The Use of Satellite Radar Imagery in the Prestige Accident

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Abstract
The support activities within the European Commission (EC) DG Joint Research Centre (JRC) during the Prestige accident are described. The basics of the methodology used to process and interpret the satellite images are introduced. Results showing the most relevant image interpretations illustrate the use of space-borne imagery in an emergency phase. Some example image interpretations are validated with results from visual inspections concurrently on the spot.

I. Introduction

On Wednesday, 13th of November 2002, the single-hulled oil tanker Prestige, flying the Bahamas flag, sent a distress call offshore the region of Cape Finisterre (Galicia, Spain). The tanker was carrying 77,000 tonnes of heavy fuel oil loaded in St Petersburg (Russia) and Ventspils (Latvia), was heading to Singapore via Gibraltar. The vessel developed a reported 30 degrees starboard list whilst on passage in heavy seas and strong wind and so requested the partial evacuation of the crew. Twenty-four of the twenty-seven crew members were evacuated by helicopter while the captain, the first mate and the chief mechanic stayed aboard. As the engine was damaged, the ship became out of control and derived according to the weather conditions. An aerial observation revealed a fuel leak at sea.

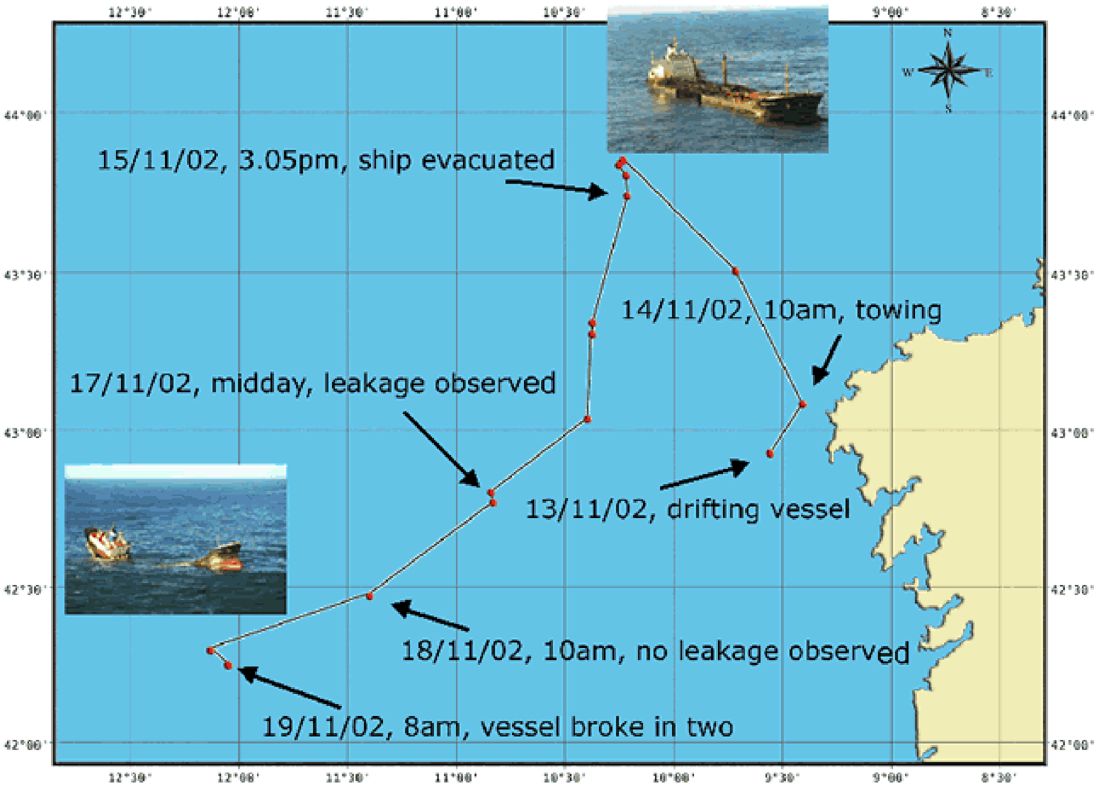

Figure 1: The positions of the Prestige Tanker from 13/11/2002 until 19/11/2002 (Cedre website http://www.le-cedre.fr/index_gb.html).

