Identification and Classification of Shoreline and Marsh-Embedded Oil on the Gulf Coast during the 2010 *Deepwater Horizon* Oil Spill

Technical Report

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Introduction

Between May and July of 2010, Ocean Imaging Corporation (OI) flew almost daily (often times twice per day) data acquisition missions as part of the response effort to document and map the oil on the surface of the ocean caused by the *Deepwater Horizon* (DWH) spill. This was the first instance when maps of oil spill distribution and thickness derived from aerial multispectral visible, near-infrared (VNIR), and thermal infrared (TIR) imagery were operationally produced and widely disseminated during an oil spill response effort (Svejkovsky et al., 2012). During the incident, OI worked closely with the Incident Command Center (ICC), BP, and the National Oceanic and Atmospheric Administration (NOAA). On many days, these partners requested that OI collect data along the shoreline, within the Mississippi Delta marshlands, and along the coastlines from Texas to Florida. These nearshore flights and data acquisitions helped to both guide Shoreline Cleanup Assessment Technique (SCAT) teams as well as provide digital documentation of spilled oil that had reached the shoreline and/or became entrained in the bays and marshlands. Over 136 mosaicked flight lines produced from over 1,000 digital multispectral camera-thermal infrared (DMSC-TIR) scenes of the coastal and Delta region between Texas and Florida were acquired between May 7 and July 29, 2010.

In 2015, NOAA asked OI to provide oil thickness/type classifications derived from the database of nearshore imagery described above. In most cases, since the 2010 classification products were generated as “Quick Turn Around” (QTA) products to get the information to the SCAT teams and other responders as fast as possible, the individual DMSC scenes and resulting flight line mosaics had to be reprocessed to deliver the most geospatially and radiometrically accurate products possible for this project. Because the data were acquired over shoreline and marsh areas, in most cases OI’s open ocean algorithm for oil thickness classification could not be used. Also, in most situations, the state of the oil along the shoreline and entrained in the marshlands was vastly different than the oil on the surface near the wellhead due to the distance traveled from the source and the time spent exposed to the elements. OI therefore used alternate methods of oil classification described below.

Data Acquisition and Preprocessing

OI’s DMSC-TIR aerial imaging system was used to acquire all of the shoreline imagery. This system consists of a 4-banded, 12-bit, digital multispectral imager flown in tandem with a Jenoptik JR-TCM640 TIR camera. The DMSC was outfitted with 20 nm-wide filters to image in the 450, 551, 600, and 710 nm wavelengths. Through experimentation, OI chose these wavelengths to represent a highly efficient channel combination for maximizing the spectral reflectance changes with increasing oil film thickness (Svejkovsky et al., 2012). The Jenoptik camera provided internally calibrated 640 x 480 pixel images with 16-bit dynamic range and

0.07°C thermal resolution at 7.5 μm to 14 μm (Svejkovsky et al., 2012). The overflight missions were flown at altitudes varying from 6,000 to 11,500 feet, depending on the specific requests from NOAA and the ICC, resulting in imagery with 0.9 to 1.8 meter ground sampling distance (GSD).

Upon completion of each flight, image data were downloaded from the DMSC onto an in-house computer hard drive and back-up copies were burned on to DVDs. Pre-processing included a two-step procedure to eliminate slight band-to-band misalignment. This was done using customized software to first compute an overall x-y direction shift of bands 1, 3, and 4 relative to band 2. Each of the 4-band shifted image frames was then run through a Fast Fourier Transform (FFT)-based pattern recognition routine, which tiles the image into 80 pixel sections and computes a secondary, regional pixel shift on each band. The pre-processed imagery was then run through an in-house customized software package to auto-georeference each of the pre-processed frames based off of the Differential Global Positioning System (DGPS) time stamp from the DMSC and the time stamp from an inertial measurement unit (IMU) integrated into the system. Once auto-georeferenced, frames were manually adjusted (shifted and or rotated) where needed. Later, the individual DMSC and TIR scenes were re-georeferenced using a 0.3 meter accurate ESRI image base layer to ensure the horizontal geospatial accuracy of the resulting classification product to at least +/- 1 meter (ESRI, 2015)

In all, 136 mosaicked flight lines were generated from the georeferenced scenes. Imagery used for classification were selected by first being located along the shoreline, near the shoreline or in the marshlands from Port Arthur, Texas to Pensacola Beach, Florida. Each flight line mosaic was then inspected for the following several characteristics to select the flight lines to be further processed and classified:

- Quality of data (e.g., radiometric balance, atmospheric contamination, band alignment, etc.)
- Percent cloud cover within the mosaic
- Presence of oil in the imagery
- Type of oil (if present) in the imagery
- Proximity from the shoreline and/or marsh regions.

