UNIVERSITY OF SOUTH FLORIDA

EARLY WARNING 4-D REMOTE SENSING SYSTEM TO ASSESS SYNOPTIC THREATS TO COASTAL ECOSYSTEMS OF FLORIDA AND OF ADJACENT STATES AND NATIONS

Research Investigator: F. Muller-Karger (University of South Florida)
Co-investigators: M. Roffer (ROFFSTM), L. Shay (University of Miami), C. Bostater (Florida Institute of Technology), N. Melo (CIMAS), D. Fries (Bioplex), S. Lohrenz (UMass Dartmouth)

SCIENCE ACTIVITIES

1) General Summary

This project organized experts from the region to determine the distribution and extent of oil and dispersants. The team uses satellite remote sensing with habitat and contaminant measurements from ships and other platforms to characterize distribution and environmental impacts.

The efforts included:

1) Assembling a database of historical satellite images collected during and after the spill from various satellite sensors (SeaWiFS, MODIS, MERIS, AVHRR visible and infrared, and synthetic aperture radar) and using the data to develop detailed maps of dispersal patterns.
2) Develop historical, including climatological, assessments of temperature and ocean color patterns in the Gulf of Mexico region.
3) Automatically recognize oil in satellite images. We used the MODIS satellite images of the region containing the Deepwater horizon spill. One immediate problem was that sun glint off the water with oil would saturate the sensor. So, while it provided a clue on where oil existed, for a good determination the team had to create its own algorithms for handling the sun glint issue (Bob Chen did this). Generally, a problem was the lack of ground truth. We reliably found oil by the deepwater horizon platform. We also found oil in the area that NOAA online spatial overlays (shape files) showed oil. However, we did not find oil in some parts of the NOAA shape files and found it outside. We were not able to confirm our results independently.
4) Collected optical data and other specific parameters in the Florida Keys area that would be most useful for comparison with satellite and airborne remote sensing products.
5) Collected 17 hours of imagery from aircraft over coastal zones affected by the spill.
6) Conducted a synthesis of oceanographic and atmospheric data acquired from an ongoing NOAA/University of Miami Project utilizing the NOAA WP-3D research aircraft (Hurricane Hunter) that made weekly flights over the eastern Gulf of Mexico.
7) A low-power LED-based ultraviolet fluorometer was conceived, based on Bioplex Technologies' original SE-300 handheld visible-light fluorometer. A proof-of-concept hand sized prototype has been developed that uses an ultraviolet LED to excite with 254 nm light while fluorescence at 350 +/- 50 nm is monitored with an embedded filtered photo detector. Fabrication of the in situ system (UV 300 FT) was completed and tests were made of the performance of the submersible packaged system.

2) Results and scientific highlights

Here we outline the results of the efforts conducted by the Institute for Marine Remote Sensing (IMaRS; PI: F. Muller-Karger). Separate reports are appended for each of the subgroups funded.

The University of South Florida focused on developing a series of analyses based on historical high-resolution Sea Surface Temperature and Ocean Color datasets collected by the USF Institute for Marine Remote Sensing. This includes data from the NOAA AVHRR polar orbiting series (e.g. NOAA 11-19), NASA Terra and Aqua MODIS, and data from the SeaStar/Orbview-2/SeaWiFS sensors. We focused on comparing these datasets with various other remote sensing ata, including AVIRIS. The results include a comprehensive analysis of ocean color patterns which have been previously (mis-)interpreted in the literature by other researchers as phytoplankton blooming as a result of the Deepwater Horizon oil spill. We also have continued to support an extensive analysis of larval fish surveys conducted by NOAA in the region (SeaMap) in the context of historical satellite imagery. A comprehensive series of weekly, monthly, and annual means, climatological products and anomalies of SST and various ocean color products has been developed for the Gulf of Mexico.

Recommendations:

- Develop interpretive oceanographic products derived in real-time from satellites, airplanes, buoys and ships for near-real time delivery that map and analyze the ocean currents and tainted water masses in the near-field (at the spill), as well as the far field. The near field analyses products must be useful for real-time responders and for contingency planning in the far field.
- Developing the capability to better coordinate access to all satellite assets and remote sensing data collected during a national emergency in real-time. While the DWH event highlighted the very critical role of remote sensing data to map the extent of the oil on a daily basis, many satellite assets were not available and not used as efficiently as possible. Further, the USA is losing its capability for space-based ocean research, particularly in coastal and shelf areas.
- The U.S. government and industry need to develop an “emergency” remote sensing system that provides:
    - High spatial resolution (meters to hundreds of meters), multispectral (VIS, near-IR, IR, and radar), high revisit capability
    - Real-time collections and
    - Open access by researchers and responders
- Continuation of low altitude (500-1,000 m) airborne missions of Northern Gulf littoral zones and ground verification of aerial extent of weathered oil in Gulf living marine resource habitats. Necessary to detect small pixel ground sampling distance (GSD) of 3-5 cm to 0.5 m in order to accurately assess areas currently impacted by weather oil and increased shore erosion in these areas.
- Develop a strategy to better coordinate and integrate into useful products the ground observations relevant to the interpretation of satellite and airborne imagery. This includes optical and various other ground truth (e.g. ships, planes, buoys) in oil spills and other oilaffected areas, and during other emergencies that affect water quality.
- Continued shoreline assessments of oil in littoral zones in Northern Gulf of Mexico in coordination and in tandem with synoptic satellite and airborne missions to understand the signals observed by remote sensing, and ultimately help assess oil impacts and ecosystem dynamics and recovery
- Development of new non-contact sensing systems and platforms for weathered oil detection (surface & subsurface) and associated effects assessments. This includes continued development of remote sensing cameras, and automated methods for oil detection using various remote sensing methods
- Continuing development of sensors such as small, expendable fluorometers that can be integrated into expendable air-deployed probes to detect subsurface oil unequivocally.

- Strong investment in capacity building, both in the workforce and in the scientific research fields related to emergency response, oil detection.
- Ensure the availability of airborne expendable probes (conductivity, temperature, depth) and platforms to deploy them during emergencies – this is the only way to ensure understanding of far-field physical and bio-geochemical conditions.

3) Cruises & field expeditions

Ship or Platform Name	**Class** (if applicable)	**Chief Scientist**	**Objectives**	**Dates**
(NOT APPLICABLE)				

4) Peer-reviewed publications, if planned (Note: a special section will focus on student and post-doctoral publications)

Bostater, C., Frystacky, H., Levaux, F., 2012, Enhanced Data Fusion Protocol for Surface and Subsurface Imaging of Released Oil in Littoral Zones, In: Proceedings of the Twenty-second (2012) International Offshore and Polar Engineering Conference, Rhodes, Greece, June 17–22, 2012, International Society of Offshore and Polar Engineers (ISOPE), ISBN 978-1-880653-94–4, pp. 808-814.

Bostater, C., Coppin, G., Leavaux, F., 2012, Hyperspectral Remote Sensing - Using Low Flying Aircraft and Small Vessels in Coastal Littoral Areas, In: Remote Sensing – Advanced Techniques and Platforms, Escalante, B. (Ed.), ISBN: 978-953-51-0652-4, 462 pp.

Mariano, A.J., G.R. Halliwell, V. Kourafalou, E. Ryan, A. Srinivasan, and M. Roffer. (2011) On the modeling of the 2010 Gulf of Mexico oil spill. J. Dynamics of Atmospheres and Oceans doi:10.1016/j.dynatmoce.2011.06.001.

Muhling, B.A., M.A. Roffer, J.T. Lamkin, G.W. Ingram, Jr., M.A. Upton, G. Gawlikowski, F.E. Muller-Karger, S. Habtes, W.J. Richards. 2012. Overlap between Atlantic bluefin tuna spawning grounds and observed Deepwater Horizon surface oil in the northern Gulf of Mexico. Marine Pollution Bull.

Hoffmayer, E.R., W.B. Driggers, J.S. Franks, D.S. Hanisko, M.A. Roffer, and L.E. Cavitt. 2011. Recent occurrences of basking sharks, Cetorhinus maximus (Gunnerus, 1765) [Chondrichthyes: Cetorhinidae], in the Gulf of Mexico. Marine Biodiversity Records 4(e87): 1-4.

Shay, L.K., M. Baringer, G. R. Halliwell, B. Jaimes, H.-S. Kim, F.D. Marks, J. McFadden, P. Meyers, S. Paul, H. Tolman, E. Uhlhorn, and J. Williams. 2010: Gulf of Mexico: Loop Current and DWH oil spill response. 7th WMO International Workshop on Tropical Cyclones (IWTC-7), November 15-21, 2010, St. Denis, La ReUnion, France. WMO Tropical Meteorology Research Series.

Shay, L.K., B. Jaimes, J. Brewster, P. Myers, C. McCaskill, E. Uhlhorn, F. Marks, G. R. Halliwell, Jr., O. M. Smedsted and P. Hogan, 2011: Airborne ocean surveys of the Loop Current complex from NOAA WP-3D in support of Deepwater Horizon oil spill. American Geophysical Union Monograph Series: Monitoring and Modeling the Deepwater Horizon Oil Spill: A Record Breaking Enterprise, Y. Liu, D. Streets, and R. Weisberg, Washington D.C. 195, 131-151.

Shay, L.K., B. Jaimes, J. Brewster, P. Myers, C. McCaskill, E. Uhlhorn, F. Marks, G. R. Halliwell, Jr., O. M. Smedsted and P. Hogan, 2012: Resolving eddy shedding variability from the Loop Current during Deep Water Horizon: Implications for coupled models. 30th AMS Conference on Hurricanes and Tropical Meteorology, 16-20 April 2012, Ponte Vedra Beach, FL (Abstract)

Shay, L.K., 2012: Airborne ocean surveys of the Loop Current complex from NOAA WP-3D in support of Deepwater Horizon oil spill. AOGS Public Lecture, AGU-Asian Oceanic and Geosciences Society, Singapore 13-17 August 2012.

Trade Manuscript (in prep):
Fries et al. Low Cost Oil Sensing Fluorometer- Sea Technology Magazine

Peer Review Manuscript (in prep):
Levaux, F., Bostater, C., Neyt, X., Feature detection in hyperspectral images using optimal multiple wavelengths, European Journal of Mechanical and Environmental Engineering (submitted) Spring, 2012 (peer review journal).

Fries et al. Embedded Oil Sensing System for Optimized Sensing and Sampling of Field Hydrocarbons- Analytical Chemistry

Hall et al. Recognizing Oil in MODIS Images, in preparation.

5) Presentations and posters, if planned (Please provide copies of each) (Note: a special section will focus on student presentations)

Bostater, C., Jones, J., Frystacky, F., Kovacs, M., Josza, O., 2010, Integration, testing, and calibration of imaging systems for land and water remote sensing, In: Remote Sensing of the Ocean, Sea Ice, and Large Water Regions 2010, Charles R. Bostater, Jr.; Stelios P. Mertikas; Xavier Neyt; Miguel Velez-Reyes, Toulouse, France, SPIE Vol. 7825.

Bostater, C., Jones, J., Frystacky, F., Kovacs, M., Jozsa, O., 2010, Image Analysis for water and subsurface feature detection in shallow waters, In: Remote Sensing of the Ocean, Sea Ice, and Large Water Regions 2010, Charles R. Bostater, Jr.; Stelios P. Mertikas; Xavier Neyt; Miguel Velez-Reyes, Toulouse, France, SPIE Vol. 7825.

Bostater, C., Jones, J., Frystacky, H., Gaelle Coppin, G., Levaux, F., Neyt, X., 2011, Airborne imaging sensors for environmental monitoring & surveillance in support of oil spills & recovery efforts, In: Remote Sensing of the Ocean, Sea Ice, Coastal Waters, and Large Water Regions 2011, Charles R. Bostater, Jr.; Stelios P. Mertikas; Xavier Neyt; Miguel Velez-Reyes, Prague, Czech Republic, SPIE Vol. 8175.

Bostater, C., Gaelle Coppin, G., Levaux, F., Jones, J., Frystacky, H., 2011, Mobile Platform Pushbroom Sensor Motion Control, Image Corrections and Spectral Band Selection: Examples of Hyperspectral Imagery Using Low Flying Aircraft and Small Vessels in Coastal Littoral Areas, In: Robots for Risky Interventions and Environmental Surveillance-Maintenance (RISE-2011), International Advanced Robotics Programme Workshop, June 20-21, 2011, Sponsored by the International Advanced Robotics Program (IARP), E. Colon (ed.), Royal Military Academy, Brussels, Belgium, 19 pp.

Bostater, C., Jones, J., Frystacky, H., 2012, Remote sensing of shorelines using data fusion of hyperspectral and multispectral imagery acquired from mobile and fixed platforms, In: Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XVIII, Sylvia S. Shen; Paul E. Lewis, Baltimore, Maryland, SPIE Vol. 8390.

Frias-Torres, S., Bostater, C., 2011, Potential impacts of the Deepwater Horizon oil spill on large pelagic fishes (Invited Paper), In: Remote Sensing of the Ocean, Sea Ice, Coastal Waters, and Large Water Regions 2011, (editors) Charles R. Bostater, Jr.; Stelios P. Mertikas; Xavier Neyt; Miguel Velez-Reyes, Prague, Czech Republic, SPIE Volume 8175.

Roffer, M. A., Review of Satellite Oceanographic Research With NOAA AOML and NMFS in the Gulf of Mexico and Straits of Florida. NOAA AOML. November 01, 2011

Roffer, M. A., Use Of In Situ And Remote Sensors, Sampling And Systems For Assessing The Extent, Fates, Impacts And Mitigation Of Oil/Dispersants. Overview of the Issues – II, Deepwater Horizon Oil Spill Principal Investigator (PI) Conference. National Science and Technology Council's Sub-Committee on Ocean Science and Technology (SOST). 25-26 October 2011, St. Petersburg Beach, Florida (Invited Plenary).

Shay, L., K., 2011: Aircraft surveys of Loop Current variability observed during Deepwater Horizon Oil Spill. Joint Subcommittee on Ocean Science and Technology Workshop on Deepwater Horizon Oil Spill, National Science and Technology Council's Sub-Committee on Ocean Science and Technology (SOST). 25-26 October 2011, St. Petersburg Beach, Florida (Invited).

Shay, L.K., B. Jaimes, J.D. Brewster, P. Meyers, C. McCaskill, S. Paul, E. Uhlhorn, F. D. Marks, and G. R. Halliwell, 2011: Real-time airborne ocean measurements and predictions of Loop Current eddy shedding during the Deepwater Horizon oil spill: Implications for hurricane intensity forecasting. 65th Interdepartmental Hurricane Conference, February 23-March 3, 2011, Miami, FL.

Joshua Kidd. 3/26/12. Detecting Surface Oil Using Unsupervised Learning Techniques on MODIS Satellite. MS Thesis Defense

6) Other products or deliverables

Maps and images are available at the following websites:

Satellite image time series:
http://imars.usf.edu

Interpreted/fused image products to track oil
http://roffs.com/deepwaterhorizon.html

Airborne data:
http://www.bostater.info/id51.html
http://www.bostater.info/id40.html
http://www.bostater.info/sitebuildercontent/sitebuilderfiles/bp_metadata_notes.pdf.

7) Data
Please provide a spreadsheet indicating the metadata and ancillary information on the location and status of the archived samples. Also, indicate if there are any issues with respect to data archiving schedule and plan. If you have a lot of metadata, representative samples will suffice. This will all be incorporated into the GoMRI database at some point in the future.

PARTICIPANTS AND COLLABORATORS

8) Project participants
Please list the participants of your project, their role(s) and contact information. No personal information will be released.* ***Note: Student/educational information will be collected elsewhere in this report.***

** We understand one person may fulfill more than one role; please list all applicable roles using the following standardized titles: Principal Investigator, Co-Principal Investigator, Scientific Participant, Technician, Lab Assistant, Administrative Support.*

First Name	Last Name	Role in Project	Institution	Email	Gender	Race	Citizenship
Frank	Muller-Karger	PI	University of South Florida	carib@marine.usf.edu			
Mitchell	Roffer	Co-I	ROFFS, inc.	roffers@bellsouth.net			
Charles	Bostater	Co-I	Florida Institute of Technology	cbostate@fit.edu			
Lynn K (Nick)	Shay	Co-I	University of Miami	nshay@rsmas.miami.edu			
David	Fries	Co-I	Bioplex	dfries@bioplextechnologies.com			
Nelson	Melo	Co-I	University of Miami				
Larry	Hall	Co-I	University of South Florida				
Steven	Lohrenz	Co-I	University of Massachusetts Dartmouth				

First Name	Last Name	Role in Project	Institution	Email
Charles	Bostater	PI	FIT	bostater@fit.edu
James	Jones	Research Technician	FIT	
Heather	Frystacky	Research Technician	FIT	

First Name	Last Name	Role in Project	Institution	Email
Lawrence	Hall	PI	Univ. of South Florida	hall@cse.usf.edu
Dmitry	Goldgof	Co-PI	Univ. of South Florida	goldgof@cse.usf.edu
Joshua	Kidd	Grad. Research Assistant	Univ. of South Florida	jkidd@mail.usf.edu
Bob	Chen	I	Univ. of South Florida	chen@monty.marine.usf.edu

MENTORING AND TRAINING

9) Student and post-doctoral participants
Please list the student participants of your project, their educational role, and other information. No personal information will be released.

