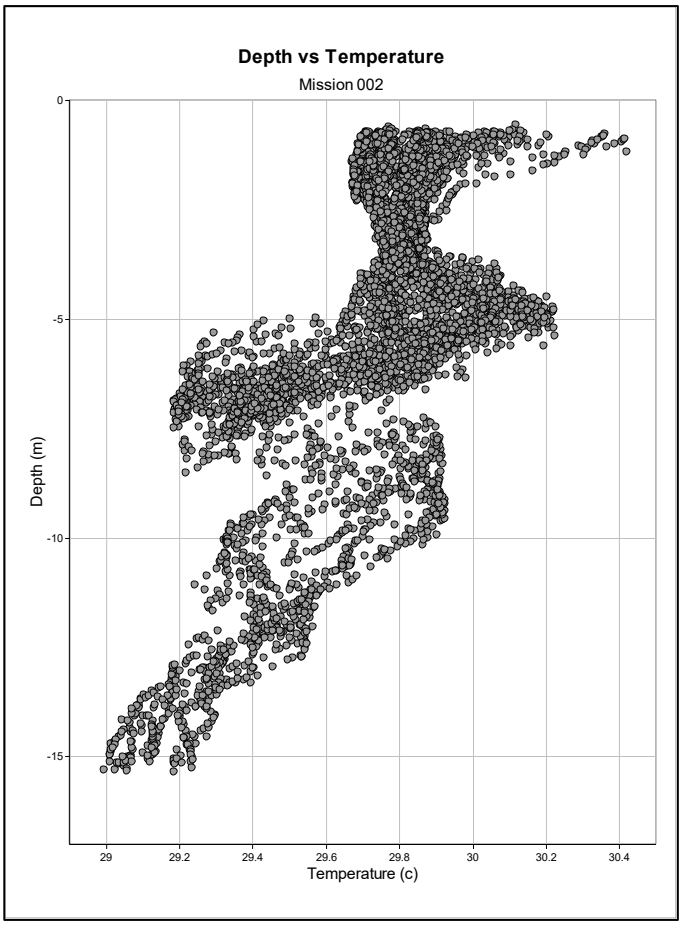


Figure 6 Temperature scatterplot—MSN 2

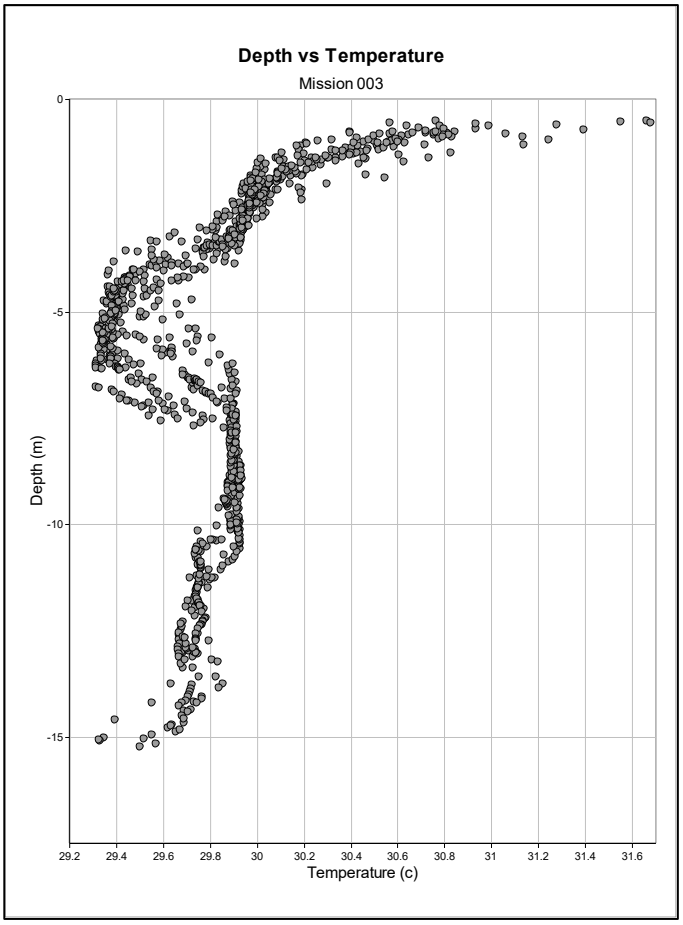


Figure 7 Temperature scatterplot—MSN 3

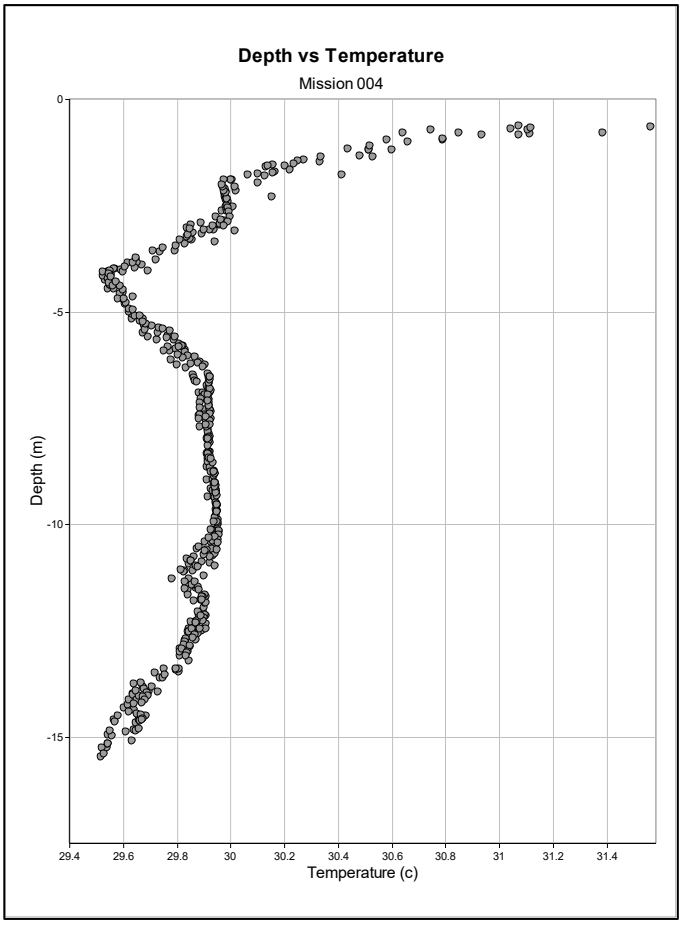


Figure 8 Temperature scatterplot—MSN 4

TEMPERATURE: MISSIONS 6-9

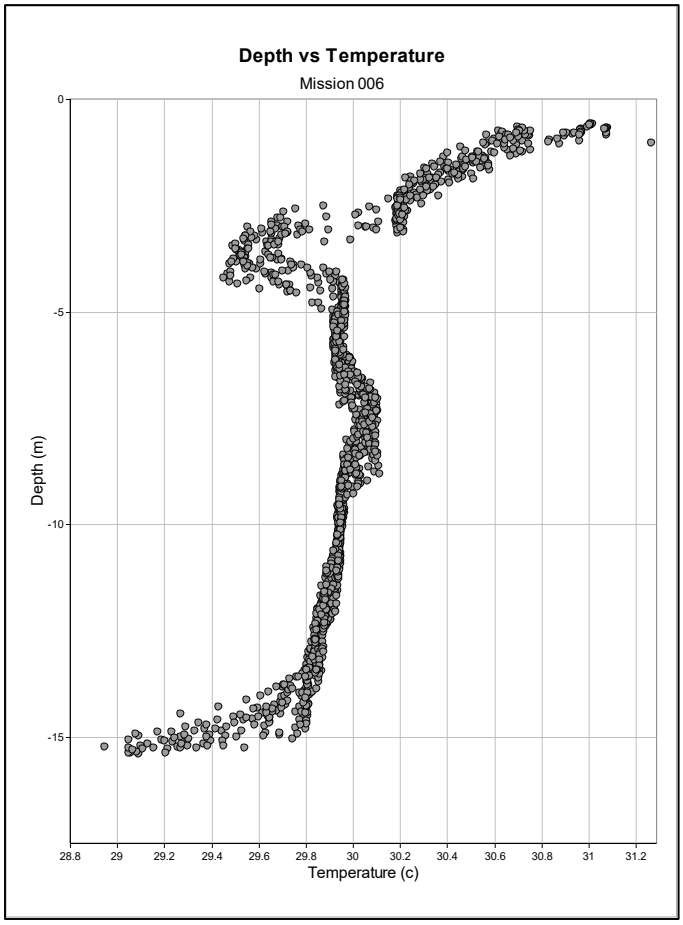


Figure 9 Temperature scatterplot—MSN 6

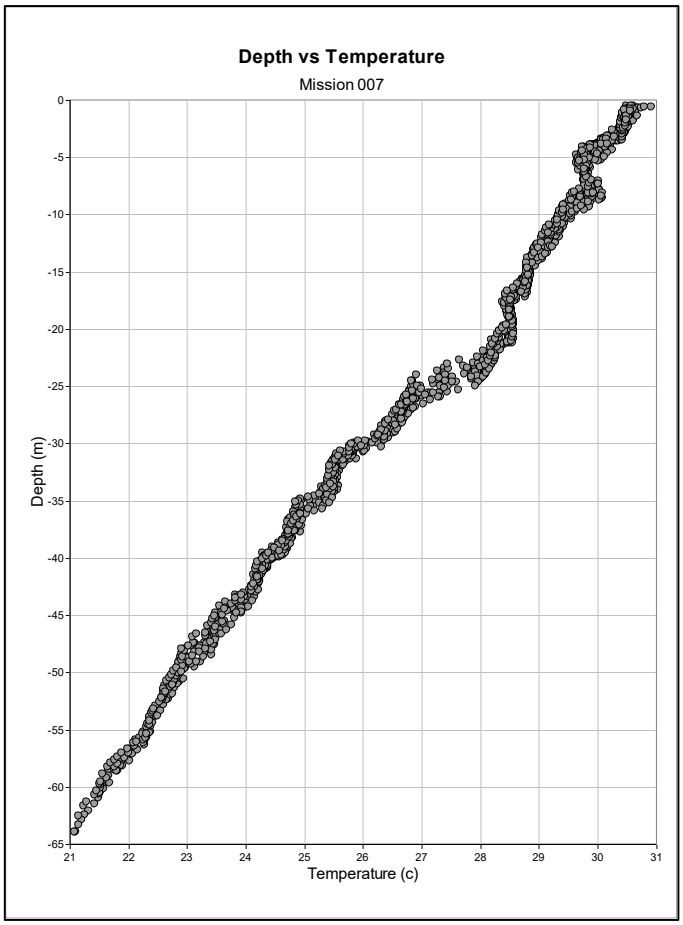


Figure 10 Temperature scatterplot—MSN 7

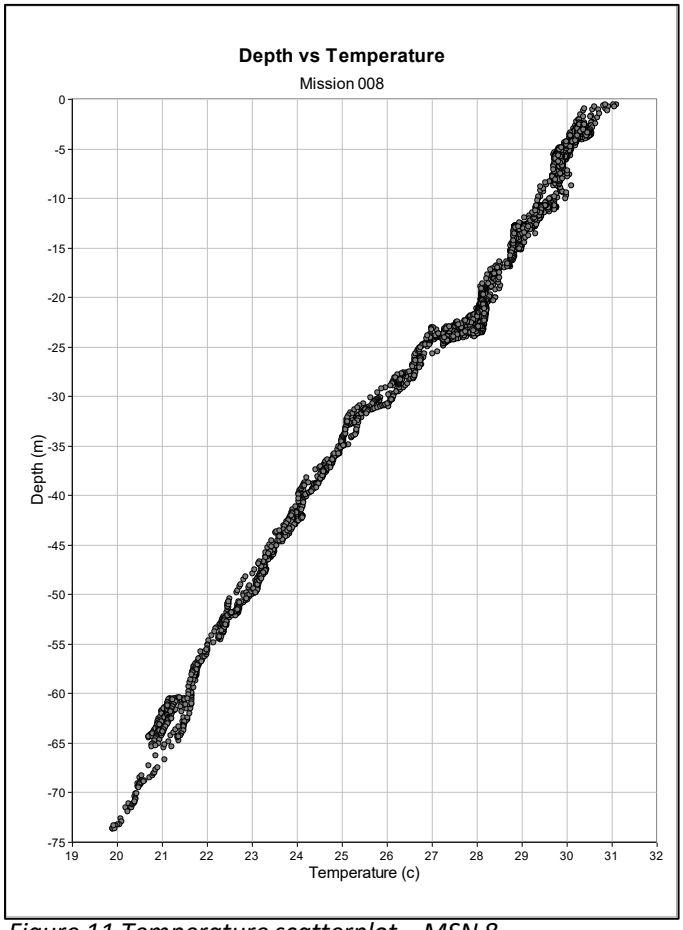


Figure 11 Temperature scatterplot—MSN 8

