A POST-CONFLICT ASSESSMENT TO INTERPRET THE DISTRIBUTION OF OIL SPILL OFF-SHORE LEBANON USING REMOTE SENSING

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(Received 7 August 2007 - Accepted 29 August 2007)

ABSTRACT

Oil slicks are common aspects of pollution that often exist in many littorals of the world. The Lebanese coast is typical to these aspects, thus oil slicks and patches are frequently observed while analyzing different satellite images. This is attributed, in a broad sense, to the oil released from ship tracks as well as from the located refineries, oil tanks and factories along the coast of Lebanon. The most severe event of this kind Lebanon has witnessed occurred on July 13th 2006 due to the bombing of the oil tanks at Jiyeh power station by the Israeli army. Consequently, several millions of fuel-oil gallons (~15000 tons) were released into the seawater covering an area of about 3000 km^2. The prevailing dynamics of the sea currents in the area, which are rather fast in northward direction, controlled the spreading regime of oil and diverted it to the north shoreline where it nearly settled.

A couple of days after the event, the spread oil was reduced and restricted to the coastline. Nevertheless, analysis of ASTER images dated on August 10th 2006 (25 days after the event) showed an abrupt existence of a huge plume into the sea. It was located south to Ez-Zahrani River outlet (16 km south to Jiyeh) and spread out about 5 km into the sea and not at Jiyeh station as it would have been anticipated.

This extended the assumption that another release of unidentified materials has taken place in that area between August 3rd and 10th 2006. Hence, a release of dense materials, different from fuel oil, was proposed to form the identified plume of August 10th 2006, a matter that needs further verification.

Keywords: marine environment, oil release, Lebanon, unidentified materials

INTRODUCTION

As a major aspect of marine pollution, oil release into the sea has become a common phenomenon, and rarely a year goes by without accidental event related to oil spread into the sea. This phenomenon encompasses a miscellany of aspects, which result either naturally or from human interference. The latter often given much attention rather than those from natural oil seeps. Normally, small-scale release of oil into the sea ascribed as “slick”, while large-scale ones called “spill” (Goodman, 1989). Most oil spills have an abrupt and fast release into seawater and resulted from severe accident, usually as ships collusions and, in few instances, due to political conflicts between different counties.

More than 700 millions of gallons of oil released each year into ocean worldwide and about 50% of this amount is attributed to down to drain (Gradwohl, 1995). However, in spite of the low percentage of released oil due to accidental events (5%), yet it is much influencing to the environment, notably because they exist in the proximity of coastal zones where human settlements are dense.

The political conflict that Lebanon has witnessed in summer 2006 is a typical example. The Jieh electrical power-station, largest Lebanese coastal station (Figure 1), was struck on July 13th 2006, thus a huge amount of heavy fuel-oil was released into the marine environment of the Lebanese coast, forming a plume of about 3000 km^2.

Greenpeace (2006) estimated the amount of released oil as around 10 million gallons, which is equivalent to 15,000 tones. This, in turn, constitutes about 27% of the total annual amount of released oil into the sea as resulted from accidental events. Even though, small-scale leakages of oil are common from tracking ships; however, the coastal zone of Lebanon has not been exposed to such environmental disaster before.

The dominant dynamics of currents along the sea of Lebanon, which are rather fast in northward direction (Kabbara *et al.*, 2001), accelerated the spreading regime of the oil spill and diverted it to the north shoreline where probably most of spread oil was settled. Thus, the Lebanese coast from Jieh (~ 163 km) was covered by oil, and even reached to southern coast of Syria.

Unfortunately, due to the continuity of the conflict after this event, no immediate remediation has been done. This increased the geographic extend of the spill and gave enough time to dense oil to sink into sea floor. Consequently, and after a couple of months from the bombing of the station, several local and foreign environmental authorities and institutes started assessing the size and magnitude of the environmental impact. This was considered as a perquisite step for cleaning-up implements as well as to highlight the hotspots in order to preclude any human activities at these affected sites. However, most of these authorities worked independently. They also obtained limited field surveys on selected sites, notably where dense oil existed. Further on, local and small-scale cleaning-up activities were implemented.