First Name	Last Name	Post-doc / PhD / MS / BS	Thesis or research topic	Institution	Supervisor	Expected Completion year
Joshua	**Kidd**	**MS**	**Satellite image segmentation**	**Univ. of South Florida**	**Hall/Goldgof**	**12/2011**
Brendan	**O'Connor**	**MS**	**Chlorophyll Anomalies and spectral data analyses using AVIRIS/MODIS**	**Univ. of South Florida**	**F. Muller-Karger**	**3/2013**

First Name	Last Name	Post-doc / PhD / MS / BS	Thesis or research topic	Institution	Supervisor	Expected Completion year

James	**Jones**	**MS**	**Airborne Sensing**	**FIT**	**C. Bostater**	**Unknown**
Heather	**Frystacky**	**BS**	**Airborne Sensing**	**FIT**	**C. Bostater**	**Spring, 2012**
Florian	**Levaux**	**MS**	**Airborne Sensing**	**FIT**	**C. Bostater**	**Fall, 2011**
Gaelle	**Coppin**	**MS**	**Airborne Sensing**	**FIT**	**C. Bostater**	**Fall, 2011**
Mate	**Kovacs**	**BS**	**Airborne Sensing**	**FIT**	**C. Bostater**	**Fall, 2010**
Oszcar	**Jozsa**	**BS**	**Airborne Sensing**	**FIT**	**C. Bostater**	**Fall, 2010**

First Name	**Last Name**	**Role in Project**	**Institution**	**Email**
David	Mann	Open Source Software	Loggerhead	<dmann@loggerheadinstruments.com>

10) Student and post-doctoral publications, if planned

a. Published, peer-reviewed bibliography (Copies of the papers are requested)
b. Manuscripts submitted or in preparation (Please note target journal, and anticipated date of submission or publication)

11) Student and post-doctoral presentations and posters, if planned (Please provide copies of each)

Title	**Presenter**	**Authors**	**Meeting or Audience**	**Abstract published (Y/N)**	**Date**
Hyperspectral Sensing	H. Frystacky	-	FIT Undergraduate Seniors	N	7/2011
Hyperspectral Sensing	M. Kovacs	-	FIT Engineering Showcase	N	12/2010
Hyperspectral Sensing	O. Jozsa	-	FIT Engineering Showcase	N	10/10

12) Images

(See IMaRS images on http://imars.usf.edu)
(Other images in attached reports)

13) Continuing Research

If you are continuing this research under another grant, please include granting authority and title of award and a very brief synopsis (2-3 sentences).

Project Title: Oil Oceanographic Analyses: Satellite Mapping the Water Masses Containing Oil.
Report Type: Final
Principal Investigator: Mitchell A. Roffer
Period Covered By Report: August, 2010-August, 2012
Name and Address Of The Recipient's Institution: Roffer's Ocean Fishing Forecasting Service, Inc. 60 Westover Drive, West Melbourne, Florida 32904-5126
Grant Number: Florida Institute of Oceanography (FIO) Quickstart Project
Project ID Number: 4711-1101 sub-award #21454

SCIENCE ACTIVITIES

1) General Summary

For this project we completed our scope of work statement which said that *ROFFS™ will provide an "Oil Oceanographic Analysis (Oil OA) for the areas affected by the Deepwater Horizon Oil. The Oil OA will be derived from a substantial number of U.S. NOAA and NASA and European (ESA) satellites with a variety of spectral (infrared, near infra-red, visible, RGB, and radar) and spatial resolutions to visualize the oil and follow the water masses associated with the spill.*" In terms of deliverables:

1. Daily oil oceanographic analysis were produced and displayed on the ROFFS™ website for the Deepwater Horizon event covering April 23, 2010 to August 03, 2010.
2. The analyses were sent to FIO institutional designees and other interested personnel (e.g. NOAA, Florida Department of Environmental Protection, Florida Oceans and Coastal Council, Senator Bill Nelson, fishermen, media, interested government and academic personnel, and private stakeholders) via email on a daily basis.
3. Research ship efforts were supported by sending the analyses directly to the appropriate vessels (e.g., Florida Institute of Oceanography R/V Weatherbird, University of Miami Walton Smith, Gulf Coast Research Laboratory R/V Tommy Munro; NOAA's R/V Nancy Foster and R/V MacArthur II), and/or support staff on a five day per week basis.
4. Verbal updates to research vessels were provided.
5. Consultations with FIO parties (e.g., Frank Muller-Karger, Bob Weisberg, Chuanmin Hu - USF; George Maul-FIT; Nick Shay, Arthur Mariano, Tom Lee, Hans Graber, Geoffrey Samuels, Villy Kourafalou-UM_RSMAS), regarding the analyses and techniques used to derive the analyses were made.
6. Satellite data and special analyses were provided to FIO researchers (Bob Hueter-Mote, David Hollander, Paula Coble, Earnst Peeples – USF, David Kerstetter and Travis Moore - NOVA, and Brian LaPointe Harbor Branch Oceanographic Institution) on a request basis.
7. Research to develop new satellite data products for use in monitoring the distribution of the oil water mixture and ocean circulation was conducted and resulted in the development of fusion data products.
8. A complete re-analysis of the satellite data derived during the surface oil spill from April 20 through August 03 was conducted. The data were combined into weekly oil coverage maps and converted to a GIS - shape file format for further analysis.

Lessons Learned

Each satellite sensor has its advantages and limitations related to spectral, spatial and temporal resolution, sun angle, atmospheric interference, swath width, surface wind, and ocean roughness conditions for detecting oil. It was realized that the multiple types of satellite imagery had to be combined to derive a more comprehensive view of the surface oil and surface ocean circulation. More frequent in-situ validation is needed over a greater distance, i.e. the far field, rather than only from ships and aircraft viewing the easy to observe surface oil in the near field. Stakeholders valued receiving the analyses and expressed their appreciation. Altimeter products should be produced for standard areas of interest like the Gulf of Mexico. Communication and data exchanges between the official emergency responders and researchers need to be improved.

2) Results and Scientific Highlights

During this project we reanalyzed the data related to the distribution and fate of the oil – dispersant – water mixture released during the Deepwater Horizon spill episode. This allowed the project personnel to use the knowledge gained during the real-time production of analyses to re-evaluate, sometimes improve, and integrate more in-situ data for validation of the satellite derived analyses. We took advantage of the increased availability of synthetic aperture radar (SAR) data from University of Miami-CSTARS and a new reduced RGB sun-glint product developed by University of South Florida-IMaRS as part of this research. Revaluation of the surface observed oil derived from the use of SAR and visible RGB (with and without sun-glint) imagery, allow a more comprehensive determination of the areas covered by the relatively obvious water masses with high concentration of surface oil compared with areas covered by the water with an unknown and substantially lower (yet significant) concentration of oil and dispersants that had come into contact with the water masses that had the obvious surface oil.

This project used a combination of infrared (IR) and visible wavelength satellites including: a) the U.S. NOAA series *(NOAA_15, 16, 17, 18, 19)*; b) U.S. NASA Aqua and Terra; and c) European Envisat and Metop_A. In addition, we used altimeter data derived from JASON-1/-2, TOPEX, ERS-2, ENVISAT and GFO satellites, as well as, data derived from synthetic aperture radar (SAR) from Envisat, TerraSARX, CosmoSkymed, CS2, Radarsat, and ERS2. The NOAA series data and Metop_A was accessed via the NOAA Comprehensive Large Array-data Stewardship System (CLASS) and had 1.1 km resolution. The Aqua and Terra provided by the University of South Florida Institute for Marine Remote Sensing (IMaRS) data at 1.1 km for IR and derived chlorophyll and 250 m for the visible RGB. The MERIS ocean color data downloaded from ESA had 1.1 km and 300 m resolution. The altimeter data were derived from the NOAA AOML altimeter page with a spatial resolution of 25 km. The SAR data resolution varied as a function of the source of the data. The project received degraded resolution from University Miami Center for Southeastern Tropical Advanced Remote Sensing (CSTARS) that varied from 1 m to 1 km, but was mostly in the 25-75 m range. From ESA it was 75 m.

The satellite observations of anomalous surface light reflectance, temperature and roughness, combined with *in situ* observations, reduced our uncertainty in defining the location of the surface oil and dispersant contamination in the near field. Unfortunately, other than a few in-situ observations there was no mechanism to quantify the oil concentration in the far field areas where the water masses were identified as likely containing contaminated water. As the oil – dispersant mixture is considered toxic at any concentration, we used the first-order estimates, i.e., sequentially track of the water that had come into contact with the oil, to evaluate a worstcase scenario of where potentially polluted water occurred. We felt it is important for ecosystem studies to know where adults, juveniles, eggs and larvae of marine organisms including marine birds would be exposed by any oil – dispersant contamination. We understood that these water masses would likely have some detectable concentration of the oil dispersant mixture even if it only had a patchy distribution.

During this research it became apparent that each available satellite sensor had its advantages and limitations related to spectral, spatial and temporal resolution, sun angle, cloud coverage, swath width, surface wind, ocean roughness and current conditions for mapping oil and surrounding water masses. While combining the data with different spatial resolution, swath width and "personalities" related to atmospheric interference and sun angle was problematic, it became apparent that the most efficient way to map the oil and the potentially contaminated water was to combine the data. Thus, we developed new techniques to overlay and fuse the data.

The surface oil slick was easily recognizable in clear satellite images in the visible part of observing spectrum, as well as, in SAR images during times of optimal wind speed. Using both visible RGB (with and without sun glint) and separate SAR images individually and in-combination the surface oil was identified on a daily basis. Often one type of imagery verified the oil's signature observed with the other type. It became apparent due to the lack of daily repeat coverage of the SAR imagery, lack of optimal wind conditions and lack of daily sun glint in the imagery that it was best, to combine the image data by three day and weekly increments to provide the most accurate and reliable depiction of the oil coverage. This was not immediately apparent during the period when we were providing the real-time analyses.

While there was no way to separate with confidence the reflectance/absorption patterns using the derived chlorophyll satellite data, these data and especially the infrared data for sea surface temperature (sst) allowed us to identify and track the water masses that came into contact with the oil pollution. The different imagery (sst and chlorophyll) provide complementary data and by studying the different images and image composites in a sequential manner we could follow the these water masses over hours, days, and weeks.

It was determined that the best format when providing the analyses to a broad audience was to produce a combination product composed of a text and graphic. The text component provided a description of the overall ocean circulation and focused on the relevant flow fields in the area of interest (e.g. Gulf of Mexico). It included a discussion of the distribution of the oil and likely short-term movements, as well as, other pertinent information including validation evidence when available. The graphic was an ocean frontal analysis derived primarily from infrared and ocean color satellite data. The background of the graphic was usually the best short-term infrared image that was derived using a variety of iterative procedures to produce a re-navigated, re-mapped, and re-calibrated image that was representative of the current oceanographic conditions. Sea surface temperature was derived from the IR data and a color sea surface temperature (sst) palette was included. There were some times, due to haze and other atmospheric interference that the ocean color – derived chlorophyll imagery provided a better depiction of the water masses and it was used instead of the IR data. Also when there were too much cloud obstruction, an image derived from the NOAA-AOML altimeter data was used. The frontal analysis was overlaid over modified NOAA NOS nautical chart. The graphic shows navigation gridlines with latitude – longitude coordinates and a coastal outline. Often important bottom topographic features were included such as canyon names and topography, other oil platforms, and named fishing areas. The graphic and text were combined in an Adobe™ PDF format. Presentation in other formats were considered, but this format was determined to be the best. The graphical data were imported into an Arc-GIS system.

The analyses were the result of interpretations of the satellite imagery integrated with other data such as currents from drifting buoys from NOAA_AOML and Horizon Marine Inc., acoustic doppler current profilers from research vessels and oil platforms, in-situ reports, as well as, winds, sea height, and sea surface temperature (SST) from buoys. The surface circulation patterns were verified from drifting buoy tracks complied by the NOAA Atlantic Oceanographic and Meteorological Laboratory and Horizon Marine Inc. and using acoustic doppler current profilers available from NOAA's National Data Buoy Center. Altimetry data were also used to validate the current direction. The presence of surface oil was verified using NOAA Marine Pollution Surveillance Reports (MPSRs) and observations from different research vessels.

3) Cruises and Field Expeditions

We supported the following research cruises by providing oceanographic analyses:

Ship or Platform Name	Class	Chief Scientist	Objectives	Dates
RV Weatherbird	115 feet	Bob Hueter	Longline Fishing Survey & Oil GOM	11/04-07/10
RV Weatherbird	115 feet	Bob Hueter	Longline Fishing Survey & Oil GOM	04/20-27/11
RV Weatherbird	115 feet	Bob Hueter	Longline Fishing Survey & Oil GOM	10/19-24/11
RV Weatherbird	115 feet	Bob Hueter	Longline Fishing Survey & Oil GOM	04/19-27/11
Vessels of Opportunity	<40 feet	Brian LaPointe	Searching for turtles and oil FL Keys	07/17-08/02/10
RV Tommy Munro	97 feet	John Incardona	Fish larvae survey GOM	07/28-08/03/10
RV Tommy Munro	97 feet	Jim Franks	Fish larvae survey GOM	05/17-06/02/10
RV Tommy Munro	97 feet	Jim Franks	Fish larvae survey GOM	05/05-28/11
RV Walton Smith	96 feet	Michelle Wood	Oil – oceanographic survey	06/05-09/10
RV Researcher/Panacea	29 feet	Travis Moore	Fish ecosystem survey FL east coast	02/09-07/09/11
RV Researcher/Panacea	29 feet	Travis Moore	Fish ecosystem survey FL east coast	05/07-09/12
RV Nancy Foster	187 feet	Ryan Smith	Oil – oceanographic survey	06/30-0718/10
RV MacArthur	224 feet	John Quinlan	Fish ecosystem survey GOM	07/21-10/02-11
RV Poseidon, RV Trident	40', 33'	Eric Newman	Fish ecosystem survey GOM	03/31-08/30/11
RV Poseidon, RV Trident	40', 33'	Eric Newman	Fish ecosystem survey GOM	03/23-08/24/12
RV Spree	100 feet	Michael Burton	Oil- fish oceanographic survey	06/26/10

4) Peer Reviewed Publications

Hoffmayer, E.R., W.B. Driggers, J.S. Franks, D.S. Hanisko, M.A. Roffer, and L.E. Cavitt. 2011. Recent occurrences of basking sharks, *Cetorhinus maximus* (Gunnerus, 1765) [Chondrichthyes: Cetorhinidae], in the Gulf of Mexico. Marine Biodiversity Records 4(e87): 1-4.

Mariano, A, V. Kourafalou, H. Kang, G.R. Halliwell, A. Srinivasan, E. Ryan, and M.A Roffer. 2011. On the Modeling of the 2010 Gulf of Mexico Oil Spill. J. Dynamics of Atmos. and Oceans 52: 322-340.

Muhling, B.A., M.A. Roffer, J.T. Lamkin, G.W. Ingram, Jr., M.A. Upton, G. Gawlikowski, F.E. Muller-Karger, S. Habtes, W.J. Richards. 2012. Overlap between Atlantic bluefin tuna spawning grounds and observed Deepwater Horizon surface oil in the northern Gulf of Mexico. Marine Pollution Bull. 64(4):697-687.

