THE USE OF SATELLITE IMAGERY TO MONITOR OIL POLLUTION IN LEBANON

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ABSTRACT

The support activities within the European Commission (EC) DG Joint Research Centre (JRC) following the oil pollution along the Lebanese coast are described. The activities primarily focused on the use of satellite imagery to provide information on the extent and possible direction of movement of the slick. The employed data were mainly Synthetic Aperture Radar (SAR) images. The possible use of low resolution optical data was also considered. After briefly describing the methodology we present the main results, in terms of most significant information extracted from the imagery. Preliminary results on the use of optical imagery are also presented. All the obtained results are discussed and validated with respect to the results from visual inspections on scene. Particular attention is finally given to the assessment of the methodology with respect to the specific operational needs of this kind of emergency.

1. INTRODUCTION

On the 13\textsuperscript{th} and 15\textsuperscript{th} July 2006 the Jieh power utility located on the Lebanese coastline was hit by Israeli bombs. The Jieh thermal power plant is located 30 km South of Beirut and 9 km North of Saida (Sidon). Part of the storage tanks caught fire and were burning for several days. The fuel that did not catch on fire was spilled into the Mediterranean Sea as a result of the blast. The Lebanese ministry of environment estimated that approximately 30,000 tons of heavy fuel oil was emitted into the sea.

A Request of assistance was made to the Monitoring and Information Centre of the European Commission (EC-MIC) on the 27\textsuperscript{th} of July by Lebanese Authority. EC-MIC activated the Charter for the emergency on the 29\textsuperscript{th} August. Concurrently also the JRC was requested by EC-MIC to provide support to the interpretation of radar satellite images over the areas affected. During the crisis, MODIS (Moderate Resolution Imaging Spectroradiometer) images have also been used to monitor the extent of the spill oil.

This paper reports on the satellite image interpretation support activity within the JRC during the Lebanon emergency phase referring to the use of SAR and MODIS images.

2. IDENTIFICATION OF OIL SPILLS IN SAR IMAGES

SAR systems detect spills on the sea surface indirectly, because of the effect on the wind generated short gravity – capillary waves [1]. The oil film damps these waves which are the primary backscatter agents of the radar signals. Consequently, provided that a moderate wind field is present, an oil spill appears dark on SAR imagery in contrast to the surrounding clean sea.

However, dark areas may be also caused by other phenomena, like algae blooms, river run-off and meteorological effects called “look-alikes” [2].

On the basis of the two above mentioned basic facts, the traditional approach to the analysis of a SAR scene to detect oil spill signature may be broadly divided in two steps:

1. Detection of dark areas in the image. Such areas are candidate features to be an oil slick;
2. Analysis of each candidate feature to discriminate between probable oil slicks and look-alikes.

The discrimination process excludes ‘easy’ look-alikes on the basis of the shapes and configurations, such as the dark patches caused by internal wave areas and rain cells. More detailed analysis is performed for the ‘difficult’ cases, taking into account the period of the year (for example it is improbable to find natural slicks in winter), the local wind conditions, a detailed analysis of the shape (borders, tails, size), as well as the analysis of the geographical location. Local wind conditions, when known, are an important element for the final decision.

The analysis can be performed in a fully automatic way, using a dedicated software package. To this aim the whole processing chain is structured in four basic functions as follows:

1. Isolation and contouring of all dark signatures, through appropriate threshold and segmentation processing of the image.
2. Extraction of key parameters for each candidate signature, which usually are related to its shape, internal structure and radar backscattering contrast.
3. Test of the extracted parameters against predefined values, which characterize man-made oil spills, usually determined through phenomenological considerations and statistical assessments.
4. Computation of probabilities for each candidate signature.

However, for the time being, a semi-automatic approach is the most commonly used. In this case some of the
above mentioned functions, usually the first two, are based on specific software algorithms while the remaining ones as well as the final decision about each candidate feature is left to an experienced operator. As previously mentioned the analysis of the shape of the feature of interest is probably the most important parameter to identify oil spill. In the case of man-made oil spill, namely intentional oily release from moving vessels, the initial conditions are quite well known and simulations may be produced assuming realistic values for the most relevant parameters concerning oil type and characteristic as well as realistic scenarios for the ‘forcing elements’ such as wind field and currents. Results of the modelling, even though qualitative, greatly help in understanding the possible shape evolution, thus improving the discrimination process.

