Research Summary:
Early Warning 4-D Remote Sensing System to Assess Synoptic Threats
To Gulf of Mexico - Florida Institute of Technology Research Contribution:
Airborne Remote Sensing
Dr. Charles Bostater, PI Summaries

Natural oil and gases that entered the marine and littoral areas of the Gulf of Mexico ecosystem from the Deepwater Horizon oil spill site represented potential threats to the near coastal and pelagic organisms (Frias-Torres and Bostater, 2011). The 4D Remote sensing project was designed to utilize data from satellite, airborne, ship borne and in-situ sensors to assess – using imagery and spatial analysis – surface and subsurface weathered oil and plumes over the Gulf of Mexico region. Satellite and airborne efforts across the littoral zone from Florida to Louisiana were conducted in order to help provide information for monitoring, forecasting, restoration, mitigation and related assessments and findings (BP Case Federal Memo, 2012, pp. 34-35).

Dr. Bostater's responsibility, acting as the FIT PI, for the 4-D remote sensing project component was: acquisition of airborne imagery in support of Deepwater Horizon oil spill recovery assessments (Bostater and Muller-Karger, 2012).

This research component responded to the Deepwater Horizon Oil Spill Conference Report, specific recommendation: "*to increase remote sensing data resolution in the near-shore and inland seas, and along coastlines, to guide response efforts on the coastal region*" (National Science and Technology Joint Subcommittee Conference Report, p. 6).

The airborne remote sensing imagery was collected from a low flying aircraft along the near coastal waters of the Florida Panhandle and northern Gulf of Mexico and into Barataria Bay, Louisiana, USA, during March 2011. Imagery was acquired from an aircraft that simultaneously collected traditional photogrammetric film imagery, digital video, digital still images, and digital hyperspectral imagery. The original purpose of the project was to collect airborne imagery to support assessment of weathered oil in littoral areas influenced by the Deepwater Horizon oil and gas spill that occurred during the spring and summer of 2010. The data acquired and related information demonstrated the utility of small spatial scale imagery to detect the presence of subsurface weathered oil along littoral areas in the northern Gulf of Mexico. Flight tracks and examples of imagery collected can be seen at www.bostater.info. The metadata files are presented and methods used to plan and acquire the imagery are described.

A suite of mobile multispectral and hyperspectral sensors were flown between ~1,000m to ~3000m altitudes in order detect subsurface features in nearby wetlands and littoral zone areas following the Deepwater Horizon oil spill. Airborne sensors and Imagery was integrated and the hyperspectral sensor was calibrated using the standard methods (Bostater, 2012). The sensors include a multispectral digital frame camera system, a traditional photogrammetric camera, and a small custom hyperspectral imaging system with custom software. Ancillary sensors include multiple differential GPS and inertial motion unit (IMU) sensing systems and twin high definition video cameras for parallax related estimations. The correction of hyperspectral pushbroom imagery utilizes ***Kalman filtering and smoothing*** and is used for image related rectification and georeferencing. The ability to image subsurface features is demonstrated using the hyperspectral imaging system, and simultaneous multi-sensor systems for environmental *monitoring and surveillance of shorelines,* water and nearby vegetation environments in littoral zones.

Airborne hyperspectral imagery offers unique benefits such as detection of land and water feature composition due to the information contained in the bi-directional reflectance distribution function (BRDF) as described by Bostater and Brooks, 2013 The reflectance signature directly shows the relative absorption and backscattering features of targets. These features can be very useful in shoreline monitoring or surveillance applications, for example, to detect weathered oil. In near real-time shoreline detection applications, processing of hyperspectral data can be an important tool and “optimal band selection” in order to select the essential bands (using the absorption and backscatter features) for material composition assessment. In this study, band selection is based upon the optimization of target detection using contrast algorithms. The common definition of “contrast” (using only one band out of all possible combinations available within a hyperspectral image) is generalized to a multiple contrast approach in order to consider all the possible combinations of wavelength dependent contrasts using hyperspectral channels. The inflection (defined here as an approximation of the second derivative) is also used in order to enhance the variations in the reflectance spectra as well as in the contrast spectrum in order to assist in optimal band selection. The results of the selection in term of target detection (false alarms and missed detection) are also compared with a previous method to perform feature detection, namely the optimal *matched filter*. For shoreline monitoring imagery is acquired using a pushbroom hyperspectral sensor mounted at the bow of a small vessel. The sensor is mechanically rotated using an optical rotation stage. This *opto-mechanical scanning system* produces hyperspectral images with pixel sizes on the order of mm to cm scales, depending upon the distance between the sensor and the shoreline being monitored. The motion of the platform during the acquisition induces distortions in the collected HSI imagery. Therefore IMU based ship motion corrections are applied to the imagery – in order to correct for the pitching motion of a vessel (Bostater, Frystacky and Levaux, 2012; Levaux, Bostater and Neyt, 2012).

