Oil Spill Detection and Monitoring Using MODIS Data

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Abstract

Oil spills frequently occur during the reconnaissance or transportation accidents. The Gulf of Mexico oil spill stemmed from a sea-floor oil gusher that resulted from the April 20, 2010 Deepwater Horizon drilling rig explosion. It was estimated that 53,000 barrels per day (8,400 m^3/d) were escaping from the well just before it was capped. The spill is causing severe damage to marine and wildlife habitats. In order to implement effective oil spill countermeasures, detection and continuous monitoring, Satellite remote sensing techniques can be used as they provide large area surveillance, site specific monitoring and tactical assistance in emergencies.

The present study is based on examining the feasibility of Moderate Resolution Imaging Spectro radiometer (MODIS) high resolution bands (250-m and 500-m) for detection and monitoring of oil spills. Twelve time series images of MODIS Aqua and Terra high resolution imagery from 20 April till 23 June 2010 were exploited for detection and monitoring of oil spill in the Gulf of Mexico. Both L1B (Level1B-only geometrically corrected) and L2 (Level2-both geometrically and atmospherically corrected) data were examined but L2 products such as RRS[1], SST[2], BRDF[3] were not suitable and they lacked the sufficient contrast range because of rigorous atmospheric correction. The 250 m data at 645,859 nm and 500 m data at 469, 555, 1240, 2130 nm were analyzed. By assessment of these individual bands and using band ratio combinations the ultimate index was obtained which can clearly indicate the oil spills and improve the contrast in the area. The result was validated by comparing with the shape files obtained from oil spill trajectory maps in NOAA[4] website. Therefore, MODIS-Aqua and Terra data with daily coverage and high resolution can be liable and cost-effective for such events.

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[1] Remote Sensing Reflectance

[2] Sea Surface Temperature

[3] Bidirectional Reflectance Distribution Function

[4] National Oceanic and Atmospheric Administration

Key words: Remote sensing, Oil spill, MODIS, Band ratio

1-Introduction

In recent years, oil spill pollution has become a serious problem with increasing oil production and transportation remote sensing plays an important role in detection and monitoring oil spills. Satellite-based technologies used for oil spill monitoring include optical sensors, microwave sensors and radars, among others (Li et al., 1997; An et al., 2000; Bartsch et al., 1987). Recently researchers paid a lot of attention to radar in order to detect the ability of Synthetic Aperture Radar (SAR) but its capability is limited in its low resolution and wind speed limit (Long Ma et al., 2009).

For microwave sensor low spatial resolution is the main problem to monitor oil spills.

In the past, Advanced Very High Resolution Radiometer (AVHRR) and Thematic Mapper (TM) Were mainly used for oil spill monitoring (Li et al., 1997; Al-Ghunaim et al., 1992; Cross, 1992; Al-Hinai , 1993; Li et al., 1994; Tseng et al., 1994).

However, AVHRR is primarily for weather forecasting and monitoring regional climatic conditions, TM is, in contrast, used for monitoring of land and resources and their technical attributes are not appropriate for oil spill monitoring (Long Ma et al., 2009).

Chust and Sagarminaga compared MODIS with MISR (Multi-angle Imaging SpectroRadiometer viewing the sunlit Earth simultaneously at nine widely-spaced angles, MISR provides radiometrically and geometrically calibrated images in four spectral bands at each of the angles. This offers a considerable advantage in detecting the oil sheen and oil slicks, as high contrast can be achieved near Brewster's angle (Fingas, M. F. and Brown, 2000) but it does not carry sensors in the NIR/mid-IR range.

Moderate Resolution Imaging Spectroradiometer (MODIS) is a very suitable ocean color sensor. It is operational on two satellites - Terra (launched in 1999) and Aqua (launched in 2002).

MODIS sensor has free near real time data with almost global daily coverage and also it has wide spectral range (36 bands). Its data exists in Mid-IR region (1240 nm and 2130 nm).It is available at high resolution (250m , 500m) and has sufficient spectral resolution to cover optical, NIR and Mid-IR regions of electromagnetic (EM) spectrum. The present study is based on assessing MODIS – Aqua and Terra data in detection and monitoring of oil spills in marine environment.

2- **Data and Material**

The Gulf of Mexico oil spill event was chosen for analysis in this paper. An oil leak was discovered on the afternoon of April 22 when a large oil slick began to spread at the former rig site in Gulf of Mexico. Approximately it had released about 4.9 million barrels (780×10^3 m^3), or 205.8 million gallons of crude oil and oil spilled area was about 2500 to 68000 sq mi (6500 to 180000 km^2).