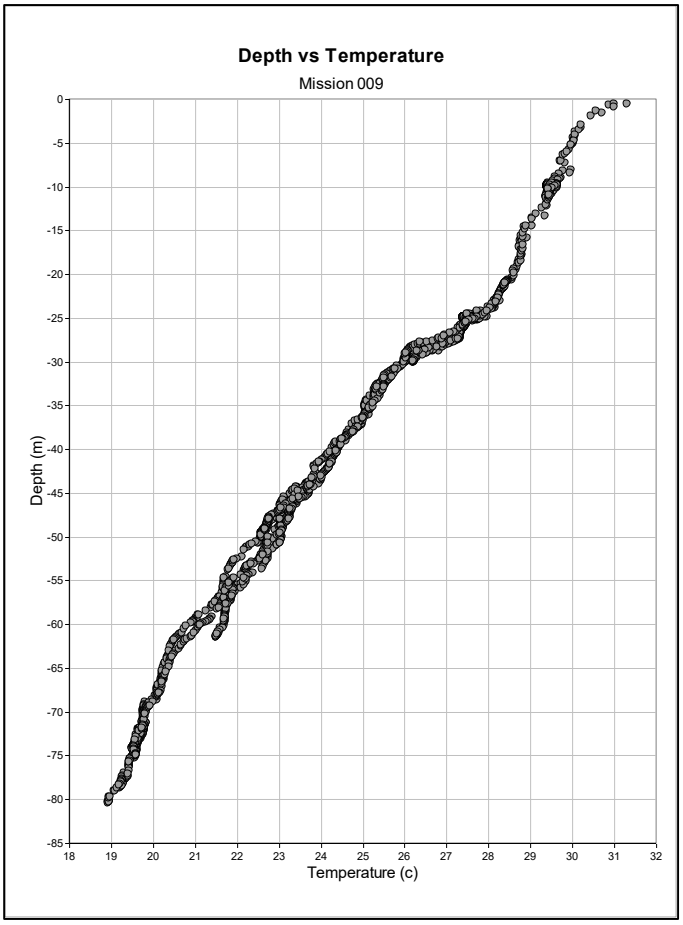


Figure 12 Temperature scatterplot—MSN 9

FDOM: ALL MISSIONS

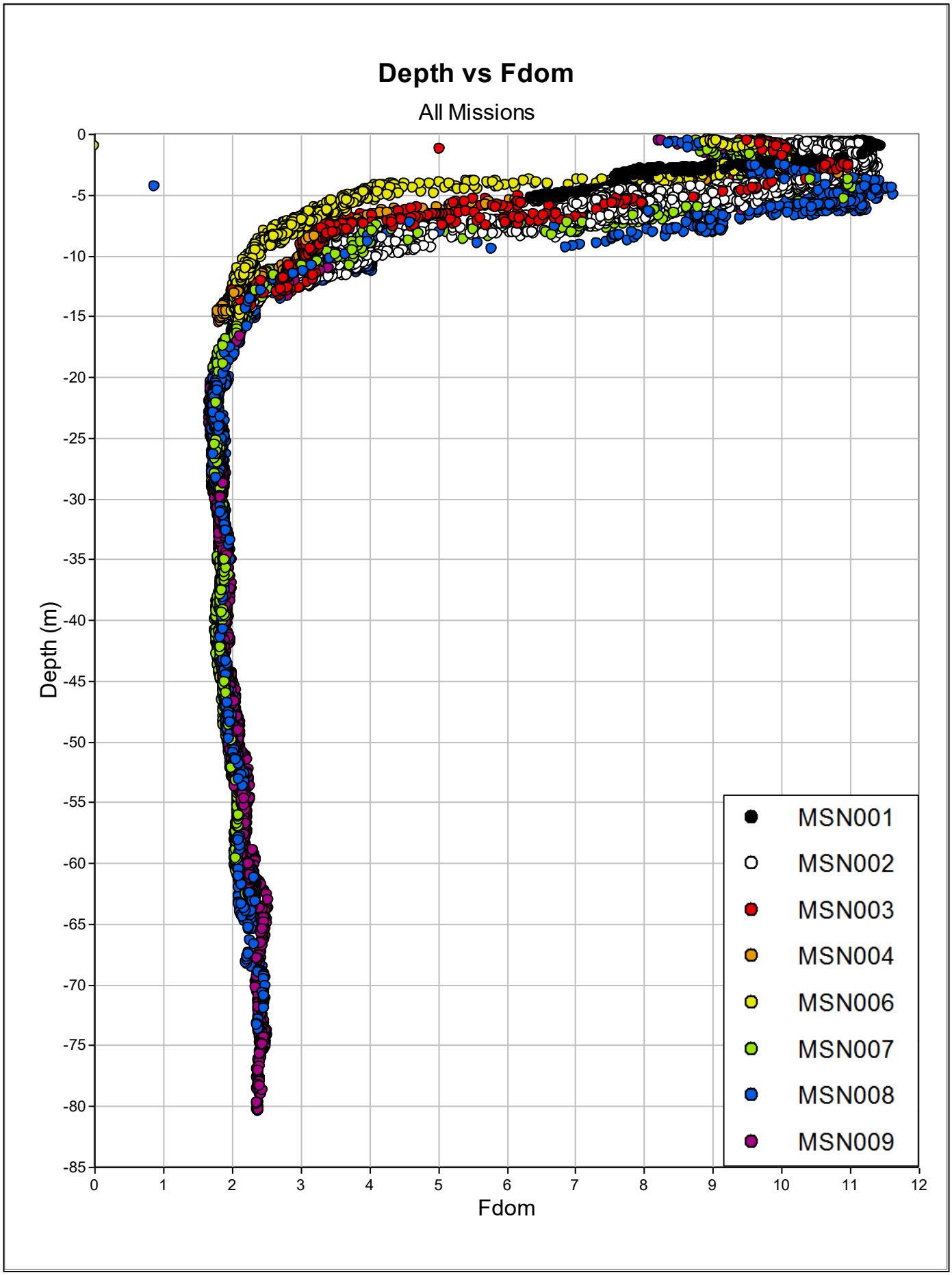


Figure 13 FDOM scatterplot—All missions

FDOM: MISSIONS 1-4

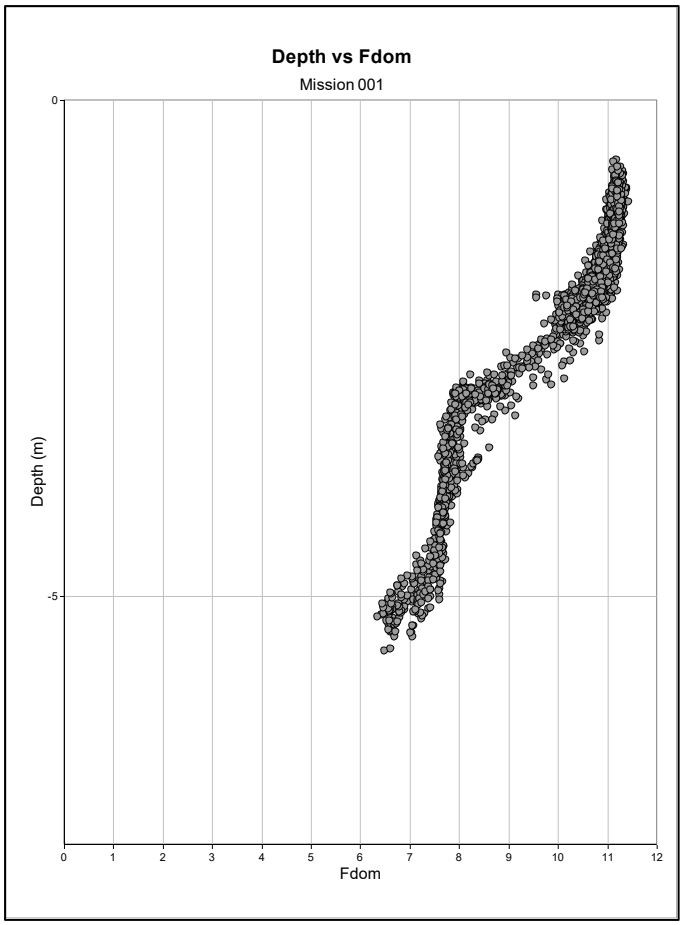


Figure 14 FDOM scatterplot—MSN 1

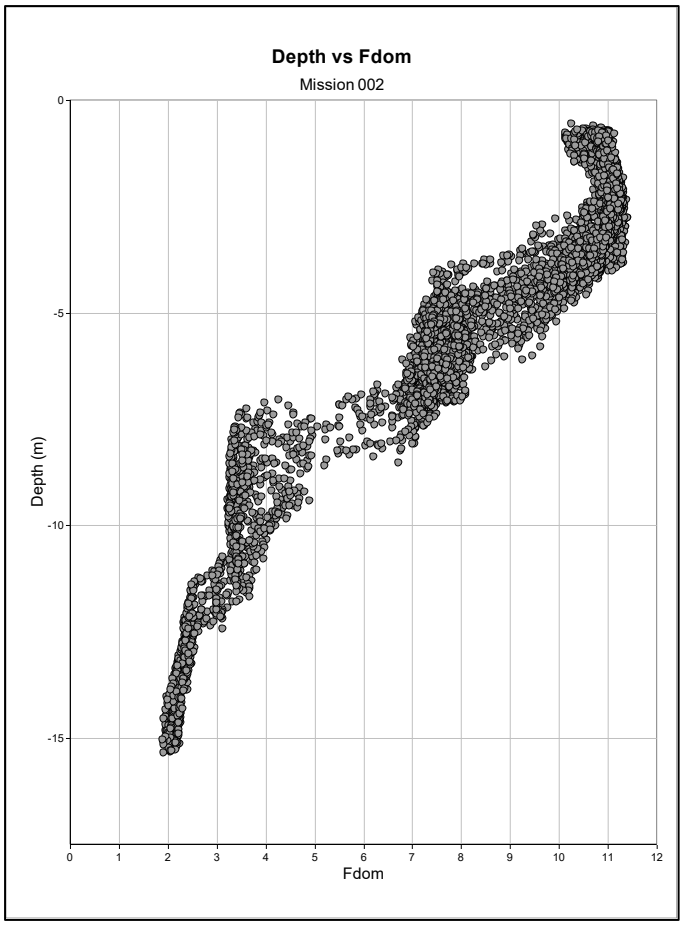


Figure 15 FDOM scatterplot—MSN 2

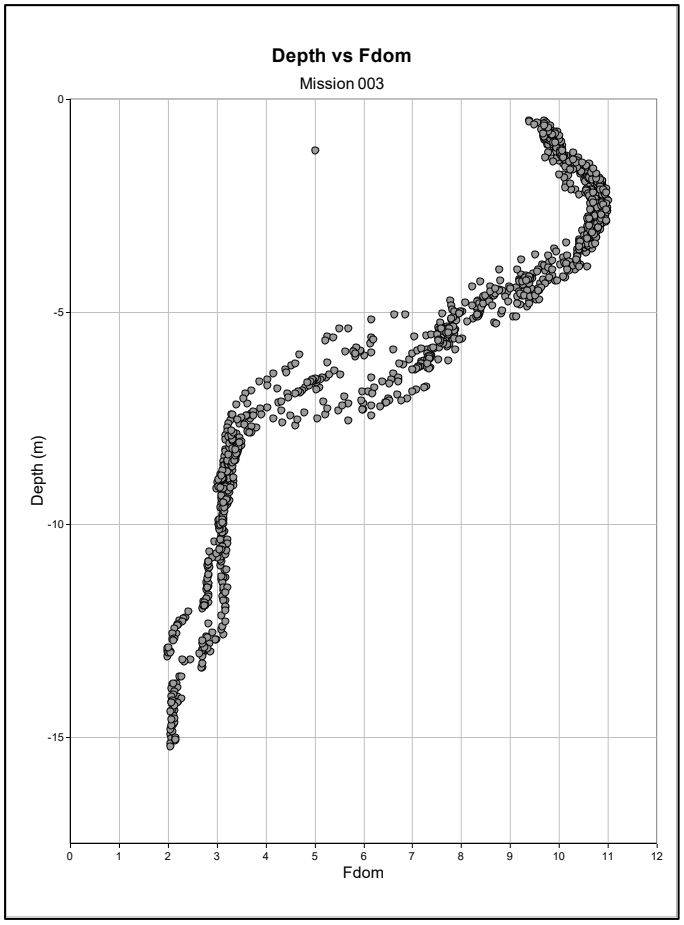


Figure 16 FDOM scatterplot—MSN 3

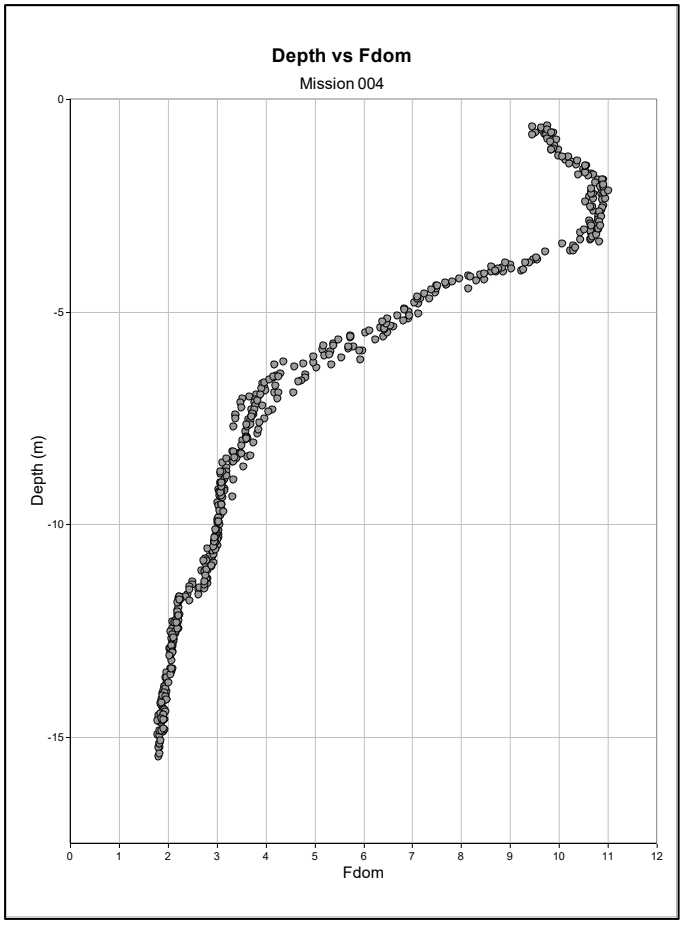


Figure 17 FDOM scatterplot—MSN 4

FDOM: MISSIONS 6-9

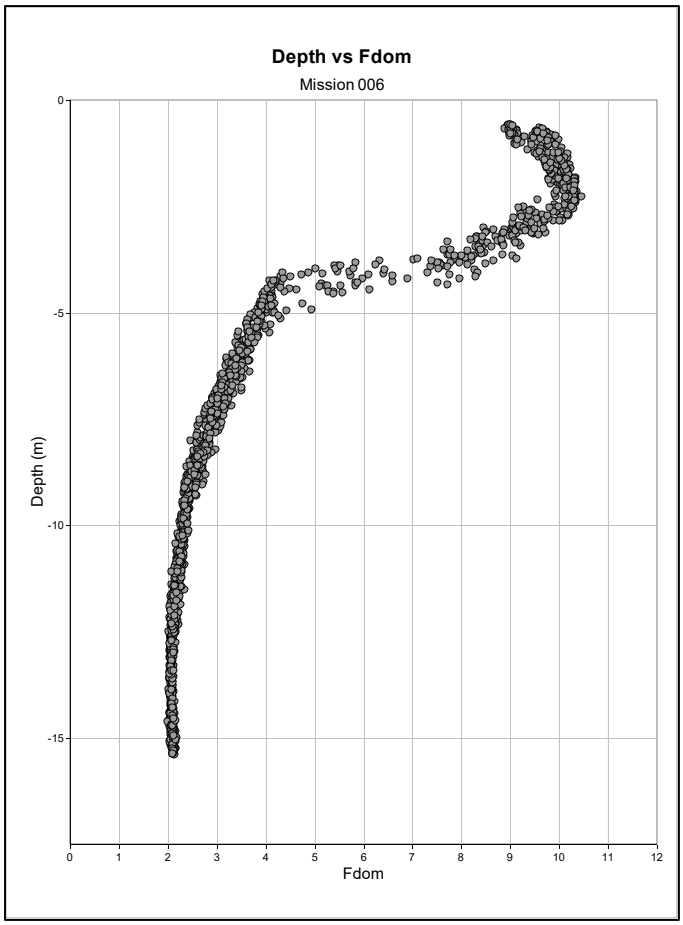