Once imagery files in these areas were located, they were then mosaicked using the ArcGIS Mosaic to New Raster tool according to corresponding flight line. These flight lines were inspected for priority oil classes before a classification algorithm was run. The presence of aged emulsified oil along the shorelines was always indicative of other oil classes, such as emulsified oil on the surface and thick sheens, and so imagery showing aged emulsified oil would always be classified. Areas showing oil emulsions took second priority, and thick sheen third priority. These oil classifications were found both along the shoreline and offshore. Many scenes showed either no oil present or very thin (sheen) oil relatively far from shore and therefore were disqualified from further processing. Of the 136 flight line mosaics, 23 were selected for final processing based on the factors listed above (Table 1).

Table 1. Dates, coverage areas, data acquisition times and GSD of DMSC-TIR flight line image mosaics processed and classified

Date	Area	Acquisition time (UTC)	GSD
05/07/10	East Bay	14:27–14:34	1.1 m
05/07/10	East Bay	14:35–14:37	1.1 m
05/19/10	East Garden Island Bay	14:46–14:50	1.8 m
05/20/10	East Bay	13:59–14:03	1.5 m
05/20/10	North Pass	14:32–14:34	.9 m
05/21/10	East Bay	13:51–13:53	1.4 m
05/21/10	North Pass	14:32–14:33	1.5 m
05/23/10	North Garden Island Bay	14:02–14:23	.9 m
06/08/10	North Barataria Bay	21:45–21:52	1.8 m
06/08/10	South Barataria Bay	21:57	1.8 m
06/08/10	West Barataria Bay	22:02–22:04	1.8 m
06/12/10	North Barataria Bay	14:01–14:03	1.8 m
06/12/10	Quatre Bayou Pass	14:30–14:33	1.8 m
06/15/10	North Barataria Bay	14:26	1.8 m
06/15/10	West Bay Batiste	14:38–14:53	1.8 m
07/04/10	South Garden Island Bay	13:47	1.8 m
07/14/10	North Barataria Bay	14:34–15:01	1.2 m
07/14/10	Bay Batiste	15:15–15:33	1.2 m
07/27/10	East Bay Ronquille	14:35–14:43	1.2 m
07/29/10	South Terrebonne Bay	15:10	1.2 m
07/29/10	South Timbalier bay	15:16	1.2 m
07/29/10	South East Timbalier Bay	15:19	1.2 m
07/29/10	South East Timbalier Bay	15:20	1.2 m

Oil Classification Methodology

Classification of DMSC shoreline data was accomplished using ArcGIS 10.3 and ERDAS Imagine 2011. As described above, workflow involved locating relevant imagery within the area of interest (AOI), mosaicking individual four band DMSC image files in .BIL format and converting to .IMG format, mosaicking the single-banded TIR image file, performing an unsupervised classification in ERDAS Imagine, and refining classes in ArcGIS.

Because of the location of the beached and/or entrained oil along with the fact that most of the oil was in an emulsified and highly weathered/aged state, OI's oil thickness algorithm was not used for these classifications. Therefore, each selected flight line was processed using an unsupervised ISODATA classification algorithm beginning with one hundred classes in ERDAS Imagine. This number of classes was found to be ideal for the resolution of the DMSC and TIR imagery. Fewer than one hundred classes tended to aggregate classes, resulting in poor class definition, while more would result in empty classes. The resulting unsupervised classifications were then imported to ArcGIS and layered underneath the source imagery. Each class was highlighted and assigned a number according to the corresponding land/water/oil cover type. This cover type could be found by either selecting individual pixels using the information tool to match the class to its record in the attribute table, or by assigning a class number to individual records based on the highlighted area. When this process was complete, the reclassify tool was run to create a new raster with up to six classes, based on the number of oil, water, artifact, and land cover types found within the flight line.

Further definition of the classes was produced by clipping out small sections of the imagery needing refinement, running the clipped portion through the aforementioned process, and mosaicking the piece back into the main raster. Aerial photographs, classified offshore DMSC imagery, expertise of the analyst, as well as flight notes from the OI crew were used to help identify and pare down the classes to their final categories. In some cases the near-infrared band in the DMSC imagery was used to differentiate the dark oil entrained in a marsh area from dark vegetation, as the reflectance from vegetation at this wavelength was distinctly higher than the reflectance from oil.