5) Presentations and Posters

Title	Presenter	Authors	Meeting or Audience	Pub. (Y/N)	Date
Finding Deepwater Horizon oil by satellite	Mitchell Roffer	M.A. Roffer	NOAA/AOML-SEFSC Workshop Gulf of Mexico Monitoring in Support of Oil Spill Efforts	Y	July, 2010
Finding oil by satellite oceanography: lessons learned future needs	Mitchell Roffer	M.A. Roffer	NSTC JSOST Deepwater Horizon Spill PI Conf., St. Petersburg	Y	Oct., 2010
Collaborative Project: Early Warning 4-D Remote Sensing System to Assess Synoptic Threats to Coastal Ecosystems of Florida and of Adjacent States and Nations	Frank Muller-Karger	Muller-Karger, F.E., L. Hall, D. Goldgof, C. Hu, L.K. Shay, C, Bostater, M.A. Roffer, D. Fries, E. Johns, N. Melo, S. Lohrenz	FIO Deepwater Horizon Principal Investigators Workshop, Orlando, FL	Y	Sept., 2010
Review of Satellite Oceanographic Research With NOAA AOML and NMFS in the Gulf of Mexico and Straits of Florida	Mitchell Roffer	M.A. Roffer	NOAA AOML Seminar	Y	Nov., 2010
Plenary invited talk: Use Of *In Situ And Remote Sensors, Sampling And Systems* For Assessing The Extent, Fates, Impacts And Mitigation	Mitchell Roffer	M.A. Roffer	NSTC SOST Deepwater Horizon Spill Conf. II, St. Petersburg, FL	Y	Oct., 2011
Modeling the overlap between Atlantic bluefin tuna spawning habitat and Deepwater Horizon Oil in Spring 2010 (Poster)	Mitchell Roffer	Roffer, MA, B. Muhling, J. Lamkin, W. Ingram, M. Upton, G. Gawlikowski, F. Muller-Karger and S. Habtes	ASLO-AGU-TOS Ocean Sciences Meeting, Salt Lake City, UT	Y	Feb., 2012
Development Of New Fusion Products Using Satellite Infrared,	Mitchell Roffer	Roffer, MA, G. Gawlikowski, M. Upton, F. Muller-	SPIE Defense, Security + Sensing	Y	Ap. 2012

Visible, Synthetic Aperture Radar And Altimetry Data During The Deepwater Horizon Oil Spill In The Gulf Of Mexico, 2010		Karger, G.J. Goni, J.A. Trinanes			

6) Other Products or Deliverables

The Oil Oceanographic Analyses are available on DVD and stored at ROFFS™ West Melbourne, FL.

7) Data

Metadata: This project used a combination of infrared (IR) and visible wavelength satellites including: a) the U.S. NOAA series *(NOAA_15, 16, 17, 18, 19)*; b) U.S. NASA Aqua and Terra; and c) European Envisat and Metop_A. In addition, we used altimeter data derived from JASON-1/-2, TOPEX, ERS-2, ENVISAT and GFO satellites, as well as, data derived from synthetic aperture radar (SAR) from Envisat, TerraSARX, CosmoSkymed, CS2, Radarsat, and ERS2. The NOAA series data and Metop_A provided by the NOAA Comprehensive Large Array-data Stewardship System (CLASS) had 1.1 km resolution. The Aqua and Terra provided by the University of South Florida Institute for Marine Remote Sensing (IMaRS) data at 1.1 km for IR and derived chlorophyll and 250 m for the visible RGB. The altimeter data were derived from the NOAA AOML altimeter page with a spatial resolution of 25 km. The SAR data resolution varied as a function of the source of the data. The project received degraded resolution from University Miami Center for Southeastern Tropical Advanced Remote Sensing (CSTARS) that varied from 1 m to 1 km, but was mostly in the 25-75 m range. From ESA it was 75 m. Additional information regarding the data and analyses are available.

8) Participants and Collaborators

First Name	Last Name	Role in Project	Institution	Email
Mitchell	Roffer	PI	ROFFS™	roffers@bellsouth.net
Gregory	Gawlikowski	Satellite Analyst	ROFFS™	greg2@roffs.com
Mathew	Upton	Satellite Analyst	ROFFS™	matt2@roffs.com
Frank	Muller-Karger	Sci. Participant	USF	carib@marine.usf.edu
Ken	Schaudt	Collaborator	Schaudt.US	kjschaudt@schaudt.us
Tom	Lee	Collaborator	UM_RSMAS	tlee8@cfl.rr.com
Michele	Wood	Collaborator	NOAA AOML	Michelle.wood@noaa.gov
Gustavo	Goni	Collaborator	NOAA AOML	Gustavo.goni@noaa.gov
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Charles	Bostater	Collaborator	FIT	cbostater@fit.edu
Jim	Franks	Collaborator	USM	jim.franks@usm.edu
Robert	Hueter	Collaborator	Mote	rhueter@mote.edu
John	Lamkin	Collaborator	NOAA NMFS	John.lamkin@noaa.gov
Barbara	Muhling	Collaborator	UM_CIMAS	Barbara.muhling@noaa.gov
Arthur	Mariano	Collaborator	UM_RSMAS	amariano@rsmas.miami.edu

Villy	Kourafalou	Collaborator	UM_RSMAS	vkourafalou@rsmas.miami.edu
George	Halliwell	Collaborator	NOAA AOML	George.halliwell@noaa.gov
Eric	Hoffmayer	Collaborator	NOAA NMFS	Eric.hoffmayer@noaa.edu
Nick	Shay	Collaborator	UM_RSMAS	nshay@rsmas.miami.edu
Chuanmin	Hu	Collaborator	USF	hu@marine.usf.edu
Sharon	Whidden	Administrative	ROFFS™	Sharon@roffs.com

9) Mentoring and Training

First Name	Last Name	Post-doc / PhD / MS / BS	Thesis or research topic	Institu tion	Supervisor	Expected Completion year
Sennai	Habtes	Ph.D.	Fisheries Oceanography	USF	F. Muller-Karger	2013
Brendon	O'Conner	M.S.	Remote Sensing & Oil	USF	F. Muller-Karger	2013
Travis	Moore	Ph.D.	Fisheries Oceanography	NOVA	D. Kerstetter	2013

10) Student and Post-Doctoral Publications

None

11) Student and Post-Doctoral Presentations

Title	Presenter	Authors	Meeting or Audience	Abstract published (Y/N)	Date
Trophic Dynamics and Ecosystem Changes within the SE Florida Coastal Pelagic Fish Community	T.A. Moore,	T.A. Moore, D.W. Kerstetter	*62nd Annual Tuna Conference*, Lake Arrowhead, CA. pp. 45. (Poster).	Y	2011
Trophic Dynamics and Ecosystem Changes within the SE Florida Coastal Pelagic Fish Community	T.A. Moore	T.A. Moore, D.W. Kerstetter	*32nd Annual Meeting of the Florida Chapter of the American Fisheries Society Presentation*	Y	2012
Trophic Dynamics of the Southeast Florida, USA Coastal Pelagic Fish Complex	T.A. Moore	T.A. Moore, D.W. Kerstetter	*63rd Annual Tuna Conference*, Lake Arrowhead, CA Presentation	Y	2012

12) Images

See below for three representative images derived during this project.

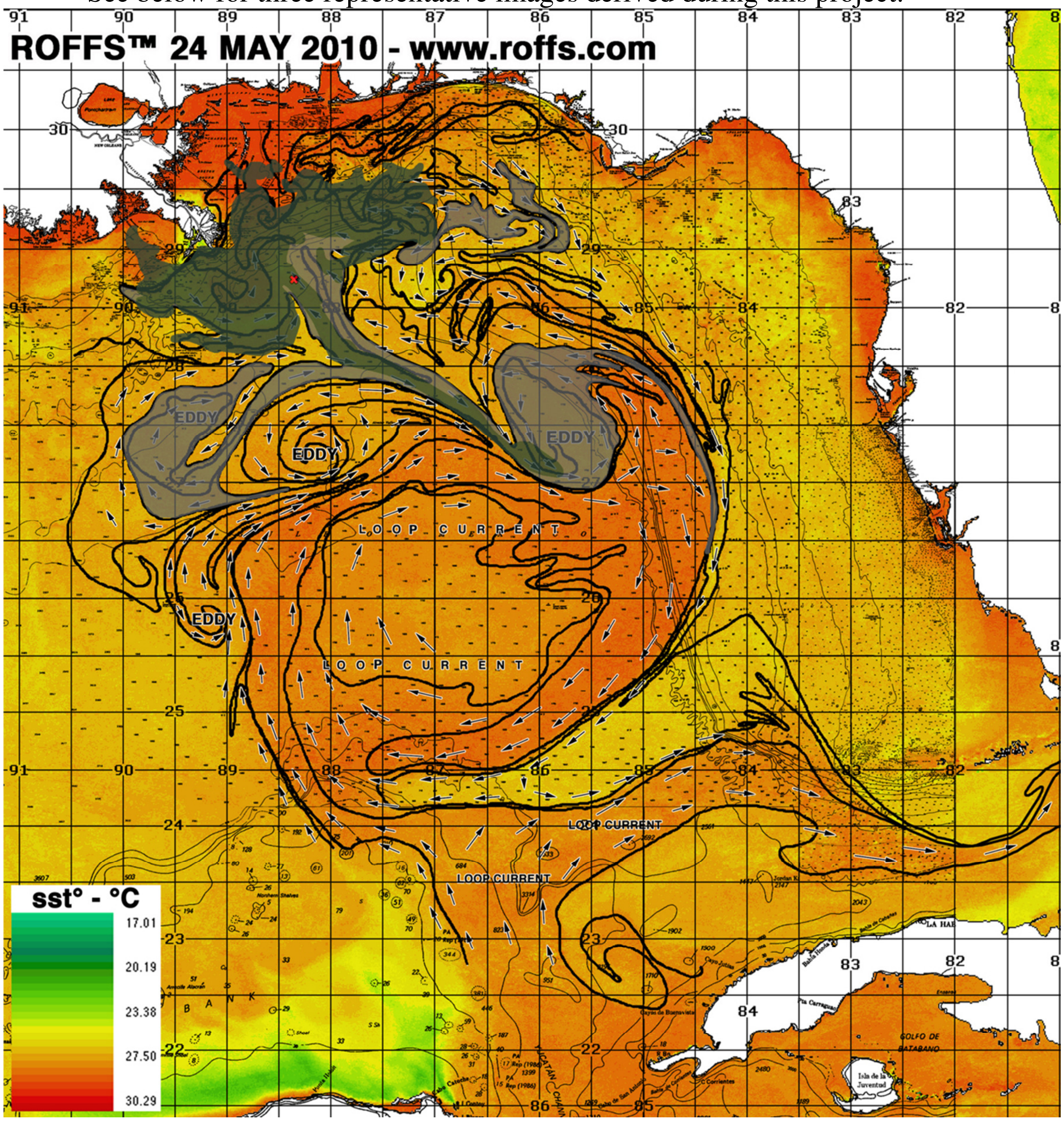


Figure 1. Is the ROFFS™ Oil Oceanographic Analysis graphic for the eastern Gulf of Mexico derived on May 24, 2010 using a infrared satellite data to derive a single image showing sea surface temperature (sst). The major water masses are outlined. The olive green colored shape indicates where surface oil was observed using visible satellite imagery with and without sun glint along with synthetic aperture radar. The grey color shape indicates where the water which come into contact with the oil containing water masses had moved. This water had unknown concentrations of Deep Horizon oil. But the presence of oil was verified by in-situ observations.

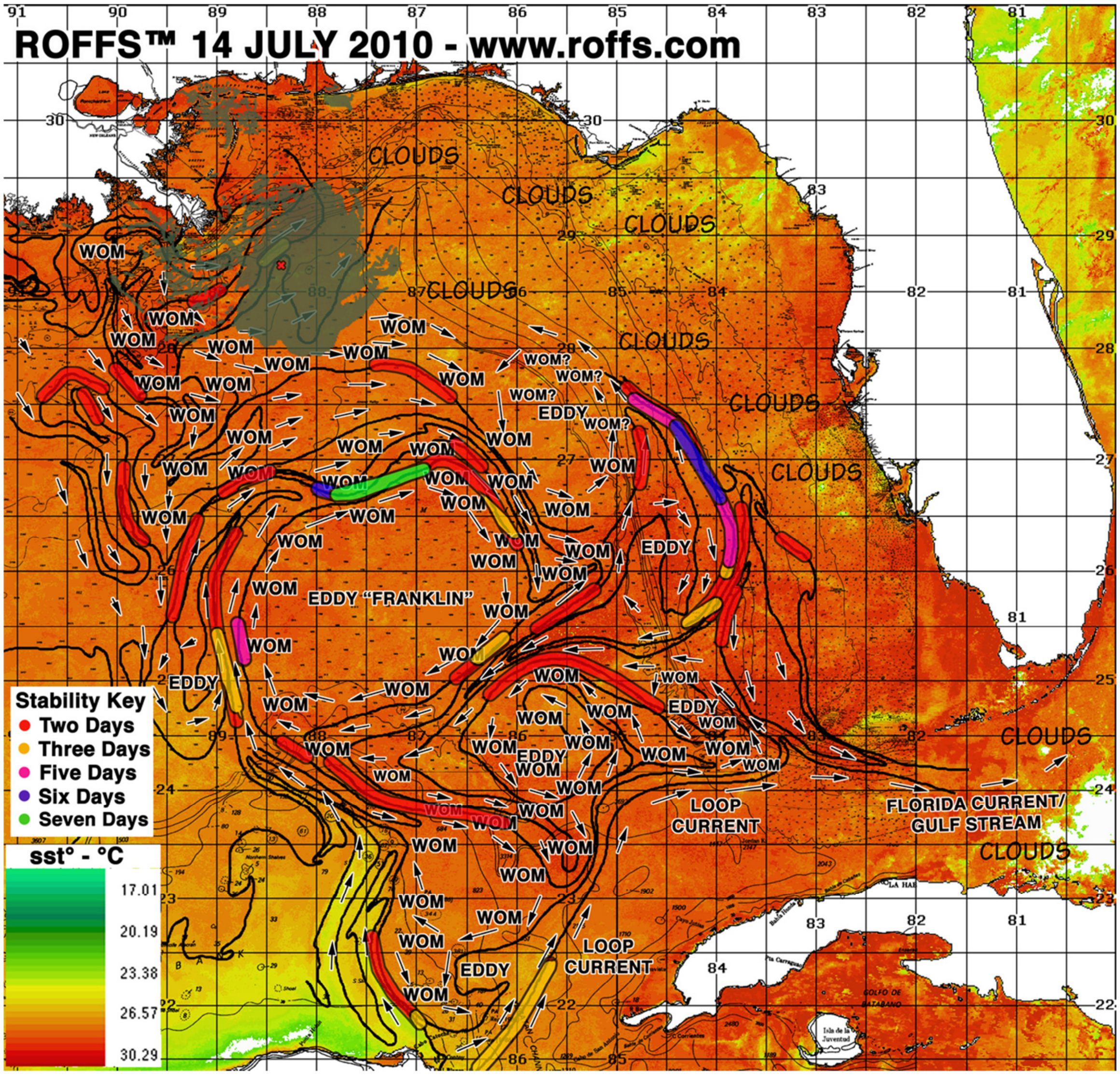


Figure 2. Is the ROFFS™ Oil Oceanographic Analysis graphic for the eastern Gulf of Mexico derived on May 14, 2010 using a infrared satellite data to derive a single image showing sea surface temperature (sst). The major water masses are outlined. The olive green colored shapes indicates where surface oil was observed using visible satellite imagery with and without sun glint along with synthetic aperture radar. The areas labeled with "WOM" are the areas where the water masses with a unknown concentration of a water oil mixture (WOM) occur. The "WOM?" are the areas that there was a good possibility of WOM but atmospheric interference prevented a more definite identification. Ocean frontal boundaries with varying amounts of stability, i.e. daily overlap, are indicated with a color code ranging from two to seven days. The stability key was developed to show the areas with the most persistent convergence which are more likely to concentrate oil, other surface particles (e.g. Sargassum weed, other flotsam) and fish, as well as, planktonic eggs, larvae and other organisms.