It should be pointed out that in case of different initial conditions, such as the release from a static source or from a ground based source, most of the knowledge and experience accumulated for the case of a release from a moving source does not apply. It is also important to recall as the volume and particularly the thickness of the oil layer cannot be estimated using radar images. SAR sensors are in general very sensitive to the presence of an oil film and also an extremely thin layer may result in a positive detection. It appears also quite difficult to identify a lower limit for the film thickness since it may depend on many other parameters, such oil type and oil physical-chemical characteristics.

All the SAR images analysed during the emergency were acquired by the sensors on board of the European Space Agency (ESA) satellites ERS2 and ENVISAT. Data were available in different formats as summarised in Tab. 1.

Table 1. Main characteristics of SAR sensors on-board of ESA’s satellites

<table>
<thead>
<tr>
<th>Platform</th>
<th>Mode</th>
<th>Resolution</th>
<th>Coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>ERS2</td>
<td>PRI</td>
<td>20 x 20 m</td>
<td>100 x 100 km</td>
</tr>
<tr>
<td>ENVISAT</td>
<td>ASAR Imaging mode</td>
<td>30 x 30 m</td>
<td>100 x 100 km</td>
</tr>
<tr>
<td>ENVISAT</td>
<td>ASAR Wide Swath mode</td>
<td>75 x 75 m</td>
<td>400 x 400 km</td>
</tr>
</tbody>
</table>

All the data were provided to the JRC directly by ESA. In case of sensors on board of ENVISAT it was possible to download directly the data from the ESA’s Rolling Archive thus minimising the time delay between the data acquisition and the availability for the interpretation. For the sensor on board of ERS2 the data were available with a delay of 2-3 days. Such a parameter has been taken into account in the selection of suitable frames along with the location and possible conflicts with other sensors and/or acquisition modes.

ASAR Wide Swath images were the preferred format, while ASAR imaging mode and ERS2 PRI were used, when available, for a close-in view on areas of particular interest. In total, in the period from 1st August – 28th August about 40 frames in one of the format of Tab. 1 were received and fully analysed.

3. EXAMPLES OF IMAGE INTERPRETATION

The ASAR WS image in Fig. 1 was acquired at 9:42 on 22nd of August. We note that in addition to clear indications of oil on the sea surface, other dark features, likely due to natural phenomena are present. This may reduce the reliability of the oil spills detection. Detailed analysis has been performed for the four areas of interest indicated by the boxes (Fig. 1).

AOI-1 – Lebanese coast from Jieh up to Batroun (approx.).

The detailed analysis, see Fig. 2, shows some dark features, contoured in red, that have been identified as oil slicks with a high confidence level. The spilled area extends from Jieh up to Beirut and further north going up to Batroun. In comparison to the previous observation of 19th of August we note the presence of oil along the coast of Beirut, which appeared clean in the previous observations. However, the overall extent of the spilled areas does not differ very much with respect to the previous observations.

AOI-2 – Lebanese and Syrian coast from Tripoli up to Tartus (approx.).

The detailed analysis, see Fig. 3, shows many dark features. Some of them (on the left side of the image) are likely to be due to natural phenomena. The features closer to the coast, contoured in red, could be oil but the confidence level of this observation is low. The dark features further north of this area are likely to be due to natural phenomena.

AOI-3 – Syrian coast from Tartus up to Al Lathqiyah (approx.).

The detailed analysis, see Fig. 4, shows many dark features. Some of them are likely to be due to natural phenomena. The features in the upper part and closer to the coast, indicated by the arrows, could be oil but the confidence level of this observation is low. The dark features further south of this area are likely to be due to natural phenomena.

AOI-4 – East of Cyprus

The detailed analysis, see Fig. 5, shows many dark features. Some of them, in particular the elongated one along the south-east coast of Cyprus, have been identified as oil slicks with high confidence level. However they are not connected to the oil leakage at Jieh, and are most likely due to oil discharges from passing vessels.

This image is a good illustration of the capability of space-borne imagery to provide an overall assessment of the situation also in areas close to the affected one and at potential risk depending on the evolution of met-
ocean conditions. Particularly, the analysis of the image allowed to conclude that the likely presence of oil in the vicinity of the coast of Cyprus was definitely not connected to the discharge from the Jieh Power Plant (Fig. 5). Other similar cases, always likely related to oil discharges from vessels, have been identified.