This two-year 4D (airborne, satellite, ship borne, and in-situ sensing) Collaborative Project organized experts at Florida Institute of Technology, University of Miami and University of South Florida in order to conduct research under Category 1 of the BP funding to Florida Institute of Oceanography - to determine the distribution and extent of oil and dispersants. The approach built on Florida's remote sensing infrastructure, long history of time series research of the oceanography of the Gulf, and strong multidisciplinary academic education programs to also contribute to Categories 2 (baseline studies) and 3 (contribute to an integrated observing system). New techniques are being developed in order to form an optimized "**image data fusion approach**" using hyperspectral and multispectral imagery collected from air and from ship measurements of littoral zones (Bostater, 2012; Bostater and Frystacky, 2012). The optimized data fusion methodology makes use of airborne and vessel mounted hyperspectral and multispectral imagery acquired along littoral zones in Florida and the northern Gulf of Mexico. The results, to date, demonstrate the use of hyperspectral-multispectral *data fusion anomaly detection along shorelines* and in surface and subsurface waters as shown below.

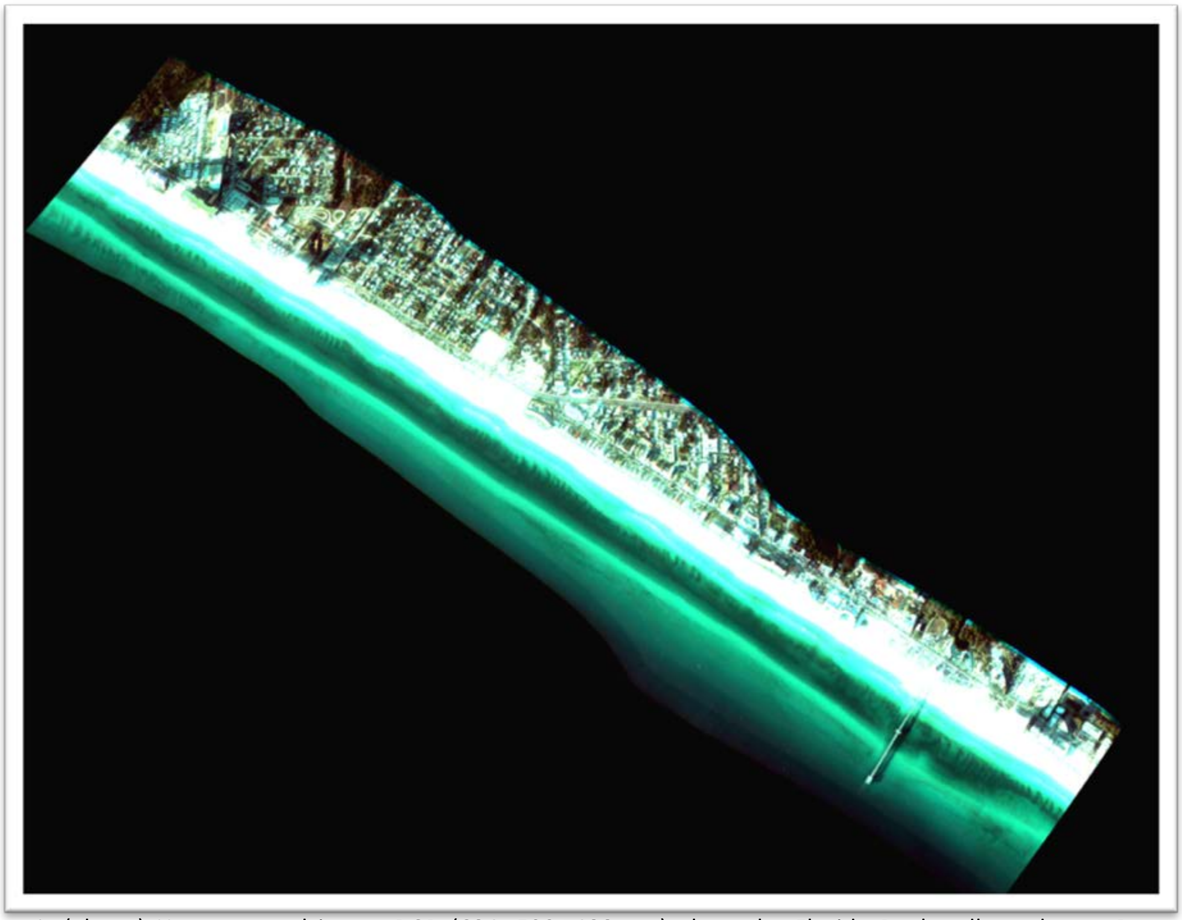

Figure 1. (above) Hyperspectral image RGB (684, 529, 488 nm) along the Florida Panhandle and near Panama Dunes Pier, in the Northern Gulf of Mexico littoral zone, N 30 11'11.05" W 85 50'1.60" acquired March 12, 2011. Note that careful selection of airborne flight conditions allowed for direct sun glint to be minimized in order for subsurface feature detection in the littoral zone. Airborne image collected and processed by Dr. C. Bostater, Marine & Environmental Optics Laboratory, Florida.

Hyperspectral imagery utilized in the data fusion analysis was collected using a custom 64-1024 channel, 1376 pixel swath width; temperature stabilized sensing system; an integrated inertial motion unit; and differential GPS. The imaging system is calibrated using dual 18 inch calibration spheres, spectral line sources, and custom line targets. Simultaneously collected multispectral three band imagery used