A GENERALISED ALGORITHM FOR OIL SPILL DETECTION ON ERS AND ENVISAT SAR IMAGES

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ABSTRACT

Different approaches have been proposed for detecting and classifying oil spills on SAR data. Several of these are based on training datasets which are used to characterize this phenomenon statistically. In case of images employed for the analysis having different pixel spacing or radiometric resolution to those used in the training set, a new classification template is required. A completely new training dataset and an algorithm optimisation are also needed. In the present paper we present an oil spill detection system which was originally developed for ERS. This has been generalised and put to use for processing ENVISAT data also. Performance of the classification process has been tested using a set of confirmed slicks, which were present on both ERS and ENVISAT images simultaneously. The results are here presented and discussed.

1. INTRODUCTION

In the last few decades, the effects of oil slicks on water surface have been studied from a theoretical and an experimental point of view. The fact that the presence of oil on the water surface changes the wind stress on the sea surface and reduces wave amplitude is a well-known observation.

Mathematical analysis of damping effect [1] [2] [3] is supported by experimental evidence, which has been carried out in tanks and at several oceanic sites [4] [5] [6] [7]. The ratios between the spectra measured in pure water and in water covered by film have a maximum in the 3-10 Hz region [8] [9]. An analysis of SAR data provides an effective way to investigate the effects on sea surface. For incidence angles higher than 20°, the Normalized Radar Cross Section (NRCS) is proportional to the spectral energy density of the sea waves having wavelength λ, according to the Bragg resonance condition (Eq. 1):

\[ \Lambda = \frac{\lambda}{2\sin(\theta)} \]

where \( \lambda \) is the radar wavelength and \( \theta \) the incidence angle of the radar beam. The microwaves which are usually employed by radar systems are Bragg resonant with short gravity sea waves. For low incidence angles the backscatter is mainly caused by specular reflection [10].

Several experimental campaigns have been carried out in different locations using airborne and spaceborne SAR systems characterised by different frequencies and different polarisations [9] [11] [12] [13] [14]. A comparison between measurements obtained with an interferential probe and the data deduced from remote sensing systems are in agreement [14] demonstrating the ability of SAR to detect oil spills.

The availability of a huge amount of SAR images acquired by both the European ERS satellite and the Canadian Radarsat has boosted the development of several oil spill detection services in different countries. Two approaches have essentially been explored. One is based on an interpretation of the image performed by experts [15]. The second is based on automatic or semi-automatic methods for identifying oil spills [16]. The first solution can be easily adapted to several sensors and image formats. However, it requires trained personnel. Although it requires the supervision of an human analyst, the automatic solution considerably reduces the number of cases to analyse, thus permitting the possibility of monitoring wide areas. Obviously, when different types of data are considered, modifying the software code becomes necessary. With the aim of distinguishing oil spills from similar oceanic features, we have developed a method named Oil Spill Automatic Detector (OSAD) [17] in the last years. The OSAD system has been tested with ERS-2 images in recent years, producing good results [18]. However, the detection algorithm needs to be modified for ENVISAT ASAR images [19].

2. DETECTION PROCEDURE

When a high resolution (for example ERS PRI) SAR datum is available, the procedure starts with the calibration of the image under analysis. The range backscattering variation is then compensated in order to obtain a value which is comparable everywhere to that at the middle of the image (in the ERS case, this is at 23°). Finally the areas at low intensity are identified. The threshold for the identification is set at the average intensity over the sea minus its standard deviation. The small areas and the large ones are discarded.
Figure 1. OSAD Detection procedure

The areas in which the transition from the high to low reflecting zone is smooth are discarded as well. Then the following features are measured: NRCS inside and outside the dark area, NRCS standard deviation both inside and outside, and a form factor that measures how the potential slick is elongated.

A detailed description of the whole process, from satellite acquisition up to the generation of a detection report, can be found in [18]. The block diagram in Fig. 1 shows the entire detection process.

The algorithm output is formatted as an HTML file in order to be sent to authorities via e-mail. Marine coastal authorities are responsible for accident prevention and containment. The other section measuring results is stored in a local archive and is accessible for consultation using the internet. The scheme of the entire process is presented in Fig 2. Fig. 3 shows the results of a system query.