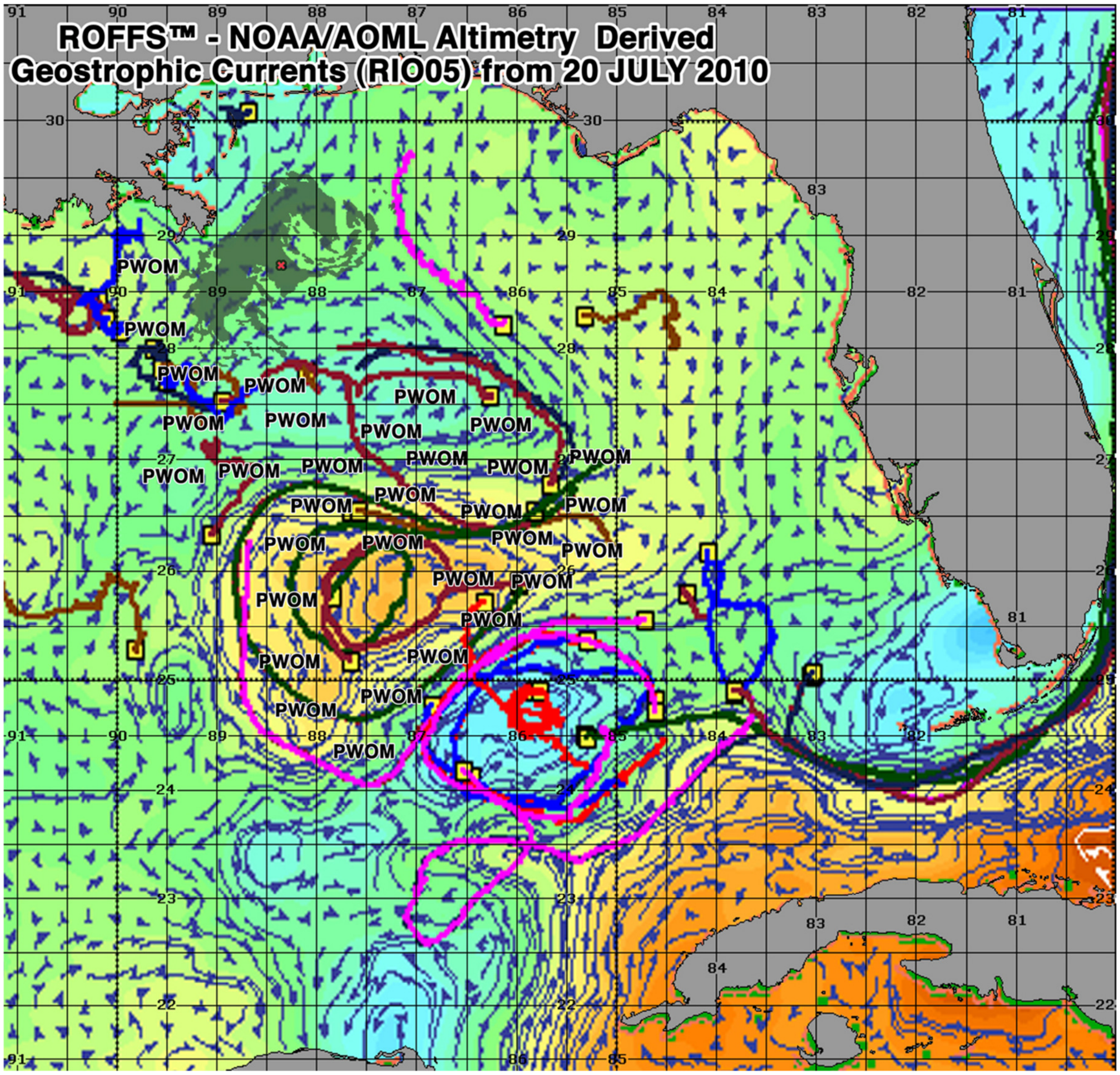


Figure 3. Is the ROFFS™ Oil Oceanographic Analysis graphic for the eastern Gulf of Mexico derived on July 20, 2010. The oil green colored shape indicates where surface oil was observed using visible satellite imagery with and without sun glint along with synthetic aperture radar. The background is derived from a NOAA/AOML altimeter image with blue arrows indicating the current flow. The drift tracks from surface buoys from NOAA AOML and Horizon Marine, Inc. are overlaid on the altimeter data which provides verification of the derived altimetry data.

13. Continuing Research

While we are continuing the development of fusion data products to improve the visualization and understanding of the currents in the Gulf of Mexico and elsewhere. This is important as satellite data from newly launched satellites (e.g. NPP) and other oceanographic data (e.g. gliders) become available. We are also preparing additional manuscripts for publication using the data derived from this research. Collaborations begun under this grant are continuing.

End of Report.

Early Warning 4-D Remote Sensing System to Assess Synoptic Threats to Coastal Ecosystems of Florida and of Adjacent States and Nations

Research Investigator:
Nelson Melo

SCIENCE ACTIVITIES

1) General Summary

This subcontract with the University of Miami/CIMAS supports Mr. Nelson Melo to provide technical expertise at sea to collect optical data and other specific parameters that would be most useful for comparison with satellite and airborne remote sensing products, and to participate in post-cruise data processing and analysis..

2) Results and scientific highlights

As part of the subcontract mentioned above, Nelson Melo participated from August 2010 to now (October 2011) in 6 bimonthly 5-day interdisciplinary cruises of the south Florida coastal waters south of the Caloosahatchee River mouth, including the southwest Florida shelf and the Florida Keys, aboard the University of Miami's R/V F. G. Walton Smith. During the cruises Melo collected and preprocessed 58 optical profiles with the PRR-2600 Profiling Reflectance Radiometer, 33 profiles with the PUV2500 ultraviolet radiometer, 13 hyper-spectral profiles with the Satlantic Hyper-Pro Radiometer and 38 surface hyper-spectral spectrums with the GER1500 hyper-spectral spectrometer. The data have been shared with the University of South Florida Institute for Marine Remote Sensing (IMaRS) and with the Optical Oceanography Laboratory Colleague of Marine Science.

3) Cruises & field expeditions

Ship or Platform Name	**Class** (if applicable)	**Chief Scientist**	**Objectives**	**Dates**
R/V "Walton Smith"		Nelson Melo	Florida Keys and W Florida hydrology and Optic	Aug. 16-20 2010
R/V "Walton Smith"		Nelson Melo	Florida Keys and W Florida hydrology and Optic	Oct.12-16 2010
R/V "Walton Smith"		Nelson Melo	Florida Keys and W Florida hydrology and Optic	Dec. 02-06 2010
R/V "Walton Smith"		Nelson Melo	Florida Keys and W Florida hydrology and Optic	Feb 21-25 2011
R/V "Walton Smith"		Nelson Melo	Florida Keys and W Florida hydrology and Optic	Apr. 04-08 2011
R/V "Walton Smith"		Nelson Melo	Florida Keys and W Florida hydrology and Optic	Jun. 07-11 2011

R/V "Walton Smith"		Nelson Melo	Florida Keys and W Florida hydrology and Optic	Aug. 02-07 2011
R/V "Walton Smith"		Nelson Melo	Florida Keys and W Florida hydrology and Optic	Oct. 20-24 2011
R/V "Walton Smith"		Nelson Melo	Florida Keys and W Florida hydrology and Optic	Dec. 11-15 2011
R/V "Walton Smith"		Nelson Melo	Florida Keys and W Florida hydrology and Optic	Feb. 27-Mar 02 2012
R/V "Virginia K"		Nelson Melo	Florida Keys hydrology and Optic	May. 12 – 24 2012

RESEARCH INSTITUTION: UNIVERSITY OF SOUTH FLORIDA

FINDING OIL IN SATELLITE IMAGES

Lawrence O. Hall, Dmitry B. Goldgof, Frank Muller-Karger

SCIENCE ACTIVITIES

1) General Summary

Narrative (1 pages maximum): Please provide a brief overview of the project and goals supported during the conduct of this project. Be sure to highlight any 'lessons learned' that could be applied to other/future oil spill related projects (e.g., management, data support, logistics, etc.). Listing accomplishments against project activities, objectives and milestones in bulleted form is acceptable.

The goal of this research was to automatically recognize oil in Satellite images. We used the MODIS satellite images of the region containing the deepwater horizon spill. One immediate problem was that sun glint off the water with oil would saturate the sensor. So, while it provided a clue on where oil existed, for a good determination the team had to create its own algorithms for handling the sun glint issue (Bob Chen did this).

Generally, a problem was the lack of ground truth. We certainly reliably found oil by the deepwater horizon platform. We also found oil in the area that NOAA online spatial overlays (shape files) showed oil. However, we did not find oil in some parts of the NOAA shape files and found it outside. So, what is real? We cannot say.

We were able to get repeatable results with just a set of satellite image bands at a 500 square meter resolution.

2) Results and scientific highlights

Narrative (2 pages maximum): This should be a summary of significant results (positive and negative) and conclusions during the conduct of this project. Listing science results and highlights in bulleted form is acceptable. In each case, please explain the impact of the result.

In an effort to track the extent and location of the oil coming from deepwater horizon the National Oceanic and Atmospheric Administration (NOAA) released reports almost daily that estimated the shape and geographical coordinates of oil floating on the surface of the gulf waters. These reports were manually generated using images captured from several different satellite-mounted remote sensing instruments, including traditional optical sensors that capture data in visible and near-infrared wavelengths, such as the Moderate Resolution Imaging Spectroradiometer (MODIS) and the Medium Resolution Imaging Spectrometer (MERIS) and Synthetic-Aperture Radar (SAR) sensors that capture the reflection of transmitted microwaves, such as the COSMO SkyMed, RadarSat I , and Envisat ASAR. In addition to providing a mechanism to track the extent of this crisis, the information released each day in these documents, coupled with wind speed and ocean current forecasts, assisted in modeling projections of where the oil may be going as well as coordinating clean up efforts. The polygonal shapes or shape-files, generated from NOAA's data would also be used to populate the New York Times web application that tracked the oil spill in real time as the data became available and the Environmental Response Management Application (ERMA) that was designed by NOAA and a group from the University of New Hampshire to assist in environmental emergencies. Figure 1 shows a true color image that was generated using Terra MODIS data from April 29th with a NOAA shape-file layer outlining the surface oil. Many researchers have concluded that there is a definite need for an automated system capable of identifying and tracking oil spills.

NASA's MODIS instrument captures data at 36 different wavelengths, each referred to as a band, ranging from approximately 405 to 14,385 nm and a spatial resolution of either 250 m, 500 m, or 1 km per side. This remote sensing device has been deployed on both the Terra and Aqua satellites as part of NASA's Earth Observing System (EOS) initiative. Every day, the Terra satellite crosses over the Gulf of Mexico from north to south at approximately 12 pm EST and the Aqua satellite crosses over the exact same region traveling from south to north at approximately 2 pm EST. The MODIS sensor data captured each day is converted to ocean color products by NASA's Ocean Biology Processing Group (OBPG) and publicly distributed on line from their site Ocean Color Web. OBPG makes MODIS products publicly available at various processing stages, or levels, such as the Level-1A version of the data containing the raw radiance counts recorded by the sensors, the Level-1B data composed of radiance counts with sensor calibration corrections, and the Level-2 data containing radiances with atmospheric corrections and custom products specific to ocean color applications such as chlorophyll-a. Due to the data's temporal coverage and accessibility on line, the Terra and Aqua MODIS satellites represent excellent candidates for monitoring surface oil in the Gulf of Mexico.

We have applied the fuzzy c-means (FCM) clustering algorithm to the same MODIS data sets used by NOAA to generate their surface oil tracking reports during the Deepwater Horizon crisis in 2010. The objective is to determine whether the FCM clustering algorithm can accurately predict the presence of surface oil using MODIS Level-2 based features by comparing the clustering results to the shape-files generated by NOAA.

A novel de-glinting equation was developed within the project. The de-glinted water-leaving radiance estimations were calculated for the 645 nm band, which has a native resolution of 250 m, the 469 and 555 nm bands, which both have a native resolution of 500 m, and the 412, 438, and 488 nm bands, which all have a native resolution of 1km. A texture feature was also calculated on each band.

In the images section for Figure 2, one can see that we find oil within the shape file (some parts are not visible due to clouds primarily). However, we find some oil outside of the shape file and miss some in it. So, if we take the shape files of clear days as ground truth, use fuzzy clustering to group the data and label it by calling the top two or three clusters by the water leaving radiance feature oil, we get the following match results using texture and water-leaving radiance features.

With the F-measure the agreement for each day is between 0.38 and 0.82 with the ideal match being a value of 1. We can visually see we find oil. From the images it is not clear there is oil (to us) in all regions in the shape file. However, this is the only ground truth available to us.

Our field of view was set to slightly exceed the shape file on each day. An important experiment is to take a fixed field of view and, across days, look at how oil moves.

3) Cruises & field expeditions

4) Peer-reviewed publications, if planned (Note: a special section will focus on student and post-doctoral publications)
   a. Published, peer-reviewed bibliography (Copies of the papers are requested)
   b. Manuscripts submitted or in preparation (Please note target journal, and anticipated date of publication or submission)

Recognizing Oil in MODIS Images, in preparation.

5) Presentations and posters, if planned (Please provide copies of each) (Note: a special section will focus on student presentations)

Title	**Presenter**	**Authors**	**Meeting or Audience**	**Abstract published (Y/N)**	**Date**
Detecting Surface Oil Using Unsupervised Learning Techniques on MODIS Satellite	Joshua Kidd		MS Thesis Defense	Y	3/26/12

6) Other products or deliverables

Please list (for example: maps, models, tools) and indicate where they can be located/obtained.

7) Data

Please provide a spreadsheet indicating the metadata and ancillary information on the location and status of the archived samples. Also, indicate if there are any issues with respect to data archiving schedule and plan. If you have a lot of metadata, representative samples will suffice. This will all be incorporated into the GoMRI database at some point in the future.

PARTICIPANTS AND COLLABORATORS

8) Project participants

Please list the participants of your project, their role(s) and contact information. No personal information will be released.* ***Note: Student/educational information will be collected elsewhere in this report****.*

** We understand one person may fulfill more than one role; please list all applicable roles using the following standardized titles: Principal Investigator, Co-Principal Investigator, Scientific Participant, Technician, Lab Assistant, Administrative Support.*

First Name	Last Name	Role in Project	Institution	Email
Lawrence	Hall	PI	Univ. of South Florida	hall@cse.usf.edu
Dmitry	Goldgof	Co-PI	Univ. of South Florida	goldgof@cse.usf.edu
Joshua	Kidd	Grad. Research Assistant	Univ. of South Florida	jkidd@mail.usf.edu
Bob	Chen	I	Univ. of South Florida	chen@monty.marine.usf.edu
Frank	Muller-Karger	Co-PI	Univ. of South Florida	carib@marine.usf.edu

MENTORING AND TRAINING

9) Student and post-doctoral participants

Please list the student participants of your project, their educational role, and other information. No personal information will be released.

First Name	Last Name	Post-doc / PhD / MS / BS	Thesis or research topic	Institution	Supervisor	Expected Completion year
Joshua	Kidd	MS	Satellite image segmentation	Univ. of South Florida	Hall/Goldgof	12/2011

10) Student and post-doctoral publications, if planned

   a. Published, peer-reviewed bibliography (Copies of the papers are requested)
   b. Manuscripts submitted or in preparation (Please note target journal, and anticipated date of submission or publication)

M.S. Thesis: Detecting Surface Oil Using Unsupervised Learning Techniques on MODIS Satellite

11) Student and post-doctoral presentations and posters, if planned (Please provide copies of each)

Title	**Presenter**	**Authors**	**Meeting or Audience**	**Abstract published (Y/N)**	**Date**

12) Images

Please attach high-resolution images and provide details including a description of the image, location, credit, date, etc. Of note: Image may be used in FIO or GoMRI promotions, so please make sure you have rights to use the image.

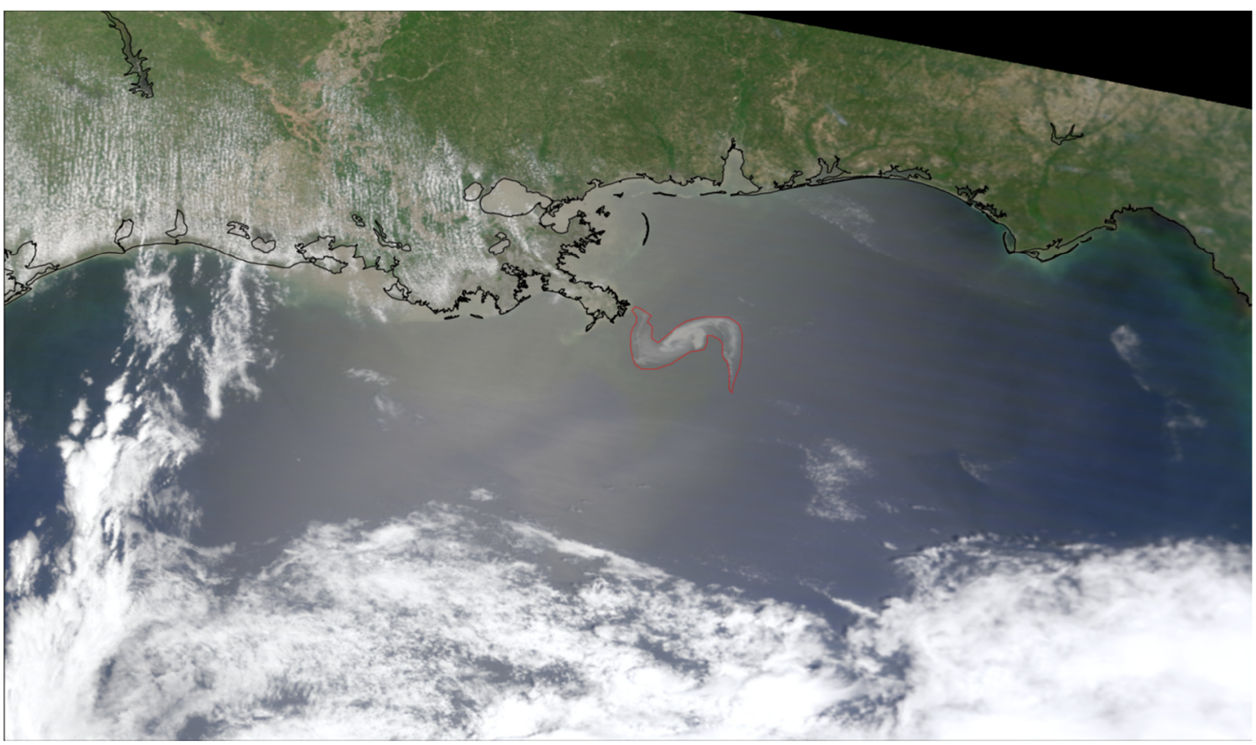


FIGURE 1: MODIS Terra Satellite Image with NOAA Shape-file Layer Outlining the Surface Oil.