Figure 18 FDOM scatterplot—MSN 6

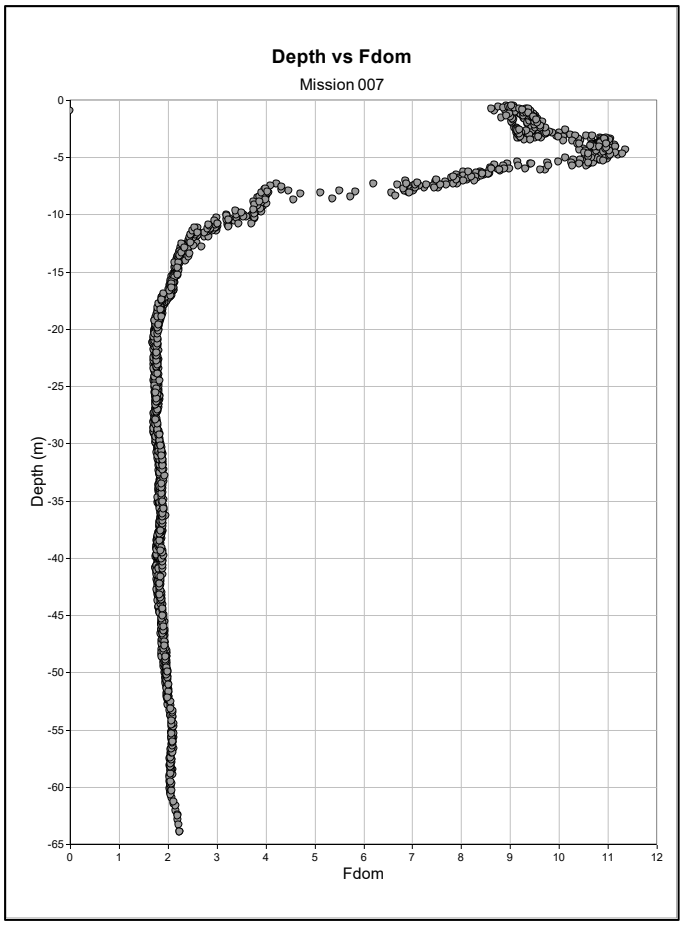


Figure 19 FDOM scatterplot—MSN 7

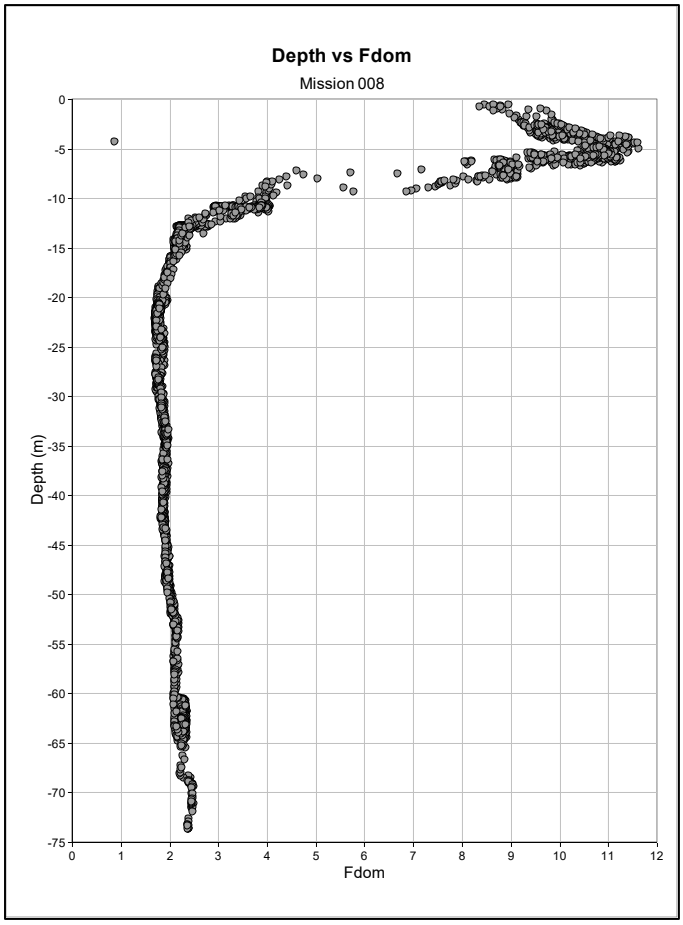


Figure 20 FDOM scatterplot—MSN 8

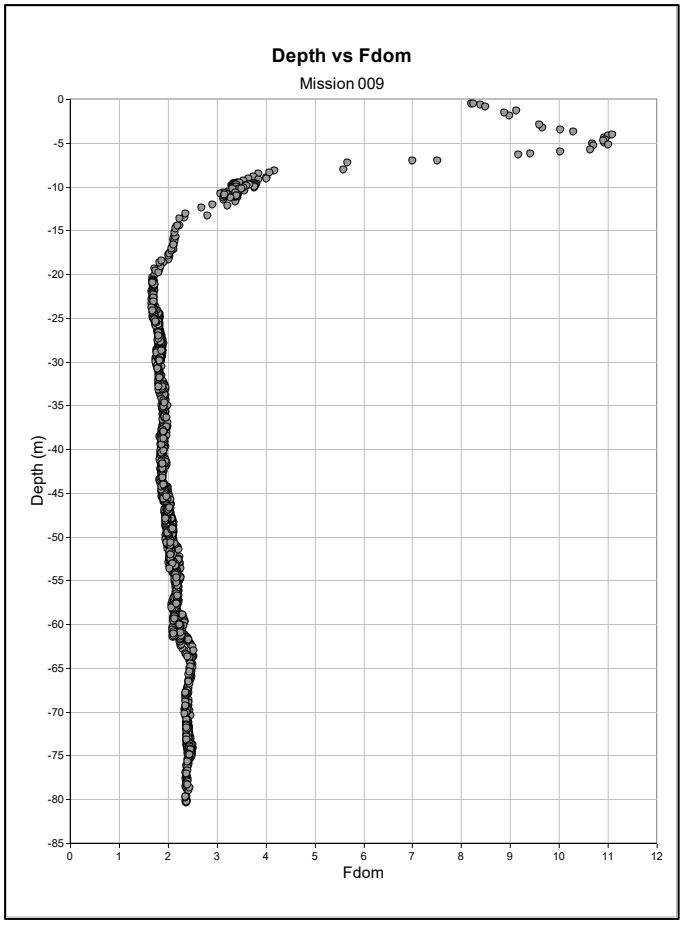


Figure 21 FDOM scatterplot—MSN 9

FDOM/BACKSCATTER: ALL MISSIONS

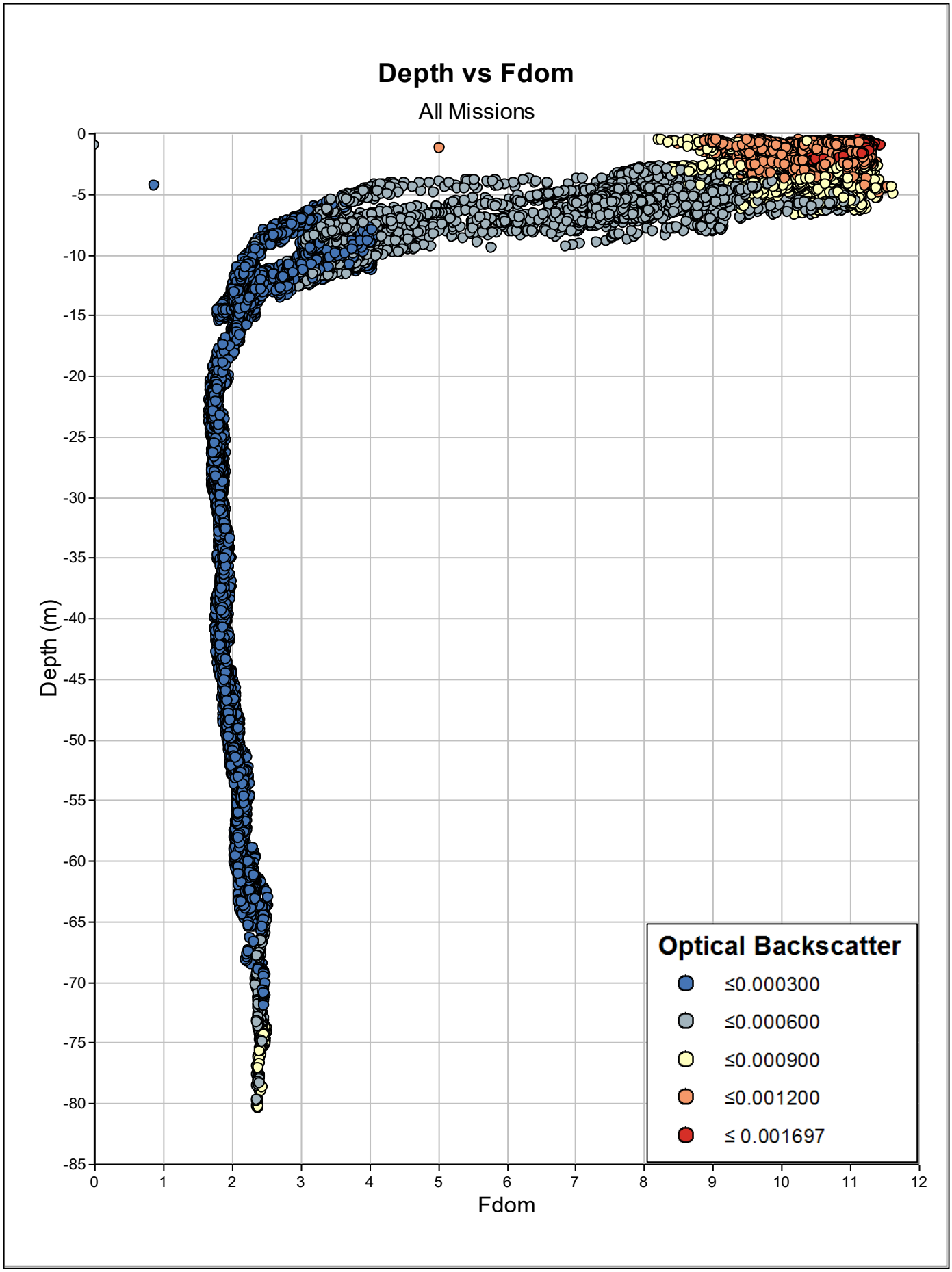


Figure 22 FDOM/Backscatter scatterplot—All missions

FDOM/BACKSCATTER: MISSIONS 1-4

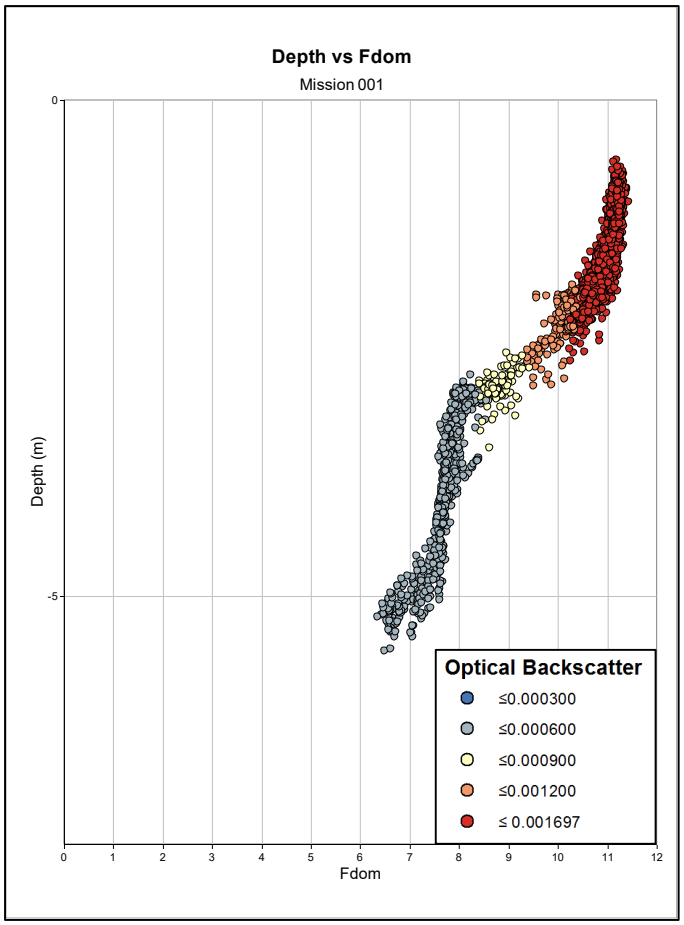


Figure 23 FDOM/Backscatter scatterplot—MSN 1

