

# Oil slick detection by SAR imagery: application on *Prestige* accident images

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## ABSTRACT

C-band SAR is well adapted to detect ocean pollution because slicks appear as dark patches on the images. In an operational context, two steps are needed to analyze these patches: slick detection and classification in order to determine slick nature. With ERS and ENVISAT images acquired during *Prestige* tanker accident, segmentation algorithms have been tested and adapted according to the image complexity. Synergetic data method has been used for classification step in comparison with aircraft tracking maps: in most cases, environmental data are sufficient to classify slicks.

## RESUME

*L'imagerie SAR en bande C est adaptée à la détection de pollution en mer dans la mesure où les nappes apparaissent dans l'image comme des taches sombres dans un environnement plus clair. Dans une perspective opérationnelle, deux étapes sont alors nécessaires pour analyser ces taches : la détection de la nappe dans l'image puis la classification pour connaître sa nature. A partir d'images ERS et ENVISAT acquises pendant le déversement du pétrolier Prestige, plusieurs méthodes de segmentation ont été testées pour la détection, à adapter selon la complexité de l'image. La connaissance des conditions environnementales par synergie de données est montrée comme une méthode efficace pour la classification, résultats validés par comparaison aux cartes de surveillance avion.*

## 1. INTRODUCTION

Ocean pollution has been recently highlighted by the *Prestige* tanker accident in Europe, like those of *Exxon Valdez* or *Erika* previously. These oil tanker accidents only account for 5% of total oil pollution worldwide and hide the regular pollution in important traffic zones, caused by oil drillings or illegal discharges. Natural slicks are also common, of biological origin made by photo-oxidation process, bacterial decomposition or of geological origin.

The objectives of slick detection are many folded. When accidents occur, polluted areas must be determined precisely in order to evaluate slick drift and protect coastlines. At present, this work is done on request by airborne surveys; an automatic detection by satellite would be helpful, moreover it would be useful to fight against illegal discharges. Besides, slicks reduce air-sea exchanges processes, yielding a significant reduction of CO<sub>2</sub> fluxes and heat transfers [1]. Thus, the slicks must be taken into account in climate change models. Natural slicks are also of interest for biologists and fishermen since they show intense biological activity in the water column. For these reasons, efficient detection means have been implemented, with airborne and satellite measurements.

Satellite detection is well adapted since it regularly produces images in difficult access areas. Furthermore, satellites allow instantaneous coverage of areas as wide as 500 x 500 km. Synthetic Aperture Radar (SAR) seems to be one of the most suitable instruments for this kind of study since it does not depend on weather (clouds) nor sunshine and allows high resolution imaging of the ocean surface with pixel size of about 10 to 75 m. SAR measurements are mainly limited by wind and sea state. Satellite surveys by ERS SAR have been used complementary to airborne survey after the *Aegean Sea* wreckage in 1992 for instance [2], and ENVISAT ASAR

satellite images have been analyzed during the *Prestige* disaster in 2002.

Tracking oil slick using SAR images should be done in two steps: detection and classification. We show here examples of detection, revealing the respective interest of four tested methods. We also applied synergetic data method for a classification step.

Slick measurements are explained in section 2; some methods are presented in section 3; then image applications are described in section 4 with two ENVISAT images of the *Prestige* tanker accident. Conclusions follow in section 5.

## 2. SLICK MEASUREMENT

Slicks modify seawater viscosity and surface tension, therefore having a strong impact on short waves (phenomenon called *Marangoni effect* [3]) measured by radars [4]. The backscatter level is decreased by slicks, which appear in the image as dark patches in comparison with the surrounding sea surface.

From previous experimental studies, the best measurement configuration to detect slicks is deduced as a function of radar parameters, slick nature and meteorological and oceanic conditions.

Each frequency band is differently affected, depending on wind speed and slick nature [5]. Several experimental studies with multi-frequencies consisting of tipping artificial slicks (MARSEN79, SAXON FPN, SAMPLEX92) have shown most important contrast with C, X and Ku-bands [6]. Wave numbers less than 80 m<sup>-1</sup> (L and S-bands) are weakly affected by slicks [7]. Strong winds are a real problem to the damping measurement. C-band frequency seems to be the most suitable frequency allowing to measure strong contrasts up to wind speed about 13 ms<sup>-1</sup> [8].