All night long, the tug boats Ria de Vigo, Alonso de Chaves, Charuca Silveira and Ibaizabal I from the Sociedad de Salvamento y Seguridad Maritima (SASEMAR), the Spanish organization in charge of the sea rescue and pollution control, tried to take in tow the oil tanker.

The emergency towing system of the ship didn't work and the different attempts failed. In the end, the Prestige was taken in tow by a ship from Smit salvage on the 14th of November. It was towed to the north-northwest all day, and then to the south. On the 15th, it was torn over 35 meters on the right side. On the 16th, its towing was turned to the south-west to avoid the Portuguese waters. On the 19th at 9 am, the vessel broke in two, coordinates 42°15N and 12°08W, at about 130 nautical miles off the Spanish coasts, west south-west of Cape Finisterre. At 12 o'clock, the stern part of the Prestige sank into 3500 meters of water. The bow part followed at about 4 pm. Figure 1 shows the geographical coordinates of the Prestige tanker.

Right after the accident of the Prestige tanker, the Monitoring and Information Centre of the European Commission, in coordination with the Spanish authorities, activated the CHARTER (International Charter Space and Major Disasters) on 14 November 2002 [1]. The Charter, through its partners Organizations (ESA, CNES, CSA, ISRO, NOAA, CONAE), aims at support the emergency management due to natural or man-made disasters providing the acquisition and fast delivery of space data of interest. The authorised users while the CHARTER was active were the Spanish Authorities (Fomento Ministry), the SHOM (French Navy), Le Cedre (France), and the EC JRC. The CHARTER was closed on 3 December 2002, two weeks after its activation.

On behalf of the Directorate General Environment (DG ENV), the Directorate General – Joint Research Centre (JRC) was activated to provide support to the interpretation of radar satellite images over the areas affected by the Prestige Tanker accident (Atlantic Coast of Galicia, Cantabrian Coast and the Bay of Biscay).

This paper reports on the satellite image interpretation support activity within the JRC during the Prestige emergency phase. It is organised in the following way: Section II is recalling the basic principles which make Synthetic Aperture Radar images suitable for the identification of oil spills at sea. Section III reports on the main results obtained. In Section IV, some conclusions are drawn.

II. Identification of Oil Spills in SAR Images

The possibility of detecting an oil spill in a SAR image relies on the fact that the oil film decreases the backscattering of the sea surface [2] resulting in a dark feature which contrasts the brightness of the surrounding clean sea. The analysis of this basic fact needs to start from a description of the different mechanisms responsible of the sea surface radar backscattering, which strongly depends on the incidence angle of the radar platform. In a quite large range of angles, approximately from 20 to 85 deg - the angular span of particular interest for space-borne observations - the main agent of radar backscattering are the wind - generated short gravity-capillary waves. The oil film has a dampening effect on these waves locally decreasing the backscattering and finally the brightness in the image. It is implicitly assumed that a light wind field exists in order to activate short gravity-capillary waves. The minimum wind field is in fact depending on the frequency of observation and the incidence angle. For operational satellites operating in C-band, a minimum wind field of 2-3 m/s creates sufficient brightness in the image and makes the oil film visible [3]. On the other end, when the wind field is too high it causes the spill to disappear. First because the short waves receive enough energy to counterbalance the dumping effect of the oil film. Then, when the sea-state is fully developed, the turbulence of the upper sea layer may break and/or sink the spill or a part of it.

As a consequence of the above brief discussion the identification of an oil spill in a SAR image includes always as first and basic step the detection of dark features. Typically, a SAR image may show some dark features that are not oil spills (i.e., in most cases due to both meteorological and/or oceanographic effects). These look-alike features pose a fundamental problem to the identification of oil slicks and require the intervention of an experienced radar image analyst. In general terms the problem can be approached in different ways, trough an automatic system completely relying on dedicated image analysis software tools, or in a semiautomatic mode, where the most critical decisions are taken by an experienced operator, able to understand and correctly interpret the images.

The basic functions of a system for automatic identification of oil spill can be described 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 manmade oil spill, usually determined through phenomenological considerations and statistical assessments.