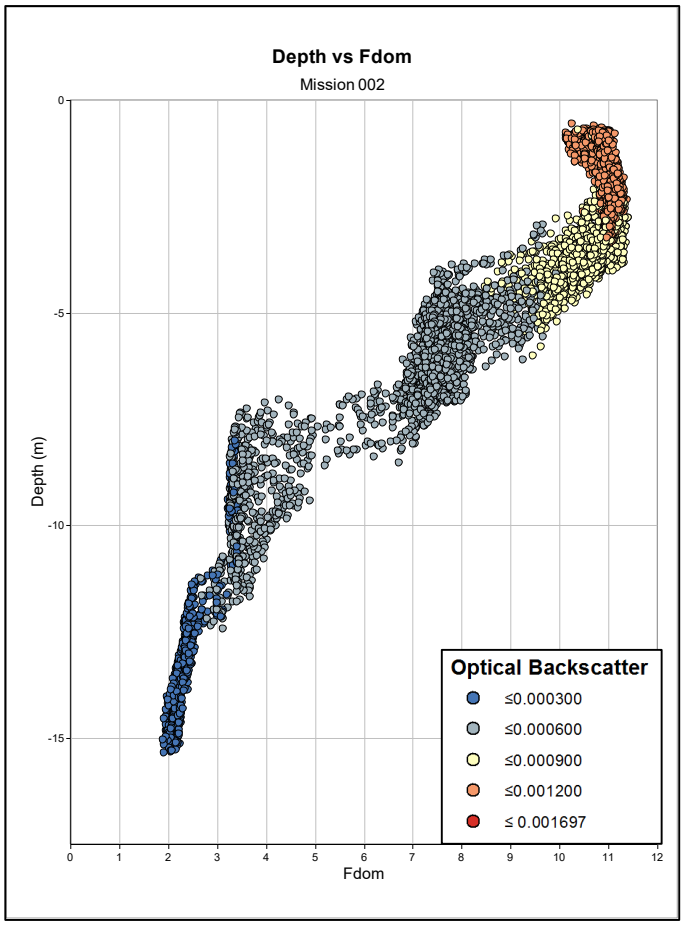


Figure 24 FDOM/Backscatter scatterplot—MSN 2

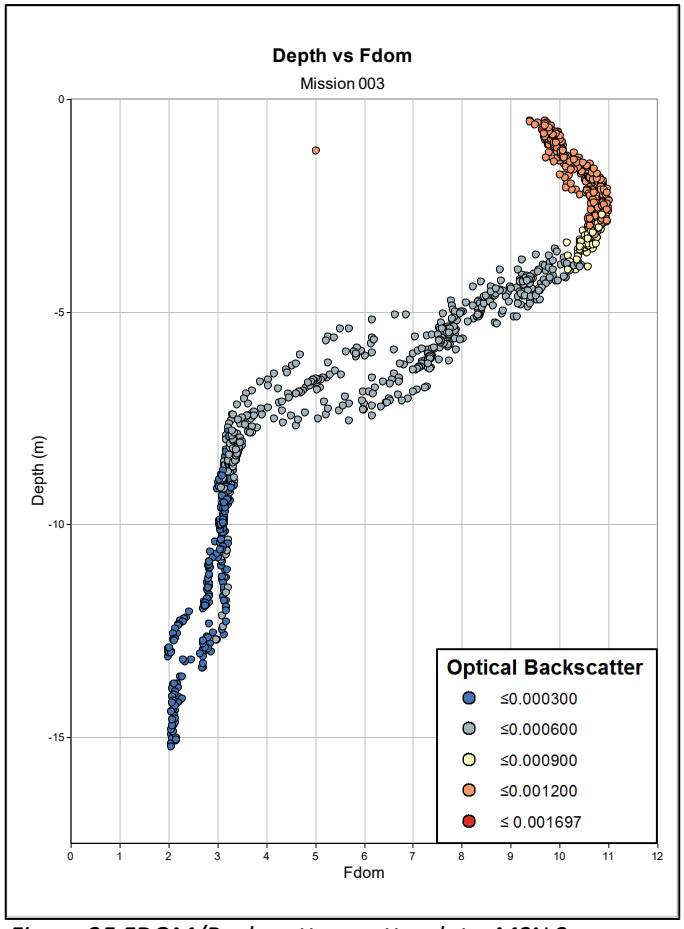


Figure 25 FDOM/Backscatter scatterplot—MSN 3

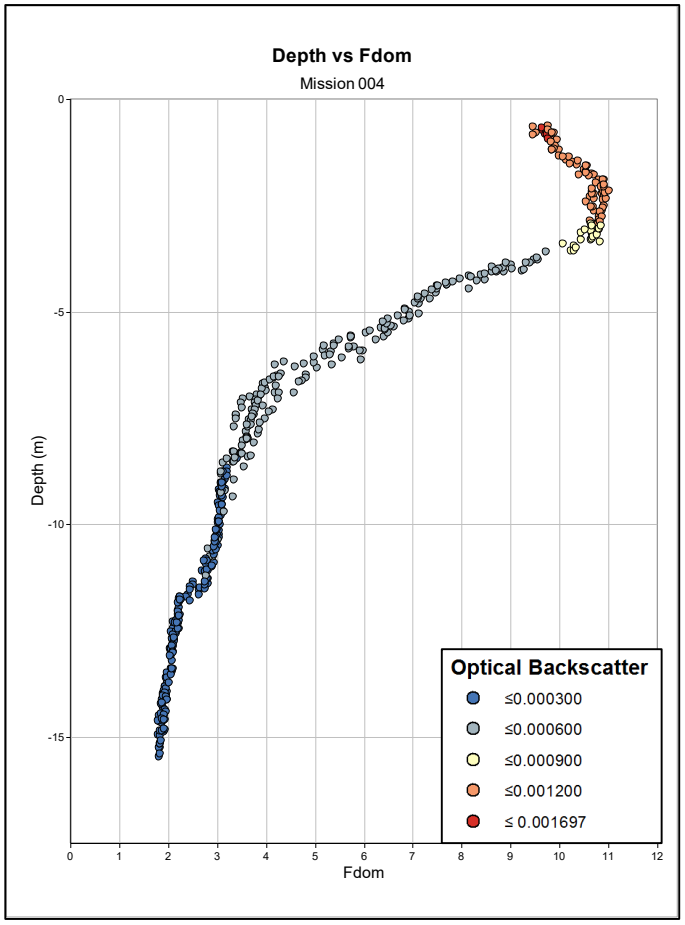


Figure 26 FDOM/Backscatter scatterplot—MSN 4

FDOM/BACKSCATTER: MISSIONS 6-9

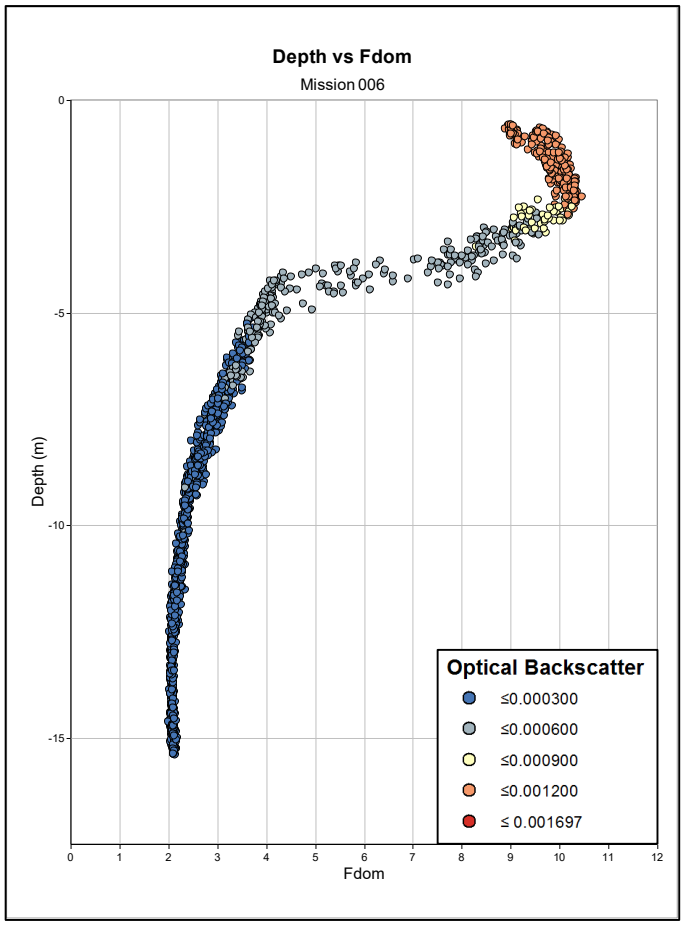


Figure 27 FDOM/Backscatter scatterplot—MSN 6

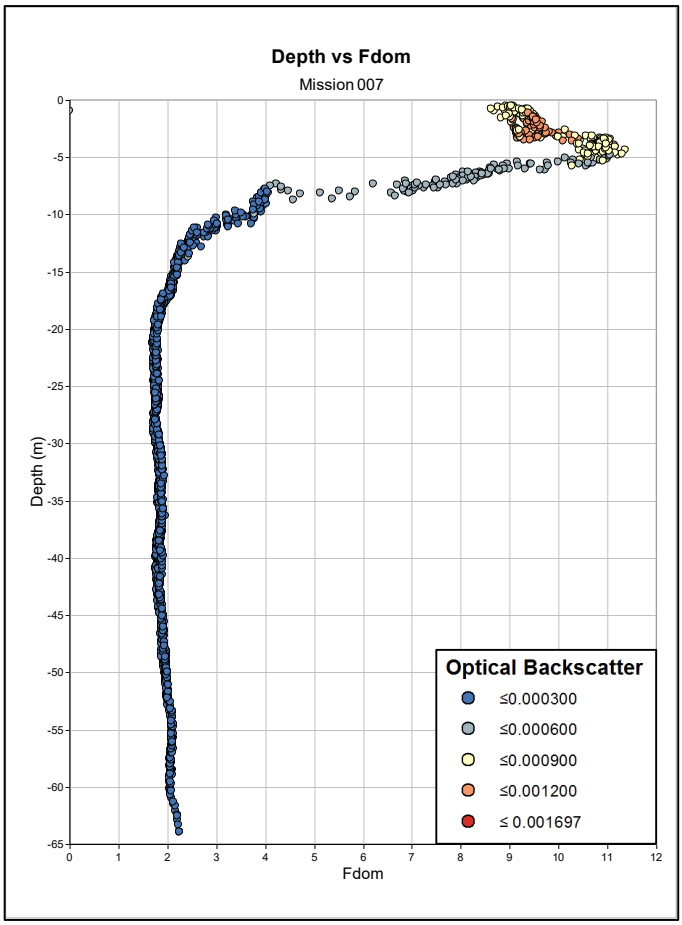


Figure 28 FDOM/Backscatter scatterplot—MSN 7

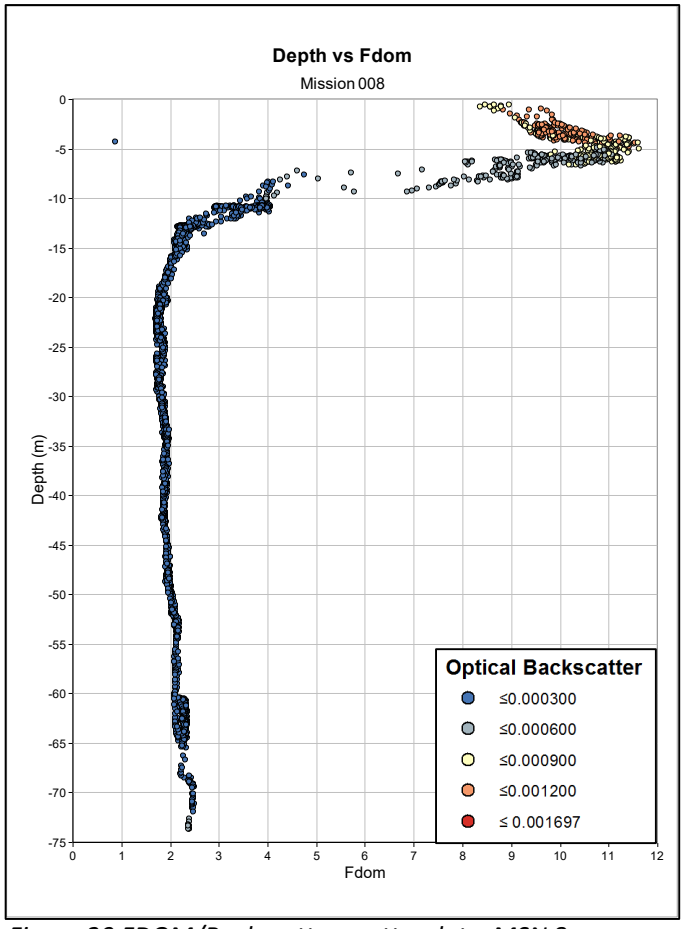


Figure 29 FDOM/Backscatter scatterplot—MSN 8