When the flight line classification was completed, the raster file was converted to a shape file and dissolved back into individual classes for delivery. Each deliverable classification included descriptive class names, a corresponding layer file containing color palette symbology, and the source imagery. The final classes represented in the thematic map shape files are:

- Land
- Cloud/Artifact
- Water/Thin Sheen
- Thick Sheen
- Oil Emulsion
- Aged Emulsified Oil.

"Aged Emulsified Oil" describes stranded oil emulsions that became concentrated and/or compressed after being beached or constrained for a length of time in a narrow area (such as a tidal stream channel). During the DWH event, these oil patches partially de-emulsified, forming a dark, tar-like (but still fluid) upper layer.

Supplemental Oblique Aerial Photographs

Aerial photographs were used as supplemental evidence of surface oiling. These photographs were sourced from either OI's or NOAA's DWH photograph archive. Since the DMSC camera system did not use standard visible (red, green, and blue) bands, combining those bands does not yield normal image from visible spectra and thus can be challenging to interpret. The photographs thus provided the end user with an additional visual aid to verify the presence of oil and appropriately classify the imagery.

Results

A total of 23 flight lines were processed, each showing the presence of surface oil of different thicknesses and emulsifications. Oil in nearshore marshes was readily apparent on June 8 and June 15, 2010 (Figures 1 and 2). Both these figures are excellent examples of remote sensing data classifying oil of varying thicknesses and emulsifications. These data were further supported by digital photographs (Figure 3). These data helped the Trustees to evaluate nearshore oil exposure and potential natural resource injuries.

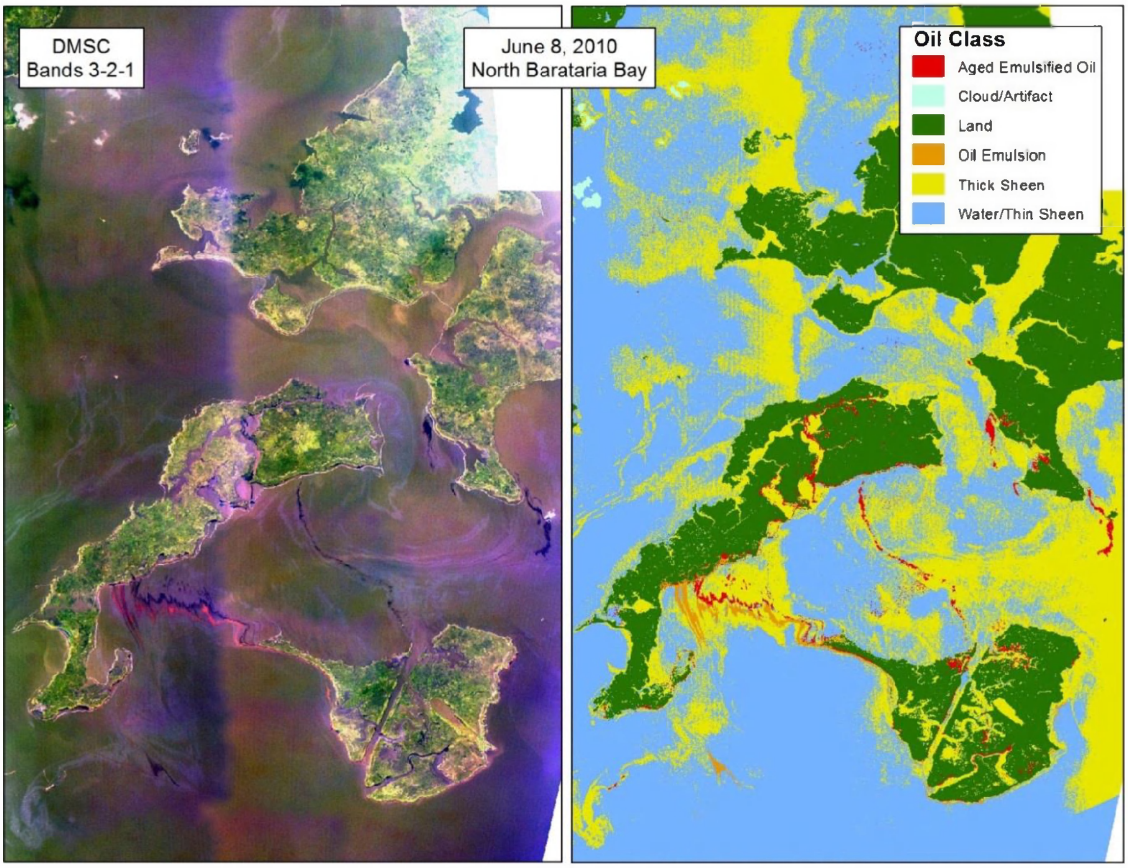

Figure 1. DMSC imagery acquired on June 8, 2010 in northern Barataria Bay, Louisiana. The visible spectra (bands 3, 2, and 1) are on the left, and the resulting oil classification derived from the DMSC-TIR data is on the right.

