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The explosion of the Deepwater Horizon oil rig on April 20, 2010 resulted in what is now considered to be the largest oil spill in US history. Oil from the spill has reached the Louisiana marshes and will continue to impact the environment. Addressing the extent and impact of the oil spill will be a focus for several years. The ability to detect, identify, and map oil in the Gulf of Mexico using in situ and remote sensing assets is presented. The Hyperspectral Imager for Coastal Ocean (HICO) is a hyperspectral sensor built by the Naval Research Laboratory (NRL) and currently operating on the International Space Station (ISS). NRL is also responsible for the mission planning, targeting, and data processing. In addition to HICO scenes of the oil spill, imagery from the MODerate Resolution Imaging Spectroradiometer (MODIS) and the Medium Resolution Imaging Spectrometer (MERIS) have been collected and processed. Spectra from oil contaminated water and from uncontaminated water were identified and the ability to separate these spectra was investigated. In addition, in situ data was collected and matched with the satellite data. Results from analyses of these data sets are presented.

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Spectral and Spatial Analysis of the Gulf of Mexico Oil Spill using Satellite and In Situ Data

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ABSTRACT

The explosion of the Deepwater Horizon oil rig on April 20, 2010 resulted in what is now considered to be the largest oil spill in US history. Oil from the spill has reached the Louisiana marshes and will continue to impact the environment. Addressing the extent and impact of the oil spill will be a focus of study for several years. Investigations into spectral characteristics of the oil provided by satellite-based sensors are presented. Imagery from the MODerate Resolution Imaging Spectroradiometer (MODIS) and Hyperspectral Imager for Coastal Ocean (HICO) have been collected and processed. MODIS provides daily remotely sensed multispectral data of the Gulf of Mexico. HICO is a hyperspectral sensor built by the Naval Research Laboratory (NRL) and currently operating on the International Space Station (ISS). NRL is also responsible for the mission planning, targeting, and data processing for HICO data. Spectra from oil contaminated water and from uncontaminated water is inspected and the ability to identify features based on these spectra is investigated.

INTRODUCTION

As of early August, 2010 it is estimated that roughly 200 million gallons of oil has spilled into the Gulf of Mexico from the ruptured pipes of the Deepwater Horizon oil rig. (NOLA Website) Remote sensing data sets may provide a means to monitor the status of the oil in the Gulf of Mexico. Remote sensors on satellite platforms used in this investigation provided data products for evaluation of the ocean. They include the MODerate resolution Imaging Spectroradiometer (MODIS) and the Hyperspectral Imager for the Coastal Oceans (HICO).

REMOTE SENSING SOURCES

Moderate Resolution Imaging Spectroradiometer (MODIS)

The Moderate Resoultion Imaging Spectroradiometer (MODIS) sensor has been providing remotely sensed data over land terrain and oceans for several years. A MODIS sensor exists on both the Terra (EOS AM) and Aqua (EOS PM) NASA satellites. Terra was launched in late 1999 and Aqua was launched in 2002. They are both in a sun-synchronous orbit. However, Terra crosses the equator traveling from north to south in the morning, while Aqua crosses the equator traveling from south to north in the afternoon. The primary ocean color wavelengths are 412, 443, 488, 531, 547, 667, 678, 748 and 869 nmeter bands. (MODIS Website)

Hyperspectral Imager for the Coastal Ocean (HICO)

The Hyperspectral Imager for the Coastal Ocean (HICO) was installed on the International Space Station (ISS) in September of 2009. It is designed to provide hyperspectral imagery for the study of the coastal ocean and adjacent land. Although the HICO sensor collects 128 contiguous spectral channels of solar reflectance in the 350 to 1070 nmeter range, its most sensitive spectral wavelength range is from 400 to 900 nmeters. Each HICO scene is roughly 50 kmeters in width by 200 kmeters in length. The HICO data flow from the ISS provides a maximum of 15 scenes per day. Standardized data processing is required to create timely HICO data products. HICO is managed by the Naval Research Laboratory (NRL).

After HICO data is downlinked to ground stations, NRL processes the data through a series of transformations. One data processing path performs atmospheric correction (Siegel, et al.) and data product generation on the full hyperspectral data set. Another data processing path convolves the data over the MODIS band wavelengths to provide data products at 100 meter ground sample distance that can be compared directly with MODIS data products. After atmospheric correction is performed, both processing paths create standard products such as normalized water leaving radiances and remote sensing reflectances from the data set.