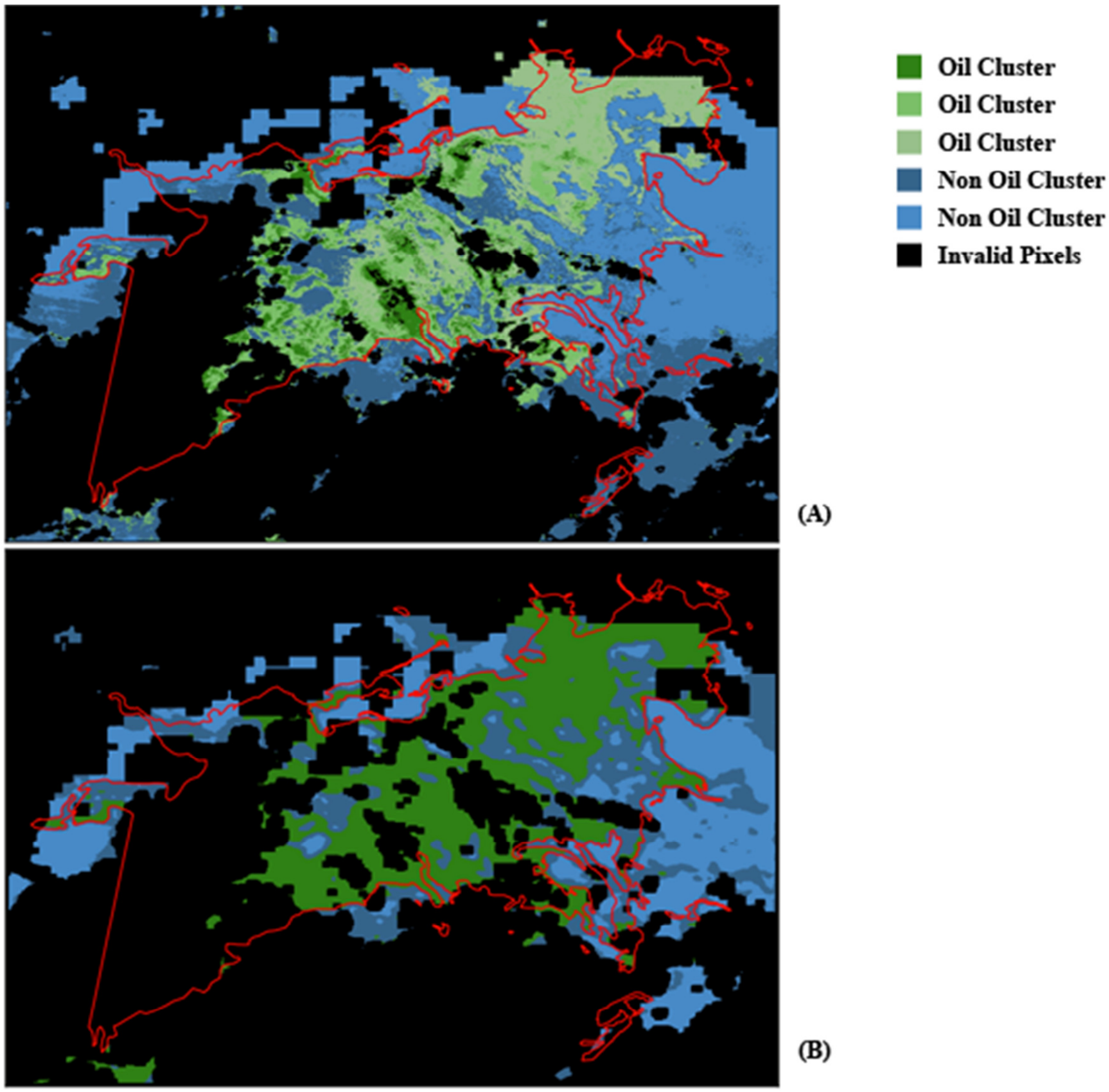


FIGURE 2: Clustering Results for June 18th. Image (A) shows the results obtained when using the de-glinted water-leaving features and 5 centroids. Image (B) shows the results when the de-glinted bands and textures are used as features with 3 centroids.

13) Continuing Research

If you are continuing this research under another grant, please include granting authority and title of award and a very brief synopsis (2-3 sentences).

Final Report: 4710-1101-02-A (with University of South Florida)

Lynn Keith Shay (PI)
RSMAS/MPO, University of Miami – 4600 Rickenbacker Causeway, Miami, FL 33149, USA
Phone: 305.421.4075 - Fax: 305.421.4696 - Cell:305.205.0305
Email: nshay@rsmas.miami.edu - Internet: http://isotherm.rsmas.miami.edu/~nick

The research grant involved a synthesis of oceanographic and atmospheric data acquired from an ongoing NOAA/University of Miami Project utilizing the NOAA WP-3D research aircraft (Hurricane Hunter) that made weekly flights over the eastern Gulf of Mexico. Throughout the DWH event, NOAA hurricane hunter aircraft conducted seven complete grids (now 13 grids) from 24 to 28°N encompassing the Loop Current and its energetic eddy field over the deep eastern Gulf of Mexico deploying sonobuoys designed develop a 3D assessment of physical oceanographic conditions. We completed deployments in Sept 2010 that included airborne expendable bathythermographs (AXBT), current (AXCP) and conductivity with depth probes (AXCTD) to provide deep-water (AXBTs to 350 m, AXCPs to 1500m, and AXCTDs to 1000 m) profiles of temperature, currents and salinity in the vicinity of the oil spill and the LC/Warm Core Eddy (WCE) complex. This project provided subsurface (and deep) temperature, salinity, and velocity profiles to initialize data assimilative ocean circulation models used to predict the surface and subsurface oil movement. These data were assimilated into ocean models (HYCOM) in a hindcast mode finding that model biases were halved and the model skill increased by ~30% by utilizing these fairly comprehensive ocean profiles. Clearly, the additional data significantly improved the simulations and trajectories derived from the model that assimilated altimetry only.

Remotely sensed data from the downward-looking radiometer and the Stepped Frequency Microwave Radiometer were processed that includes SSTs and brightness temperatures over the spill (ground zero) as well as over the Loop Current and its complex eddy field. A clear finding that has emerged from the analysis of the meteorological data is that the the lower part of the atmospheric boundary maintains higher equivalent potential temperatures over the warm eddy features compared to over the cold frontal eddies. This has implications for forecasting from coupled models for tropical storms and cold air outbreaks. Project personnel worked with team members on a pilot program to integrate inexpensive fluorometers into air-dropped sensors and other platforms. The collaboration involved integrating this new sensor with sonobuoy technology to be deployed from aircraft. However, due to budget constraints (and scope of the work to install of the newly developed sensors in old sonobuoy technologies) this segment of the project had to be deferred until additional funding becomes available.

During the grant, we participated in the JSOST workshop on the Deepwater Horizon Oil in October (St. Petersburg, FL) organized by the Department of Marine Science at USF as well as presenting these results at national and international meetings.

Publication/Presentations:

Shay, L.K., B. Jaimes, J. Brewster, P. Myers, C. McCaskill, E. Uhlhorn, F. Marks, G. R. Halliwell, Jr., O. M. Smedsted and P. Hogan, 2011: Airborne ocean surveys of the Loop Current complex from NOAA WP-3D in support of Deepwater Horizon oil spill. American Geophysical Union Monograph Series: *Monitoring and Modeling the Deepwater Horizon Oil Spill: A Record Breaking Enterprise,* Y. Liu, D. Streets, and R. Weisberg, Washington D.C. **195,** 131-151.

Shay, L.K., B. Jaimes, J. Brewster, P. Myers, C. McCaskill, E. Uhlhorn, F. Marks, G. R. Halliwell, Jr., O. M. Smedsted and P. Hogan, 2012: Resolving eddy shedding variability from the Loop Current during Deep Water Horizon: Implications for coupled models. *30th AMS Conference on Hurricanes and Tropical Meteorology*, 16-20 April 2012, Ponte Vedra Beach, FL (Abstract)

Shay, L.K., 2012: Airborne ocean surveys of the Loop Current complex from NOAA WP-3D in support of Deepwater Horizon oil spill. AOGS Public Lecture, AGU-Asian Oceanic and Geosciences Society, Singapore 13-17 August 2012.

BIOPLEX: EXPENDABLE SUBSURFACE OIL FLUOROMETER

David Fries

SCIENCE ACTIVITIES

1) General Summary

For wide-area sentinel monitoring of oil-spill contaminated waters, it was proposed that a low-cost in-situ fluorometer system for hydrocarbon monitoring be developed for possible integration into low-cost "disposable" deployment devices. The tasks for this sub project included: 1) Develop a fluorometer system; 2) Integrate the fluorometer into an in situ packaged system; 3) Combine the oil sensor system with a low cost buoy system. To take advantage of the fluorescent characteristics of oil, a low-power LED-based ultraviolet fluorometer was conceived, based on Bioplex Technologies' original SE-300 handheld visible-light fluorometer. A proof-of-concept hand sized prototype has been developed that uses an ultraviolet LED to excite with 254 nm light while fluorescence at 350 +/- 50 nm is monitored with an embedded filtered photo detector. Fabrication of the in situ system (UV 300 FT) was completed and tests were made of the performance of the submersible packaged system. The linearity and sensitivity range of the prototype design was completed. Linear detection range of carbazole, as a hydrocarbon indicator, using the UV-300-FT fluorometer was determined at $10^2 – 10^3$ ppb concentrations.

As an initial step toward wireless surface communications of fluorescence data, we employed a modified Bioplex POLYNAS low cost buoy system. The buoy was constructed using inexpensive, durable, flexible and lightweight PVC. Fluorescence data was successfully transmitted wirelessly from the surface float system. The full integration of the optical sensor module into a Type-A sonobuoy is the logical next stage for follow on development. We have made initial advancement in this direction with the design of a Type-A sonobuoy compatible optical sensor subsystem. We have employed a sensor emulation approach for our sensor-sonobuoy integration design.

From this work, two publications are in process, and several follow on research projects have been spawned targeting an adaptive sampling system, a field data logging unit, and an educational fluorometer sensor kit.

In summary, to date we have successfully developed a prototype low-power ultraviolet fluorometer capable of detecting crude oil in the low to mid ppm range. While the sensitivity is not suitable for trace analyses, it meets the project goals of providing low-cost "first-response" sentinel detection. The prototype has low power requirements and can potentially be mass-produced at relatively low-cost, within the target objective.

2) Results and scientific highlights

The detection of oil below the surface is difficult and depends on the state of the oil (liquid vs. solid, etc.). An expendable optical fluorescence system was the target development. Results were focused around three tasks defined in our statement of work.

A) *Develop a fluorometer system*

The small form factor UV fluorometer takes advantage of the inherent short wavelength fluorescent characteristics of oil-spill hydrocarbons. A proof-of-concept hand sized prototype has been developed that uses an ultraviolet LED to excite with 254 nm light while fluorescence at 350 +/- 50 nm is monitored with an embedded filtered photo detector. An added advantage of the 254 nm UV LED is the provision for simultaneous microbial antifouling of the single optical flow-through channel. The 254 nm wavelength is a germicidal wavelength that has proven advantageous in an application normally complicated by marine fouling. Preliminary benchtop testing of a prototype handheld unit indicates detection sensitivity in the 10^2 ppb range at $1/15^{th}$ the cost of commercially available sensors that exhibit a 10-100X sensitivity advantage. With improved optics and electromechanical packaging, similar or better sensitivity can be expected. The system is low cost (bill of materials approximately $700) (Figure 1, left) allowing it to be deployed to detect and monitor oil spills and as a sentinel system around sensitive marine environments or in coastal areas to monitor for oil runoff.

B) *Integrate the fluorometer into an in situ packaged system*

With the ultimate goal of repackaging the prototype sensor into a small footprint sensor for packaging in standard 4-1/2" diameter Type-A sonobuoys (or similar low-cost deployable buoy systems), improvements have been ongoing to adapt the prototype hand sized UV fluorometer for passive flow of water through the detector block. The previously solid printed circuit board on which the SE-300 detector block was mounted was modified to accommodate a highly UV-transparent glass tube. Necessary rearrangements of PCB components were made to ensure continuity of electrical circuitry. Similarly, the detector block on which optical components are mounted was bored out to the same diameter. With the glass tube sealed in place (Figure 1, right), water is able to passively flow through the detector block during sensor descent through the water column, without damaging open optical channels or the PCB. The current prototype flow-through fluorometer incorporated glass tubing specifically chosen for its high-degree of transmittance of light in the deep ultraviolet range (≤ ca. 270 nm). Such highly transparent material allows for similar or increased excitation of hydrocarbons over more expensive alternatives (e.g. quartz), while maintaining a fluidic path that is ideal for drop-sonde deployments. Additionally, the increased diameter compared with the earlier SE-300 provides a substantially larger path length, contributing to enhanced sensitivity.

Early experiments with crude oil demonstrated detection sensitivity in the low to mid ppb range (Fig. 2). In order to provide better characterization of the sensitivity of the new UV-300-FT instrument, dilution studies were conducted with carbazole (M.W. 167.21), an aromatic heterocyclic organic compound commonly used as a hydrocarbon standard for calibrations and other validation testing. Tests were made of the performance of the in situ packaged system. Figures 3 and Figure 4 show the raw fluorescence of the in situ packaged system and its linearity and sensitivity range, respectively.

3) *Combine the oil sensor system with a low cost buoy*

As an initial step toward wireless surface communications of fluorescence data, we employed a modified Bioplex POLYNAS low cost buoy system. (Figure 5) The buoy was constructed using inexpensive, durable, flexible and lightweight PVC. The wide variety of components easily available at any hardware store makes configuring and building this platform an easy task. The shape of the buoy is a cylindrical core with orbital rings that provide the buoy with floatation for stable handling and attachment points. The buoy is topped off with the high gain 2.4GHz antenna, which is commercially available in a PVC enclosure, making mating to the buoy seamless. This configuration allowed the oil sensor with an RS-232 interface to be connected to the platform (see Figure 5, right). The wireless sensor network buoy platform is built around the Lantronix WiPort 802.11b 2.4 GHz transmitter, as such it supports both Ad-hoc and infrastructure modes of communications. So far, the buoy has only been tested in a real world deployment in the infrastructure mode, where the buoy has been within the 2-mile range of the remote transmitter. This limitation can be overcome by using the WiPort modules in their Ad-hoc mode with a mesh-networking module that can be integrated into the WiPort's firmware with a simple software upgrade. For data communications demonstration, a wireless laptop was used as a base access point to demonstrate communications between the oil fluorometer-WiPort mesh client and the PC access point. Figure 6 shows real time transmitted data over the transmitter-receiver channel.

The full integration of the sensor system into a Type-A sonobuoy is the logical next stage of development. We have made some advancement in the design of a Type-A sonobuoy form-factor compatible system. However, given engineering and proprietary constraints of the sonobuoys a direct mating was not possible without additional development support. To that end, fully functional integration required collaboration with a commercial sonobuoy design/manufacturing firm.

ERAPSCO, a joint venture between Sparton Corp. and Ultra Electronics – USSI, has a long and well-established history in the design and manufacture of sonobuoys for a wide range of military and specialty industrial applications. We have had several design meetings with ERAPSCO engineers. We have created a Model Q36 based system design that allows the sensor to transmit using the standard carrier signal within the range of 134-176 MHz, with 375 kHz spaced channels and an audio output linked to sensor output at 1200-2800. We have employed a sensor emulation approach for our sensor-sonobuoy integration design. In this approach, we have configuring the output of the optical (oil) sensor to deliver 0-2.5 V analog output with amplitude modulation at audio levels precisely in the range of the current housed thermistor/temperature sensor. The sensor output modifies the oscillator of the sonobuoy and creates a frequency to depth (rate of descent) file. Labeling of the frequency to fluorescence units instead of temperature is a simple task. This allows for ease of signal detection and processing and is the most cost effective path for any subsequent platform integration.