The choice of polarization depends on radar frequency and wind speed. Some experiments have shown that there

is no real difference between HH and VV polarization for slick study; however, VV polarization seems to be the most suitable for C-band, notably with strong wind [7].

Reflection mode of the incident radar wave is function of the incidence angle. There are two backscattering mechanisms: Kirchhoff mechanisms for 0 to 15° incident angles, and Bragg reflection for 20 to 70° angles which allows the observation of gravity-capillarity waves highly damped by slicks. The reflection backscattering coefficient decreases as the incidence angle increases [9], it is also function of wind speed. According to wind constraints and radar frequency used, the most suitable incident angles is ranging from 20 to 45°.

Wave damping, function of slick nature, is more important for oil slicks than for natural films [6]. The higher the elasticity, the higher the image contrast, but there is no linear relation. Therefore, it is not easy to distinguish slick nature from contrast. Thickness is also related to slick nature: oil slicks are thicker than natural films. Marangoni damping is valid for thick layers [3], but no experiment specifies thickness boundary size corresponding to boundary damping effect; thus, this is not a good criterion in order to classify slicks.

Otherwise, a radar measurement limitation is that slicks can only be detected if they are “new” slicks (radar wave does not penetrate ocean surface), and they are quickly carried in sub-surface, due to wave mixing.

Some conditions induce the same effects as slick appearance on satellite images: for example, weak backscatter areas exist for weak wind place, like in the lee of an island. Some other conditions like oceanic internal waves for example, quickly distort slicks, which become less dense, thus less easy to be detected. SAR measurement is also limited to sea state related to meteorological conditions. When there is not enough wind, capillary waves are not created, thus the radar backscattering becomes weak, and contrast is insufficient. Otherwise, too much wind induces an important backscattering and the contrast decreases. Moreover, waves induced by strong wind quickly drag slicks in the ocean sub-surface, where it cannot be detected.

For correct SAR measurement with C-band frequency, the wind speed has to be higher than 2-3  $\text{ms}^{-1}$ , the upper wind speed value is less obvious to determine, but some images have been made up to 10-14  $\text{ms}^{-1}$ , considering the parameters we previously discussed (wavelength, incident angle, slick nature...). In other words, the wind is a limitation for natural film generation, which can only exist for wind speed up to 3-5  $\text{ms}^{-1}$  [10].

### 3. IMAGE ANALYSIS

Several approaches exist for slick analysis from satellite images. Automatic analysis of SAR images is not applied routinely yet. For most of the tanker accidents it has been shown that the analysis must still be supervised. In cases of such disasters, quick results have to be obtained.

#### 3-1. Detection step

In order to obtain operational analysis, the first step consists of locating slicks in the image and of detecting contours. This can be performed by several methods: filters, gradients, morphological mathematics, etc... Here, we have tested four algorithms [11]:

1) a succession of median and Sobel filters followed by a morphological mathematics combination of dilatation and erosion was performed.

2) a simple algorithm using smoothing followed by thresholding and Sobel filter, this method is used for the Mediterranean sea pollution detection [12].

3) a combination of gradient and attenuation relative to background level followed by morphological filters, it is used in the SARTool software from BOOST Technologies (<http://www.boost-technologies.com>).

4) a complex algorithm of ocean surface characterization, based on multi-scale analysis of the observed data because oil and sea spectra have different distribution signatures [13].

#### 3-2. Classification step

Second, classification determines the nature of the slicks: oil slick, low wind area, biological trash favored by upwelling areas, etc... For that, statistical methods have been tested successfully; it consists of assigning probability for each slick to be due to pollution [14]. As a complementary layer of analysis, ancillary data should be systematically used to understand meteorological and oceanic conditions [15].

For our study, we have daily maps of aircraft survey [16], linked to slick drift forecast by Météo-France: from Centre de Documentation de Recherche et d'Expérimentations sur les pollutions accidentelles des eaux (CEDRE) for the French coast ([www.lecedre.fr/fr/prestige/carto.html](http://www.lecedre.fr/fr/prestige/carto.html)), and from La voz de Galicia (newspaper) for the Spanish coast ([www.lavozdegalicia.es/especiales/prestige/index.jsp](http://www.lavozdegalicia.es/especiales/prestige/index.jsp)).