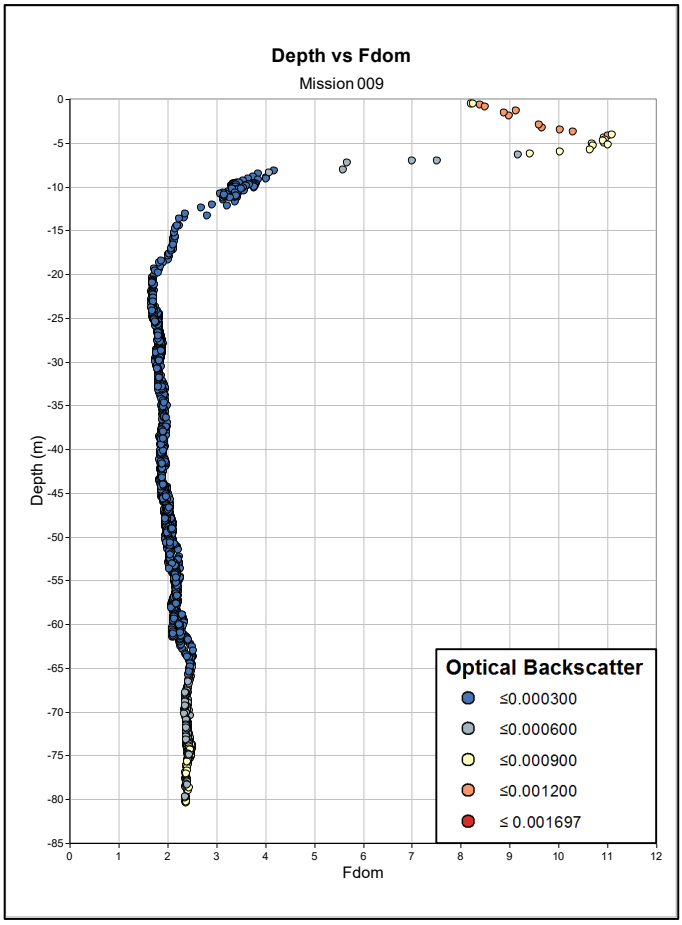


Figure 30 FDOM/Backscatter scatterplot—MSN 9

BACKSCATTER: ALL MISSIONS

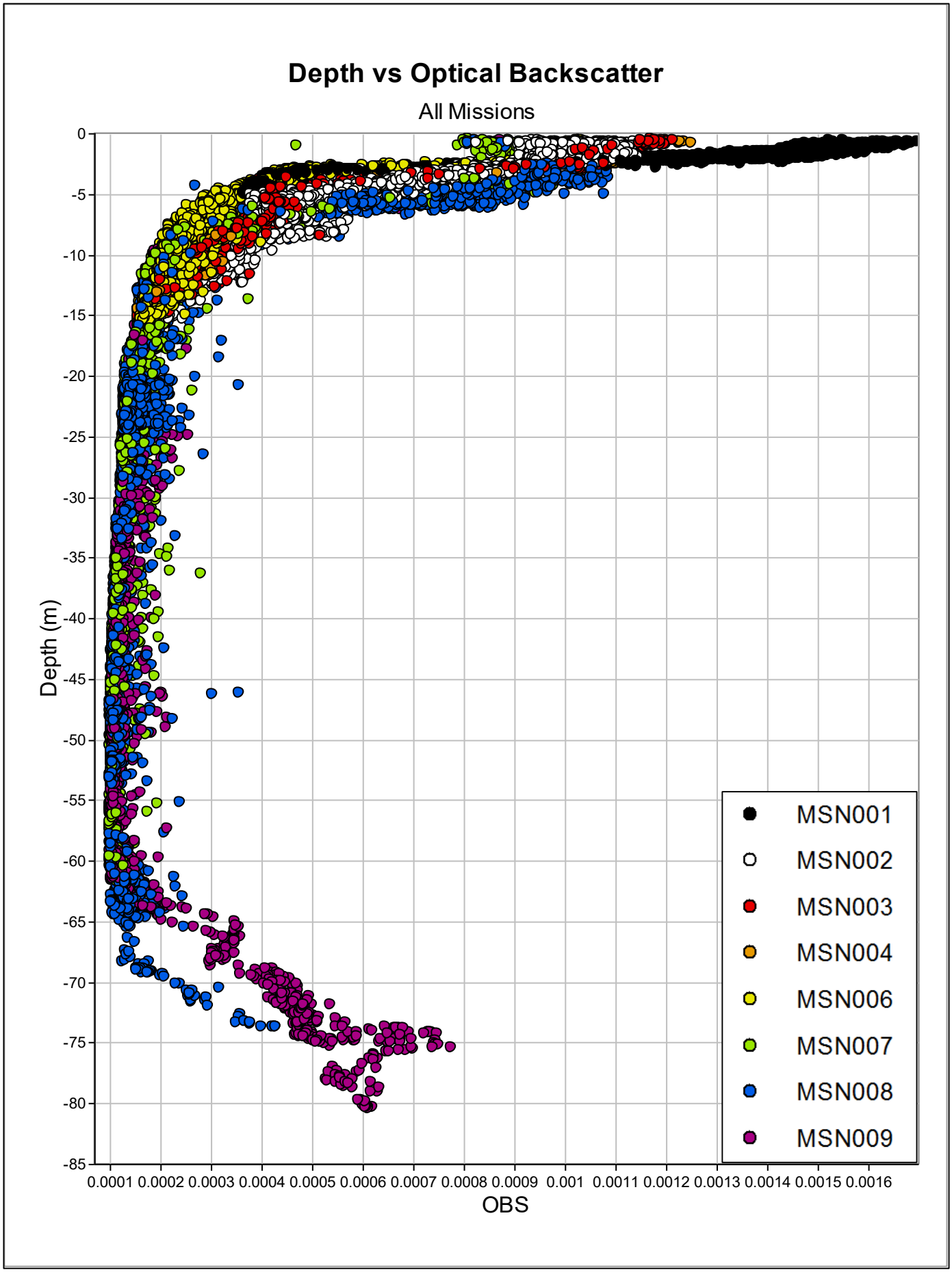


Figure 31 Optical backscatter scatterplot—All missions

BACKSCATTER: MISSIONS 1-4

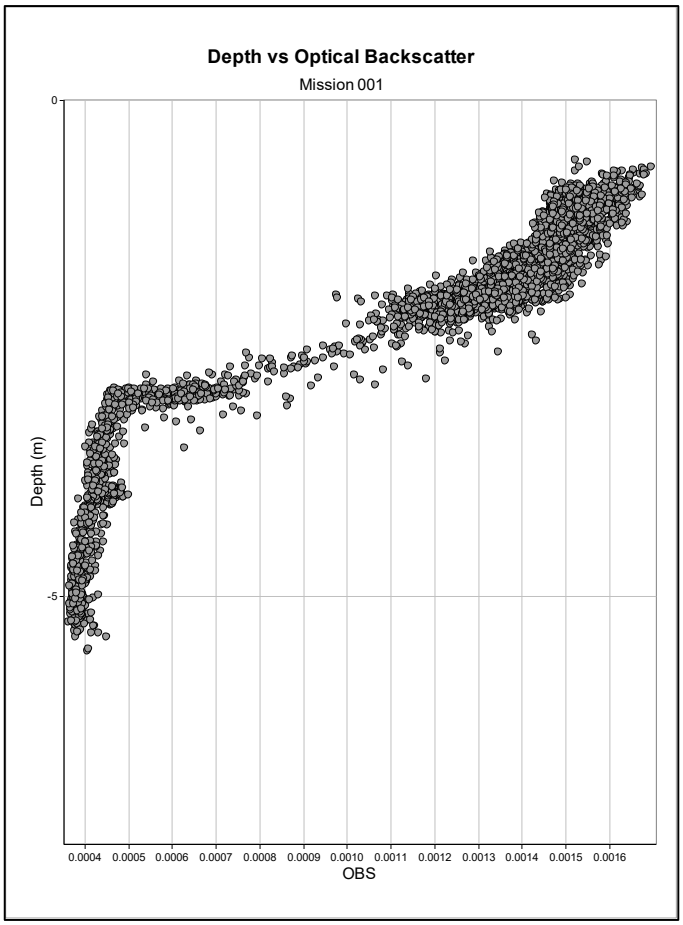


Figure 32 Optical backscatter scatterplot—MSN 1

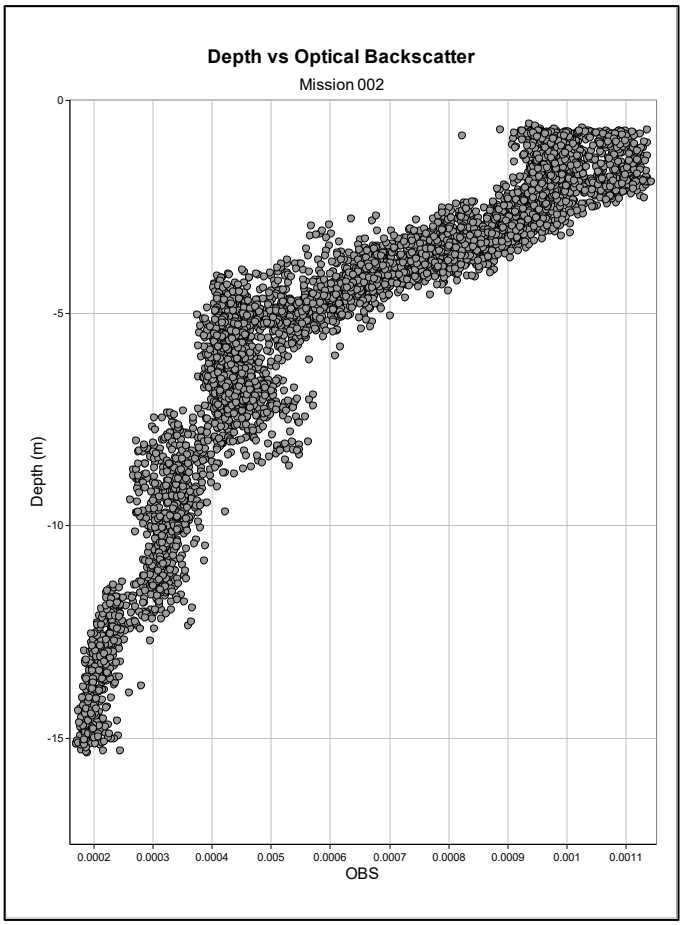


Figure 33 Optical backscatter scatterplot—MSN 2

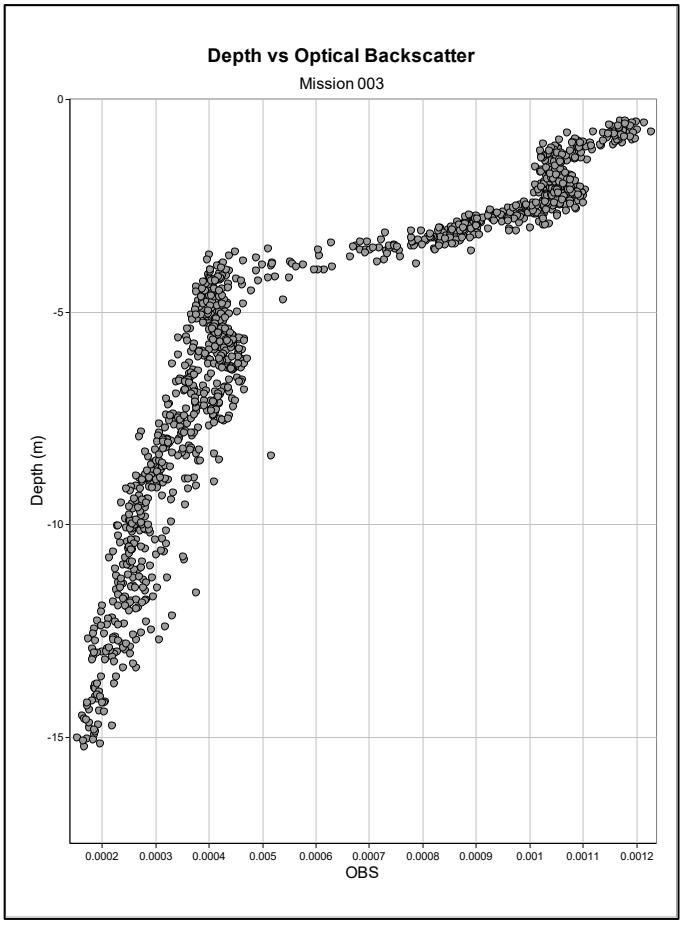


Figure 34 Optical backscatter scatterplot—MSN 3

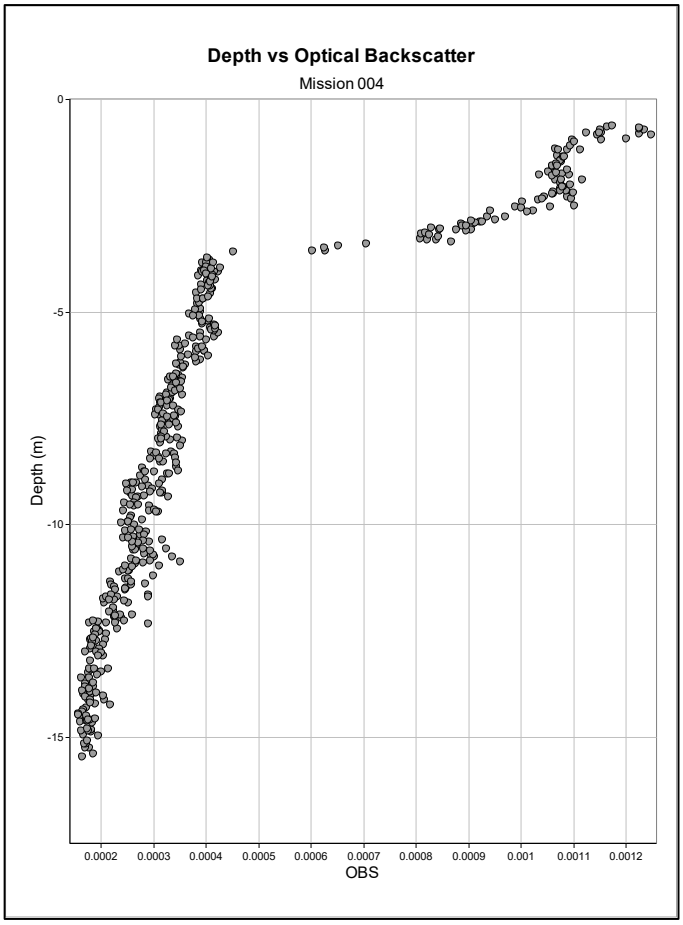