In summary, to date, we have successfully developed a prototype low-power ultraviolet fluorometer capable of detecting crude oil in the low to mid ppm range. While the sensitivity is not suitable for trace analyses, it meets the project goals of providing low-cost "first-response" sentinel detection. The prototype has low power requirements and can potentially be mass-produced at relatively low-cost, within the target objective.

3) Cruises & field expeditions

Ship or Platform Name	**Class** (if applicable)	**Chief Scientist**	**Objectives**	**Dates**
NONE				

4) Peer-reviewed publications:

Trade Manuscript (in prep):
Low Cost Oil Sensing Fluorometer- Sea Technology Magazine
Peer Review Manuscript (in prep):
Embedded Oil Sensing System for Optimized Sensing and Sampling of Field Hydrocarbons- Analytical Chemistry

5) Presentations and posters:

Title	Presenter	Authors	Meeting or Audience	Abstract published (Y/N)	Date
Bioplex's Handsized dual-channel fluorometer core	FMK	FMK , Fries et. al.	GOM Reviews ??	Y online	?

6) Other products or deliverables:
NONE. (HOWEVER PROJECTS HAVE EMERGED THAT CAN LEAD TO NEAR TERM PRODUCTS. SEE SECTION 13)

7) Data

NONE APPLICABLE. (HOWEVER DATA FILES OF TRANSMITTED DATA AVAILABLE UPON REQUEST)

PARTICIPANTS AND COLLABORATORS

8) Project participants

First Name	Last Name	Role in Project	Institution	Email
David	Mann	Open Source Software	Loggerhead	<dmann@loggerheadinstruments.com>

MENTORING AND TRAINING

9) Student and post-doctoral participants

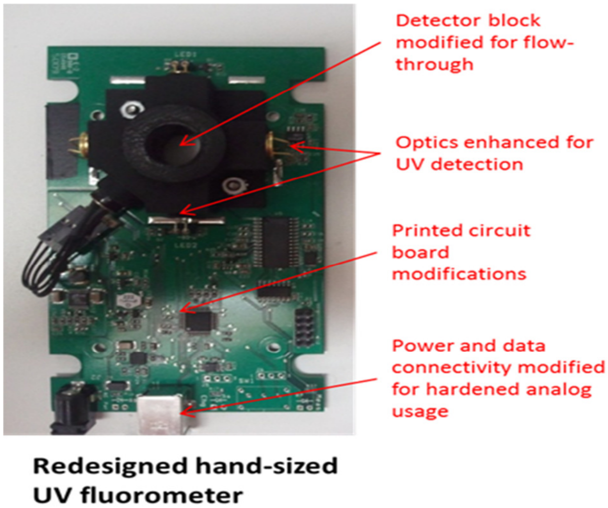
First Name	Last Name	Post-doc / PhD / MS / BS	Thesis or research topic	Institution	Supervisor	Expected Completion year
NONE						

10) Student and post-doctoral publications, if planned
NONE

11) Student and post-doctoral presentations and posters, if planned (Please provide copies of each)

Title	Presenter	Authors	Meeting or Audience	Abstract published (Y/N)	Date
NONE					

12) Images



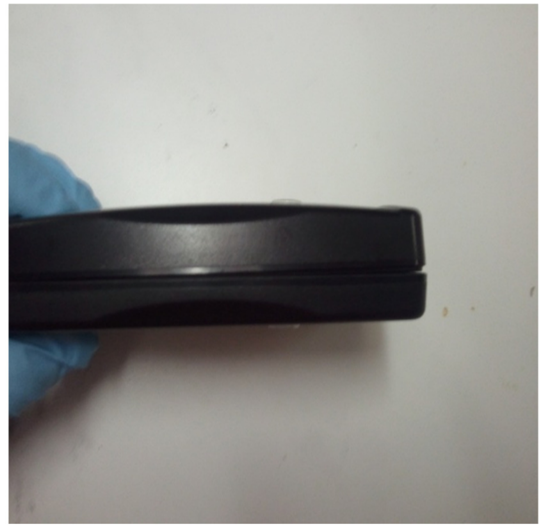


Figure 1: SE-300 Modified for flow-through applications. LEFT: Detector block integrated with PCB and detector block modified to accommodate glass tubing. Modifications highlighted. RIGHT: Profile of assembled prototype handheld ultraviolet flow-through fluorometer with glass tube protruding top and bottom.

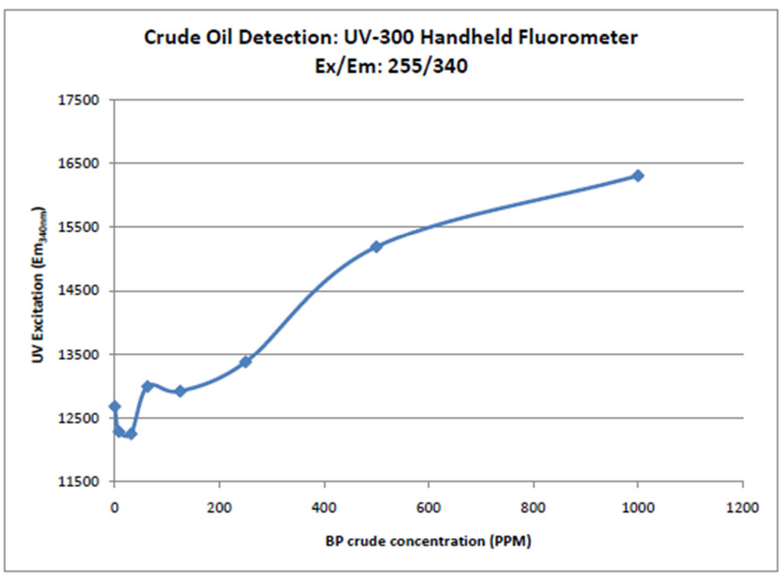


Figure 2: Initial dynamic range detection was on the order of $10^2 – 10^3$ ppm crude oil (concentrations greater than ca. 10^3 ppm exhibit reduced emission counts, likely due to inhibition caused by saturation; not shown). Extrapolated to carbazole equivalents "CE" units, as described in progress reports, this correlates to a pure hydrocarbon detection range of ca. 10^2-10^3 ppb.

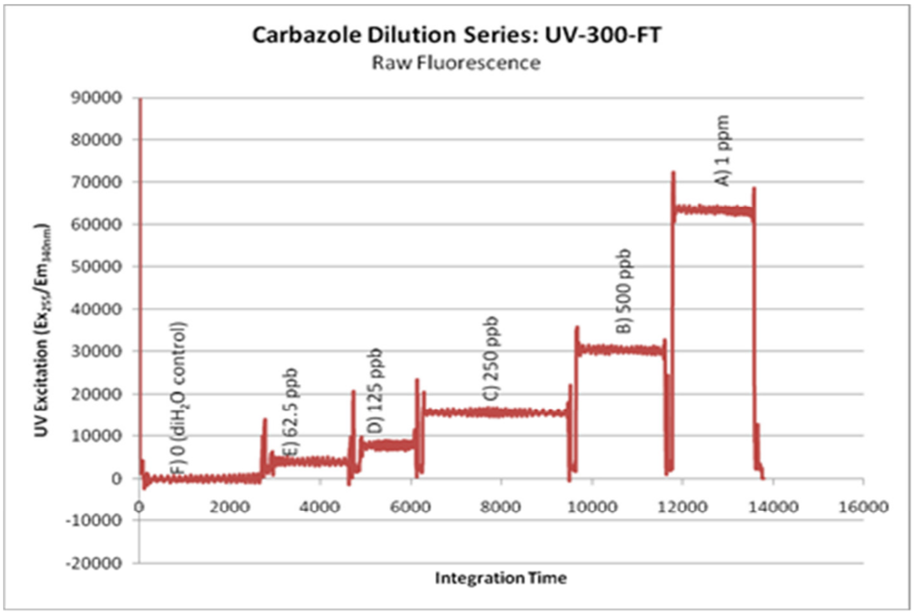


Figure 3: Raw fluorescence output of UV channel from UV-300-FT instrument. Sample: carbazole solubilized with MeOH, diluted in diH_2O at indicated concentrations.

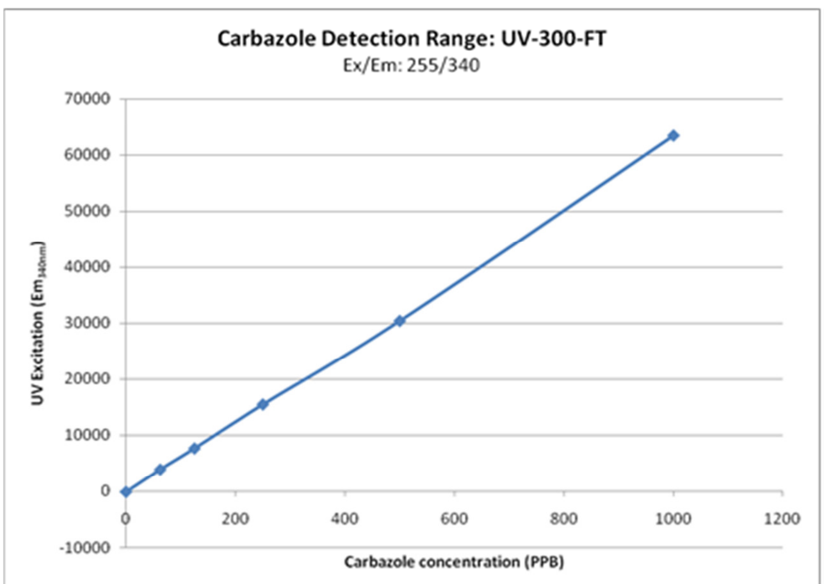


Figure 4: Linear detection range of carbazole using UV-300-FT fluorometer at 10^2 – 10^3 ppb concentrations.

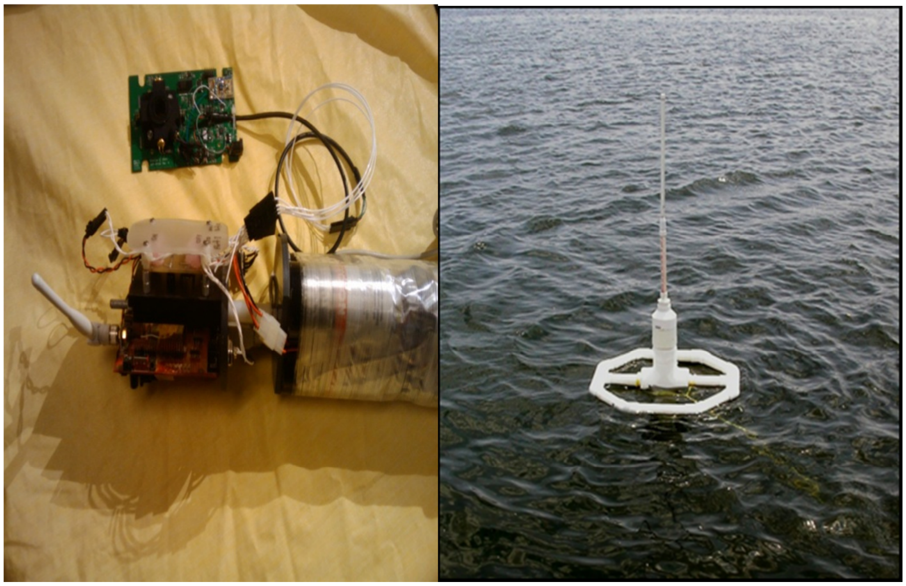


Figure 5: Left, internal construction of oil sensing transmitter system: UV300 FT, WiPort 802.11 and battery stack. Right, POLYNAS Wireless Surface Buoy made of commonly available materials: Telemetry- 802.11b Power -Lead Ac id/NiMH Sensor- PCB based power controller- less than $500 BOM

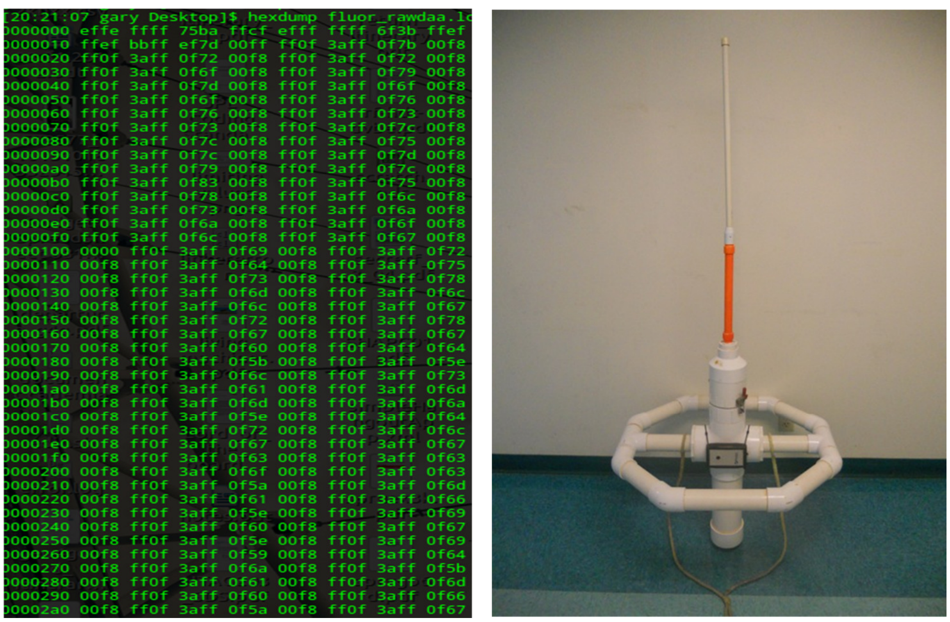


Figure 6: Right image, exhibits the UV 300 FT connected to POLYNAS Wireless 802.11b buoy system. Left image, displays 8 Bytes per reading, per channel, real, streaming data, transmitted over Wiport from the attached Fluorometer, (HEX representation.)

Figure 7: Disassembled "Type A" Sonobuoy. A design was completed with ERAPSCO to emulate the thermistor load via the oil sensor subsystem output of 0-2.5V, amplitude modulation for the Q36 ERAPSCO sonobuoys.

13) Continuing Research

Several Bioplex (INTERNALLY FUNDED) derivative projects have emerged from this work:

1. Flourometer-Mass Spec based Adaptive Sampling System – with SpyGlass Inc
2. Field Data Logging Flourometer System- using Open Tag Sourceware
3. Educational Fluorometer Field Sensor Kit- targeting science education corps

FLORIDA INSTITUTE OF TECHNOLOGY: 4D REMOTE SENSING BP QUICKSTART PROJECT - AIRBORNE REMOTE SENSING SUBPROJECT FINAL REPORT

Dr. Charles Roger Bostater, Jr.