4. PRELIMINARY RESULTS ON THE USE OF MODIS DATA

Until now satellite optical sensors have not been of much use for oil spill detection. High resolution optical sensors (e.g., SPOT, IKONOS) do not provide daily observations, and data with limited spatial coverage are expensive. Traditional sensors (e.g., SeaWiFS, AVHRR) have coarse spatial resolution (~1 km per pixel), lack of coverage, and lack of algorithms for data processing and interpretation [3]. The new optical sensor technologies provide potentiality for oil spill monitoring in marine environment. From one side, derived products from optical sensors (like pigmentation concentration and sea surface temperature maps) can contribute to the largest challenge in oil spills detection with SAR images: the accurate discrimination between oil spills and look-alike [4]. On the other side, the new medium-resolution optical sensors (e.g., NASA-MODIS and ESA-MERIS) show potential direct capability for oil spill monitoring in the marine environment [5].

Optical sensor can detect oil in the marine environment because in comparison with seawater, oil is characterized by higher refractive index and absorption [6]. Hence, when oil is floating on the sea surface, the reflected signal will increase and the signal leaving the water body (the so called water leaving radiance) will decrease. As a net effect, an optical contrast between the oil slick and the surrounding seawater will appear. The impact of the oil film on the resulting optical contrast is in general a rather complex multivariable problem but with great potential on operational applications. Radiative transfer simulations [7] show that the optical contrast can range from positive to negative, depending on several different parameters: oil type, oil thickness, illumination and observation geometry, optical properties of the water body, sea surface state (wind, sea surface roughness). According to simulations, even very thin oil film can change the optical signal leaving the water surface, hence creating a detectable optical contrast. In principle there is a potential to retrieve oil thickness indications from the optical contrast, once all other relevant parameters are known. Actually, features observed in the MODIS images could also correspond to oil sheens.

Since the optical signal can penetrate through the sea surface inside the water body, even submerged oil slicks can create an optical contrast, as well as oil droplets dispersed in the sea (emulsions). In the latter case, radiative transfer simulations showed always a positive contrast [8].

Last but not least, the MODIS optical sensor acquires the signal at different wavelengths, so that information on the target spectral signature can be retrieved. This could help to discriminate between oil features and look-alikes: for example phytoplankton blooms could be ruled out if no positive contrast occurs at 555- and 645-nm.

MODIS is a key instrument aboard the Terra (EOS AM) and Aqua (EOS PM) satellites. Terra’s orbit around the Earth is timed so that it passes from north to south across the equator in the morning, while Aqua passes south to north over the equator in the afternoon. Terra MODIS and Aqua MODIS are viewing the entire Earth’s surface every 1 to 2 days, acquiring data in 36 spectral bands, or groups of wavelengths. These data are meant to improve the understanding of global dynamics and processes occurring on the land, in the oceans, and in the lower atmosphere.

To inquire the reliability of these data, match-ups between MODIS and correspondent ENVISAT ASAR data have been performed and analysed. During the Lebanon crisis two full resolution MODIS images per day have been downloaded as soon as they were made available by the MODIS team. Generally this was within few days after their acquisition. In order to analyse MODIS capability in detecting oil features, match-ups between MODIS L1B and correspondent SAR data have been made. MODIS 250-m resolution data have been selected at L1B processing stage and not atmospherically corrected, since at that time no reliable and validated operational atmospheric correction code was available for our purpose. Different results have been obtained. In some cases the match-up between the two sets of data was very good. Fig. 6 to Fig. 9 show the results obtained for the 6th and the 22nd of August. The data have been stretched to enhance the contrast. The arrows indicate possible oil features.

In both cases the same features observed in the SAR images are detectable in the MODIS images. The match-up is generally better for Terra MODIS data, which are acquired within a shorter time delay. Clearly no data from the sea are available in case of cloud cover: this explains for example why no feature around Tartus is detected in the MODIS images of Fig. 6b. In other cases, while SAR was able to detect possible oil spills, no feature was visible on the correspondent MODIS images.

Fig. 10 to Fig. 12 show the example of the 5th of August, image acquired the day before that of Fig. 6. It is interesting to notice that, for both Terra and Aqua satellites, the area of interest was at the scan edge of the image, and hence it was observed in off-nadir view. Generally whenever an off-nadir view of the area occurred, no dark feature was detected by MODIS.
5. DISCUSSION

The results of work done and primarily of the radar images interpretation were delivered to EC-MIC through dedicated reports. Ten reports have been issued in the period from 1st Aug – 28th Aug. The information in the reports was mainly concerning 8 radar images as summarized in Tab. 2. The table also contains the information concerning the time elapsed from the acquisition of each image and the time of issuing of the corresponding reports, hereinafter referred to as Delta Time. Such a parameter is the most important to assess on the operational performances of the work done. It is important to note that such a time includes:

- The time for downloading the raw data to the receiving station and for the SAR processing;
- The time for downloading the processed data to our premises;
- The time for data post-processing and interpretation.