Figure 35 Optical backscatter scatterplot—MSN 4

BACKSCATTER: MISSIONS 6-9

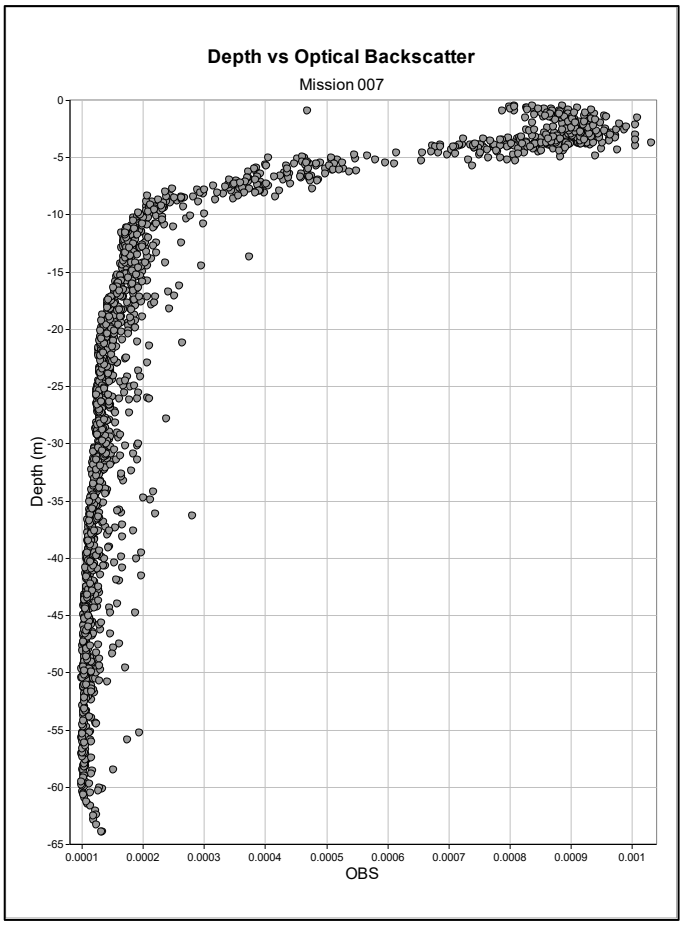


Figure 36 Optical backscatter scatterplot—MSN 6

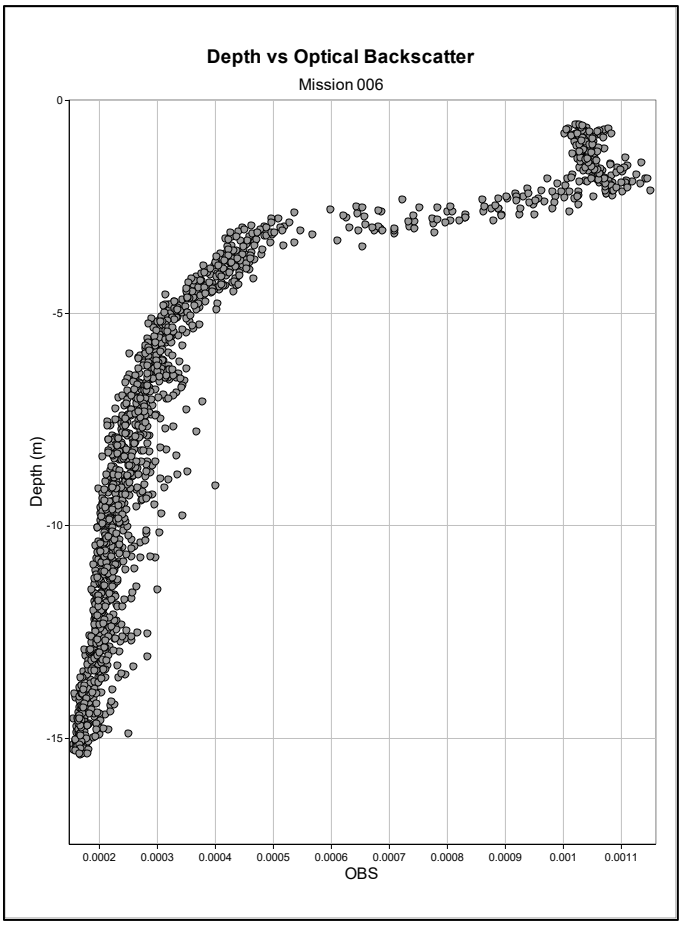


Figure 37 Optical backscatter scatterplot—MSN 7

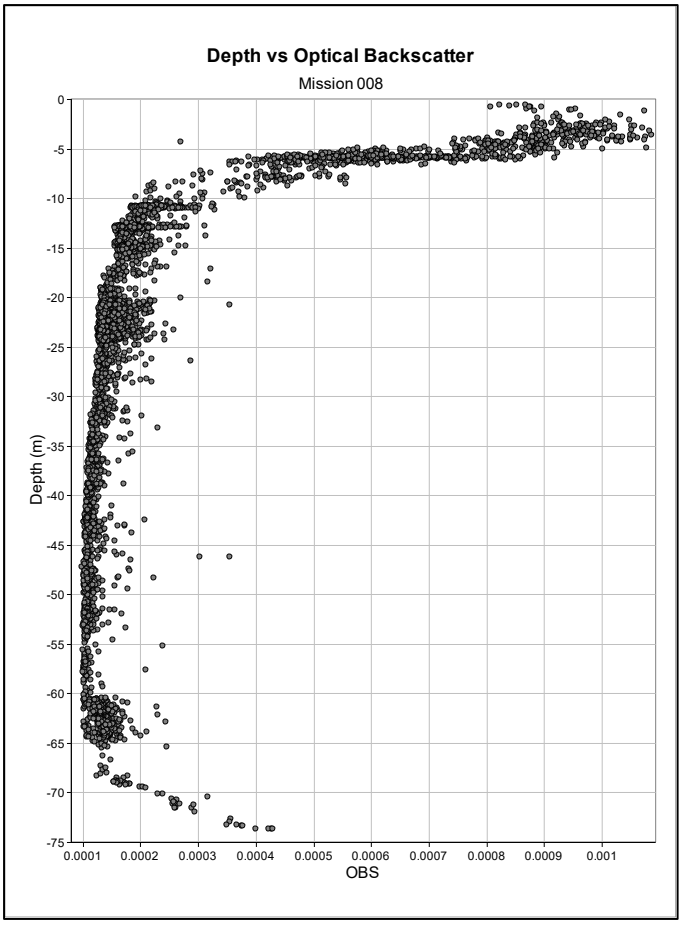


Figure 38 Optical backscatter scatterplot—MSN 8

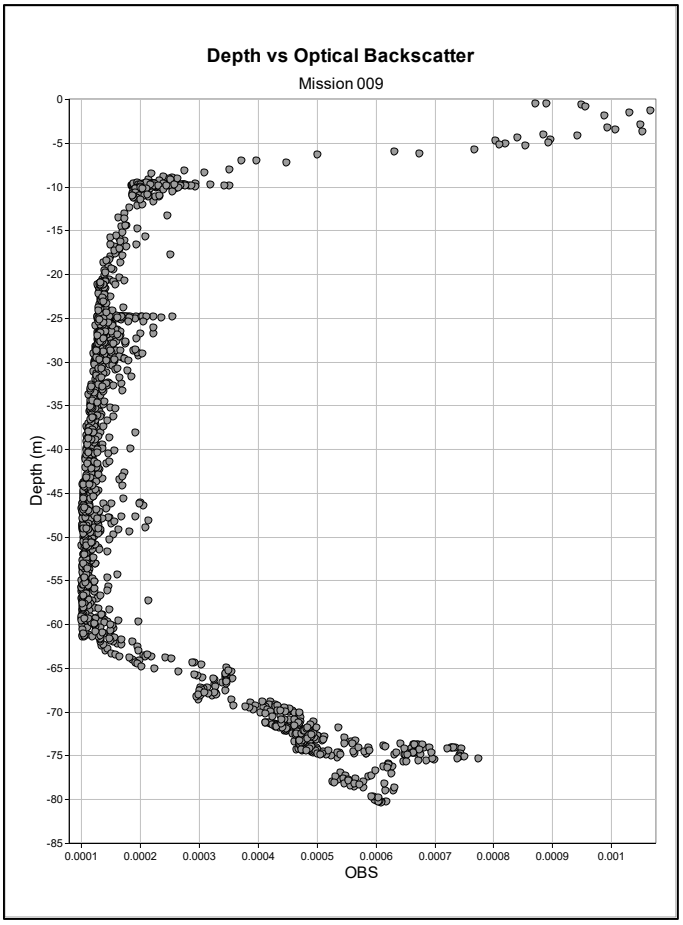


Figure 39 Optical backscatter scatterplot—MSN 9

SALINITY: ALL MISSIONS

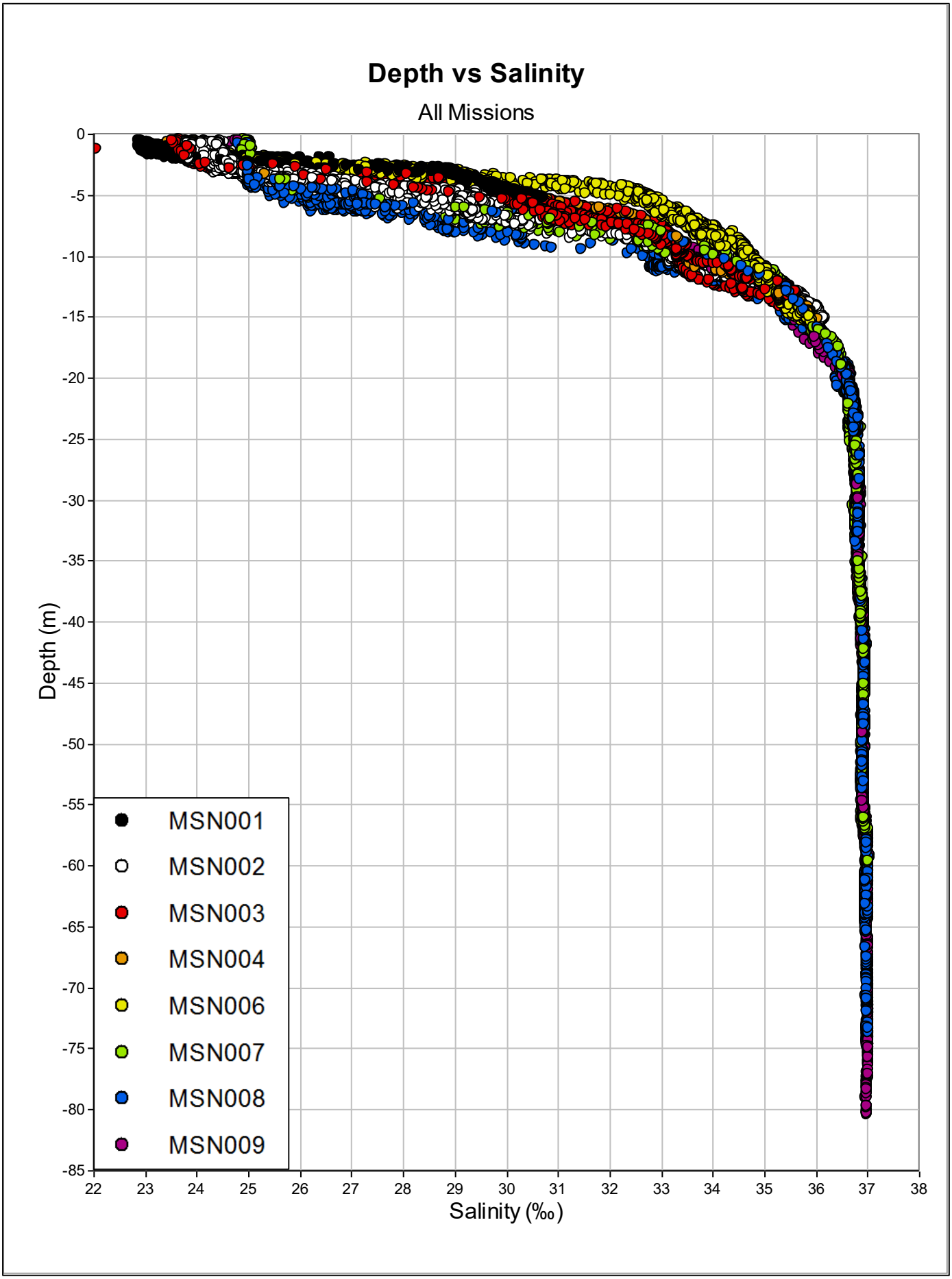