In the present study, both Aqua and Terra MODIS data were evaluated. With regard to occurrence time of oil spill and weather condition, the L1B data were acquired from Ocean Color database for twelve time series between 20th April and 27th June 2010 for the area from 21° N to 33° N and 92° W to 82° W for Gulf of Mexico. MODIS L1B data were downloaded from NASA Level1 and Atmospheric Archive and Distribution System (LAADS) and detection and monitoring of that oil leaking event were evaluated by using MODIS images. Some data between the time series was not considered due to cloud cover. The applied images are listed in Table 1.

Satellite	Acquisition		Image property
	Time	Date	
Aqua	18:55	25 April 2010	MYD021KM.A2010115.1855.005.2010116172427
Aqua	18:50	4 May 2010	MYD021KM.A2010124.1850.005.2010126055705
Aqua	19:05	9 May 2010	MYD021KM.A2010129.1905.005.2010131021258
Terra	16:40	17 May 2010	MOD021KM.A2010137.1640.005.2010138011841
Aqua	18:35	22 May 2010	MYD021KM.A2010142.1835.005.2010143173431
Terra	16:45	24 May 2010	MOD021KM.A2010144.1645.005.2010145012606
Aqua	18:55	27 May 2010	MYD021KM.A2010147.1855.005.2010148193756
Terra	16:45	9 June 2010	MOD021KM.A2010160.1645.005.2010161012707
Aqua	19:05	10 June 2010	MYD021KM.A2010161.1905.005.2010162161037
Aqua	18:55	12 June 2010	MYD021KM.A2010163.1855.005.2010164163057
Terra	16:40	18 June 2010	MOD021KM.A2010169.1640.005.2010170011603
Terra	17:00	23 June 2010	MOD021KM.A2010174.1700.005.2010175013944

Table 1.the examined images for existence of oil signature in study area.

3- **Research Methodology**

The data processing flow chart is presented in Fig1:

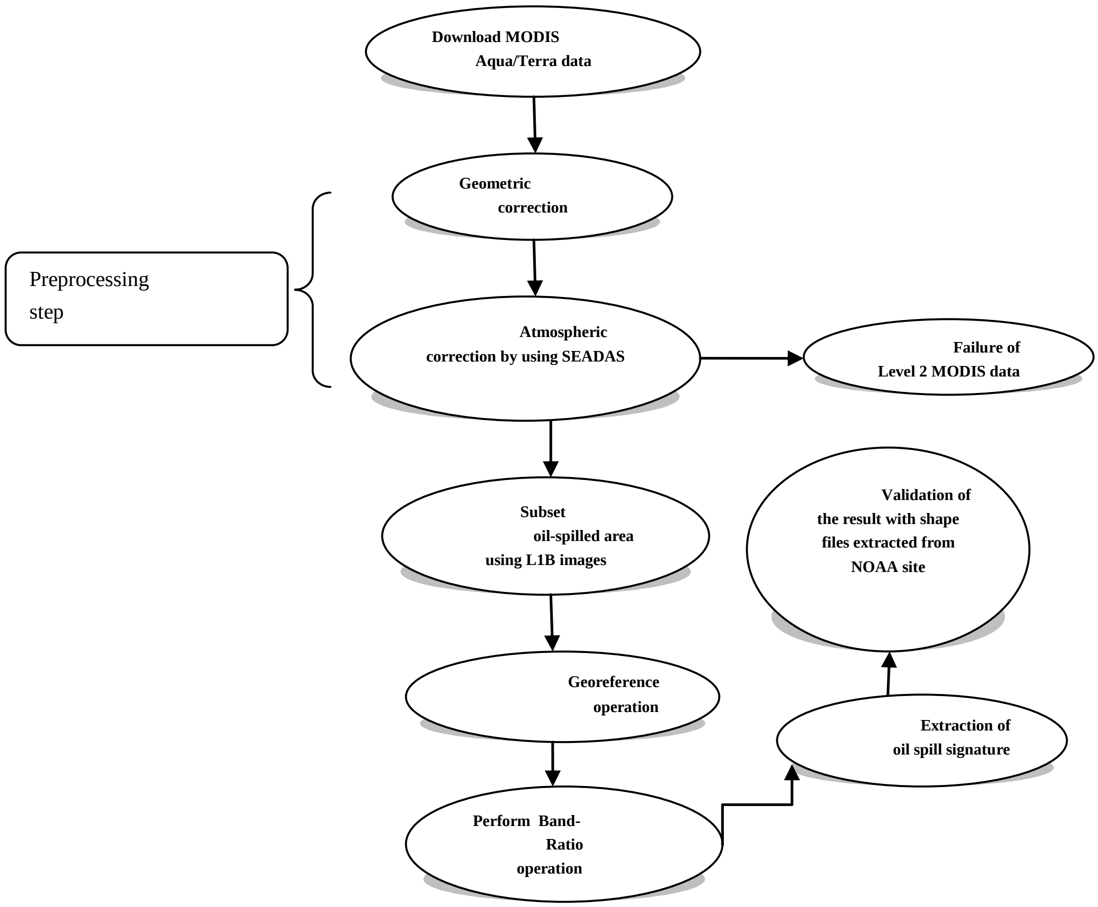

Fig1.Oilspill extraction procedures.