DATA COLLECTION

Moderate Resolution Imaging Spectroradiometer (MODIS)

MODIS data can be downloaded from the Level 1 and Atmosphere Archive and Distribution System (LAADS) website (ladsweb.nascom.nasa.gov/data/search.html). The LAADS website allows the user to specify the sensor type, data type, date/time, and geographic location of desired MODIS Level 1 data products. MODIS Level 1B data products for several dates were downloaded and inspected. The area around the Deepwater Horizon location for many scenes was covered either partially or completely by clouds. However, there were some scenes that were relatively cloud-free across the area.

The relatively cloud-free MODIS scenes with noticeable oil features are also the scenes that experience sun glint through the region of the oil spill. Since the sun glint reflects differently from uncontaminated water and water mixed with oil, it was possible to visually identify the location of the oil in these images. Unfortunately, the sun glint also confounds the ability to extract data products such as water leaving radiances and remote sensing reflectance from the data set.

The area of the oil spill in the 05/28/10 MODIS scene was near but just outside the sun glint region. This allowed for it to both visually reveal the extent of the oil spill while at the same time provide data that could be processed to produce remote sensing reflectance. In addition, a HICO scene for this same day was acquired. The MODIS scene for 05/28/10 was processed to remotely sensed reflectance in preparation for comparison with data acquired from the HICO sensor.

Hyperspectral Imager for the Coastal Ocean (HICO)

Before HICO was launched, NRL assembled a "target deck" of desired ocean targets scenes which has been updated over time. After the explosion of Deepwater Horizon a variety of targets were created around the explosion site and the nearby marshlands of Louisiana and Mississippi. HICO data collection began on May 6, 2010. Due to the orbit of the ISS, targets around the Deepwater Horizon explosion site and nearby coastal environments are not always in the HICO field of view. Although there are times that the ISS orbit takes the HICO sensor out of view of the region for several days, in general the explosion site or nearby coastal regions can be imaged by HICO about every 2 days. On the days that the region can be imaged, usually there is only one orbit that brings the sensor close enough for data collection. In addition, on the days that the area can be imaged, often cloud coverage prevents a clear view of the coastal region.

Although there are several factors that might prevent a HICO scene from being acquired on an ISS orbit, in general one of the target scenes is selected for each ISS orbit. To perform this selection for each ISS orbit, a list of potential target scenes is created by using the ISS ephemeris data and solar positions to determine what target scenes will be visible during the ISS orbit. The scene selected for acquisition on any given orbit is often but not always the scene from the potential scene list with the smallest sensor zenith angle. If a target scene with a larger sensor zenith angle is more desirable, for example, due to the need to create an extended time series database of a given area or to collect data coincident with in situ data collection mission, then the target scene with higher sensor zenith angle will be selected as the target scene to be acquired for that particular ISS orbit. Commands are sent through NASA to the ISS and the HICO sensor to schedule the selected target scenes for acquisition.

The initial collection of HICO target scenes for investigating the oil spill included areas around the Deepwater Horizon explosion site. Additional tiles were added to cover marshlands and barrier islands in southern Louisiana and Mississippi. Targets were selected for acquisition based not only on the sensor zenith angle for each target scene, but also on the collection frequency of previously acquired targets. Figure 1 shows the ascending and descending HICO Oil Spill tiles targets. In some cases the locations were adjusted slightly and the label updated to provide a more descriptive name than simply a sequential number.