Figure 40 Salinity scatterplot—All missions

SALINITY: MISSIONS 1-4

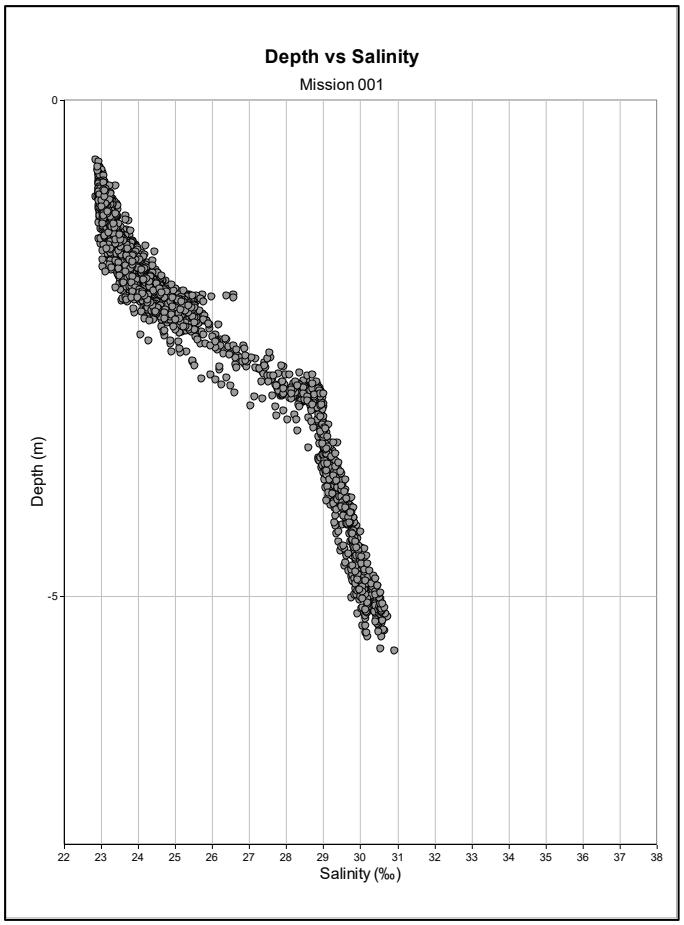


Figure 41 salinity scatterplot—MSN 1

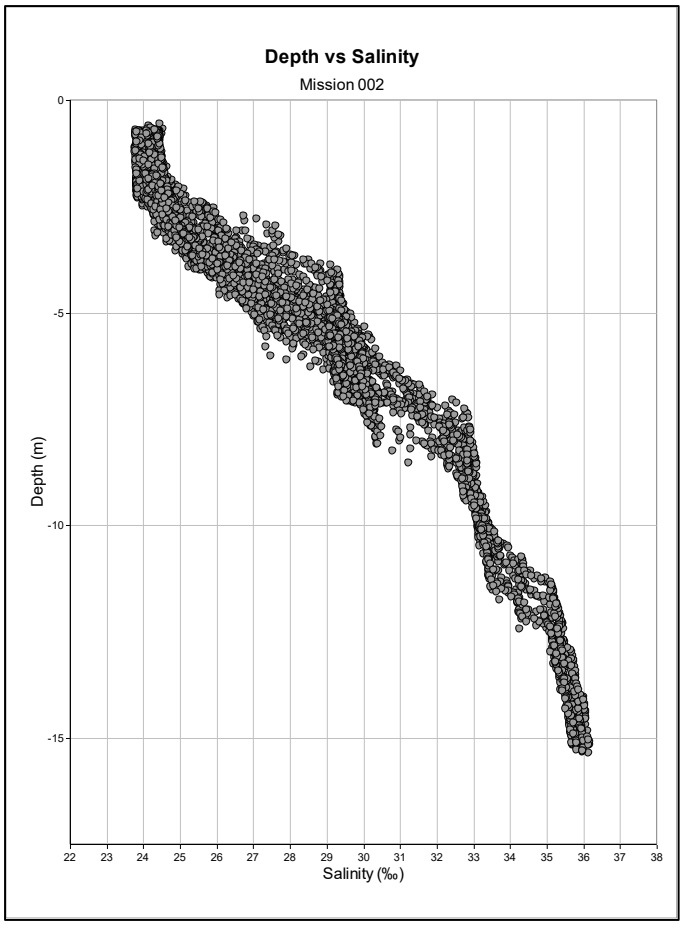


Figure 42 salinity scatterplot—MSN 2

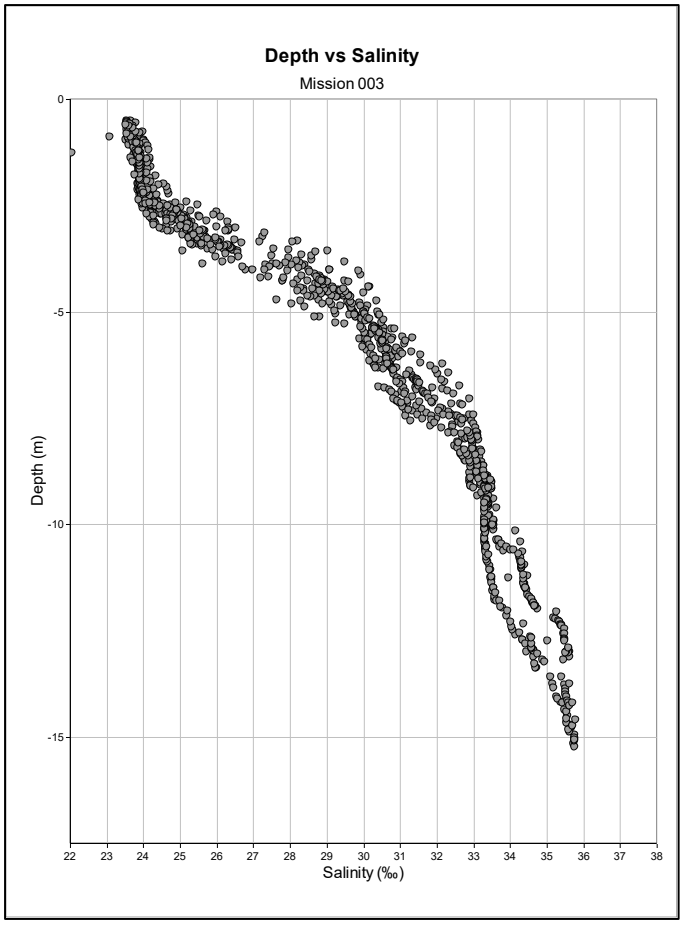


Figure 43 salinity scatterplot—MSN 3

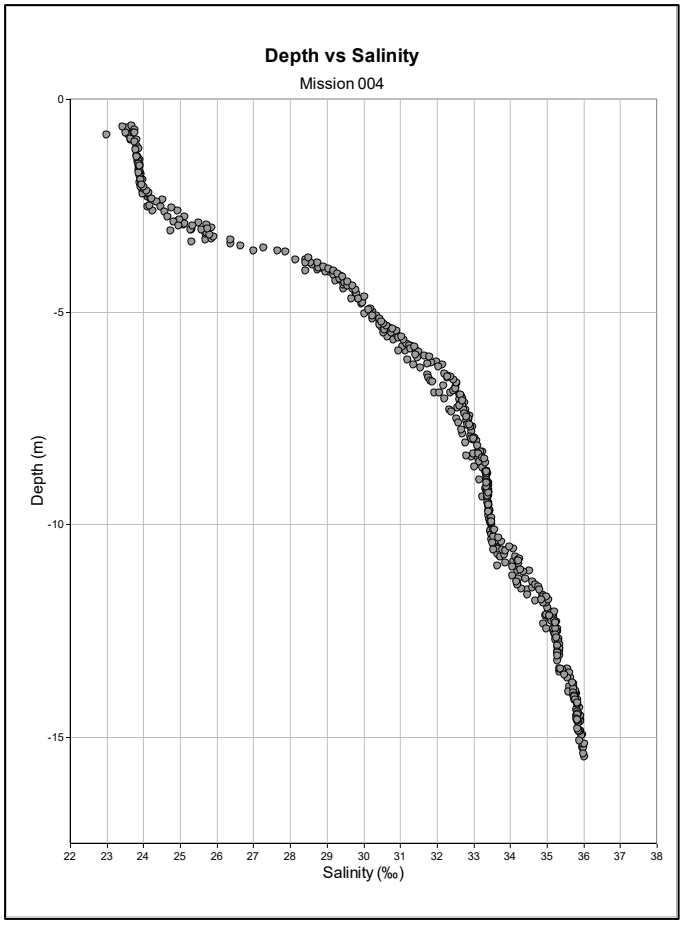


Figure 44 salinity scatterplot—MSN 4

SALINITY: MISSIONS 6-9

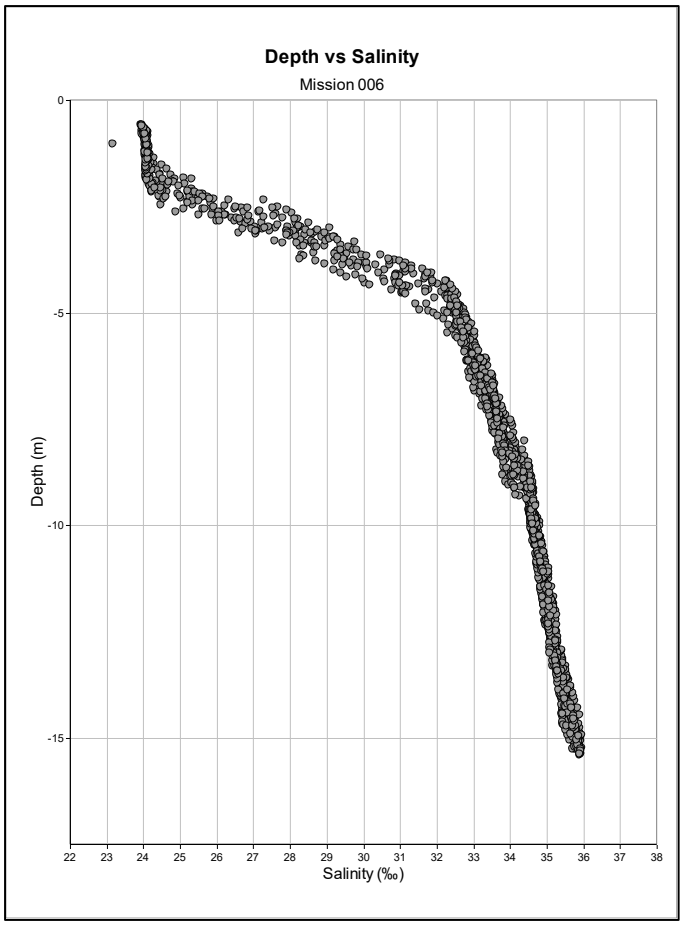


Figure 45 salinity scatterplot—MSN 6

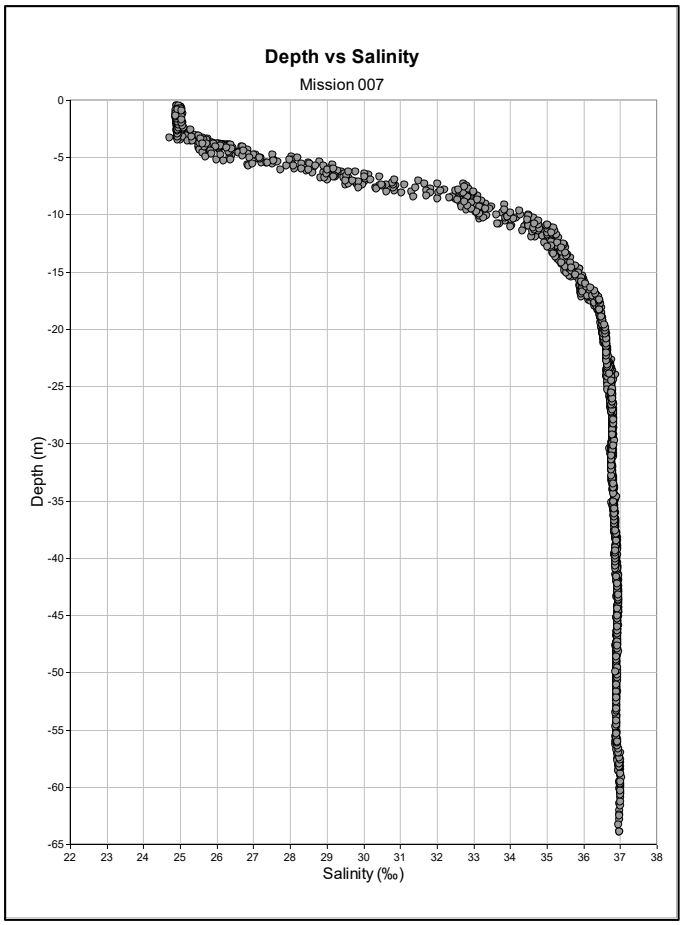


Figure 46 salinity scatterplot—MSN 7