4. Computation of probabilities for each candidate signature.

The approach can be also more sophisticated taking into account relevant environmental parameters having an impact on the spill shape, such as the time history of wind fields and currents [4]. While the two first steps do not require too much assistance from the image analyst, the two last steps, basically concerning the discrimination of oil spills from other like-alike, strongly rely on the experience and ability of the operator.

III. SAR Images Interpretation

In support of the operational phase, the following working scheme was adopted:

- Provision of radar images through the Charter (first phase, in the period 14/11/2002 to 5/12/2002) and then directly from the European Space Agency (second phase, in the period 6/12/2002 to 5/3/2003).
- Interpretation of images by the JRC and delivery of relevant information to DG-ENV;
- Distribution of the interpreted images by DG-ENV, as annex to Infosheets on the Prestige accident, to all Member States.

The activity concerning the satellite image processing and interpretation in support to the management of the emergency phase consisted of the following tasks:

- Image geo-location (i.e. transforming the image from a radar internal reference system to a geographical one (lat-long))
- Image equalization to get a uniform range profile of the sea-backscatter and suppressing the amplitude modulation due to the Bragg scattering.
- Image segmentation to identify dark features.
- Image interpretation identifying possible oil slicks signatures.

The final product is a geo-located radar image with the indication of likely spilled areas. For each likely spilled area a level of confidence (low-medium-high) is also provided. When possible, in order to ease the image interpretation, suitable geographical reference points (e.g. towns or other clearly recognisable geographical features) are also indicated. Out of the 169 images provided to JRC about 30 have been identified as being of interest (a possible oil slick signature was present with at least a low level of confidence) and then delivered to DG-ENV. On average the time delay from the image acquisition to the delivery of the final results to DG-ENV was about 9 hours. In practice, the bottleneck in this process was the delivery of the images by the image provider. It must be noted that a great number of the images were acquired be the ESA ENVISAT satellite, which was in its commissioning phase and the image delivery scheme was not yet fully operational. Consequently, it can be concluded that the overall efficiency was quite good.

The first image interpretation produced at the JRC is shown in figure 2. The ENVISAT wide swath radar image (area extent of about 400 km x 400 km) acquired on 17 November 2002 shows a huge low brightness region (coloured in red) right at the position of the tanker. Such a feature, despite the very unusual shape and extent, was preliminary interpreted as an oil discharge. The overlay of the geolocated satellite image and the ship track provided a confirmation of the interpretation.

In figure 3, the oil slicks observed in the ENVISAT image of 17/11/2002 (coloured in red) and that in the Radarsat image acquired on 25 November (coloured in cyan) are shown. Both oil spills are clearly located along the tanker track. It must be noted that the extent of the oil spill is in both cases huge.

Figures 4 and 5 show, respectively, two ENVISAT wide swath images acquired on 9 December and 13 February. In both images, a fresh oil slick has been observed right at the wreckage position, which indicated that the oil was still being released by the wreck. The observation made in the first image is confirmed by a visual inspection which was almost concurrent with the satellite acquisition.