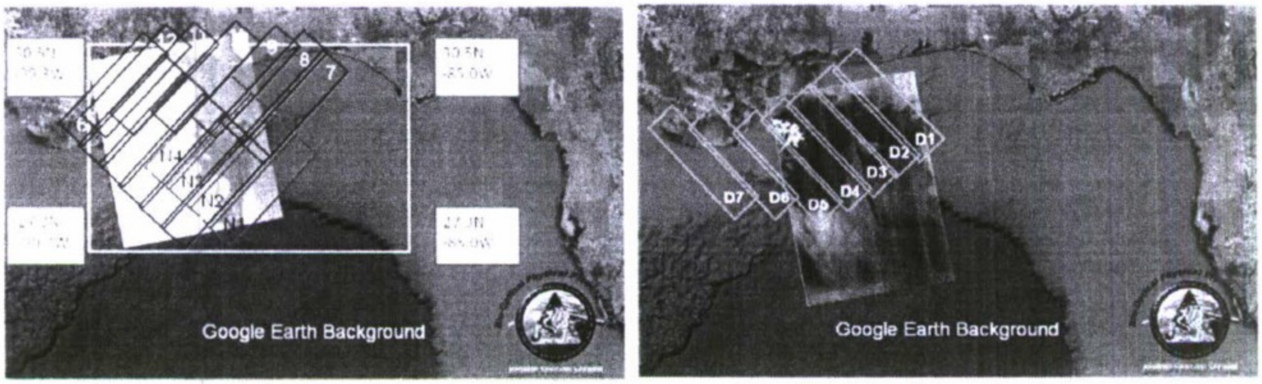

Figure 1.Oil Spill Targets for Ascending and Descending HICO Passes

A subjective visual evaluation of the cloud conditions/quality for each image date was performed. The top 10 image scenes shown in the Table 1 were sorted according to this subjective evaluation. The date, time and tile label for each of these HICO scenes are listed in the table.

Table 1. HICO Image of 2010 Gulf of Mexico Oil Spill
(Data Coverage Quality is a subjective evaluation of data quality and oil in image)

	Date	Local Time	Tile	Conditions	Data Coverage Quality
1	05/28/10	8:21:30	New_4Ascending	Light Clouds	9
2	06/07/10	12:31:11	2Descending	Light Clouds	8
3	06/13/10	10:26:28	HornCatShip Islands	Cumulus Clouds	8
4	07/08/10	15:41:36	New_5Ascending	Light Clouds	8
5	05/24/10	9:55:10	New_4Ascending	Light Clouds	7
6	06/11/10	10:08:04	HornCatShip Islands	Cumulus Clouds	7
7	05/12/10	14:30:25	1Ascending	Clouds	6
8	05/26/10	9:08:47	New_4Ascending	Significant Clouds	5
9	06/20/10	7:12:55	1Descending	Various Clouds	5
10	07/10/10	14:59:02	New_5Ascending	Saturated Cumulus Clouds	5

The geographical position of the HICO tiles for ten of these dates is shown in Figure 2. This provides a visual reference for the size of the HICO scene and also depicts the type of coverage over the oil features near the Deepwater Horizon site that is available by a collection of HICO scenes. As previously mentioned, an Aqua MODIS scene collected on 05/28/10 was also relatively free of cloud cover. Data products were generated from both the 05/28/10 HICO and MODIS scenes for comparison.

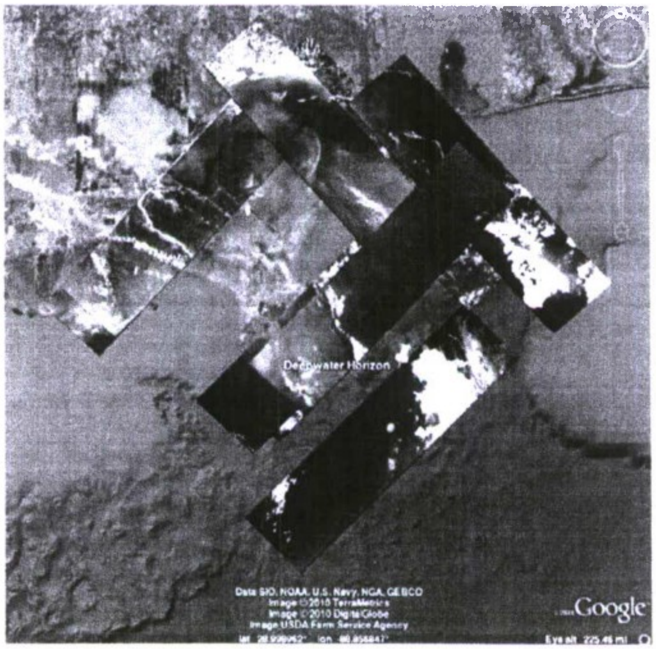

Figure 2. Ten HICO scenes overlaid on Google Earth background (geolocation is approximate)

ANALYSIS

The 05/28/10 MODIS scene was processed for remote sensing reflectances (Rrs). A subset of the MODIS true-color image is shown in Figure 3a. The image is shown again in Figure 3b with a region of interest over uncontaminated water location highlighted in green and also a region of interest location with a mixture of oil and water highlighted in red.