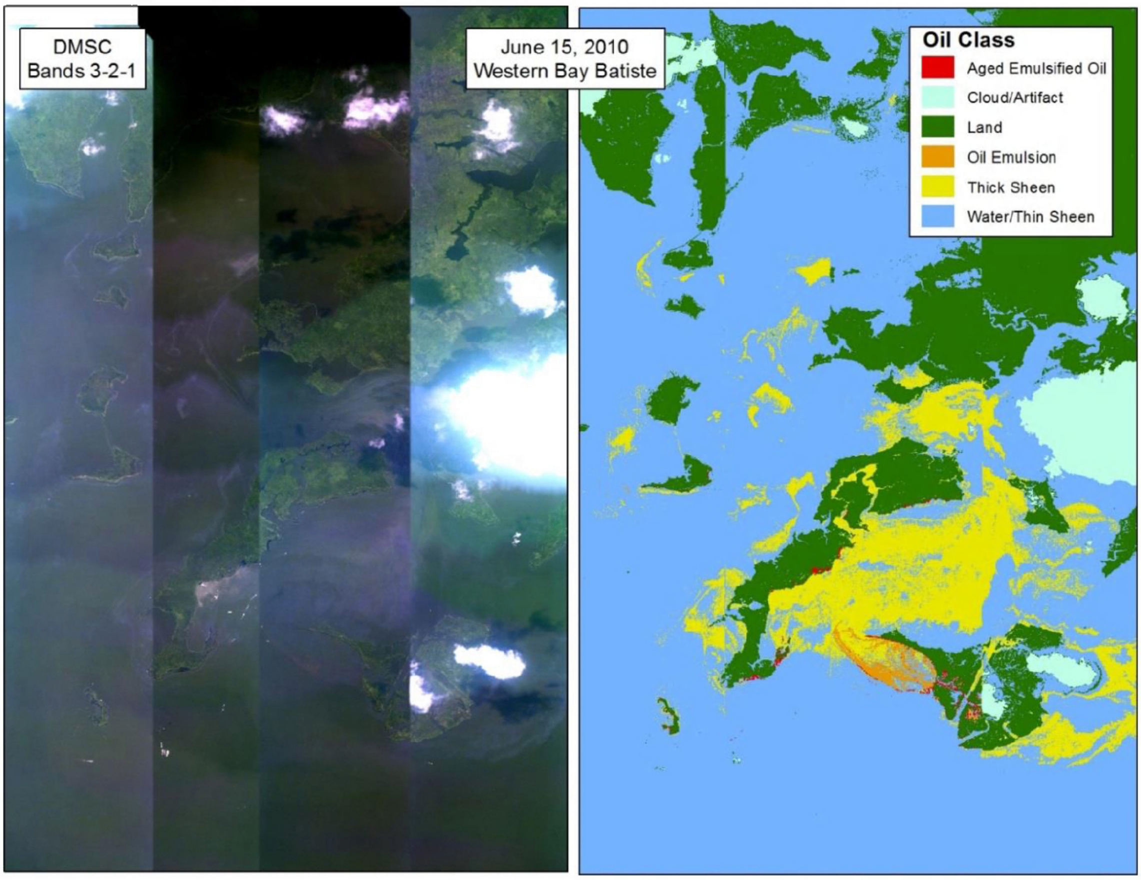

Figure 2. DMSC imagery acquired on June 15, 2010 in the western side of Bay Batiste, Louisiana. The visible spectra (bands 3, 2, and 1) are on the left, and the resulting oil classification derived from the DMSC-TIR data is on the right.