Other satellite data have been used as synergetic data: SeaWinds on QuikSCAT for wind measurements (speed and direction); MODIS on Terra and Aqua satellites for sea surface temperature, showing fronts, currents and upwellings appearing near the coasts; Advanced Very High Resolution Radiometer (AVHRR), Meteosat, for infrared and visible radiations, revealing atmospheric fronts, clouds passes, cyclones, etc...; SeaWIFS for chlorophyll along coasts. The operational oceanography forecast MERCATOR has been used to understand North Atlantic currents, sea surface temperature and salinity vertical profiles. NOAA's Wave Watch III model provided sea state forecast. Moreover, BOOST Technologies company has implemented the SARTool software, allowing the geolocation-visualization-analysis of several satellite images, bathymetry and coastline for quick visual comparisons. CMOD-IFR2 algorithm was also used to evaluate wind speed from SAR images.

### 4. APPLICATION

#### 4-1. Case study

In 2002, the *Prestige* tanker accident off the Spanish coasts has been a major environmental disaster because of the huge quantity of oil dumped in the ocean, drifting over large distances. We chose this example for two main reasons: first, daily aircraft surveys were performed, providing maps of detected surface oil slicks; second, many images have been acquired over the region during the oil spill drift. Our study is based on 14 SAR images (ENVISAT and ERS).

#### 4-2. Detection

The image presented in figure 1 has been acquired by

the ENVISAT satellite, four days after the beginning of the *Prestige* tanker drift and two days before its final wreck. Slicks are visible from the tanker over an area of about a hundred kilometers. This case is very interesting for testing segmentation methods [11] because of the ambiguity of the area under study (Fig. 2a).

The *Prestige* tanker appears as a bright point southwest of the slick (Fig. 2a). From this point, two polluted “arms” drift towards north and east, probably due to the spread of two kinds of oil mixed in the tanker [13]. Although the slick is clearly defined around the tanker, because outlines are sharply stood out, the drift part is more complex.

We have applied the algorithms presented before (Fig. 2b to 2f). Method 2 is not efficient for this image: Fig. 2c presents blurred slick boundaries and no pollution near the tanker. Methods 1 and 3 highlight top and bottom slick outlines and show a non-polluted area in the middle of the two principal polluted “arms”, smaller with method 1 (Fig. 2b) than with method 3 (Fig. 2d). Method 4 applied with two classes (Fig. 2e) presents the same slick shape as Fig. 2b and 2d, except another polluted area from north to south at the east of the study area. This method is applied with three classes (Fig. 2f): grey corresponds to oil, white to clean sea and black an intermediate between these two first classes. The synergetic data study of this area reveals that the ambiguous zone from north to south (black in Fig. 2f) is probably not due to pollution, the synergetic data study revealed that it is related to a weak wind area with low radar backscattering due to atmospheric phenomenon [16]. The two polluted « arms » are well detected with the tested methods except method 2, which is efficient with basic examples only. Method 4 used with three classes is a promising technique, bringing additional information as it yields statistical characterization of each class.

The ambiguity of the area between the two polluted “arms” is revealed by the different results of segmentation: is it an area where oil is in sub-surface or is it a mixture between oil and water? Expert report is needed in order to process the classification step.

#### 4-3. Classification with synergetic data

The SAR image of December, 9 (figure 3a) is a good example of the need of synergetic data to understand the high and low backscattering levels [16]. This image has been acquired by the ENVISAT satellite at 10:53 UTC. Conditions on this day are inferred from visible and infrared radiation images, which present an atmospheric depression west of Spain, confirmed by SeaWinds data some hours before at 5:54 UTC (figure 3c). Hence, cloudy weather is present with strong wind speed gradients, characterized by low and high backscatter levels areas. The low backscatter, in the West of the image, corresponds to the centre of the atmospheric depression with counter clockwise rotating winds (figure 3c), weaker than the surrounding region where wind speed is higher than  $15 \text{ ms}^{-1}$  (higher backscatter). Oil slicks have been observed by aircraft near the coast the day before (figure 3d), but a speed of  $15 \text{ ms}^{-1}$  is too large for slick detection by SAR. Nevertheless, a slick is detected in the area of lower backscattering near the centre of the atmospheric depression where winds are weaker (figure 3b). This is a 15 kilometre long slick, with straight shape (south to north) extending from a round

patch (south boundary), where a (non-identified) boat is detected as a very high backscatter level value.