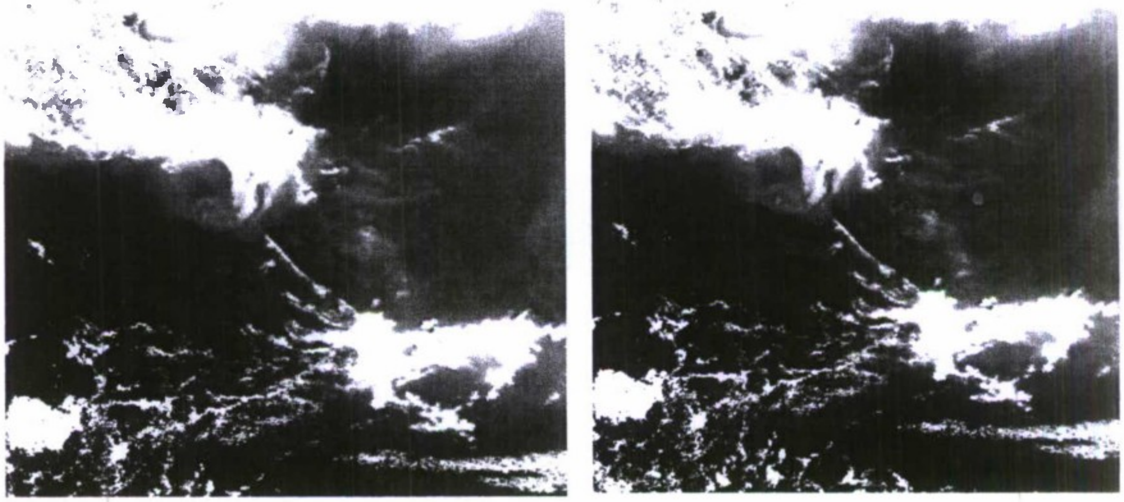

Figure 3. a) MODIS 05/28/10 true color scene, b) water, and oil/ water regions in green and red respectively

Remote sensing reflectance values were drawn from the areas designated in green region of interest for the uncontaminated water spectra and areas designated in red region of interest for the mixed oil/water spectra. The graph of the MODIS remote sensing reflectance spectra for these two types of areas are shown in Figure 4. The graph shows the mixed water/oil spectra initially lower than the uncontaminated water, but then intersecting and crossing the uncontaminated water spectra around the 525 nmeter wavelength.

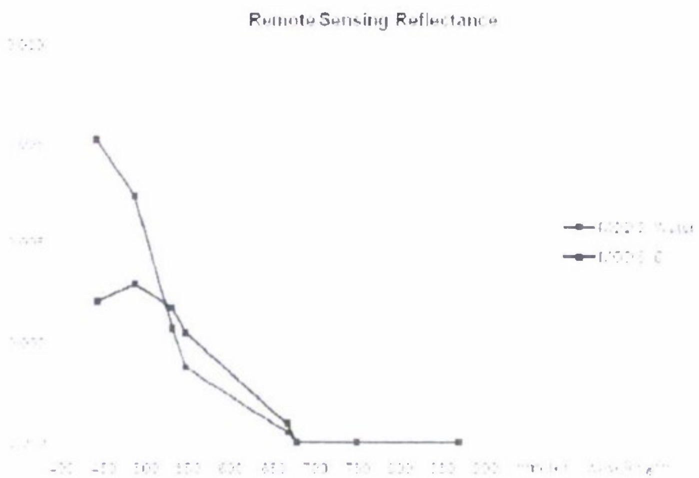

Figure 4. MODIS remote sensing reflectance for uncontaminated water and mixed oil/water

The spatial resolution of MODIS is 1 kmeter. This results in the oil features to be mixed significantly with phytoplankton and other minerals in the water within the cell size of one MODIS pixel. The spatial resolution of HICO is 100 meters, which lends itself to more detailed spatial discrimination of the data. Although each HICO data set shown in Table 1 was processed, some scenes were obscured by cloud cover and not all the scenes contained clearly discernable oil phenomenon.