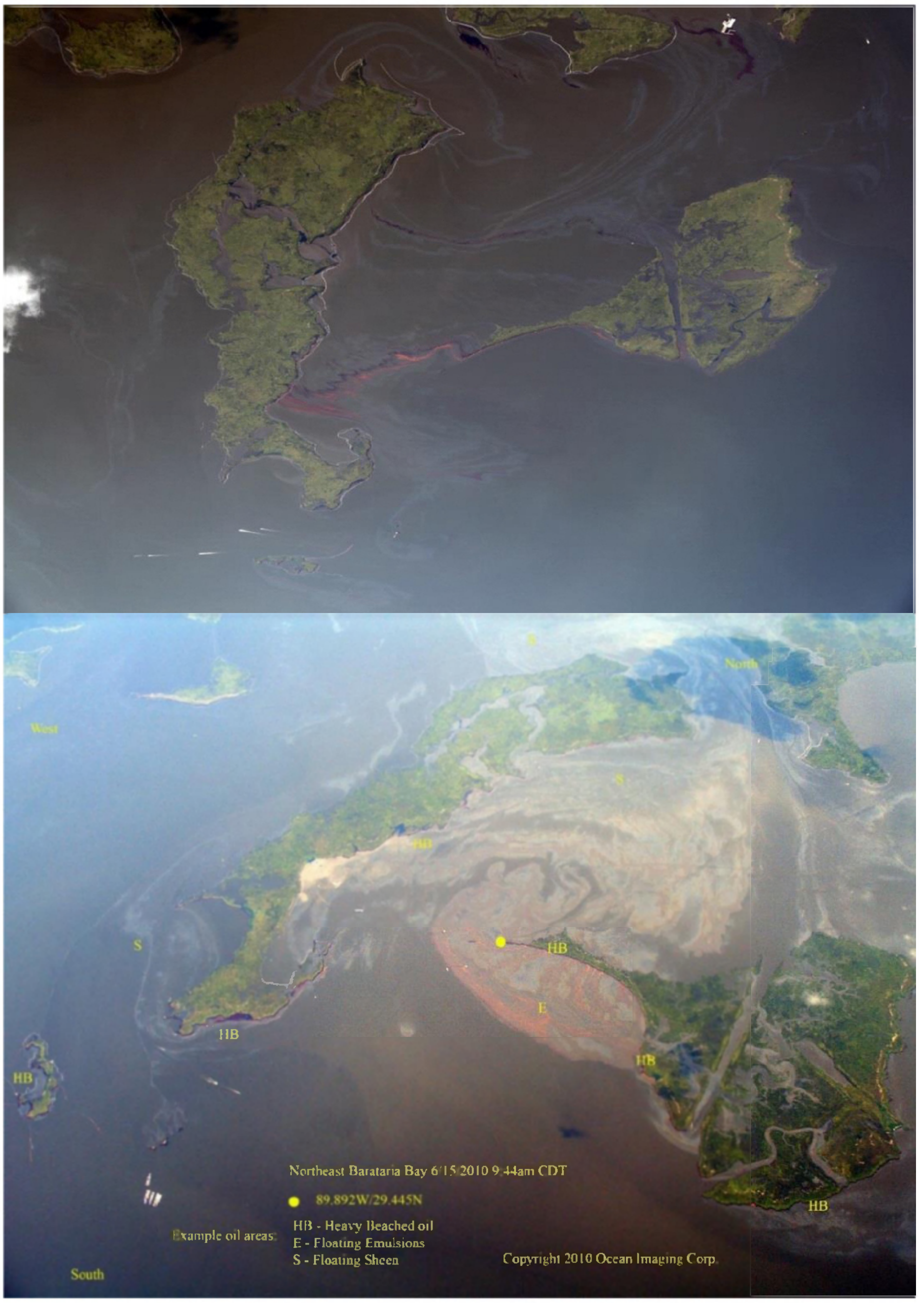

Figure 3. Sample oblique aerial photographs showing oil in Barataria Bay on June 8 (top) and June 15, 2010 (bottom). These photographs, collected concurrent with remote sensing data, helped technicians to classify the oil extent in the DMSC-TIR imagery.

References

ESRI. 2015. ArcGIS: World Imagery. Available: http://www.arcgis.com/home/item.html?id = 10df2279f9684e4a9f6a7f08febac2a9. Last modified: August 24, 2015.

Svejkovsky, J., W. Lehr, J. Muskat, G. Graettinger, and J. Mullin. 2012. Operational utilization of aerial multispectral remote sensing during oil spill response: Lessons learned during the *Deepwater Horizon* (MC-252) spill. *Photogrammetric Engineering and Remote Sensing* 78(10):1089–1102.