By the end of the conflict, the informal news exposed this event in different worldwide media. They just posted it as satellite image views with brief discussions, like those exposed by NASA, CSA and ESA. Yet, the magnitude of the catastrophic problem was not clearly viewed, as well as no scientific-based information on the flow behaviour and geography of this spill was identified five months before the event occurred. Therefore, the Lebanese National Council for Scientific Research (CNRSL) was the first to introduce detailed information concerning the oil spill of Jiyeh station. In this respect, remote sensing was applied through analyzing different types of satellite images, with a special emphasis to ASTER sensors (CNRS, 2006). Thus, several related studies have been done, but focused on the environmental impact assessment of oil on the marine waters (Khalaf *et al*., 2006) and not on the geographic extent of oil.

The availability of the high-spatial-resolution ASTER images at the date of August 10th 2006, made it possible to obtain a post-conflict assessment. This study aimed to characterize the Jiyeh oil spill/ or any floating material on sea surface that resulted from the conflict. It utilized remote sensing applications, which are able to produce a comprehensive view of sea surface. Nevertheless, the abrupt enlargement in the area of the existed plume southern of the Jiyeh station, which opposes to the influence of dominant sea currents, made it a questionable issue. This, in turn, suggests another release of unidentified materials 25 days after the bombing of the station.

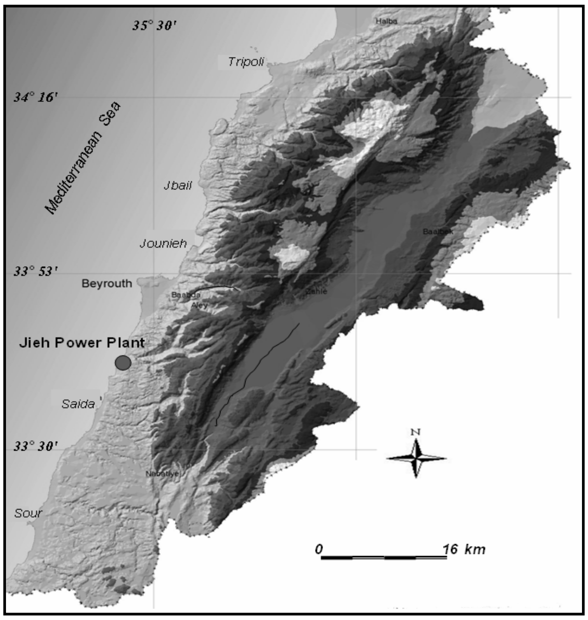

Figure 1. Location map of Jiyeh power station.

MATERIALS AND METHODS

Recently, the application of remote sensing has been utilized in several disciplines to study Earth's surface, with particular emphasis to monitor natural disastrous events and those caused by human (Fingas, 1990; Lu, 2003). This is typically applied to oil spills control, including large area surveillance, site specific monitoring and tactical assistance in emergencies. It is also able to provide essential information to enhance strategic and decision-making, decreasing response costs by facilitating rapid oil recovery and ultimately minimizing impacts (Mullin, 2006).

The detection and monitoring of oil spills would be perfect if all the processed satellite images are characterised by high special and spectral resolution, and have short retrieval time (time needed to acquire an image to the same place). ASTER images, which were selected to be used in the present study, have these specifications. Analysis and processing of the satellite images is obtained using the Environment for Visualization Images (ENVI) software, V 4.3.

In addition to ASTER images, MODIS and RADARSAT-1 images were utilized for comparative analysis. The selection of these images was dependant on their availability on the suitable time for obtaining a sequential order to monitor the oil plume behaviour.

ASTER images

ASTER (Advanced Space-borne Thermal Emission and Reflection Radiometer) covers a wide spectral region from visible to thermal infrared with 14 spectral bands, and high spatial, spectral and radiometric resolution. It has 15 m spatial resolution (bands 1-3); six SWIR bands with 30 m spatial resolution (bands 4-9) and five TIR bands with 90 m spatial resolution (bands 10-14).