According to the oil spill extraction flowchart, geometric correction such as bow-tie correction has been performed on all MODIS images (Fig 2).

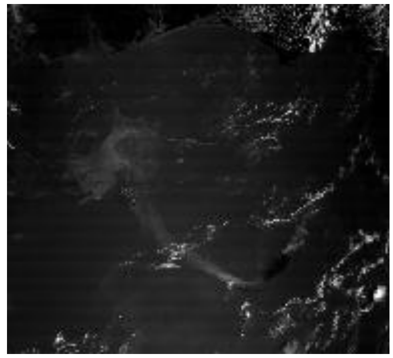

Fig 2.MODIS Image subset with geometric correction (17 May 2010)

It is found that the shorter wavelengths were more sensitive to optical signature of oil. The shorter wavelength at blue 469 nm band is normally found to be contaminated with the signatures of biogenic materials (Hu et al., 2003). Therefore, in order to remove these effects, L1B data at all wavelengths were normalized with respect to 469 nm (band1-500 m MODIS) (H.Srivastava and T.P.Singh., 2009). The level-1B data was atmospherically uncorrected and geometrically corrected while the MODIS level-2 was geometrically and atmospherically corrected. It has BRDF data products at six HMODIS wavelengths were computed, along with water-leaving (Lw) and normalized Water-Leaving (nLw) radiances and RRS.
The MODIS –Aqua and Terra L1B data were processed to L2 using SeaDAS 5.2.0. SeaWiFS Data Analysis System (SeaDAS Version 5.2.0) is a comprehensive image analysis package for the processing, display, analysis, and quality control of ocean color data.
In L1B to L2 processing, l2gen, 4 codes were used. L2 products were generated from a corresponding L1B product. The L2 products have geophysical values for each pixel generated by applying the sensor calibration, atmospheric corrections and bio-optical algorithms. The products generated include sea surface temperature (SST), Bidirectional Reflectance Distribution Function (BRDF), Remote sensing Reflectance (RRS) in high resolution bands. By visualizing of L2 products no specific signature of oil was found (Figure 3).

Fig 3. L2 product generated by SeaDAS 5.2

The data was then projected in Geo (lat/long) projection with WGS84 datum. Therefore, in order to identify the oil spill area, it is necessary to consider L1B data which is geometrically corrected. The MODIS –Aqua L1B data at spectral bands 469, 555,645, 859, 1240 and 2130 nm were then visualized. In order to identify the signatures of oil spill, band ratio operations were examined by using different combinations of bands. The normalized L1B data at each band were evaluated for determining oil signature.

4- Results and Analysis

The results showed that the different and sum ratio of B4 (band 2-500m) 555 nm and B1 (band1–250m) 645 nm normalized by B3 (band1-500m) 469nm produced significant results. The algorithm for retrieving oil spill is given below:

Oil spill index= [(B4/B3)-(B1/B3)] / [(B4/B3) + (B1/B3)]

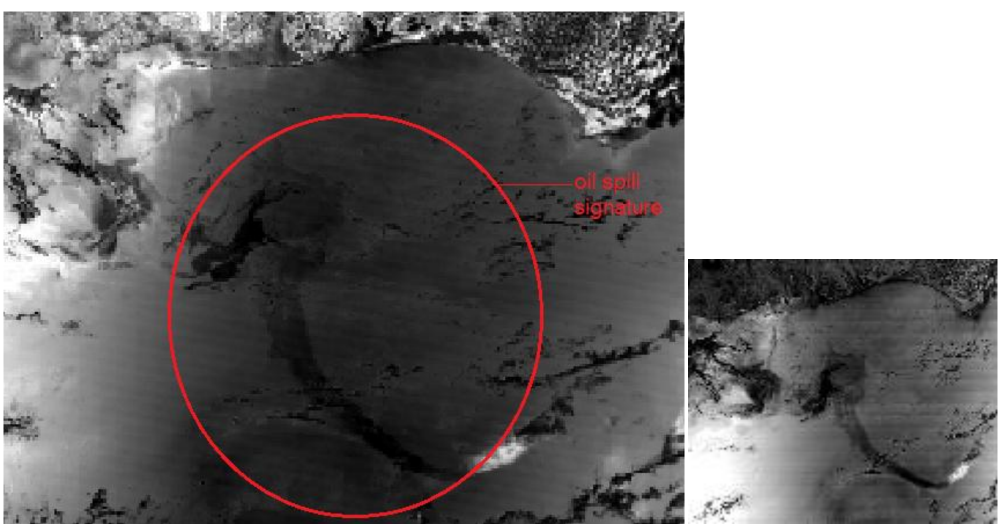

Fig 4.The area showing the band-ratioed image of Gulf of Mexico. The negative radiances are indications of oil spill and they are marked.