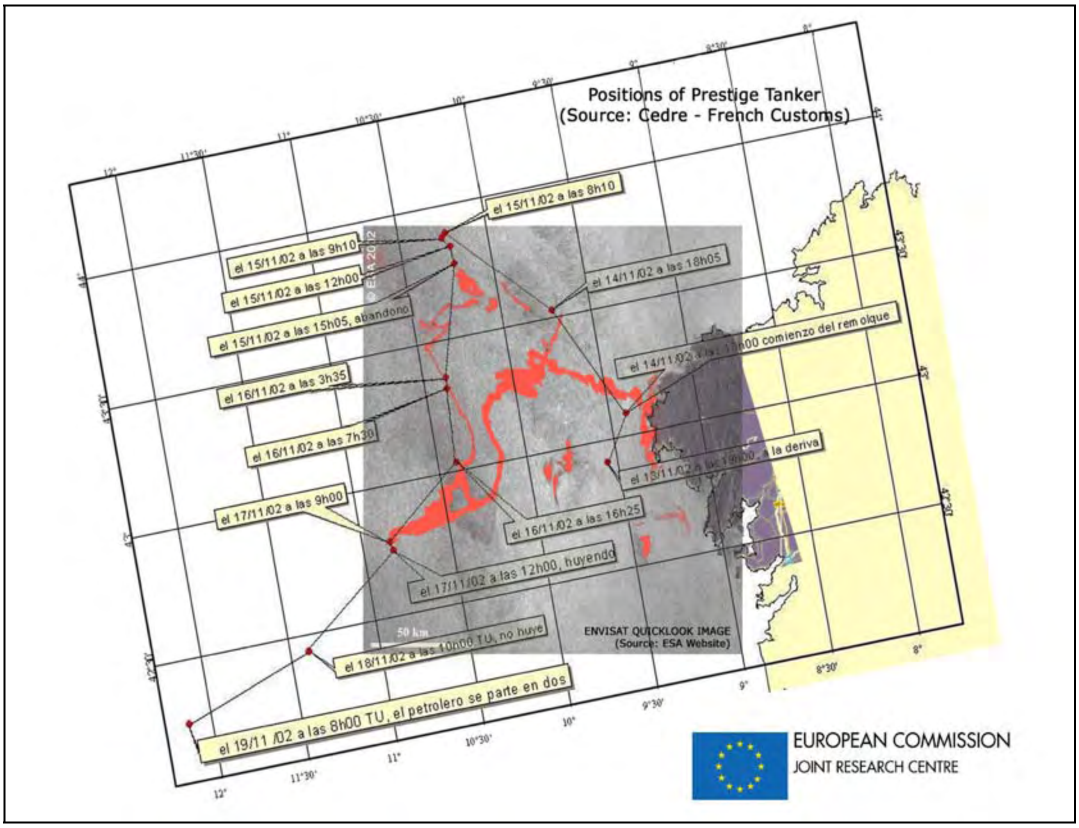

Figure 2: Overlay of the ENVISAT ASAR image of 17 November and the map showing the tanker coordinates in the period 13 to 19 November.