ASTER has a swath width (dimensions of each image scene) of a 60 km x 60 km. Therefore, in order to cover the whole Lebanese coast, four image scenes are acquired in August 10th 2006. While ASTER images of previous years) were used for comparison purposes. The selected ASTER images were ordered based on images availability and purpose of study. Table 1 shows the retrieved data, which are listed within the *Aster L1A Reconstructed Unprocessed Instrument Data V003.*

TABLE 1

Retrieved ASTER Data for Lebanon Obtained from EOSDG of NASA

Date	Data Granule ID (Local Granule)
10/8/2006	AST_L1A#00308102006082728_08132006081412.hdf
	AST_L1A#00308102006082737_08132006081420.hdf
	AST_L1A#00308102006082746_08132006081429.hdf
	AST_L1A#00308102006082754_08132006081438.hdf

Images analysis

All four ASTER images were merged together by applying a *Mosaicking* procedure in order to attain a full and comprehensive view of the study area. The major digital procedures applied for these images were the band combination as a first step. In this regard, and for a better feature discrimination of oily water into the sea, the order of bands were as follows:

- VNIR (15m, 3 bands): bands order as 3-2-1
- SWIR (30m, 6 bands): bands order as 7-9-5, 5-7-6 and 8-4-7
- TIR (90m, 5 bands): bands order as 14-12-14

The analysis followed several steps to attain the most discriminated features on the images. Normally, band combination is primarily applied and thus accompanied with consequential digital applications such as: enhancement, interactive stretching, density slice colouring and contouring.

RESULTS AND DISCUSSION

Several image types were utilized to detect and monitor the existed oil spill. Hence, it produced different preliminary studies describing oil spread. These images are, in addition to ASTER, MODIS-Terra, RADARSAT-1 (SAR) and Landsat 7 ETM+. Nevertheless, particular concern was given to ASTER images. Thus, a huge plume was viewed from these images (Figure 3), and more certainly the date of August 10^{th} 2006. Unfortunately, acquired ASTER images between the date when Jiyeh station was bombed and August 10^{th} (~25 days) were cloudy and difficult to analyze.

Dimensional aspects of the plume

The existing plume, as detected in the ASTER image of August 10^{th} 2006, formed a leave-like shape (Figure 2). The acute dark colour of the material constituting the oil plume showed that this plume emerged from the southern coast and expands northward to the Chekka region. Measuring the plum shows that it has a vast areal coverage of ~ 3087 km^2, with an average width of about 21 km and an estimated length of about 147 km.

No accurate estimates for the depth of the floating materials could be obtained from satellite images. Even though RADARSAT-1 has the capability for water penetration, but does not exceed 30 cm. Besides, the relative thickness was assessed depending merely on the visible colour of floating materials on sea surface (CNRS, 2006). In other words, the obtained assessment of densities was dependant on colour density, which ranges from blank (very dense) to pale blue (very low density), in which the later represents the clear sea water (Figure 2).

Hydrologic patterns of the plume

The spread materials into the sea showed different hydrologic patterns that resulted from many physical factors such as, sea currents, terrestrial water outlets and wind.

1. Sea currents: This is the most influencing factor that governs the spread dynamic of any material on sea surface and, thus, it forms different patterns according to the power, velocity and direction of these currents (Maged & Ibrahim, 1999).

The majority of sea currents in the area is northward and slightly N-NE (Kabbara *et al.*, 2001). Hence, if the Jiyeh station is the source of any released material (*e.g.* fuel-oil); this material would have moved from the station northward. Also, in this case the density of the released materials would have decreased as the material moves away from the source.

This is the case in Jiyeh station where the density of the plume was at the maximum in the south and appeared as sheen (less than 0.001mm, according to Mullin (2006)) in the north. In addition, the width of the plume was reduced in the north and almost disappeared beside Chekka area. However, dense belts are also observed among the thinner sheens like those belts along Batroun-Chekka (Figure 2).

Moreover, local currents were marked on the analyzed ASTER images. These encompass relatively small-scale area and often with cyclonic patterns. A good example of that is well illustrated in the vicinity of Jouneih (Figure 2).