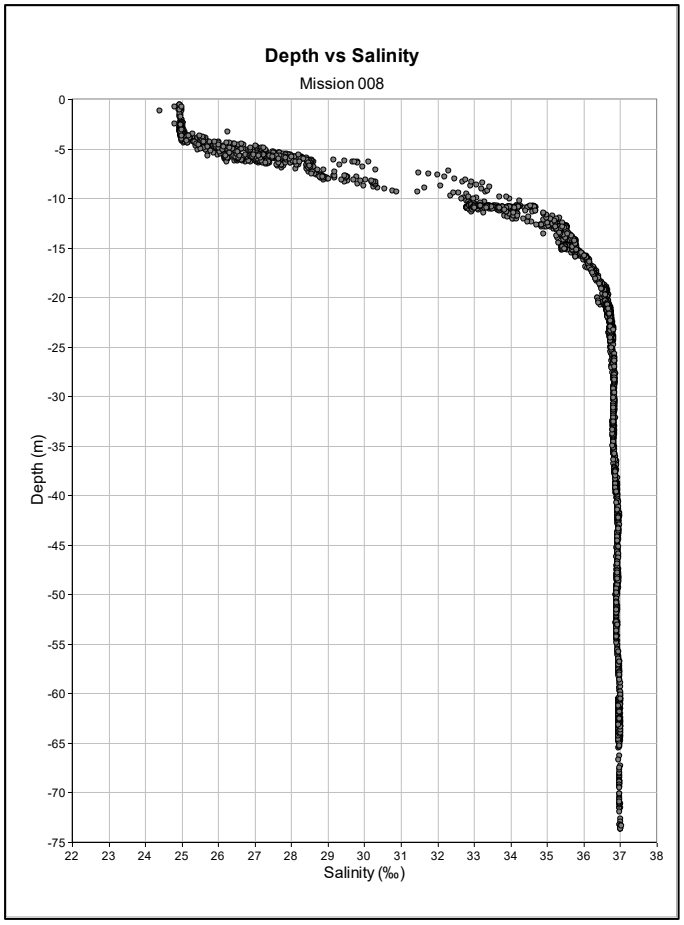


Figure 47 salinity scatterplot—MSN 8

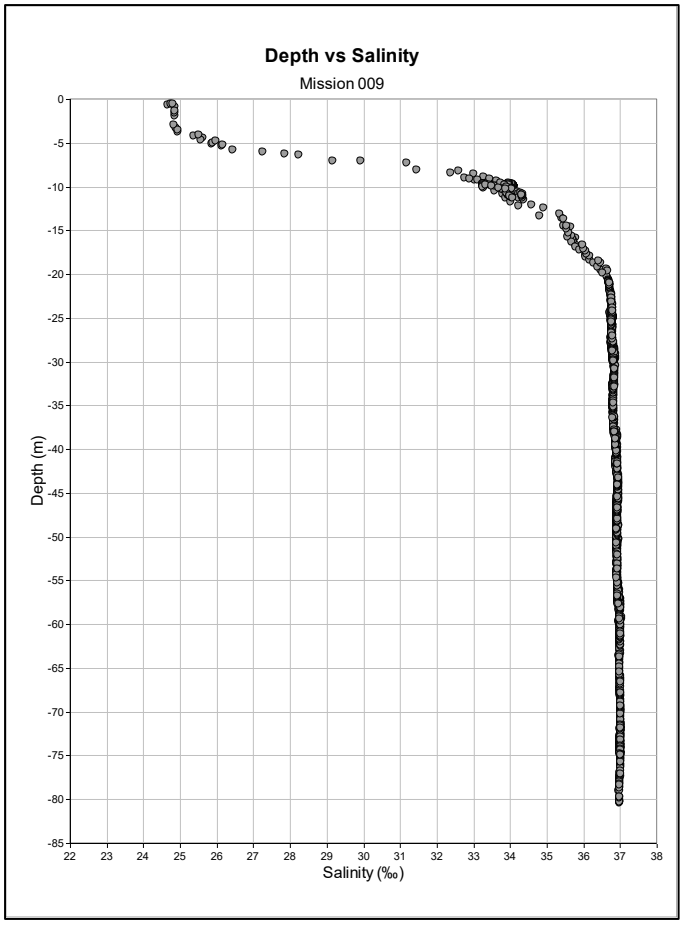


Figure 48 salinity scatterplot—MSN 9

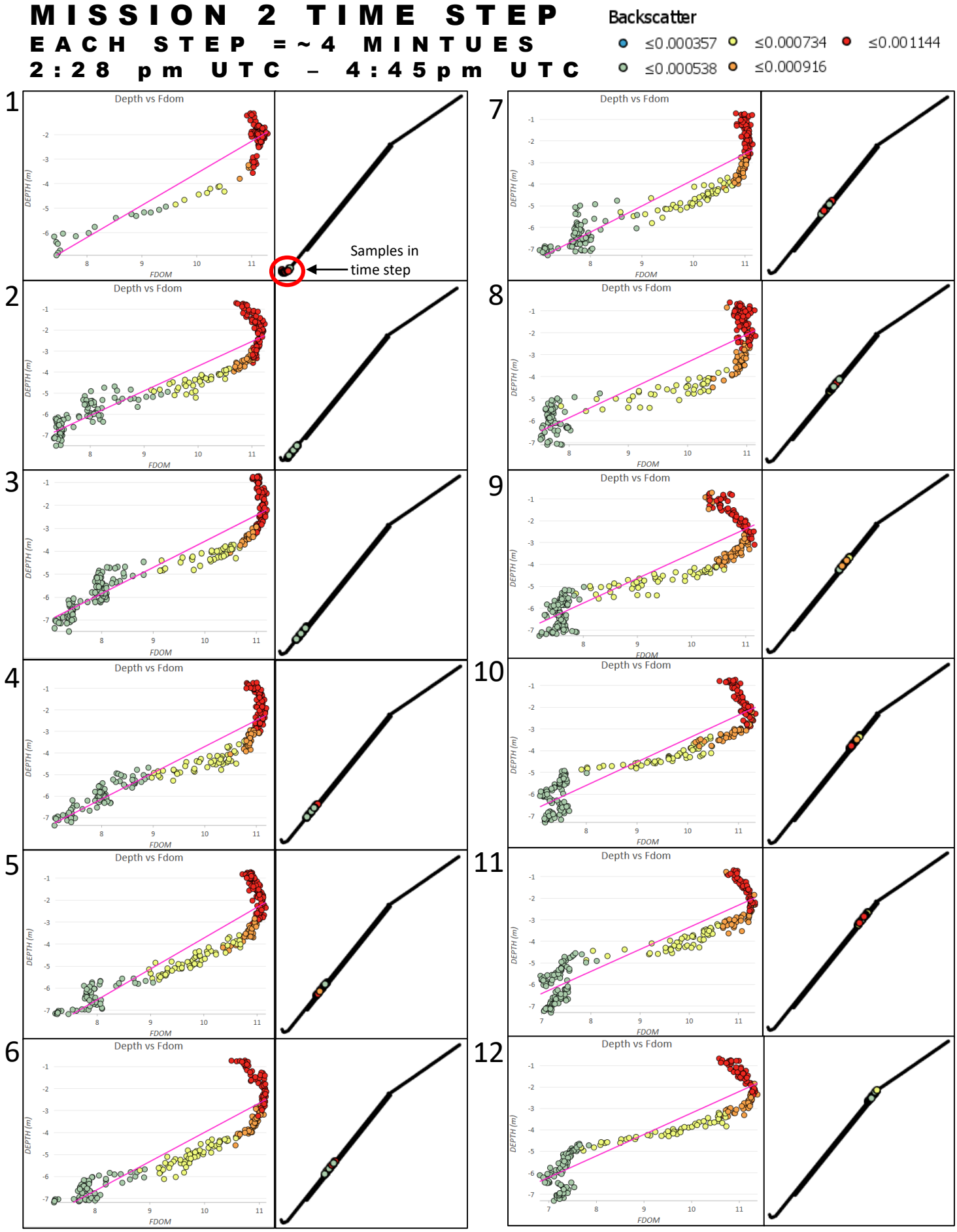


Figure 49 Mission 2 time steps—1-12

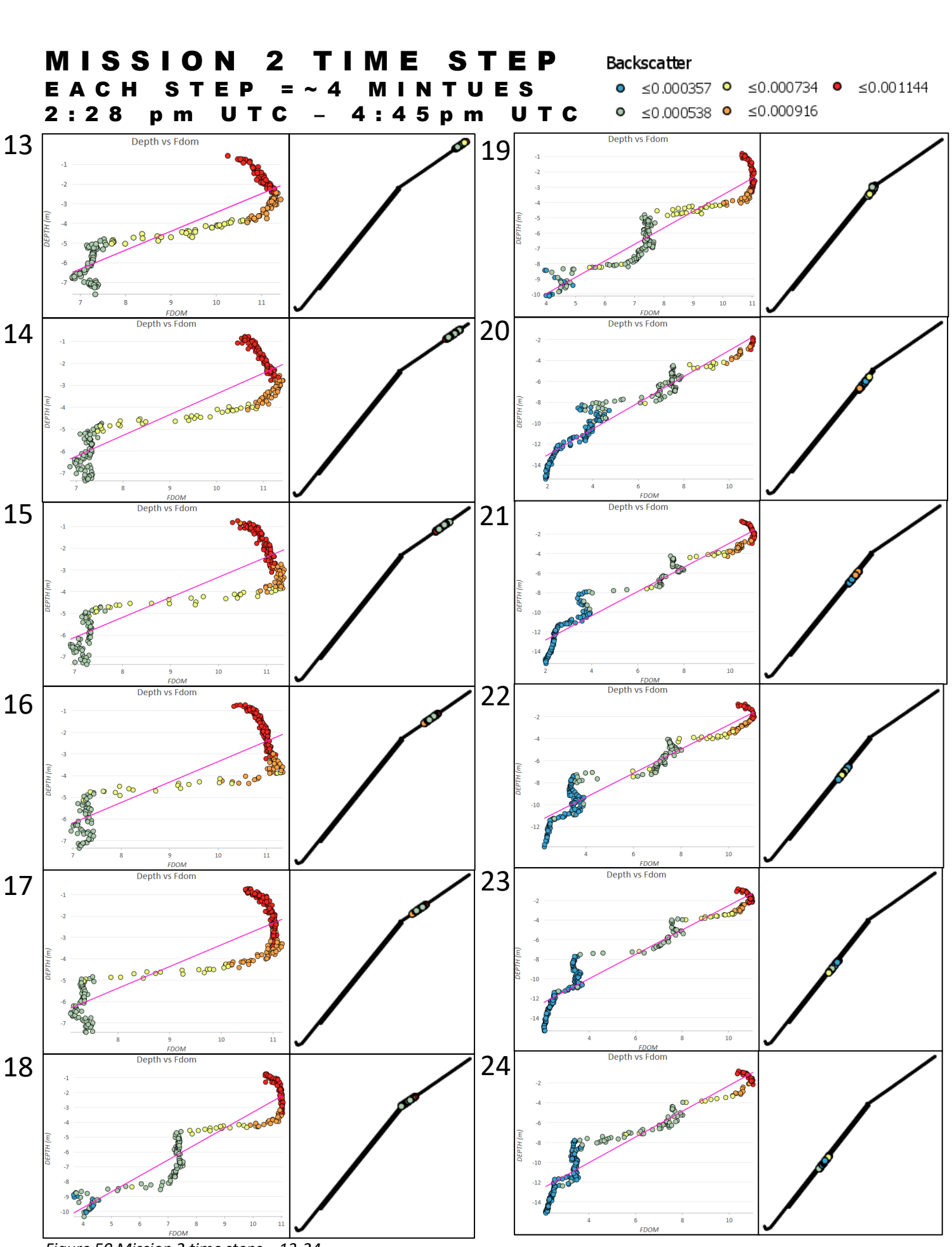


Figure 50 Mission 2 time steps—13-24

MISSION 2 TIME STEP
EACH STEP = ~4 MINTUES
2:28 pm UTC – 4:45pm UTC

Backscatter
≤0.000357 ≤0.000538 ≤0.000734 ≤0.000916 ≤0.001144

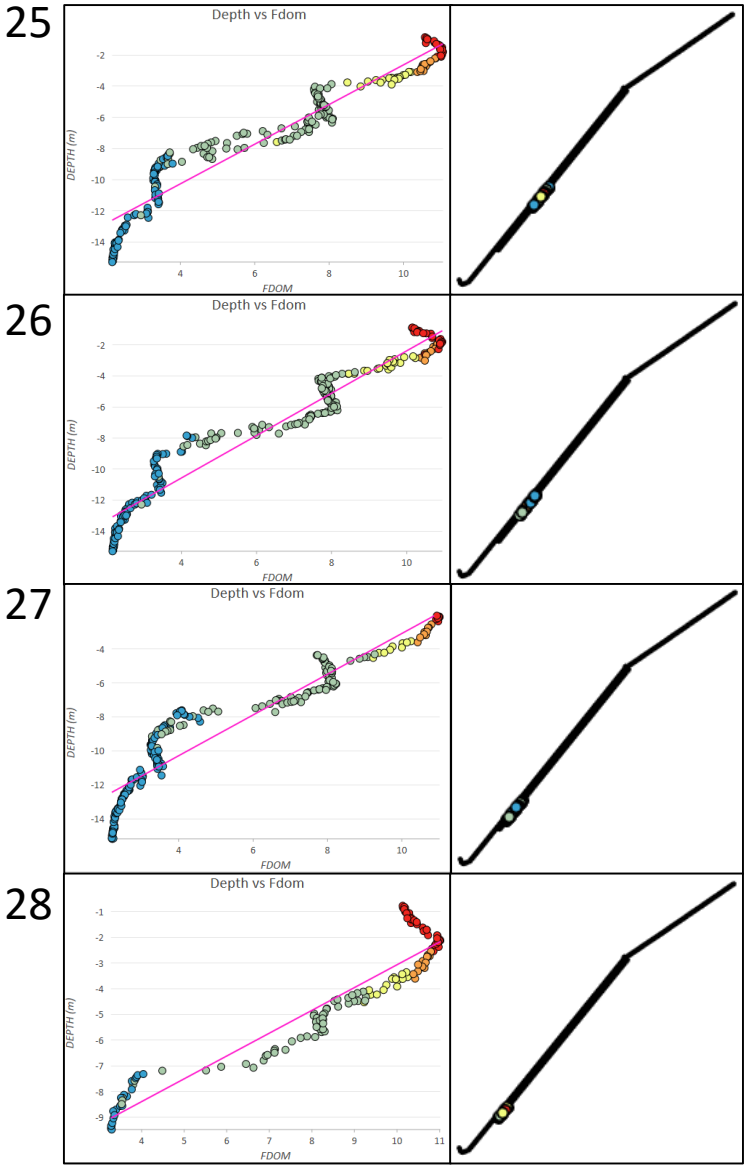


Figure 51 Mission 2 time step—25-28