in the data fusion analysis is derived either a 12 inch focal length large format camera using 9 inch using high speed AGFA color negative film, a 12.3 megapixel digital camera or dual high speed full definition video cameras. Pushbroom sensor imagery is corrected using custom ***Kalman* filtering and smoothing** (Bostater, Coppin and Levaux, 2102) in order to correct images for airborne platform motions or motions of a small vessel. Custom software developed for the hyperspectral system and the optimized data fusion process allows for post processing using atmospherically corrected and georeferenced reflectance imagery. The optimized data fusion approach allows for detecting spectral anomalies in the resolution enhanced data cubes. Spectral-spatial anomaly detection is demonstrated using simulated embedded targets in actual imagery. The approach allows one to utilize spectral signature anomalies to identify features and targets that would otherwise not be possible. The optimized data fusion techniques and software has been developed in order to perform sensitivity analysis of the synthetic images in order to optimize the singular value decomposition model building process and the 2-D Butterworth cutoff frequency selection process, using the concept of user defined "feature areas". The data fusion "synthetic imagery" forms a basis for spectral-spatial resolution enhancement for optimal band selection and remote sensing algorithm development within "spectral anomaly areas". The methods are applied to imagery intended to support Deepwater Horizon oil spill remediation and recovery efforts. Sensitivity analysis demonstrates the data fusion methodology is most sensitive to (a) the pixels and features used in the SVD model building process and (b) the 2-D Butterworth cutoff frequency optimized by application of K-S nonparametric test. The optimized image fusion approach is transferable to sensor data acquired from other platforms, including autonomous underwater vehicles using near real time processing.

An example data fusion process image using hyperspectral imagery with airborne photogrammetric imagery that are simultaneously acquired from multiple sensors and cameras is shown in figure 2 below.