Figure 5a shows a subset of the 05/28/10 scene containing the oil phenomenon. A mask was created to cut out the clouds that were adjacent to the areas of water and mixture of oil and water. The area covered in Figure 5 is located between the Deepwater Horizon explosion site and the mouth of the Mississippi River. Fingers of emulsified oil can be see extending horizontally across the image. Smaller localized concentrations of emulsified oil can also be seen in the center of the image. Figure 5b shows the same image with the regions of interest created over the uncontaminated water depicted in green, the regions of interest created over oil and water mixture locations depicted in orange, and the regions of interest created over the emulsified oil locations depicted in red.

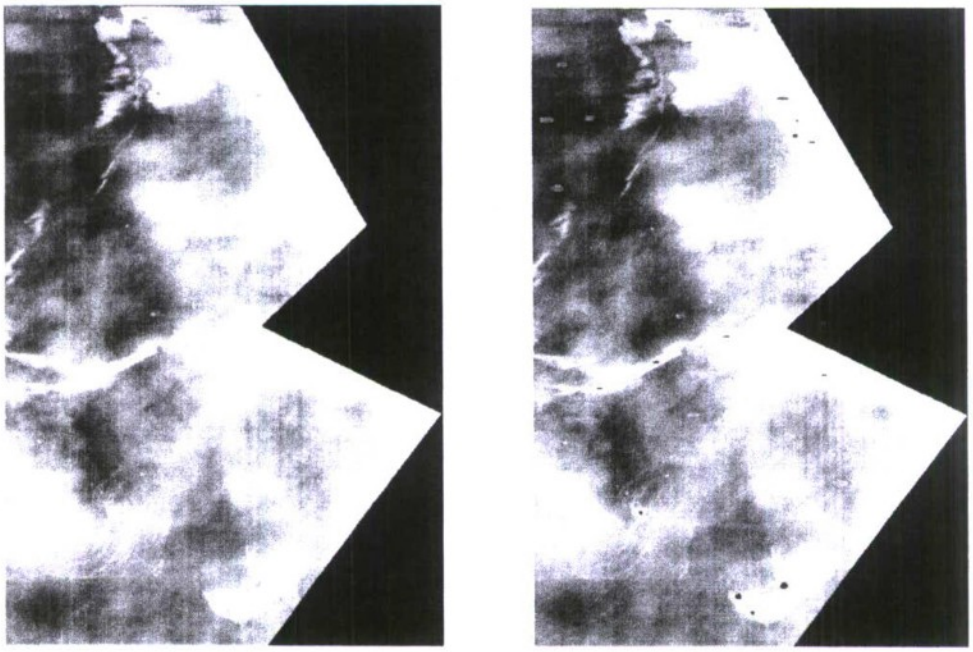

Figure 5. a) HICO 05/28/10 true color scene, b) water, oil, and emulsified oil regions in green, yellow and red respectively

The HICO data was processed to remote sensing reflectance. The mean of the remote sensing reflectance spectra drawn from the water, oil/water and emulsified oil regions of interest were computed and are shown in Figure 6. The spectra for the water feature is higher than the spectra from the oil features through the visible bands with the greatest difference being in the 443 nmeter band. Then it intersects the spectra for the emulsified oil feature near the 500 nmeter wavelength and also intersects the spectra for the oil/water mixture feature near the 525 nmeter wavelength.