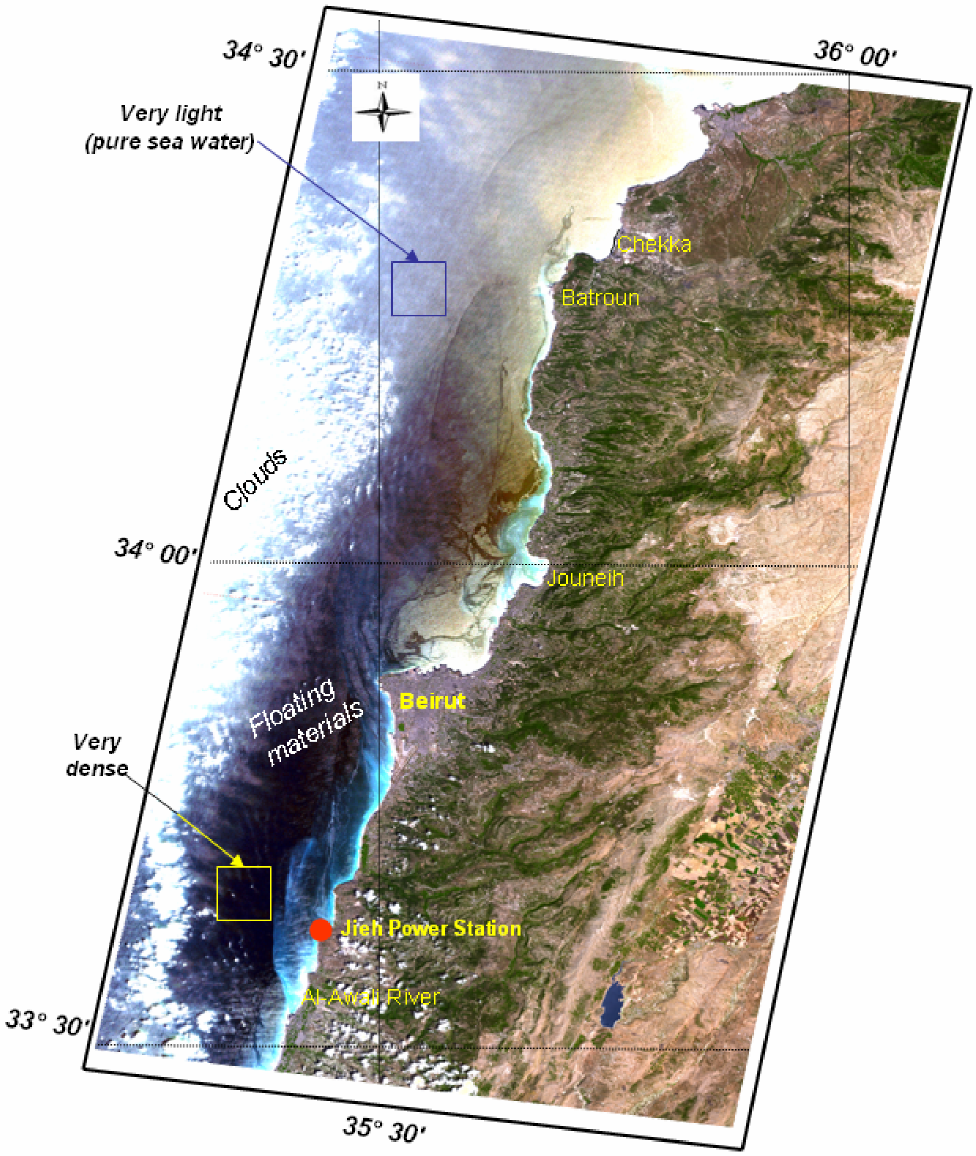

Figure 2. The huge plume of supposedly oil along the Lebanese coast as detected from ASTER image (10th August 2006).

2. Terrestrial water: Is an additional major factor that controlling the floating material on sea surface. It works mainly to push this material (liquid or solid) away from the coastline, notably where river courses outlet their waters. The outlets from rivers and streams create elongated break patterns and reduce the density of seawater (Patin, 2006). A clear example can be shown right next to the outlet of Al-Awali River in the south, where a plume of approximately 12 km exists (Figure 2).

3. Wind effect: This has less influence on floating materials on sea surface and often exists on a temporary basis, since wind has rapid dynamic changes.