Concerning the first aspect precise information is missing but we presume that the standard procedure for data processing implemented at the Italian Processing and Archiving Facility (I-PAF) in Matera was applied. This means that in most cases the processed data of interest were available for downloading within 2 – 3 hours from the acquisition. The transfer of data was performed through the usual internet connection thus without employing a special link. The transfer rate was varying but we never experienced a speed higher than 150 Kb/sec.

The final step was the only one under our full control and usually requires not more than 15 minutes including the report preparation. The availability of the processed image on the server was checked manually by the operator and in some cases this has introduced a further delay. Finally we have to stress that the work was done according to a procedure defined ‘on the way’ since no predefined standard procedure was on place.

Nevertheless we note that in many cases the performances are fully acceptable in operational terms. In five cases out of 8 the results were delivered within 8 hours from the acquisitions. Concerning the remaining 3 cases the first has a huge delay but due to the fact that the image was acquired much before the start of the activities while the second, with a much smaller delta time but still unacceptable in operational terms, is also in the initial phase of the activities. The last case has also a quite big delta time and this is mainly due to the late acquisition time.

In particular, we notice a big improvement in the performances with respect to the previous case of the Prestige Tanker accident [9]. The main reason for this is the much better performances of the procedure implemented at ESA PAF to process and deliver SAR data.

The results have shown the capability of MODIS to detect oil features. Nevertheless it must be still investigated why in some cases MODIS fails; this will help establishing under which conditions MODIS can produce reliable indications of oil spill occurrence.

It is important to underline that in all the above cases it is essential and unavoidable a correct and accurate removal of the atmospheric contribution. The L1B data shown in the previous figures are top-of-atmosphere (TOA) data. This means that they include the entire signal coming from the atmosphere, which can be more than 90% of the overall signal and that, for our purposes, represents just noise.

![Table 2. Delivery time versus acquisition time for the most interesting images over the area.](image)

<table>
<thead>
<tr>
<th>ACQUISITION Time</th>
<th>DELIVERING Time</th>
<th>DELTA Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>21st July</td>
<td>2nd August 18:12</td>
<td>11dd 8hh 37mm</td>
</tr>
<tr>
<td>3rd August 9:40</td>
<td>4th August 18:28</td>
<td>1dd 8hh 48mm</td>
</tr>
<tr>
<td>6th August 9:45</td>
<td>6th August 13:05</td>
<td>3hh 20mm</td>
</tr>
<tr>
<td>9th August 9:54</td>
<td>9th August 18:00</td>
<td>8hh 6mm</td>
</tr>
<tr>
<td>19th August 9:37</td>
<td>19th August 15:55</td>
<td>6hh 18mm</td>
</tr>
<tr>
<td>22nd August 9:42</td>
<td>22nd August 15:41</td>
<td>6hh</td>
</tr>
<tr>
<td>25th August 9:48</td>
<td>25th August 13:08</td>
<td>3hh 20mm</td>
</tr>
<tr>
<td>27th August 21:39</td>
<td>28th August 14:45</td>
<td>17hh 6mm</td>
</tr>
</tbody>
</table>

Not corrected TOA data have no geophysical meaning: these data can just allow detecting the location of the possible oil features, but no further information can be drawn, since the contrast and the spectral signal at TOA are not those at sea level.

Further scientific work must be carried on to establish and validate an atmospheric correction procedure tailored for the retrieval of the optical contrast and the spectral information in presence of oil features.

6. CONCLUSIONS

During the Lebanon crisis monitoring activities at sea either by naval means or aerial surveillance were not possible and space imagery turned out to be a unique source of information for the assessment of the situation. The complex context caused by the war has to be taken into account when drawing the conclusions on the use of satellite SAR images in support to the emergency phase. In addition, it is important to distinguish the technical/scientific aspect from the operational one.