SCIENCE ACTIVITIES (FLORIDA INSTITUTE OF OCEANOGRAPHY (FIO) QUICKSTART PROJECT, PROJECT ID NUMBER: 4711-1101

General Summary

Overview of the project and goals supported during the conduct of this project (Florida Institute of Oceanography (FIO) Quickstart Project Project ID Number: 4711-1101)

The budget to FIT included 2 scopes of work and components:

1) *Subcontract (**sub-award #201454, dated 11/17/2010**) to Mitchell Roffer's business firm (Roffers Fishing Service). His company was to provide the team near daily satellite imagery synthesized along with inputs from the remote sensing team's efforts of satellite data analysis, imagery analysis, ship board and airborne missions. He was to tasked to integrate other FIO research data provided that will provide - in image format, a quick assessment for the oil spill disaster analysis of the distribution, transport, fate and effects of the oil and oil dispersants in the Gulf of Mexico and Florida's treasure – the near coastal living marine resources aquatic habitats that were eminently endangered. Mitch has already provided you a breakdown of his personnel costs, and expenses for his critical element to this project and Florida's community. He will be making his information available to the public via his continuation of existing web based imagery & products. He will receive a subcontract from FIT on the funds provided to FIT. Dr. Roffer has directly provided a final report to Dr. Frank Muller-Karger.*

2) *The second component which is unique to the 4D remote sensing project was the airborne imaging work. In concept, this element as designed to provide rapid high profile and critical image acquisition for our research needs for 15 flights, budgeted for 1 hour mission flights. Seventeen hours were conducted during the project. The budget reflected the closest possible needs in order to carry out these airborne photography missions, with the closest possible estimates to cover the exact costs to conduct the flights. These aerial photo or image acquisition flight costs included funds for educating and involving students during the project period as well. Human resources budgeted costs are related to setup, collection and to interact with the team's agreed upon work. Funds were budgeted for operation of a state of art the hyperspectral imaging system - made available to the project for helping to protect Florida's living marine resources. No direct costs associated with the utilization of this calibrated digital imaging system for this research and education teaming agreement was made. Costs for purchasing aerial photogrammetric films and associated processing costs for outside services and supplies was budgeted along with direct aircraft* fuel *costs and equipment related repairs and maintenance costs for the proposed work.*

<u>'Lessons learned'</u> that could be applied to other/future oil spill related projects (e.g., management, data support, logistics, etc.) include the following:

- *Approval for funds to begin the project was given provided October 9, 2010. This was after the oil spill. Oil in littoral zones – marshes, and shorelines - were known to exist, but most of the shorelines visited by tourists had been removed. Faster response time funding approval would be needed in order to detect oil Gulf surface waters.*
- *Flights were planned originally to occur in the Florida Keys and waters on the western and eastern shores of Florida. Future plans when developing a scope of work would need to consider the needs for Florida Panhandle, Louisiana, and Mississippi flights since no known oil reached the lower Florida peninsula.*
- *The ability to secure flight air traffic control approvals from the Big Bend area to Houma, Louisiana involved approvals each time weather forecasts suggest a window of opportunity. Seven different ATC approvals were required. The extent of the approval process was not clearly known when the flights were conceived during the summer of 2010, partly because of the unknown aerial extent of the oil spill.*
- *Flight data clearly showed the value high spatial resolution imaging. Flights were conducted with multiple sensors acquiring imagery at low altitude (1,500 feet to 4,500 ft) with ground sampling distances or pixel sizes ranging from ~0.5 m to ~5 cm. Each flight utilized a maximum of 5 different imaging systems. This turned out to be an excellent approach, since each system allowed detailed examination of oil in the littoral zone of the Gulf of Mexico impacted areas.*
- *Knowledge concerning the existence of weathered oil is lacking.*

Accomplishments against project activities, objectives and milestones:

- *17 flights occurred during 4 different missions during the spring of 2011. Weather did not permit flights before the end of the project period in August 2012.*
- *As proposed, a web site was established as proposed and selected imagery can be downloaded and/or ordered. Meta data is also available. See: http://www.bostater.info/id40.html*
- *"Weathered oil" was observed in airborne shallow littoral areas of the Gulf of Mexico.*
- *The BP funding to FIT provided funds for image acquisitions as planned. Other funds allowed for detailed analysis and development of publications and is summarized below.*

Results and scientific highlights

A substantial effort was spent during this project in planning the flights and checking weather, obtaining aircraft clearance and approvals for flights along the northern Gulf of Mexico. Extreme care was taken to insure the flights were conducted during cloud free sky conditions, and minimal water surface wave conditions based upon the previous work reported by Bostater, et al., 2009(a, b). In addition, tide state and antecedent rain conditions, wind speed and direction were also factored into the decision making before conducting any flights. Without adherence to all of the conditions mentioned above, it would be impossible to image subsurface features (such as weathered oil) in littoral zones. The quality of the imagery collected can be seen by viewing images displayed on the web site (www.bostater.info). We are still in the process of mosaicking, georeferencing and correction hyperspectral data and scanned color negative film imagery along the Florida Panhandle, followed by performing data fusion analysis to help *observe subsurface water features such as "weathered oil". Examples of results from the project are reported in the listed publications below and in images on the website at (www.bostater.info). Example images are shown below.*

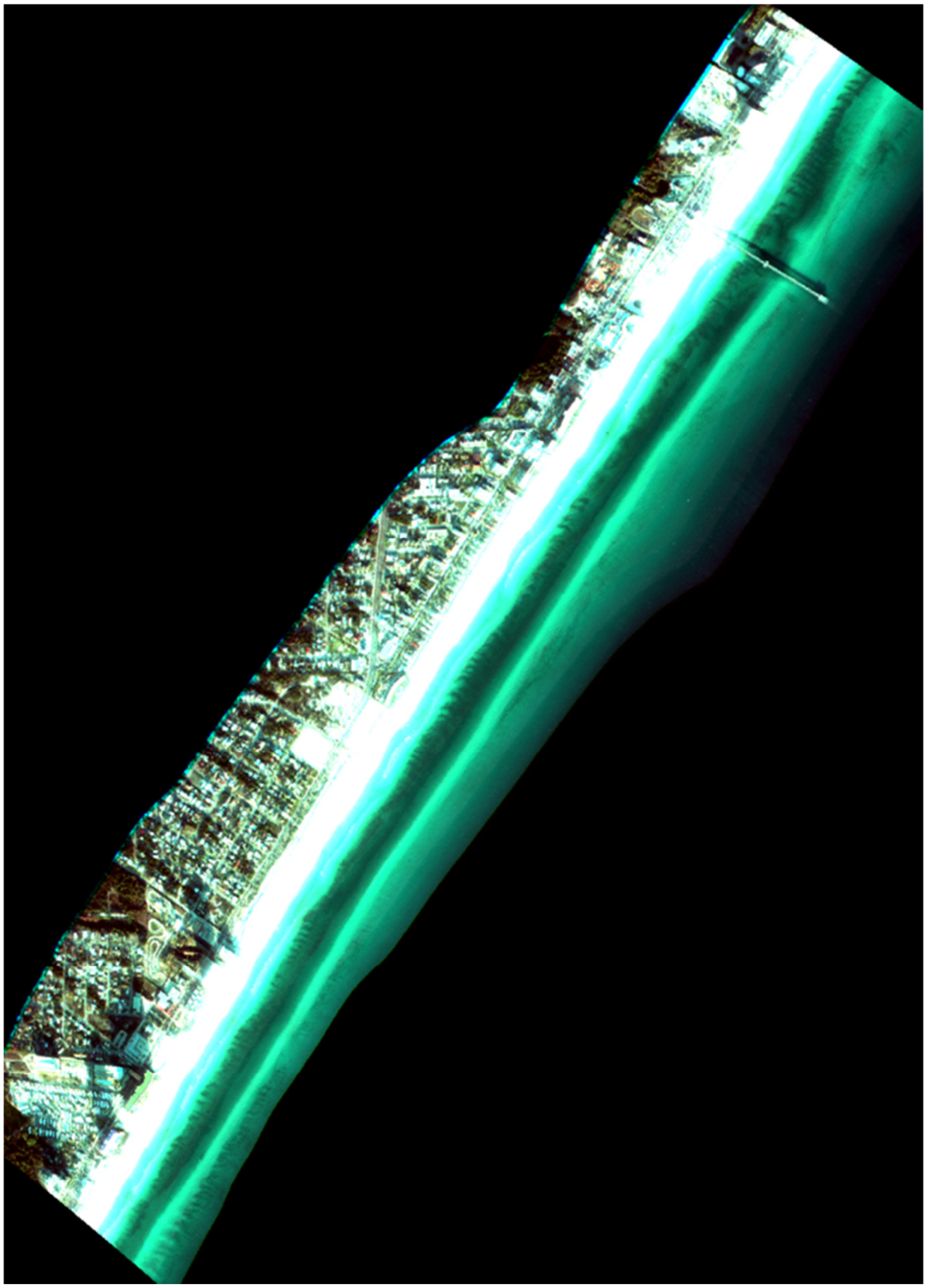


Figure 1. Hyperspectral image RGB (684, 529, 488 nm) along the Florida Panhandle and near Panama Dunes Pier, in the Northern Gulf of Mexico littoral zone, N 30 11'11.05" W 85 50'1.60" acquired March 12, 2011. Note that careful selection of airborne flight conditions allowed for direct sun glint to be 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 Institute of Technology.

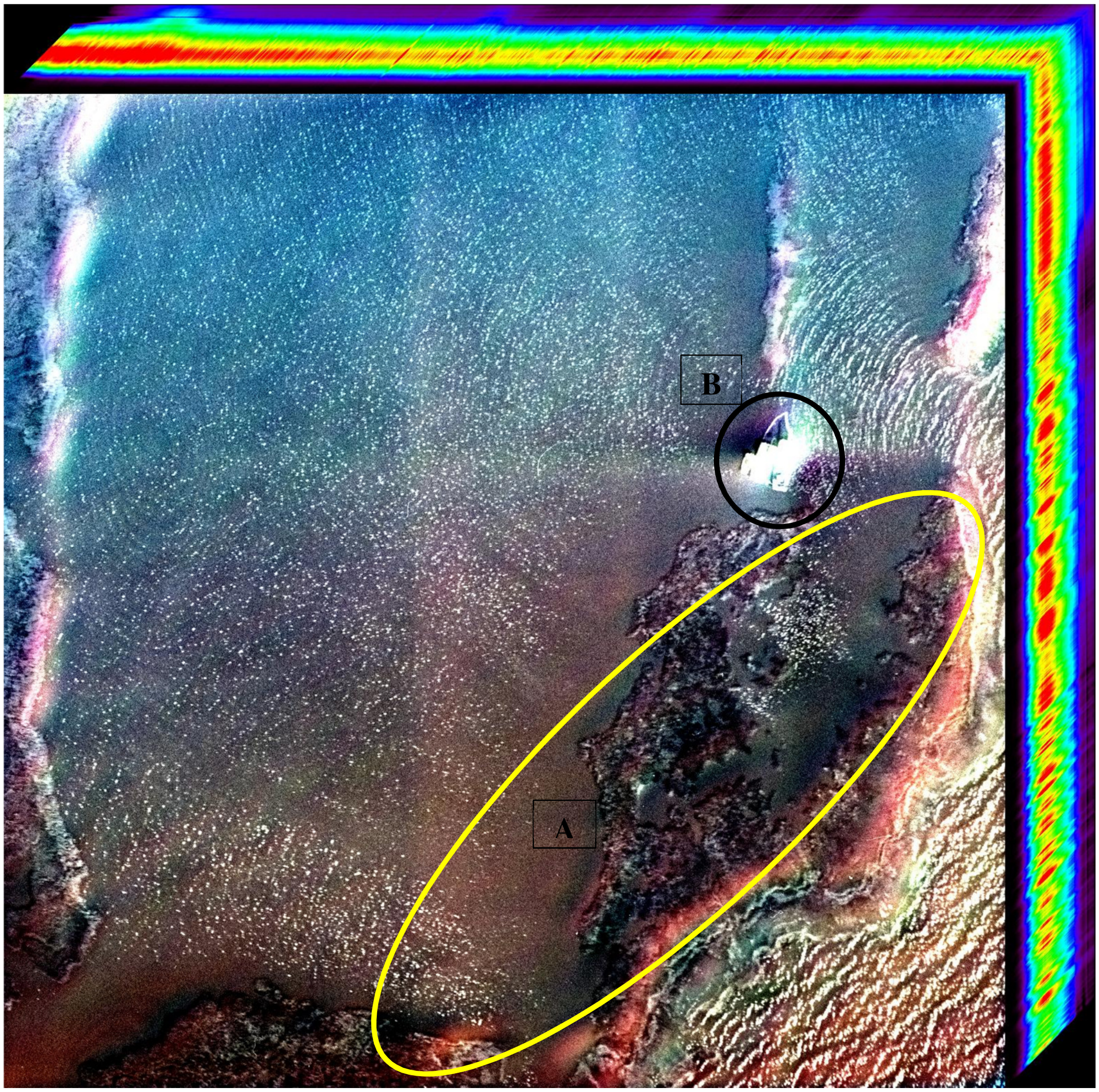


Figure 2. An airborne hyperspectral data fusion image cube RGB display. The image subset shown above is a "data fusion" of a scanned AGFA color negative image with ~10 cm pixel (GSD) spatial resolution and a hyperspectral airborne image scene with ~ 0.5 m pixel (GSD) collected on March 21, 2011. Weathered 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, Florida Institute of Technology.

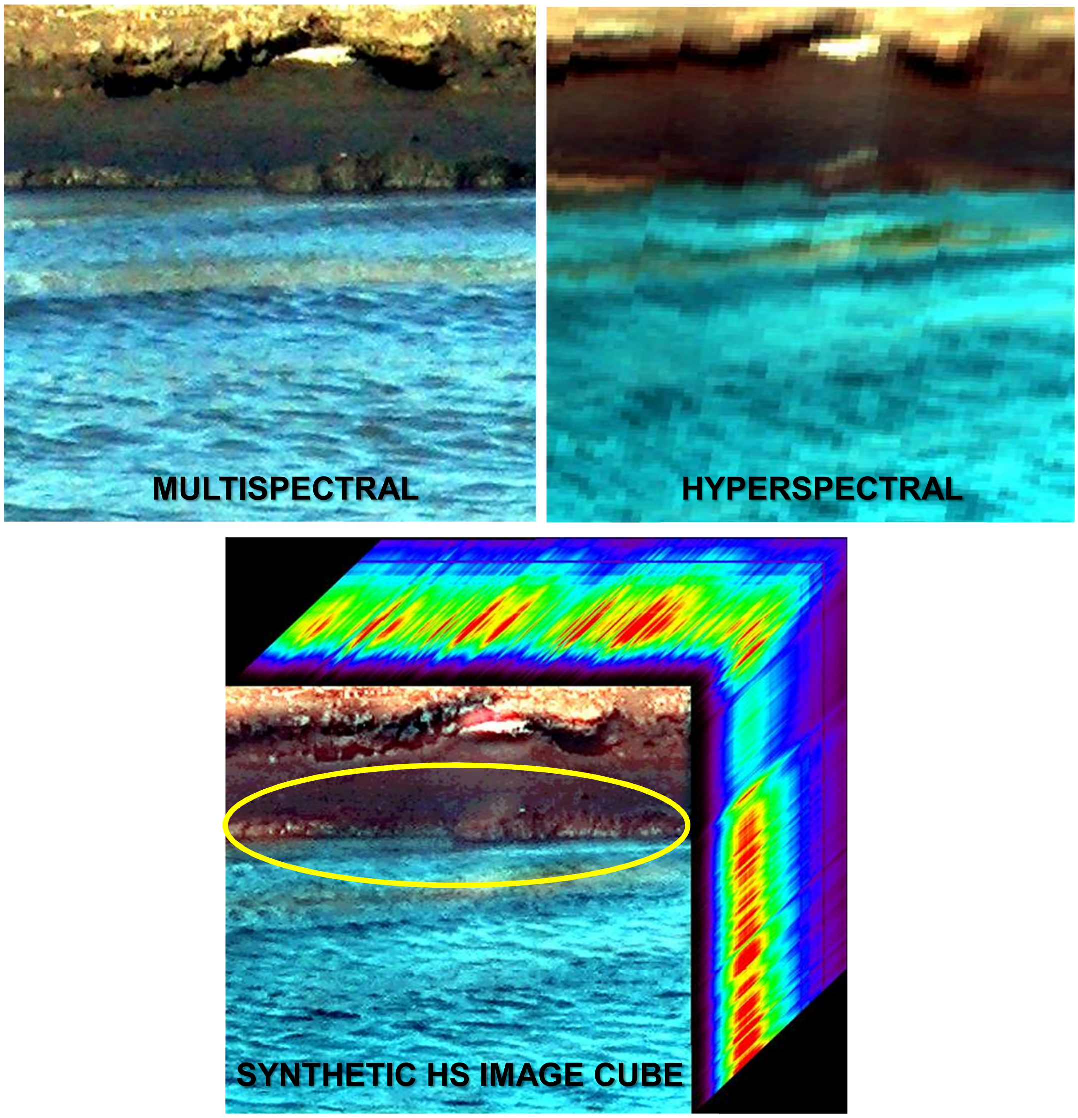


Figure 3. Example of shoreline hyperspectral and multispectral imagery used to synthesize a "synthetic" hyperspectral image cube with ~ 5 mm pixel (GSD) spectra. The ***optimized data fusion protocol and techniques*** (Bosatter, 2012 (a,b) utilizes digital multispectral RGB camera imagery, and a vessel 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.

Cruises & field expeditions

Ship or Platform Name	Class (if applicable)	Chief Scientist	Objectives	Dates
Aircraft Mission 1		Charles Bostater	Low Altitude Aerial Imaging	3/12/2011
Aircraft Mission 2		Charles Bostater	Low Altitude Aerial Imaging	3/13/2011
Aircraft Mission 3		Charles Bostater	Low Altitude Aerial Imaging	3/21/2011
Aircraft Mission 4		Charles Bostater	Low Altitude Aerial Imaging	3/22/2011

Peer-reviewed publications, if planned (Note: a special section will focus on student and post-doctoral publications)

a. Published, peer-reviewed bibliography

- Bostater, C., Frystacky, H., Levaux, F., 2012, Enhanced Data Fusion Protocol for Surface and Subsurface Imaging of Released Oil in Littoral Zones, In: Proceedings of the Twenty-second (2012) International Offshore and Polar Engineering Conference, Rhodes, Greece, June 17–22, 2012, International Society of Offshore and Polar Engineers (ISOPE), ISBN 978-1-880653-94–4, pp. 808-814.