Analysis of source materials

Based on the concept that sea currents in the area are northward (Kabbara *et al.*, 2001), the flow of any material must start from Jiyeh station, as a source point, and spread towards north. Nevertheless, this is not the case when looking at the processed ASTER images (Figure 3). In view of this, it is assumed that a suspicious release of unidentified materials (presumably Oil), other than those from Jiyeh station, has taken place several days after the Jiyeh tanks were bombed. In order to confirm this assumption, Table 2 summaries the principal physical elements diagnosing the existence of these materials south to Jiyeh station.

The existence of other materials was evidenced from the available satellite images of different types. Figure 5 shows three different image types with a sequential time order. They show the consequence of the spread oil (or other materials) on the sea surface.

It is obvious from the MODIS image that the oil spill in 23^{rd} of July (10 days after the event) took a crescent shape that flamed in the NNE direction. The size of the spill is reduced in August 3^{rd}, 20 days from the event, as observed in the RADARSA-1 image (Figure 4). In the RADARSAt-1 image the Jiyeh station appear to be the major source (start-point) of the spread oil and remained oil was restricted to the coast.

TABLE 2

Physical Elements Used to Diagnose the Existence of Unidentified Materials on Sea Surface of Lebanon

Major element	Normal condition	Actual condition*
Oil density at source	Dense and viscous oil must found close to the Jiyeh station	Materials close to Jiyeh station are characterized by low density (Figure 3)
Dynamics of sea currents	All materials at Jiyeh station must flow northward	There are spread materials to the south of the station (Figure 3)
Fuel-oil homogeneity	Fuel-oil must appear on sea surface with a homogeneous distribution	There is no obvious homogeneity in the spread materials, and sharp contacts often exist
Time factor	After 25 days from the initial bombing of Jiyeh tanks, oil must disappear and limited to closed patches	After 25 days from the initial bombing of Jiyeh tanks, the spread materials own a large areal extent (> 3000 km^2)

* As observed from ASTER images

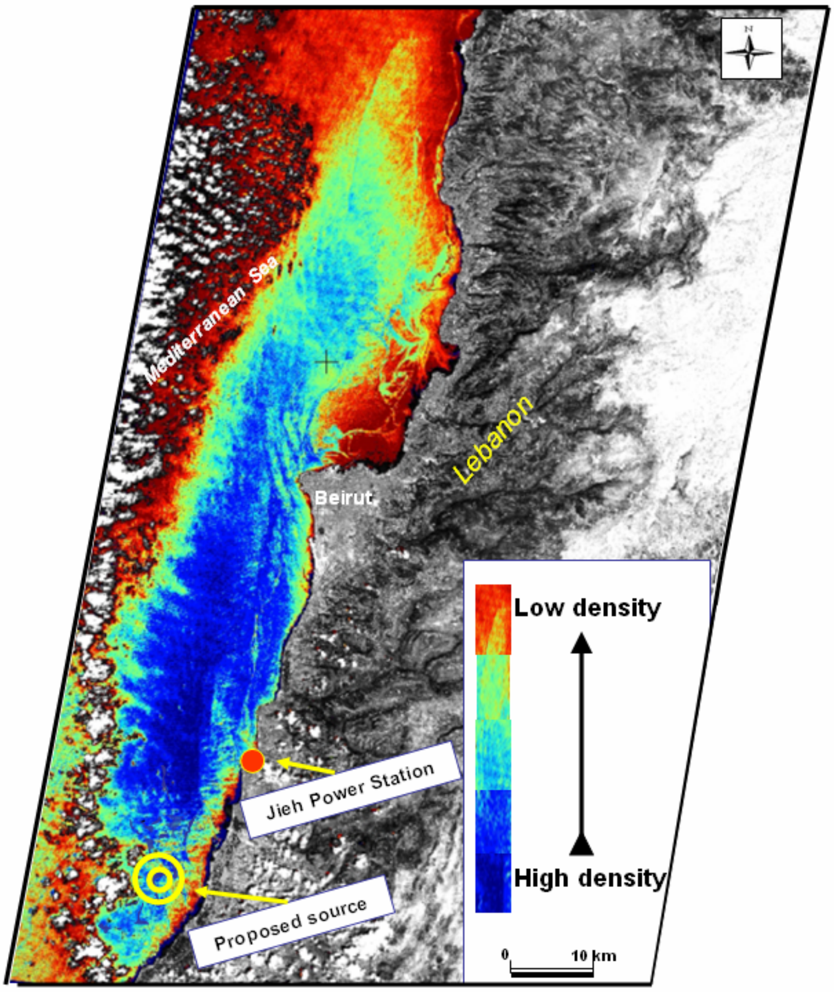

Figure 3. Classified ASTER image showing different densities of the spread materials, as well as proposing another source of release south to Jiyeh station.