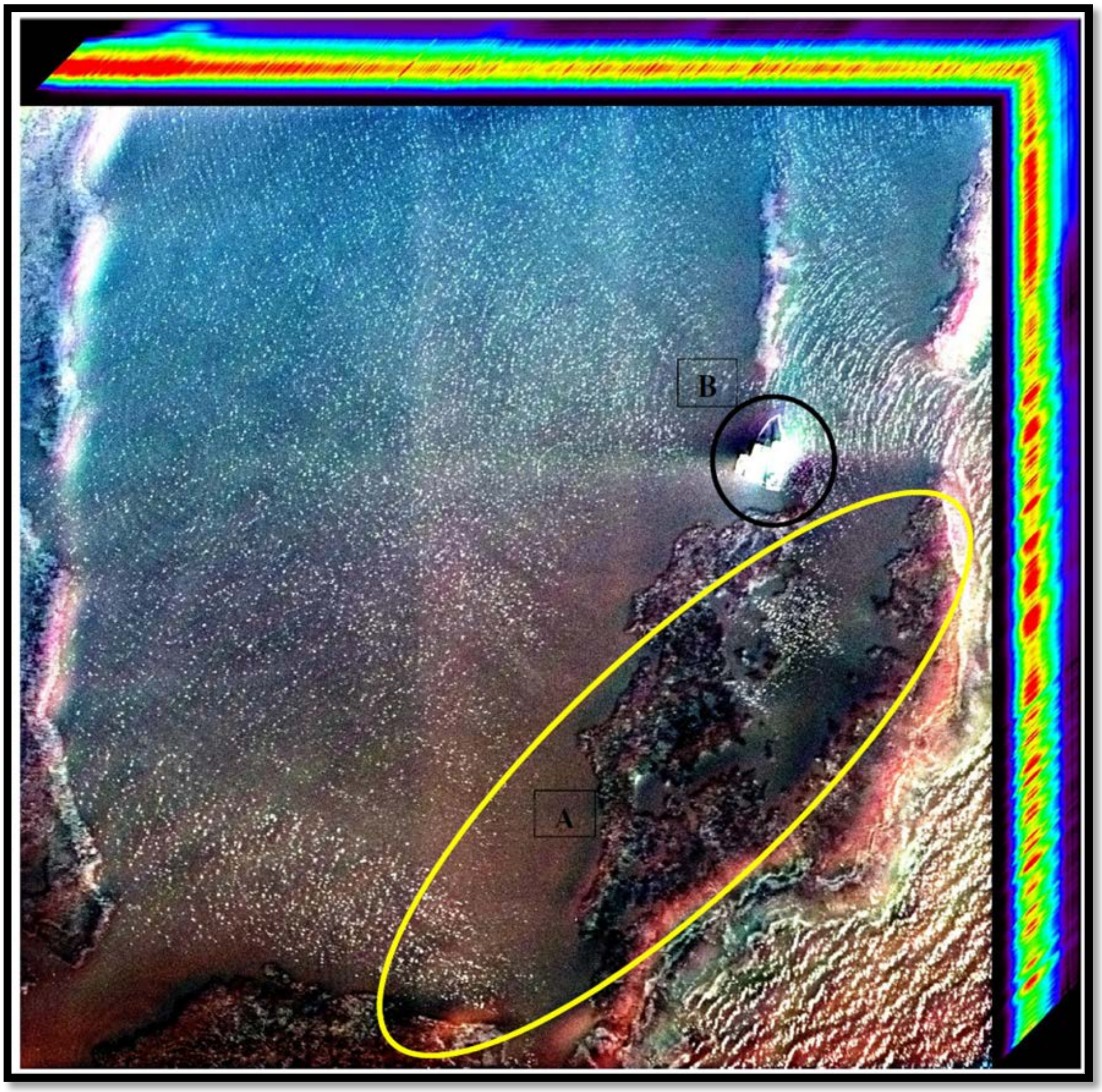

Figure 2. An airborne hyperspectral data fusion *image cube* RGB display. The image subset shown above is a "data fusion" of a scanned AGFA color negative image with ~10 cm pixel (GSD) spatial resolution and a hyperspectral airborne image scene with ~ 0.5 m pixel (GSD) collected on March 21, 2011. Weathered oil is visible in the coastal littoral zone and marsh area (**A**) in the Northern Gulf of Mexico. A restoration surface vessel (**B**), not observable in the raw hyperspectral image is visible in the fused hyperspectral image collected and processed by Dr. Bostater, Marine & Environmental Optics Laboratory.

The overall project is intended to combine satellite and airborne observations collected by the remote sensing team with habitat (Frias-Torres and Bostater, 2011) and contaminant measurements from ships and other platforms to characterize oil and dispersant distribution and their potential environmental impacts. The team used extensive connections in the fisheries, oil and other industries, and established robust collaborative linkages with other biogeochemical, ecological, and modeling efforts to combine observations and minimize uncertainties in the identification and spatial characterization of surface and subsurface weathered oil. Synoptic assessments utilized real-time satellite images (MODIS and synthetic aperture radar sensors) and detailed maps of coastal habitats impacted by the contaminants derived using large-scale GIS maps of the Gulf Region. Other sensors launched from NOAA hurricane hunter aircraft crossing the Gulf, and meticulous shipboard observations of oil presence and composition collected by Dr. Bostater and other teams allowed for synoptic assessments and have helped target coastal areas for high spatial resolution digital imaging and mapping using the airborne camera system. An example shipboard hyperspectral and multispectral digital image of a "weathered oil shoreline is shown in figure 3 below, along with the synthetic data fusion image (bottom frame).