  Abstract: An enhanced data fusion methodology that combines multispectral and hyperspectral airborne or vessel images of the water surface and subsurface is described. The optimized image analysis techniques utilize simultaneously acquired and georeferenced images along a littoral zone or open water. Data acquired after the offshore Deepwater Horizon (DWH) oil spill, in the northern Gulf of Mexico, is used to demonstrate the protocol. Mathematically based techniques that utilize singular value decomposition, discrete cosine filtering, two dimensional (2D) Butterworth filters, combining the high and low pass filtered result followed by using the 2D inverse cosine filter yields a spectral-spatial sharpened hyperspectral data cube are described. The fused synthetic imagery has the high spatial resolution of the multispectral imagery with pixel sizes of ~3-10 cm. The inherent value of the final optimized product lies in the ability to apply derivative based reflectance spectroscopy algorithms designed to spectrally discriminate potential subsurface weathered oil residue in the littoral zone or open waters using ultra high spatial resolution spectral images.
  (http://www.isope.org/publications/publications.htm)

- Bostater, C., Coppin, G., Leavaux, F., 2012, Hyperspectral Remote Sensing - Using Low Flying Aircraft and Small Vessels in Coastal Littoral Areas, In: Remote Sensing – Advanced Techniques and Platforms, Escalante, B. (Ed.), ISBN: 978-953-51-0652-4, 462 pp.

  Abstract: Large field of view sensors as well as flight line tracks of hyperspectral reflectance signatures are useful for helping to help solve many land and water environmental management problems and issues. High spectral and spatial resolution sensing systems are useful for environmental monitoring and surveillance applications of land and water features, such as species discrimination, bottom top identification, and vegetative stress or vegetation dysfunction assessments1. In order to help provide information for environmental quality or environmental security issues, it is safe to say that there will never be one set of sensing systems to address all problems. Thus an optimal set of sensors and platforms need to be considered and then selected. The purpose of this paper is to describe a set of sensing systems that have been integrated and can be useful for land and water related assessments related to monitoring after an oil spill (specifically for weathered oil) and related recovery efforts. Recently collected selected imagery and data are presented from flights that utilize an aircraft with a suite of sensors and cameras. Platform integration, modifications and sensor mounting was achieved using designated engineering representatives (DER) analyses, and related FAA field approvals in order to satisfy safety needs and requirements. (http://www.intechopen.com/books/remote-sensing-advanced-techniques-and-platforms/hyperspectral-remote-sensing-using-low-flying-aircraft-and-small-vessels-in-coastal-littoral-are).

b. Manuscripts Other bibliography

- Bostater, C., Jones, J., Frystacky, F., Kovacs, M., Josza, O., 2010, Integration, testing, and calibration of imaging systems for land and water remote sensing, In: Remote Sensing of the Ocean, Sea Ice, and Large Water Regions 2010, Charles R. Bostater, Jr.; Stelios P. Mertikas; Xavier Neyt; Miguel Velez-Reyes, Toulouse, France, SPIE Vol. 7825.

  Abstract: Imagery is presented along with calibration and testing procedures of several airborne imaging systems. The low altitude airborne systems include a cooled hyperspectral imaging system with 1024 spectral channels and 1375 spatial pixels. The hyperspectral imaging system is collocated with a full resolution high definition video recorder for simultaneous HD image acquisition, 12.3 megapixel digital images for multispectral "sharpening" the hyperspectral imagery, or large frame 9 inch film cameras yielding scanned aerial imagery with approximately 2200 by 2200 pixel multispectral imagery. Two high spectral (252 channels) and radiometric solid state spectrographs are used for collecting upwelling radiance (sub-meter pixels) and a downwelling irradiance using a fiber optic irradiance sensor. These sensors are utilized for cross calibration and independent acquisition of ground or water reflectance signatures. The upwelling spectrograph is integrated to collect signatures collocated with a 12.3 megapixel Nikon D2Xs with 5 HZ WAAS GPS input for mixed pixel analysis in conjunction with the other sensing systems. In addition to the airborne hyperspectral sensors, traditional photogrammetric imagery can be collected from dual 9 inch frame cameras capable of using a combination of panchromatic, color or color infrared film types. The panchromatic film can be collected with special filters designed to create spectral windows, such as the "red edge" which is useful for land or shallow submerged vegetation and live coral detection. The 9 inch film negatives are scanned to produce over 250 megapixel scanned multispectral imagery for sub pixel assessments us and image fusion sharpening of the hyperspectral imagery. The scanned imagery covers larger spatial regions and is thus useful for geospatial registration, rectification, and spatial sharpening of the hyperspectral imagery along flight lines. All of the airborne sensor systems allow for modern research in the use of sun and sky glint regions in imagery to identify water surface wave field characteristics as well as ***oil slicks***. The systems described provide unique data sets of for modern airborne or satellite remote sensing algorithm development and testing of radiative transfer models.
  (https://proceedings.spiedigitallibrary.org/proceeding.aspx?articleid=725079)

- Bostater, C., Jones, J., Frystacky, F., Kovacs, M., Jozsa, O., 2010, Image Analysis for water and subsurface feature detection in shallow waters, In: Remote Sensing of the Ocean, Sea Ice, and Large Water Regions 2010, Charles R. Bostater, Jr.; Stelios P. Mertikas; Xavier Neyt; Miguel Velez-Reyes, Toulouse, France, SPIE Vol. 7825.

Abstract: Carefully collected airborne imagery demonstrates the ability to see water surface features as well as shallow bottom features such as submerged vegetation and manmade targets. Traditional photogrammetric imagery and airborne digital imagery both suffer from a loss in image clarity due to a number of factors, including capillary and small gravity waves, the water column or in-situ constituents. The use of submerged as well as surface man-made calibration targets deployed during airborne or in-situ subsurface image acquisitions forms a preliminary basis for correcting imagery in order to improve subsurface and surface features and their detection. Methods presented as well as imagery at 490 nm, 532 nm and 698-700 nm clearly show subsurface features in shallow waters. The techniques utilized include the use of large frame cameras with photogrammetric films in combination of special filters, such as a Wratten # 70, in order to provide narrower spectral features near the vegetative "red edge" to be used to improve interpretation of hyperspectral push broom imagery. Combined imagery from several sensors and platforms, including autonomous underwater vehicles, form the basis of data fusion for surface and subsurface automatic feature extraction. Data presented from a new hyperspectral imaging system demonstrates the utility of sub-meter hyperspectral imagery for use in subsurface feature detection. (http://spie.org/x648.html?product_id=870728)

- Bostater, C., Gaelle Coppin, G., Levaux, F., Jones, J., Frystacky, H., 2011, Mobile Platform Pushbroom Sensor Motion Control, Image Corrections and Spectral Band Selection: Examples of Hyperspectral Imagery Using Low Flying Aircraft and Small Vessels in Coastal Littoral Areas, In: Robots for Risky Interventions and Environmental Surveillance-Maintenance (RISE-2011), International Advanced Robotics Programme Workshop, June 20-21, 2011, Sponsored by the International Advanced Robotics Program (IARP), E. Colon (ed.), Royal Military Academy, Brussels, Belgium, 19 pp.

Abstract: Collection of pushbroom sensor imagery from a mobile platform requires correction of the platform motions using inertial measurement units (IMU's) as well as DGPS in order to create useable imagery for environmental monitoring and surveillance of shorelines in freshwater, littoral or harbour areas. This paper will present a suite of imaging systems used during collection of hyperspectral imagery during recent northern Gulf of Mexico airborne missions to detect weathered oil in coastal littoral zones. Underlying concepts of pushbroom imagery, the needed corrections for directional changes using DGPS and corrections for platform yaw, pitch, and roll using IMU data is described as well as the development and application of optimal band and spectral region selection for developing remote sensing algorithms. Pushbroom sensor and frame camera data collected in response to the recent Gulf of Mexico oil spill disaster will be presented as the scenario documenting the environmental monitoring and surveillance techniques using mobile sensing platforms. Data was acquired during the months of February, March, April and May of 2011. The low altitude airborne systems include a cooled hyperspectral imaging system with 1024 spectral channels and 1375 spatial pixels flown at 3,000 to 4,000 feet. The hyperspectral imaging system is collocated with a full resolution high definition video recorder for simultaneous HD video imagery, a 12.3 megapixel digital images for multispectral "sharpening" the hyperspectral imagery, a large frame 9 inch film mapping camera that yields scanned aerial imagery with approximately 2200 by 2200 pixel multispectral imagery (255 megapixel RGB images. Two high spectral (252 channels) and

radiometric sensitivity solid state spectrographs are used for collecting upwelling radiance (sub-meter pixels) and a downwelling irradiance using a fiber optic irradiance sensor. These sensors are utilized for cross calibration and independent acquisition of ground or water reflectance signatures and for calculation of the bi-directional reflectance distribution function (BRDF). Methods are demonstrated for selecting optimal spectral regions and bands for discrimination, detection and characterization of weathered oil in the Northern Gulf of Mexico in response to the Deepwater Horizon oil spill disaster. The imagery presented and described allow for modern research in the use of sun and sky glint regions in imagery to identify water surface wave field characteristics as well as oil slicks. The systems described provide unique data sets of for modern airborne or satellite remote sensing algorithm development and future testing of radiative transfer models useful in studying the environment at small spatial scales. (http://www.bostater.info/id51.html)

- Bostater, C., Jones, J., Frystacky, H., Gaelle Coppin, G., Levaux, F., Neyt, X., 2011, Airborne imaging sensors for environmental monitoring & surveillance in support of oil spills & recovery efforts, In: Remote Sensing of the Ocean, Sea Ice, Coastal Waters, and Large Water Regions 2011, Charles R. Bostater, Jr.; Stelios P. Mertikas; Xavier Neyt; Miguel Velez-Reyes, Prague, Czech Republic, SPIE Vol. 8175.

  Abstract: Collection of pushbroom sensor imagery from a mobile platform requires corrections using inertial measurement units (IMU's) and DGPS in order to create useable imagery for environmental monitoring and surveillance of shorelines in freshwater systems, coastal littoral zones and harbor areas. This paper describes a suite of imaging systems used during collection of hyperspectral imagery in northern Florida panhandle and Gulf of Mexico airborne missions to detect weathered oil in coastal littoral zones. Underlying concepts of pushbroom imagery, the needed corrections for directional changes using DGPS and corrections for platform yaw, pitch, and roll using IMU data is described as well as the development and application of optimal band and spectral regions associated with weathered oil. Pushbroom sensor and frame camera data collected in response to the recent Gulf of Mexico oil spill disaster is presented as the scenario documenting environmental monitoring and surveillance techniques using mobile sensing platforms. Data was acquired during the months of February, March, April and May of 2011. The low altitude airborne systems include a temperature stabilized hyperspectral imaging system capable of up to 1024 spectral channels and 1376 spatial across track pixels flown from 3,000 to 4,500 feet altitudes. The hyperspectral imaging system is collocated with a full resolution high definition video recorder for simultaneous HD video imagery, a 12.3 megapixel digital, a mapping camera using 9 inch film types that yields scanned aerial imagery with approximately 22,200 by 22,200 pixel multispectral imagery (~255 megapixel RGB multispectral images in order to conduct for spectral-spatial sharpening of fused multispectral, hyperspectral imagery. Two high spectral (252 channels) and radiometric sensitivity solid state spectrographs are used for collecting upwelling radiance (sub-meter pixels) with downwelling irradiance fiber optic attachment. These sensors are utilized for cross calibration and independent acquisition of ground or water reflectance signatures and for calculation of the bi-directional reflectance distribution function (BRDF). Methods are demonstrated for selecting optimal spectral regions and bands for discrimination, detection and characterization of weathered oil in the Northern Gulf of Mexico waters and littoral zones in response to the Deepwater Horizon oil spill disaster. The techniques allow for the use of sun and sky glint regions in imagery to identify water surface wave field characteristics as well as oil slicks. The systems described provide unique data sets for remote sensing algorithm development and future testing of radiative transfer models useful in studying weathered oil fate, distribution and extent.
  (http://proceedings.spiedigitallibrary.org/proceeding.aspx?articleid=1269648)

- Frias-Torres, S., Bostater, C., 2011, Potential impacts of the Deepwater Horizon oil spill on large pelagic fishes (Invited Paper), In: Remote Sensing of the Ocean, Sea Ice, Coastal Waters, and Large Water Regions 2011, (editors) Charles R. Bostater, Jr.; Stelios P. Mertikas; Xavier Neyt; Miguel Velez-Reyes, Prague, Czech Republic, SPIE Volume 8175.

  Abstract: Biogeographical analyses provide insights on how the Deepwater Horizon oil spill impacted large pelagic fishes. We georeferenced historical ichthyoplankton surveys and published literature to map the spawning and larval areas of bluefin tuna, swordfish, blue marlin and whale shark sightings in the Gulf of Mexico with daily satellite-derived images detecting surface oil. The oil spill covered critical areas used by large pelagic fishes. Surface oil was detected in 100% of the northernmost whale shark sightings, in 32.8 % of the bluefin tuna spawning area and 38 % of the blue marlin larval area. No surface oil was detected in the swordfish spawning and larval area. Our study likely underestimates the extend of the oil spill due to satellite sensors detecting only the upper euphotic zone and the use of dispersants altering crude oil density, but provides a previously unknown spatio-temporal analysis. (http://proceedings.spiedigitallibrary.org/proceeding.aspx?articleid=1269651)

- Bostater, C., Jones, J., Frystacky, H., 2012, Remote sensing of shorelines using data fusion of hyperspectral and multispectral imagery acquired from mobile and fixed platforms, In: Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XVIII, Sylvia S. Shen; Paul E. Lewis, Baltimore, Maryland, SPIE Vol. 8390.

  Abstract: An optimized data fusion methodology is presented and makes use of airborne and vessel mounted hyperspectral and multispectral imagery acquired at littoral zones in Florida and the northern Gulf of Mexico. The results demonstrate the use of hyperspectral-multispectral data fusion anomaly detection along shorelines and in surface and subsurface waters. Hyperspectral imagery utilized in the data fusion analysis was collected using a 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 was derived either a 12 inch focal length large format camera using 9 inch 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 Kalman filtering and smoothing 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. (http://proceedings.spiedigitallibrary.org/proceeding.aspx?articleid=1354594)

c. Manuscripts submitted or in preparation (Please note target journal, and anticipated date of publication or submission)

- Levaux, F., Bostater, C., Neyt, X., Feature detection in hyperspectral images using optimal multiple wavelengths, European Journal of Mechanical and Environmental Engineering (submitted) Spring, 2012 (peer review journal).

Presentations and posters, if planned (Please provide copies of each) (Note: a special section will focus on student presentations)

Title	Presenter	Authors	Meeting or Audience	Abstract published (Y/N)	Date

Other products or deliverables

Quarterly Reports have been submitted to USF and each report contained example imagery and results. Imagery and image snapshots, metadata, can be viewed and ordered at http://www.bostater.info/id40.html. MODIS satellite imagery showing the sky conditions during the flights are also shown on the website as well as the planned flight lines.

Data

Metadata and ancillary information on the location and status of the archived samples are available at http://www.bostater.info/sitebuildercontent/sitebuilderfiles/bp_metadata_notes.pdf. A image request form in word format is downloadable from the web site as well as the planned flight lines for the missions.

PARTICIPANTS AND COLLABORATORS

Project participants

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Charles	Bostater	PI	FIT	bostater@fit.edu
James	Jones	Research Technician	FIT	
Heather	Frystacky	Research Technician	FIT	

MENTORING AND TRAINING

Student and post-doctoral participants

First Name	Last Name	Post-doc / PhD / MS / BS	Thesis or research topic	Institution	Supervisor	Expected Completion year
James	Jones	MS	Airborne Sensing	FIT	C. Bostater	Unknown
Heather	Frystacky	BS	Airborne Sensing	FIT	C. Bostater	Spring, 2012
Florian	Levaux	MS	Airborne Sensing	FIT	C. Bostater	Fall, 2011
Gaelle	Coppin	MS	Airborne Sensing	FIT	C. Bostater	Fall, 2011
Mate	Kovacs	BS	Airborne Sensing	FIT	C. Bostater	Fall, 2010
Oszcar	Jozsa	BS	Airborne Sensing	FIT	C. Bostater	Fall, 2010

Student and post-doctoral publications, if planned

d. None

Student and post-doctoral presentations and posters, if planned (Please provide copies of each).

Title	Presenter	Authors	Meeting or Audience	Abstract published (Y/N)	Date
Hyperspectral Sensing	H. Frystacky	-	FIT Undergraduate Seniors	N	7/2011
Hyperspectral Sensing	M. Kovacs	-	FIT Engineering Showcase	N	12/2010
Hyperspectral Sensing	O. Jozsa	-	FIT Engineering Showcase	N	10/10

Images

See previous section.

Continuing Research:

The US Dept. of Education, FIPSE, Atlantis STARS (Sensing Technology and Robotic Systems), Continuing Dual degree international undergraduate and graduate program between the US and EU, has provided the funding for analysis of the data acquired from this project reported in this final report and that is ongoing today.