Oil slick classification by SAR imagery using synergetic data

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Abstract- **C-band SAR is well adapted to detect ocean pollution because backscatter is reduced by oil slicks that appear as dark patches on the image as the increase of viscosity due to the presence of oil damps gravity-capillarity waves. In order to classify these dark patches, we used ancillary satellite data and numerical models that yield environmental parameters from which slick nature can be deduced. ERS and ENVISAT images acquired during *Prestige* tanker accident have been tested, and then results have been compared with aircraft surveys. We conclude that in most cases environmental data are sufficient to classify slicks, and synergetic data should be used to improve oil slicks detection.**

Key words: **Synthetic Aperture Radar, oil slick, pollution detection, slick classification, synergy.**

I. INTRODUCTION

Ocean pollution has been recently highlighted by the *Prestige* tanker accident in Europe, like those of *Exxon Valdez*, *Erika* or *Aegean Sea* previously. These oil tanker accidents only account for 5% of total oil pollution worldwide and hide the regular pollution in important traffic zones like the Mediterranean (Pavlakis et al., 2001) and the Baltic seas (Johannessen et al., 1999), the Atlantic ocean (Gade and Ufermann, 1998), and the Malacca strait (around Singapore), caused by oil drillings or illegal discharges. Natural slicks are also common, of biological origin made by photo-oxidation process or bacterial decomposition (fecal material, plankton, algae…) or of geological origin (bottom oil seeping). With regular passes over oceans, satellites are useful to get statistical information about slicks all over the world ocean. Counting all kinds of slicks, 10% of the ocean surface is estimated to be covered by slicks (Scott, 1999).

The objectives of slick detection are the followings. 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. It would be useful to fight against illegal discharges. Besides, slicks reduce air-sea exchanges processes, such as surface evaporation, formation of whitecaps and spray, yielding a significant reduction of CO_2 fluxes and heat transfers (Scott, 1999). Thus, the slicks must be taken into account in climate change models. In other ways, natural slicks are 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, they allow instantaneous coverage of areas as wide as 500 x 500 km. Slicks modify seawater viscosity and surface tension, therefore having a strong impact on short waves measured by radars (Hühnerfuss et al., 1983; Alpers and Hühnerfuss, 1988). Backscatter level is decreased by slicks, which appear as dark patches in comparison with their surroundings. 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 (Girard-Ardhuin et al., 2003). Satellite surveys by ERS SAR have been used complementary to airborne survey after the *Aegean Sea* wreckage in 1992 for example (Lichtenegger, 1994), 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 focus on the classification part here, showing the interest of synergetic data. Classification methods are presented in Section II, then we focus on the synergetic method applied to two ENVISAT images of *Prestige* tanker accident in Section III. Conclusions follow in Section IV.

II. IMAGES ANALYSIS

Several approaches exist for slick analysis from satellites images. Automatic analysis of SAR images is not applied routinely yet. The example of the *Prestige* tanker has shown that analysis must still be supervised. In cases of such disasters, quick results have to be obtained. In order to obtain operational analysis, the first step consists of locating slicks in the image and of detecting contours, which can be performed for example with segmentation methods. 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 in assigning probability for each slick to be due to pollution. Solberg et al. (1999), for example, show that 94% of cases are well analyzed with this method. This analysis is based on oil pollution observations: pollution is mainly located in intense traffic area, near harbors, refineries or offshore oil rigs, associated with thick slicks. The knowledge about favored locations of upwelling appearance and slick shape and size observations is of importance: illegal discharges are often associated with elongated and straight slick, large areas cannot be covered by natural film, etc...

As a complementary layer of analysis, ancillary data should be systematically used to understand meteorological and oceanic conditions. For example, knowing wind speed allows eliminating some cases. Under 2 ms^{-1}, a weak backscattering area is more probably due to wind and not to pollution. Beyond 10 to 14 ms^{-1} each detected slick is an oil slick because natural slicks are quickly mixed in sub-surface by turbulence in such conditions. Waves are thus also an important parameter. Sea surface temperature maps show upwelling areas and facilitate the analysis of some cases. Recently, wind and tidal currents history have been combined with SAR images in order to determine slick age and original shape (Espedal and Wahl, 1999). We will focus here on a synergy method, consisting of the use of satellite data and numerical models that yield parameters like wind, surface current, wave height, sea surface temperature, etc… providing information on the environmental conditions, from which slick nature can be deduced.