Concerning the first aspect the following general comments can be made:

- Satellite observations provided useful information due to their capability to cover large and remote areas; particularly, useful information can be provided on the overall situation helping to identify pollution cases not related to the one of interest.
- No information on the oil slick thickness can be provided. Such a limitation has a potentially high
impact on the operational value of the observation
since it does not help in managing and optimising
the resources to respond to the emergency.
• Some of the detections still suffer for a low
reliability.

The limitations on the use of space imagery do not
specifically concern the oil pollution identification in
case of accidental spilling but are a part of the general
problem of detecting and identifying marine oil
pollution. The additional problem in case of an accident
is lack of knowledge of the characteristics and of the
behaviour of the discharged oil after a long time at sea.
In summary we recognized a clear need for additional
research effort on the following aspects:
• Refinement of sensors and methodologies to
improve the reliability of the identification of oil
slicks (reduction of the false positives and false
negatives rate). Possible research directions include
the refinement of tools for the analysis of images
acquired by a number of different sensors, such as
RADAR, IR, UV, Passive Microwave, etc., the
fusion of information from different sensors as well
as the integration of auxiliary data (meteo and
oceanic data).
• Refinement of sensors and methodologies to
improve the retrieval of oil slick thickness and the
detection of submersed oil. Physical-chemical
characteristics of the oil are strongly modified after
a long time at sea. This process may lead to the
creation of dense oil patches (i.e. tar balls) which are
very difficult to be detected, in particular by
remote sensing tools. In addition the determination
of the oil slick thickness becomes important to
estimate the volume of the discharged oil. This is
essential to estimate the overall impact on the
environment and help the response operations.
• In the actual case models and simulations for the
prediction of oil slicks movement have been timely
applied with very positive results. A better
integration between simulations and observational
data is anyway possible and advisable in order to
further improve the results.

Concerning the operational aspect we stress again the
clear improvement with respect to the previous case
(Prestige Tanker accident). Anyway there is still a big
margin for improvement. The goal of providing relevant
information from the space imagery within 1 hour from
the satellite pass is totally feasible. The central element
for this is the implementation of a dedicated service able
to minimise the time for raw data processing and the
time for data transfer to the technical body in charge of
the image interpretation.

Match-ups between the NASA MODIS optical sensor
and the ENVISAT SAR showed that MODIS is able to
detect oil features.
With its higher resolution bands, its two daily
acquisitions, and the possibility to obtain near real-time
data free of charge, MODIS shows great potential in the
operative use for oil spill monitoring in the marine
environment. Nevertheless the conditions under which
MODIS is able to detect oil features with high reliability
(e.g., wind speed, illumination and observation
geometry, atmospheric optical thickness ...) are still to
be defined.

MODIS shows additional potential to retrieve oil
thickness indications and spectral information of the
observed target, which could help in the discrimination
process. In both cases an accurate removal of the
atmospheric contribution is crucial and unavoidable,
since not corrected data have no geophysical meaning.
A highly accurate, validated and operational
atmospheric correction procedure for the retrieval of oil
spill information must be established.

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8. FIGURES

Figure 1. The ASAR WS image acquired on the 22nd of August at 9:42. Four areas of interest (AOI) were identified.

Figure 2. AOI-1 of Fig. 1. Lebanese coast from Jieh up to Batroun (approx.)

Figure 3. AOI-2 of Fig. 1. Lebanese and Syrian coast from Tripoli up to Tartus (approx.)

Figure 4. AOI-3 of Fig. 1. Syrian coast from Tartus up to Al Lathqiyah (approx.)
Figure 5. AOI-4 of Fig. 1. East of Cyprus

Figure 6. ENVISAT ASAR image acquired on the 6th of August 2006 at 7:45 UTC

Figure 7. NASA MODIS Aqua L1B data for Band1 (645-nm, 250-m resolution) acquired on the 6th of August 2006 at 10:25 UTC

Figure 8. ENVISAT ASAR image acquired on the 22nd of August 2006 at 7:36 UTC
Figure 9. NASA MODIS Terra L1B data for Band1 (645-nm, 250-m resolution) acquired on the 22<sup>nd</sup> of August 2006 at 08:50 UTC

Figure 10. ENVISAT ASAR image acquired on the 5<sup>th</sup> of August 2006 at 19:30 UTC

Figure 11. NASA MODIS Terra L1B data for Band1 (645-nm, 250-m resolution) acquired on the 5<sup>th</sup> of August at 08:05 UTC

Figure 12. NASA MODIS Aqua L1B data for Band1 (645-nm, 250-m resolution) acquired on the 5<sup>th</sup> of August at 11:20 UTC