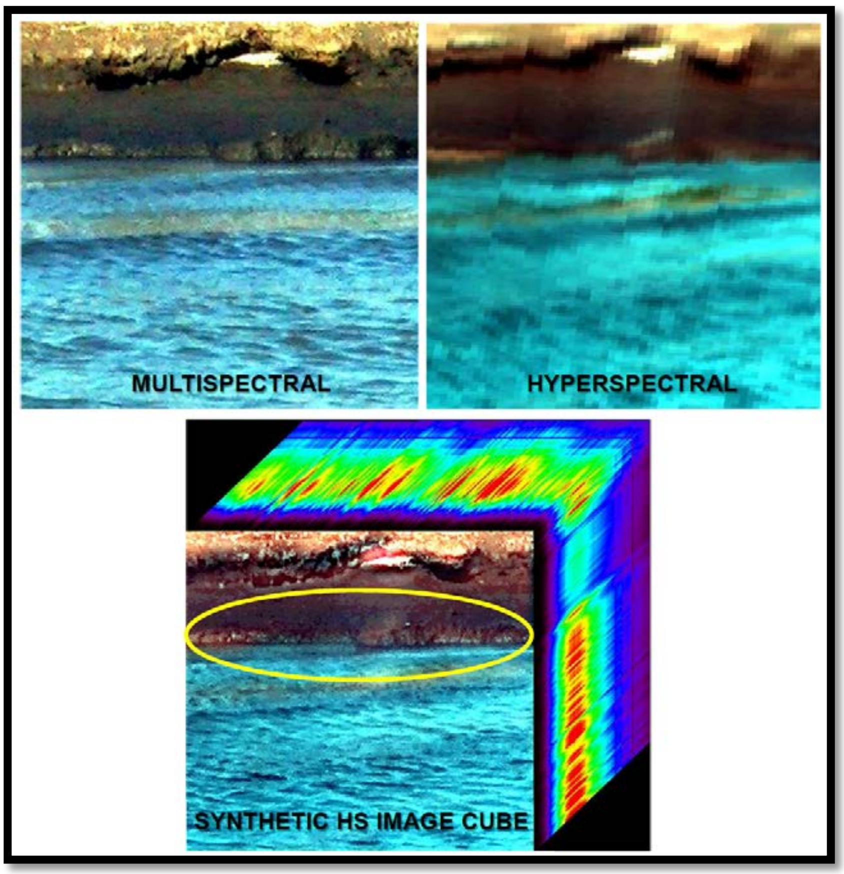

Figure 3. Example of shoreline hyperspectral and multispectral imagery used to synthesize a "synthetic" hyperspectral image cube with ~ 5 mm pixel (GSD) spectra. The ***optimized data fusion protocol and techniques*** (Bostater, 2012 (a,b) utilizes digital multispectral RGB camera imagery, and a vessel mounted hyperspectral imaging system mounted on a surface vessel for littoral zone surveillance and environmental monitoring of weathered oil and resulting "vegetation dysfunction" from Bostater, 2012, peer reviewed publications listed in this final report. Note the ability to obtain spectral reflectance and radiance of capillary and small gravity waves in the littoral zone. The area outlined is weathered oil on a shoreline. Hyperspectral and multispectral imagery was collected in February, 2011, and processed by Dr. Bostater, Marine & Environmental Optics Laboratory, Florida Institute of Technology. These data and analysis results were acquired with a related project and utilized knowledge obtained from the BP funded airborne imagery.

The airborne information is still being synthesized into manuscripts and written reports to support other BP funded consortia studies, numerical forecasting efforts, and mitigation plans. The reports build on products we generated during the blowout incident and which were made available openly to decision makers and the general public. From a scientific and technical point of view, the project evaluates the various strategies used by different experts for manual image interpretation, and will lead to strategies for automated image thematic classification. The project will help understand the impact of the contaminants along the coasts of U.S. Gulf, over spatial scales ranging from centimeters to over a thousand kilometers.

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