III. SYNERGY METHOD APPLICATION: *PRESTIGE* ACCIDENT EXAMPLE

1) *Case study*

In 2002, the *Prestige* tanker accident off Spanish coasts has been a major environmental disaster because of the huge quantity of oil-dumped in the ocean, drifting over large distances. We choose this example for two main reasons: first, daily aircraft surveys were performed, giving maps of detected surface oil slicks; second, many images have been acquired over the region during the oil spill drift.

2) *Data*

We have daily maps of aircraft survey, linked to slick drift forecast by Météo-France (Daniel et al., 2003): from *CEntre de Documentation de Recherche et d'Expérimentations sur les pollutions accidentelles des eaux* (CEDRE) for the French coast (www.le-cedre.fr/fr/prestige/carto.html), and from *La voz de Galicia* (newspaper) for the Spanish coast (www.lavozdegalicia.es/especiales/prestige/index.jsp).

ESA provided ENVISAT and ERS images over the area of the *Prestige* wreckage during months. Other satellites 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 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.

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.

3) *Images analysis*

Two SAR image examples are analyzed with synergetic method to prove its ability and interest in certain cases.

A) December 9th 2002

The SAR image of December 9th (figure 1*a*) is a good example of the need of synergetic data to understand the high and low backscattering levels. This image has been acquired by ENVISAT satellite at 10h53 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 05h54 UTC (figure 1*c*). This induces cloudy weather 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 center of the atmospheric depression with counter clockwise rotating winds (figure 1*c*), weaker than surroundings where wind speed is higher than 15 ms^{-1} (higher backscatter). Oil slicks have been observed by aircraft near the coast the day before (figure 1*d*), but 15 ms^{-1} is too fast for slick detection by SAR. Nevertheless, a slick is detected in the area of lower backscattering near the center of the atmospheric depression where winds are weaker (figure 1*b*). This is a 15 kilometer 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 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 13th to 19th November show the exact location of the *Prestige* wreck (19th), 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, oil slick is visible at the location where *Prestige* sank (shown in red figure 1*d*) in waters deeper than 3500 m (Kondrachoff-Samuel and Parthiot, 2003), 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.

B) December 2nd 2002

The SAR image presented here has been acquired by ENVISAT on the *Prestige* tanker oil drift area on December 2 at 22h30 UTC (figure 2*a*). The study area is near the coast at the North of the image (figure 2*a*, *b*), showing a dark patch with weak contrast, which can be an oil slick or another phenomenon.

On that day, the weather was cloudy (visible radiation maps), with a strong North/North-Westerly flux, confirmed by the direction of wind rolls detected in the image (figure 2*a*). Wind speed can be retrieved directly from SAR image, using the CMOD-IFR2 algorithm (figure 2*c*), showing values from 5 to over 15 ms^{-1}, the upper limit for reliable slick detection by SAR. Moreover, winds are not offshore and implies that this black patch does not correspond to weak winds due to orographic effect. Large waves from the Northwest (4 m significant wave height) are present in the area, clearly visible in the figure 2*b*. Sea surface temperature maps show temperature gradients near the coast, but previous information about wind and waves imply that the detected slick should not correspond to cold water upwelling or other kind of natural slick because they are less thick than oil slick and should be quickly drowned in sub-surface in such conditions.

These synergetic data show that this patch cannot correspond to a natural slick and thus must be an oil slick. This conclusion is confirmed by slick observation map of this day (figure 2*d*) where coastal pollution is marked, corresponding to the second black tide of the *Prestige* tanker pollution, arrived the day before. The oil slick (figure 2*b*) presents higher contrast on its Northern boundary, because wind and waves are coming from that direction. Extensions of the slick to the South are probably due to wind-induced drift. Wind conditions (figure 2*c*) imply that no slick can be detected where wind speed is higher than 15 ms^{-1}, although aircraft observations detect pollution. This image shows that oil pollution near the coast can be detected by SAR on cloudy day.