3. ENVISAT DATA CHARACTERISTICS

The availability of new observation capabilities (above all ENVISAT) has encouraged an extension of the approach adopted for ERS to these data as well. Naturally, taking into account the differences among the aims and accordingly modifying the classification algorithm has been essential. The major changes were adopted to the following features: calibration, compensation for the incidence angle, slick features measurements and classification. While the absolute calibration of wide swath (WSM) and precision (IMM) images has been implemented and tested without any particular problem, the correction for the angle of incidence has needed an extra effort because the solution adopted for ERS has not been viable. The new products have an incidence angle ranging form 16° to 42°, while the ERS range is from 19° to 26°. In this extended interval scattering is specular for small incidence angle and follows the Bragg mechanism at higher incidence angles. In absence of an analytic expression for the radar backscattering we decided to assess the value for compensation directly from data. For this purpose, we selected a uniform marine image (see Fig. 4). Particular attention has been devoted to obtaining an image with uniform intensity. The image covers a portion of Atlantic Ocean near the Canary Islands. The lower part (land free) has been used for the analysis. A set of hundred range lines has been selected and averaged. The maximum value has been normalized to 1 (see Fig. 5). A fit has been made employing an exponential function to obtain the following analytical expression (Eq. 2):

\[
F(x) = 19.4\exp(-0.18x) + 0.06
\]

Compensation was done imposing a unitary correction value at 23°, like in the ERS case. This new solution has been previously tested successfully with a few earlier ERS images. The dependence of the slick features measurements from image radiometric resolution has also been a problem. In fact, using our approach the threshold under which a pixel is considered inside the slick is the average image intensity over the sea minus half of the standard deviation, which depends from the image radiometry. However, from this point of view ENVISAT and ERS are different, because their radiometric resolutions are different.
In order to use the same solution adopted for ERS we have used for threshold that which had been previously defined. However, we multiplied it by a scale factor (the ratio between the radiometric resolutions of the ENVISAT image used and the ERS PRI one). The same approach has been adopted in the classification function,
in which the backscattering standard deviations inside and outside the slick are the relevant terms.

Finally, we found that the variation ranges of some parameters which are necessary for the classification were larger in the ENVISAT case than in the ERS. The solution was then to implement a second classification method. The two methods were used alternatively depending on the measurements results. If the measurements were within the range used for setting up the classification model, we used the classification function developed for ERS. Vice-versa, we used a compound probability approach only for those measurements within the acceptance ranges, and we ignored those measurements which were more then 3 standard deviations deviant from the training set average.

The verification of the upgraded OSAD capability was conducted on a set of ERS and ENVISAT data acquired on the same areas (less then one hour apart) throughout the Mediterranean Sea.

4. ALGORITHM VALIDATION

After a three-year analysis of the interventions made by the Italian Environment Ministry along the Italian coasts, we selected 4 areas of interest. These have been particularly exposed to the oil spill risk, because of an intense maritime traffic. These include the eastern Sicily coast, the southern and northern Tyrrenian sea and the southern Adriatic sea. For these sites we have chosen ENVISAT data which was both in the image mode (Fig. 6) and the wide acquisition mode (Fig. 7) and the corresponding ERS data. The selected images are summarised in Tab. 1.

The scenarios reported here are the result of an assessment of the areas of interest and an intervention aimed at opposing the effects of pollution.

Table 1. Selected ENVISAT images

<table>
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<th>Product no.</th>
<th>Prod. Type</th>
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<th>Orbit</th>
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<td>7698</td>
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The differences between the homologues ENVISAT and ERS images are negligible. The same backscattering pattern over the sea is easily identifiable. The results produced by OSAD on ERS and ENVISAT data in high resolution mode are practically identical, while the difference in the probability to be oil slick for the ENVISAT wide swath mode and ERS PRI were within 15%. The main discrepancies have been found on slicks of reduced extension. This result can be explained by the fact that the variance of a few pixels on the slick measurements is obviously higher and this affects the classification procedure negatively.

5. CONCLUSIONS

The oil spill detection algorithm (previously developed and tested with ERS-2 PRI images) has been re-designed for ENVISAT images, both for precision (IMM) and wide swath (WSM). This modification has been possible without changing the structure of the algorithm. This has been achieved by redefining a new set of parameters for computing the probability to be an oil spill for dark area on the image.
The algorithm has been tuned using a training dataset of ENVISAT images containing verified oil slicks and look-alikes. Algorithm performances have been tested using a set of ERS and ENVISAT images of selected oil spills, in order to assess whether the detection is dependent on image type. Preliminary results show similar performances for both satellites. For this reason, the possibility of using different satellites for oil spill detection allows better monitoring activities, because of a higher number of available input images. As a final point, we would like to point out that using ENVISAT wide swath images makes it possible for scientists to monitor larger areas in a single software run.

6. ACKNOWLEDGEMENTS

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7. REFERENCES