In order to classify this slick (natural origin or oil slick), we need to know other environmental information to test our synergetic method. Wave Watch III model gives a 1 m significant wave height. In this calm sea condition, the detected slick can thus be natural or oil slick. Infrared images (AVHRR) of sea surface temperature are perturbed by clouds, but still show some fronts, with cold areas in the North of the image and near the detected slick. These cold areas are disconnected from the coast and are thus unlikely to be related to upwelling. Moreover, the slick length is too large to be natural. Using all these information, we can conclude that this slick is very likely an oil slick.

Maps of *Prestige* tanker drift from 13<sup>th</sup> to 19<sup>th</sup> November show the exact location of the *Prestige* wreck (19<sup>th</sup>), which is exactly the place where the slick is detected, 20 days later. Aircraft observation maps show that from early December, the Galician coast is more and more polluted by oil. On December 8, an oil slick is visible at the location where the *Prestige* sank (shown in red figure 3d) in waters deeper than 3500 m [17], which means that the tanker continues to leak oil.

This case shows that oil slick can be detected from SAR images, even when backscatter is strongly perturbed by atmospheric phenomena. This image reveals the advantages and shortcomings of SAR detection. Slicks are well detected in a particular area of the image with weak backscatter, nevertheless no other slick can be detected near the coast where winds are too strong.

## 5. CONCLUSION

SAR appears to be a suitable instrument for the study of ocean pollution, well adapted because it does not depend on weather nor sunshine, which is an advantage when compared to optical measurements, also used for pollution study. Furthermore, it allows instantaneous coverage of areas as wide as 500 x 500 km.

SAR image analysis is done in two steps: detection and classification, which can be done using several methods.

The segmentation methods applied on 46 areas of the 14 images give good results with simple images, but for complex and ambiguous areas, other methods are needed as shown on the example presented in this paper. Tests show that basic methods (filters, gradients, morphological mathematics) are efficient with simple images without ambiguity. For complex areas (and only for them), the original approach based on ocean surface characterization is better than other methods, allowing characterizing each class and then better understanding ambiguous areas of the image.

Our synergetic data application, based on the *Prestige* tanker pollution, is a good example because aircraft observations are available to confirm our conclusions. Knowledge of environmental conditions such as meteorological conditions, wind speed and direction, wave height, sea surface temperature, currents, allows us to draw conclusions about slick origin and show the qualities of this method.

This is the first step in the way of operational survey, with regular satellite passes, quick data transmission and rapid detection analysis, helpful for the following classification step in order to speed up decision process in

case of illegal discharges for example

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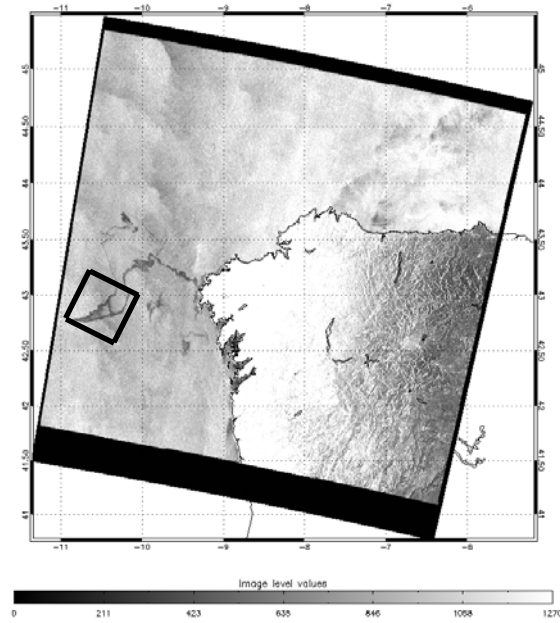


Figure 1. ENVISAT ASAR image, November, 17<sup>th</sup>, 2002 acquired at 10h45 UTC (Wide Swath mode, orbit 3741, polarization VV) off spanish coast after Prestige tanker wreck on November 13<sup>th</sup>. The square shows the study area ©ESA.