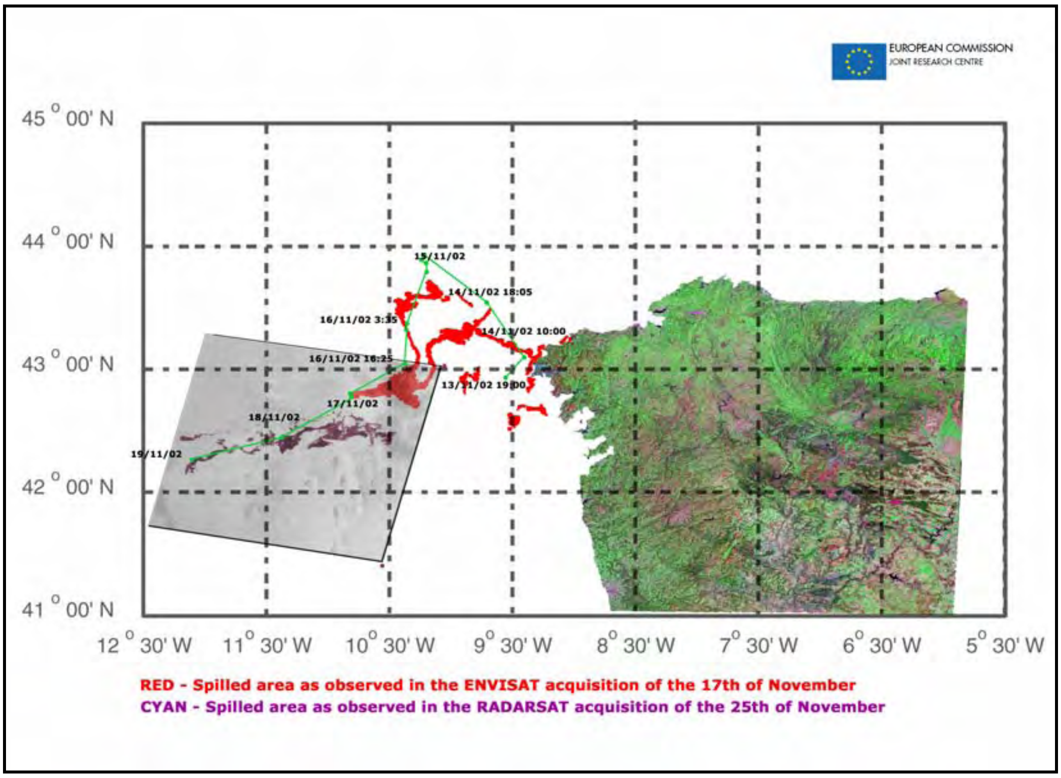

Figure 3: Oil spills observed on 17 November (ENVISAT ASAR, in red) and on 25 November (Radarsat) west of the Galician Coast.

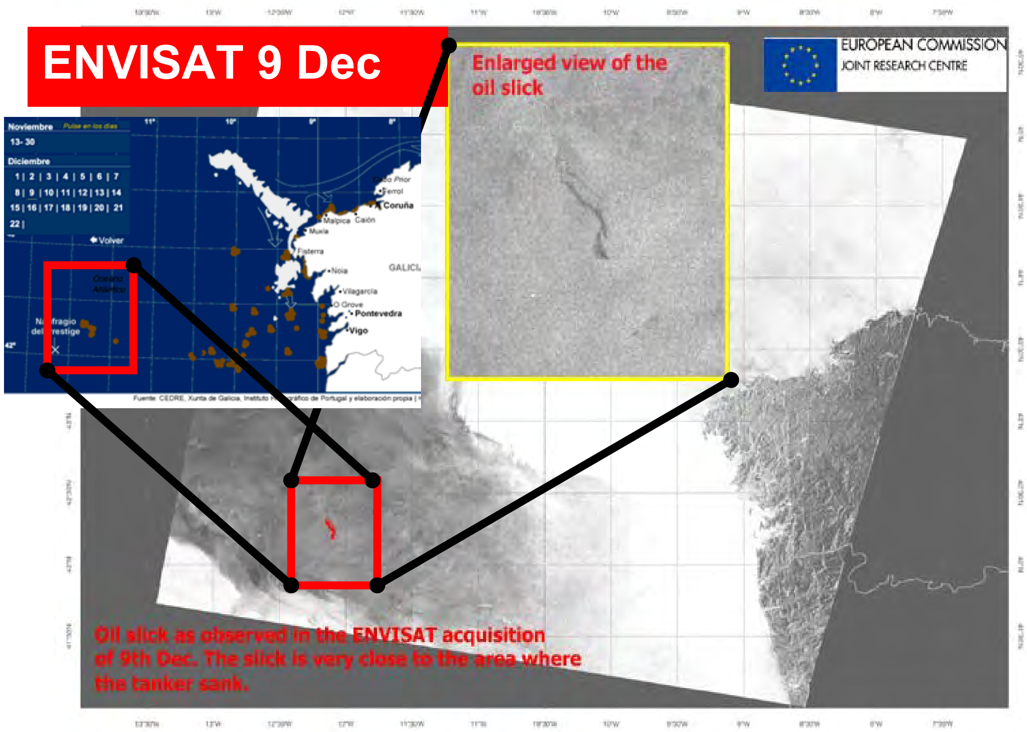

Figure 4: Oil spill observed on 9 December (ENVISAT ASAR, coloured in red) west of the Galician Coast.