As shown in the Figure 4, the oil spill signatures were identified clearly. For validation of this result, oil spill trajectory files were downloaded from NOAA website.
NOAA oceanographers use specialized computer models to predict the movement of spilled oil on the water surface. They predict where the oil is most likely to go and how soon it may arrive there. During a major spill response, they generate trajectory maps that show their predictions. A trajectory predicted Oil on the water is moved by currents and winds. Using currents and winds predictions from a variety of sources, as well as available observations, the NOAA oceanographers run several leading computer models to forecast the movement and spreading of the oil. They also use satellite imagery analysis and observations reported by trained observers who have made helicopter over flights back and forth across the potentially affected area, recording locations where oil is seen (NOAA’s National Ocean Service, Office of Response and Restoration, May 5, 2010).
The result was validated by comparing with georeferenced-shape files obtained from oil spill trajectory PDF maps which are present in NOAA website. The reprojected-images have been devided into two classes (oil and water). By overlaying the shape files and classified-images the oil spilled areas were computed (Figure 5). Therefore, an error matrix generated using unseen training data provided an average overall accuracy of 58.8%with an average of kappa coefficient of %43 for five time series images (Table 2).

DATE	**Overal Accuracy**	**Omission Error (oil/not oil)**	**Commission Error (oil/not oil)**	**Producer's Accuracy (oil/not oil)**	**User's Accuracy (oil/not oil)**	**Kappa Error%**
2010/05/09	*0.55*	0.35/0.69	0.29/0.75	0.65/0.30	0.70/0.25	47
2010/05/17	0.2	0.84/0.67	0.59/0.88	0.15/0.33	0.41/0.14	31
2010/05/22	0.66	0.30/0.35	0.57/0.15	0.69/0.65	0.44/0.84	29
2010/05/24	0.78	0.09/0.29	0.35/0.07	0.90/0.71	0.65/0.92	57
2010/06/09	0.75	0.34/0.11	0.09/0.38	0.66/0.88	0.90/0.62	50

Table 2.Accuracy assessment for five time series images.

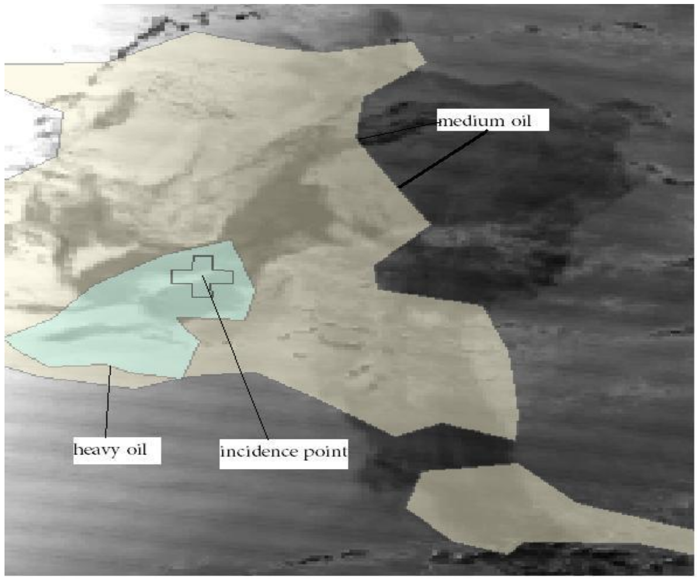

Fig 5. Overlaid shape file extracted from NOAA website PDF trajectory files -17 May 2010.

5- Conclusions

The contrast between oil spill and its background (ocean water) in images is due to their differences in spectral characteristics so how to correctly monitor real-time oil spill plays an important role in emergency managements.

The present study was formulated in order to examine band ratio methods because band ratios operation of specific bands could emphasize certain features. It has been observed that shorter wavelengths of visible channel are more sensitive to signature of oil and difference and sum ratio of B4 (band 2-500m) 555 nm and B1 (band1–250m) 469 nm normalized by B3 (band 1-500m) 469 nm were found the most suitable to retrieve oil spill signature in the case study.

Some parameters have direct effects on kappa error such as type of oil(heavy, medium or light oil),cloud existence, sun glint.

It has found that MODIS Aqua and Terra high resolution data were feasible to retrieve the signatures of oil spill by using band ratio method. Although MODIS sensor provides high temporal resolutions and strong capability to detect real time oil spills, its ability is limited by weather conditions (e.g., cloudy days). Oil spill monitoring can benefit from the use of other technologies, such as radar.

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