After seven days from the last observation (in August 10th), a large volume of released materials was reappeared into the sea next to the Lebanese coast where it formed a plume shape, as exposed in the ASTER images (Figure 4). This might suggest that the release of unidentified materials have occurred between these two dates (3rd and 10th August 2006). As obvious from the images, the area located south to Ez-Zahrani River outlet (~16 km south to Jiyeh station), is most likely the main source of the unidentified material.

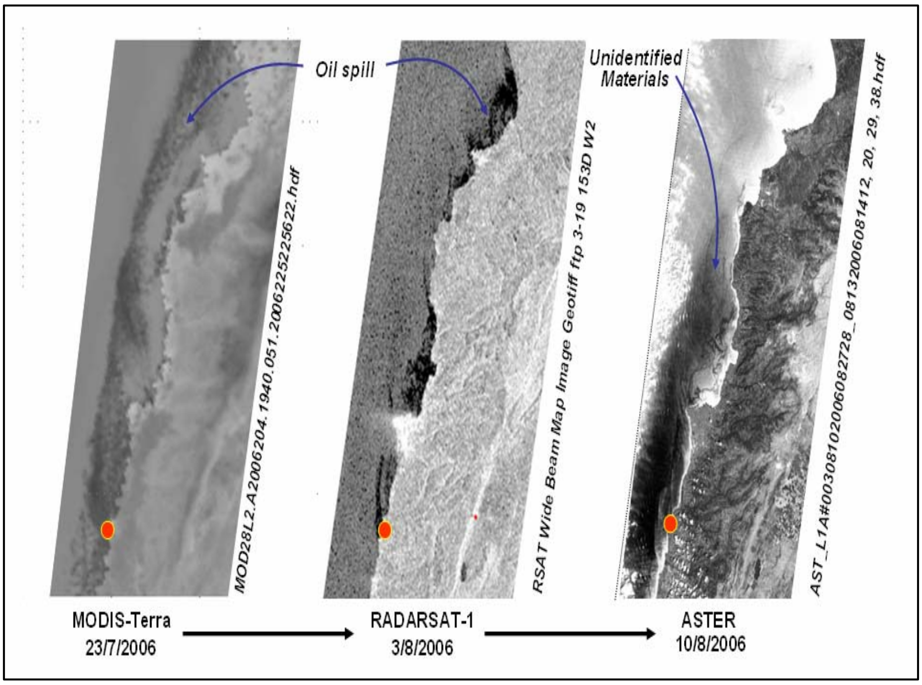

Figure 4. Three types of satellite images showing the change in the floating materials (including fuel-oil) along the Lebanese coast.

CONCLUSION

In remote sensing studies, usually field verification is applied to confirm the detected observations on the processed satellite images. In this view, rarely these studies obtained without field survey. However this was not the case in the present. Whilst it was impossible to apply it on the real-time due to the continuity of the conflict. Therefore, it depended mainly on the observations from the analyzed images and consequently the dimensions and behavior of the oil spill (or any floating materials) were assessed.

Two major gaps are considered in this research. First, is the assurance of different oil densities distributed on several places in the sea. Second, is the verification of the suspicious source materials that existed south to Jiyeh station, as seen on the ASTER image of August 10th 2006. For the latter, which is the main scope of this study, all indications proved the existence of materials other than the released fuel-oil from Jiyeh tanks. The anticipated time of release of these materials is between August 3rd and August 10th.

In order to confirm the anomalous existence of floating materials (oil or any other material type) into the sea, a comparative analysis was applied to ASTER and MODIS images as shown in Figures 5 and 6. Whilst the for RADARSAT-1 images, the dark tone into sea water is well proved by many authors (Mikala, 1995; Gade & Uferman, 1998; Mansor *et al.*, 2002).