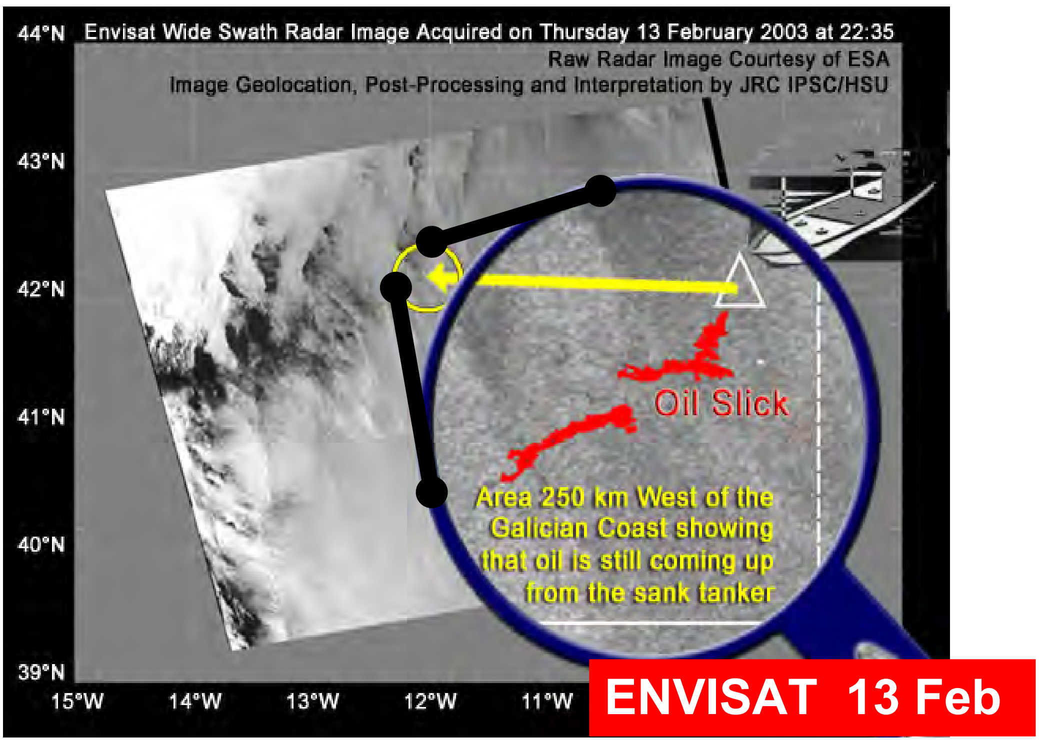

Figure 5: Oil spill observed on 13 February (ENVISAT ASAR, coloured in red) west of the Galician Coast right at the wreckage position of the Prestige tanker.

The image interpretation in figure 6 shows a mosaic of two ERS-2 images acquires on 16/12/2002, where some oil spills were identified. This observation can be correlated with the actual situation at sea as reported by the responsible authorities. It must be noted that only a small region near the coastline was patrolled and therefore no confirmation data is available for the whole image. Nevertheless, the oil spills that fall into the patrolled area have all been confirmed (lower left corner of the image).

Finally, in figure 7, the oil spills observed on 8 February in an ENVISAT and an ERS-2 image are shown. The actual situation at sea as reported by the responsible authorities is shown in figure 8. Again, the presence of several oil slicks is confirmed by the visual inspections on the day the satellite image was acquired. The fact that the oil slicks are observed in two images acquired by different satellites, as well as in the visual inspections, gives a high confidence to these observations.