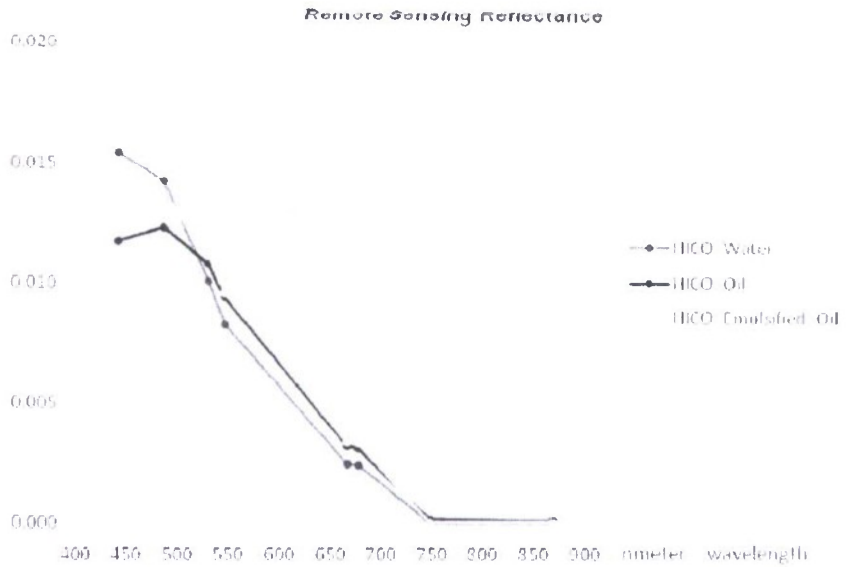

Figure 6. HICO remote sensing reflectance for uncontaminated water and mixed oil/water

For comparison, the HICO and MODIS spectra were graphed together in Figure 7. The amplitude of the HICO spectra is larger than the amplitude of the MODIS spectra, which could be related to sensor zenith angle and acquisition time of the day differences. The similarities in the shape show the respective spectra of the oil/water mixture starting lower than the uncontaminated water spectra and intersecting the uncontaminated water spectra near the 525 nmeter wavelength.

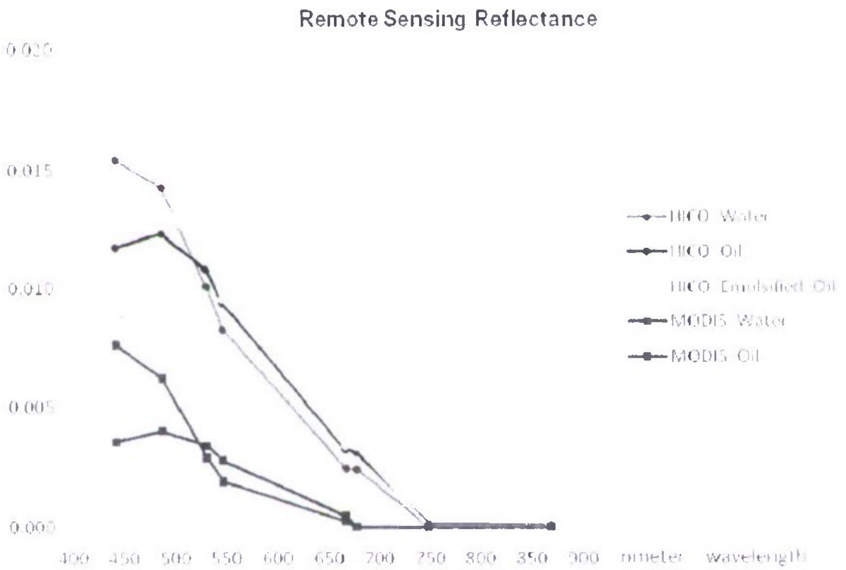

Figure 7. HICO/MODIS remote sensing reflectance spectra water and oil/water mixtures

The HICO sensor's remote sensing reflectance spectra drawn from the water, water/oil, and emulsified oil regions of interest were used to provide statistics for training classes for classification. Maximum Likelihood, Mahalanobis, Minimum Distance to the Mean, and Spectral Angle Mapper (SAM) classifiers were used to create classified images. The results from the Maximum Likelihood and SAM classifiers did not delineate the features well. However, the results from the Mahalanobis and Minimum Distance to the Mean did produce interesting results.

The results of the classifications along with the corresponding true-color composite image are shown in Figure 8. The green region depicts the areas where the classifier identified the pixel as uncontaminated water. The orange region depicts the areas where the classifier identified the pixel as a mixture of oil and water. The red region depicts the areas where the classifier identified the pixel as emulsified oil.

Unfortunately definitive ground truth for the areas acquired in the HICO data set are not available for this study. However, a loose mapping shows the area at the upper left of the true-color image to be uncontaminated water. Most of the central part of the image is mixture of oil and water. The strands of emulsified oil can be seen stretching across the middle of the image with a few strands visible on the top and bottom of the image. The results of the Minimum Distance to the Mean and the Mahalanobis classifiers identify the locations of the features of the uncontaminated water and oil/water mixture as classes shown in green and orange respectively. These classifiers also identified strands of emulsified oil as a class shown in red. These class features correlate visually with the uncontaminated water, oil/water mixture and emulsified oil features in the true-color image.