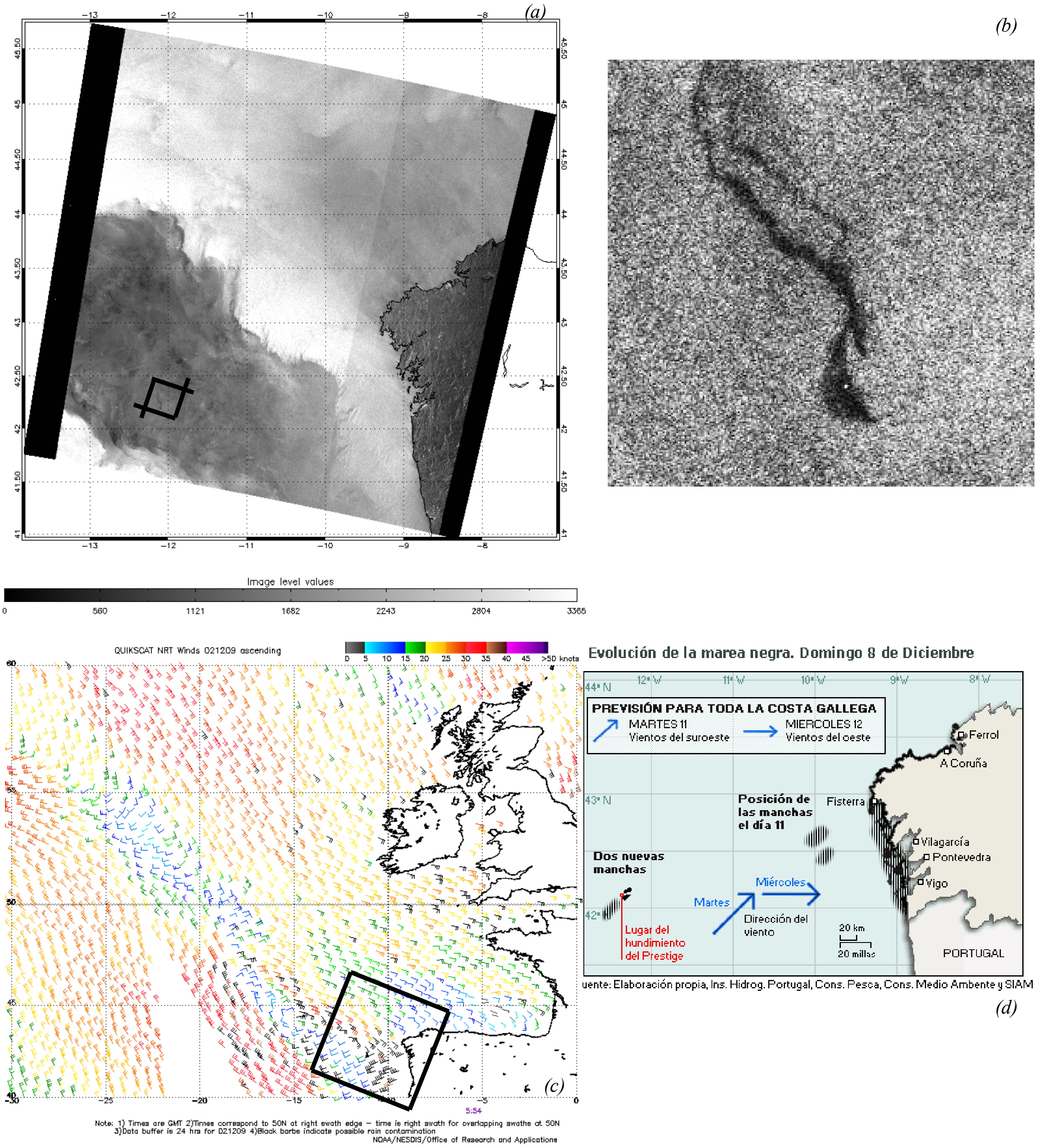

Figure 1 : *(a) ENVISAT ASAR image, December 9th 2002, 10h53 UTC. Wide Swath mode, polarization VV, orbit 4056, surface area: 472 x 445 km ©ESA. The black square shows the study area (b) Zoom on the study area (surface area: 19 x 19 km) (c) Wind field map from SeaWinds data at 05h54 UTC ©NOAA (d) Oil pollution observations map from aircraft survey on December 8 2002 ©La Voz de Galicia newspaper.*