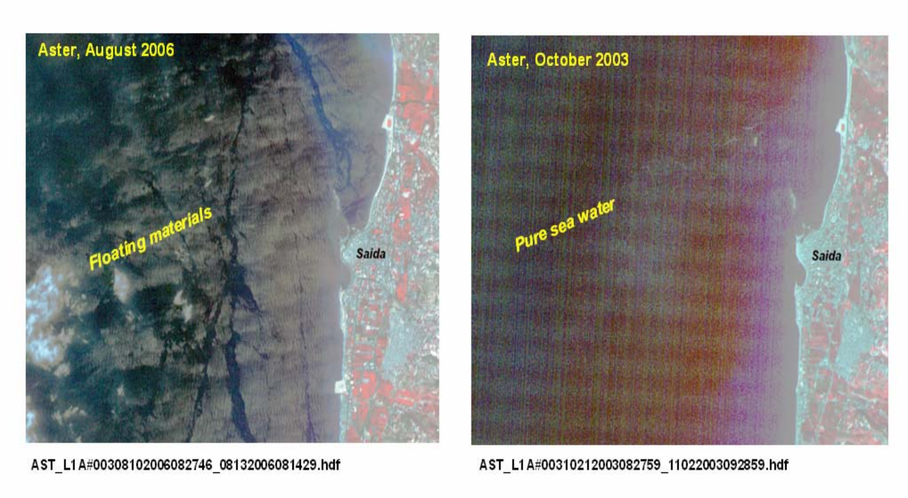

Figure 5. Comparative analysis of two ASTER images of the same place (Saida coast, South Lebanon) at different dates before and after the bombing of Jiyeh station.

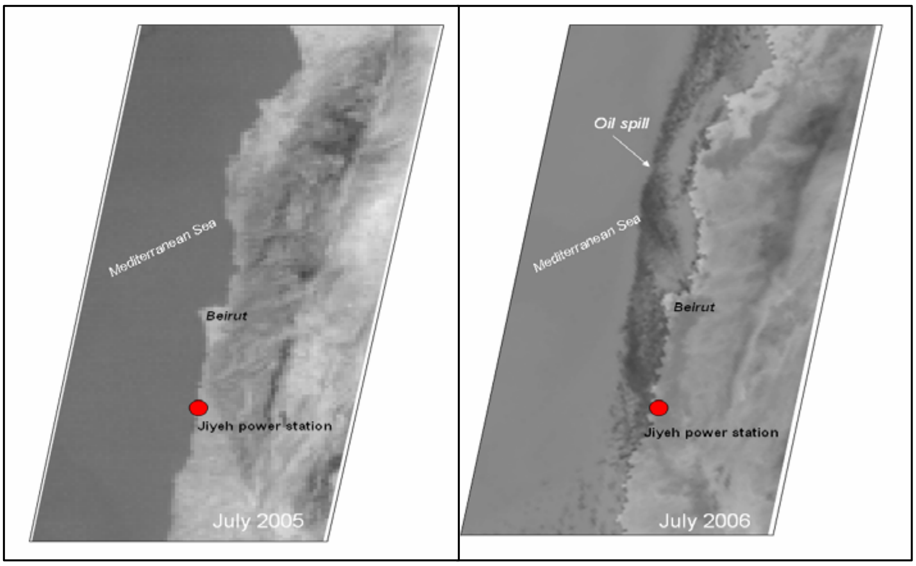

Figure 6. MODIS images before (July 2005) and after (July 2006) the bombing of Jiyeh station.

Two approaches are proposed for further confirmation to the probable released materials south to Jiyeh station. These are:

1. Obtaining a deep sampling in the sites were these materials exposed. Thus followed by laboratory analysis of the collected water and sediments samples.
2. Applying an isotopic analysis in different spots in the marine of Lebanon, notably in the southern coast, depending on a comparative analysis between the radioactivity before and after the conflict.

The present study proved that remote sensing technology is a valuable tool to detect and monitor the offshore oil spill along the Lebanese coast.

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