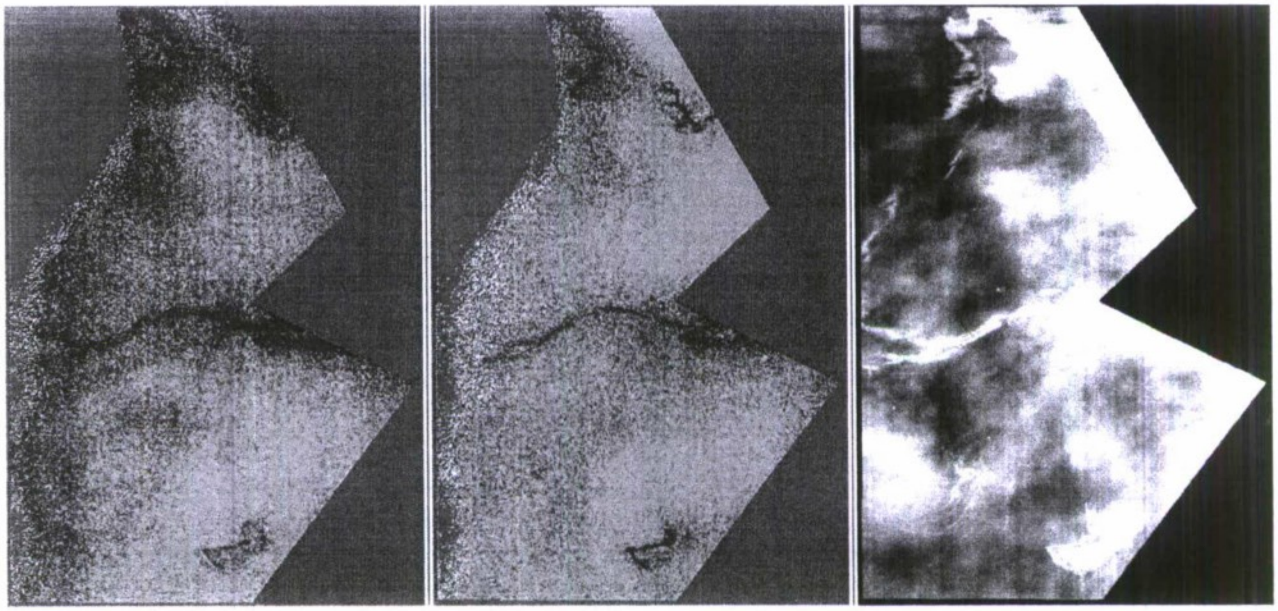

Figure 8. a) Minimum Distance to the Mean Classification, b) Mahalanobis Classification, c) True-Color Image

CONCLUSIONS

Remote sensed data may prove to be a useful tool in identifying oil spilled into water from ruptured oil pipes. MODIS data shows spectra taken over uncontaminated water to be initially higher in the visible wavelengths than spectra taken over a mixture of water and oil from the Deepwater Horizon oil spill. The water spectra intersects the mixed oil/water spectra near the 525 nmeter range and then is lower through the infrared region of the spectra. Similar spectra is demonstrated in the remote sensing reflectance drawn from the HICO data. The spatial resolution of the HICO sensor allows for more features of the mixed oil/water spectra to be investigated. The spectra from the HICO sensor was used for classification of the uncontaminated water and the water mixed with oil. Additional work that can be performed includes inspecting multiple dates of imagery. Also, data from other remotely sensed platforms can provide a more robust dataset for comparison.

REFERENCES

Siegel, David A. Menghua Wang, Stéphane Maritorena, and Wayne Robinson, 2000, Atmospheric Correction of Satellite Ocean Color Imagery: The Black Pixel Assumption Applied Optics, Vol. 39, Issue 21, pp. 3582-3591 (2000) doi:10.1364/AO.39.003582

MODIS Website, http://modis.gsfc.nasa.gov/ , last accessed 07/28/10

NOLA Website, http://www.nola.com/news/gulf-oil-spill/index.ssf/2010/08/local_officials_environmentali.html