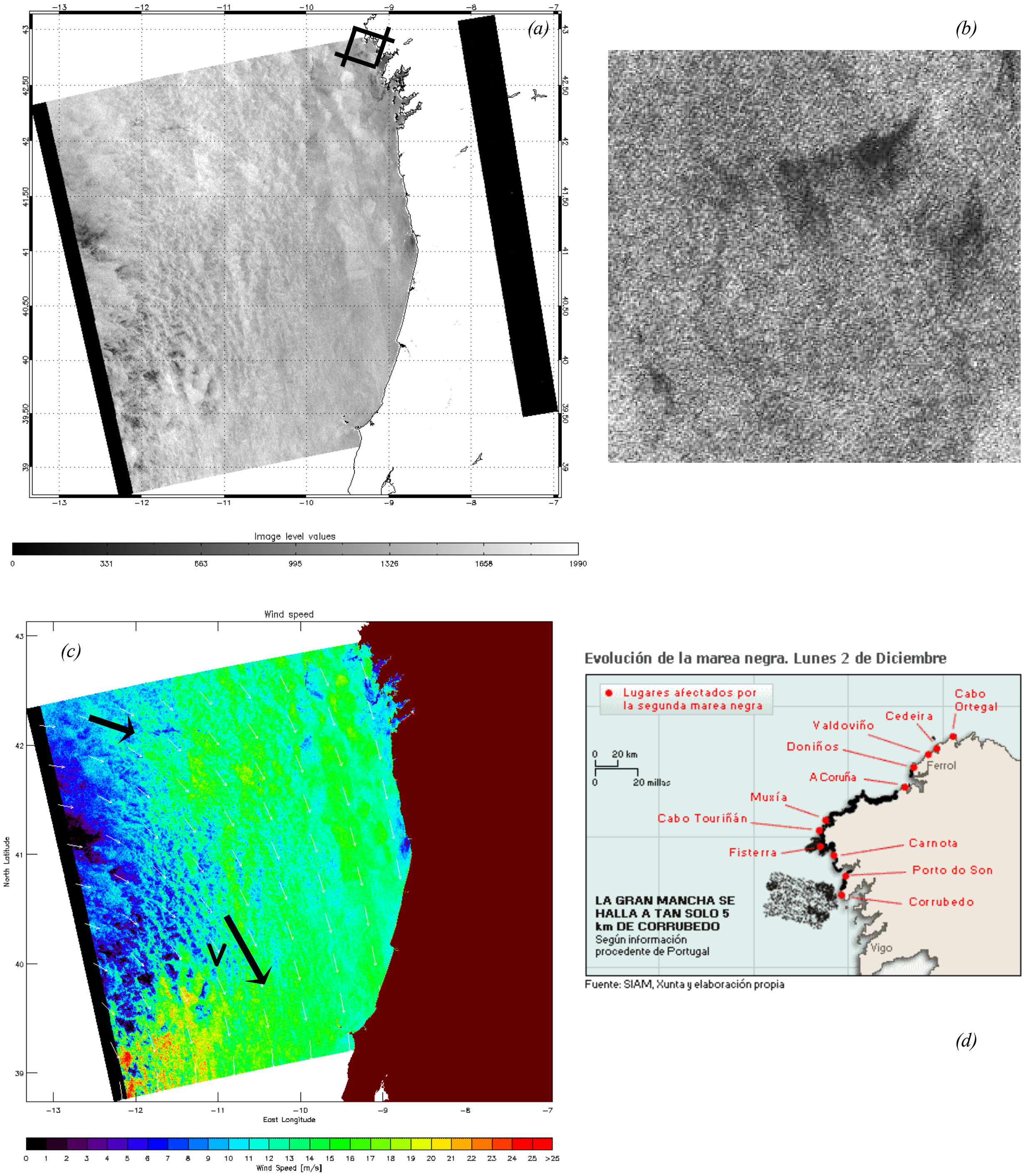

Figure 2: *(a) ENVISAT ASAR image, December 2nd 2002, 22h30 UTC. Wide Swath mode, polarization VV, orbit 3963, surface area: 469 x 405 km ©ESA. The black square shows the study area (b) Zoom on the study area (surface area: 19 x 19 km). (c) Wind field map from (a) applying CMOD-IFR2 algorithm (d) Oil pollution observations map from aircraft survey on December 2 2002 ©La Voz de Galicia newspaper.*

IV. CONCLUSION

SAR appears to be a suitable instrument for the study of ocean pollution, well adapted because it does no 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 with several methods. We focus on synergetic method applied on a real case. Our study, based on *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 in the most of the cases, 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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