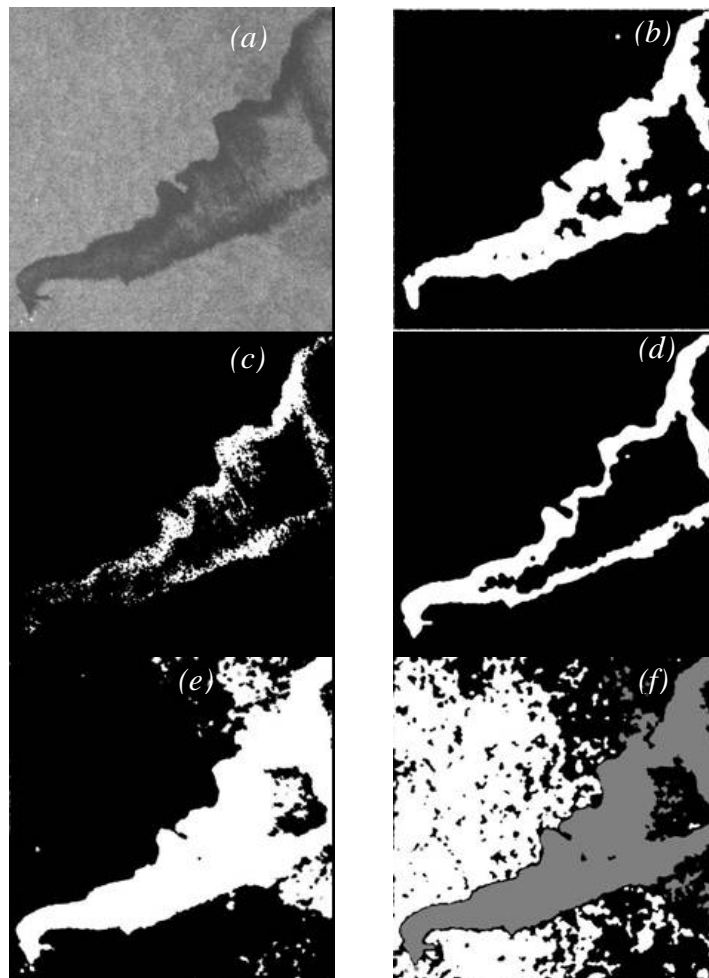
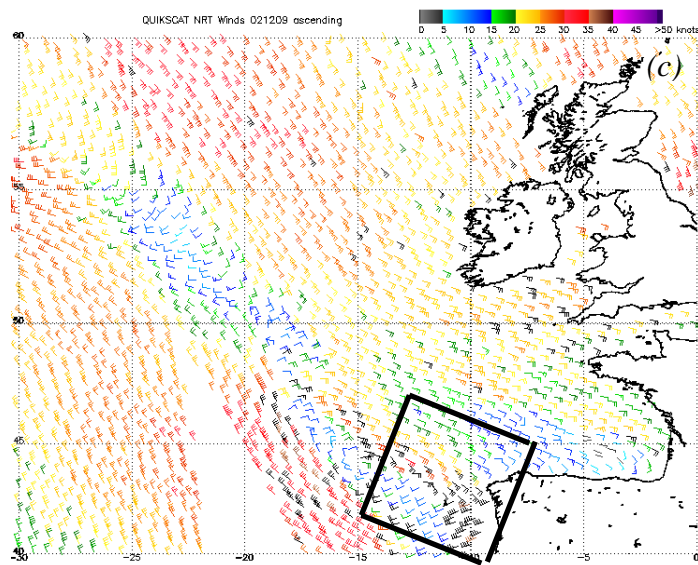
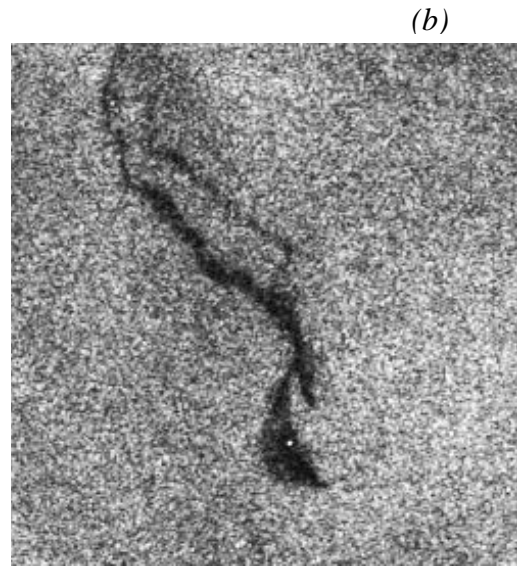
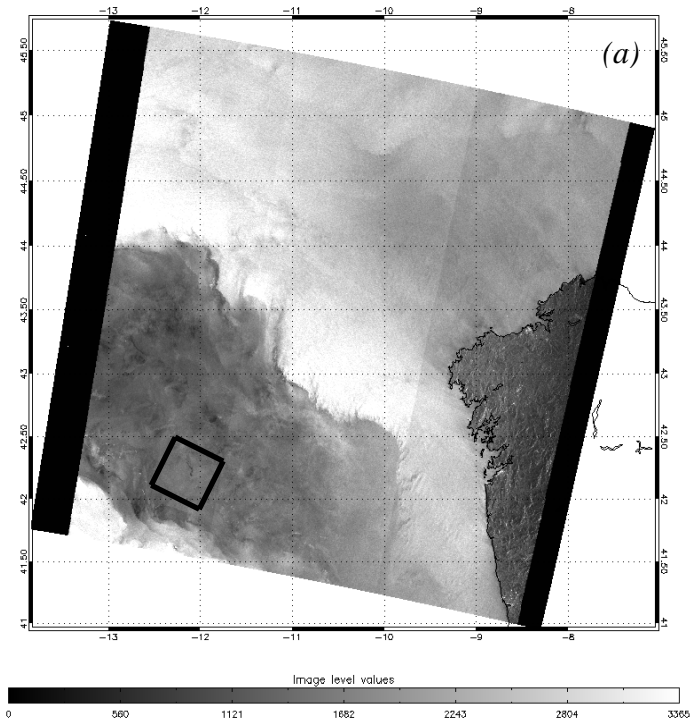
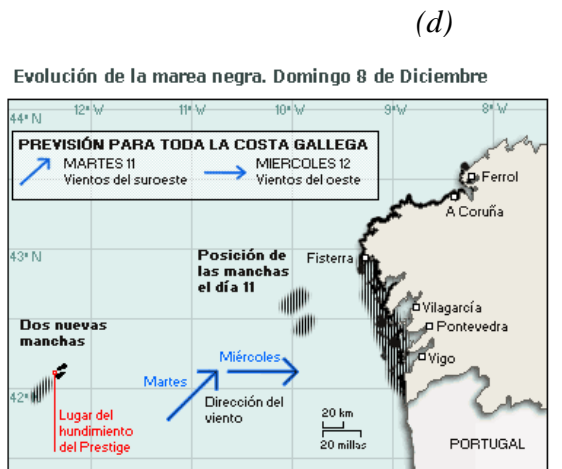


Figure 2. a) Study area shown in Fig. 1 (size: 38 km x 38 km). Study area analysis of a) with methods described in section 3.1: b) method 1, c) method 2, d) method 3, e) method 4 with 2 classes, f) method 4 with 3 classes.



Note: 1) Times are GMT 2) Times correspond to SON at right swath edge - time is right swath for overlapping swaths at SON  
 3) Data buffer is 24 hrs for O21209 4) Black bars indicate possible rain contamination  
 NOAA/NESDIS/Office of Research and Applications



Fuente: Elaboración propia, Ins. Hidrog. Portugal, Cons. Pesca, Cons. Medio Ambiente y SIAM

**Figure 3 :** (a) ENVISAT ASAR image, December 9<sup>th</sup> 2002, 10h53 UTC. Wide Swath mode, polarization VV, orbit 4056, surface area: 472 x 445 km ©ESA. The black square shows the study area (b) Zoom on the study area (surface area: 19 x 19 km) (c) Wind field map from SeaWinds data at 05h54 UTC ©NOAA (d) Oil pollution observations map from aircraft survey on December 8<sup>th</sup> 2002 ©La Voz de Galicia newspaper.