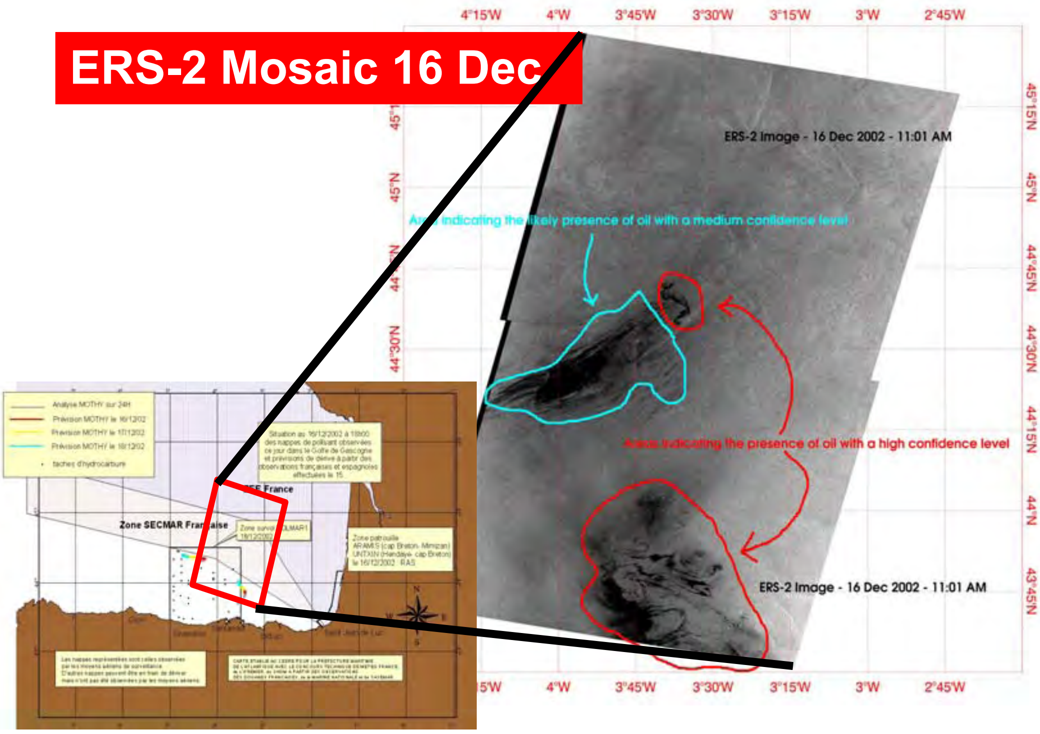

Figure 6: Oil spills observed on 16 December (mosaic of two ERS-2 images) north of the Basque Coast and the situation at sea as reported by the responsible authorities on a daily basis (Courtesy of Le Cedre).

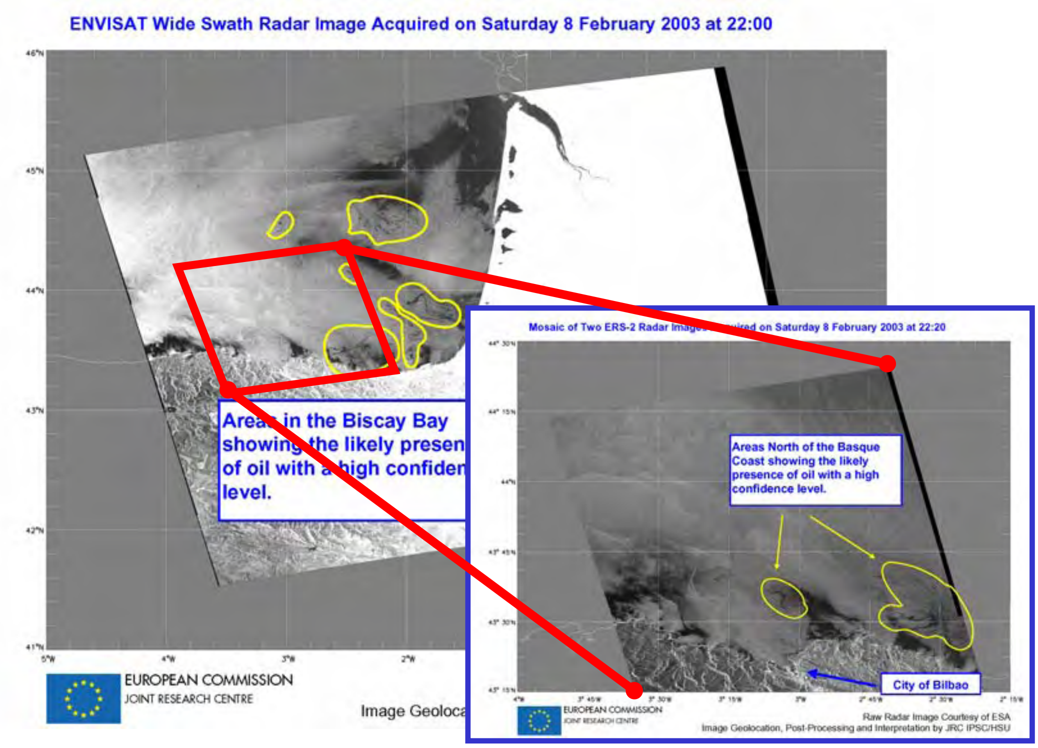

Figure 7: Oil spills observed on 8 February in both an ENVISAT and an ERS-2 image over the Biscay Bay.

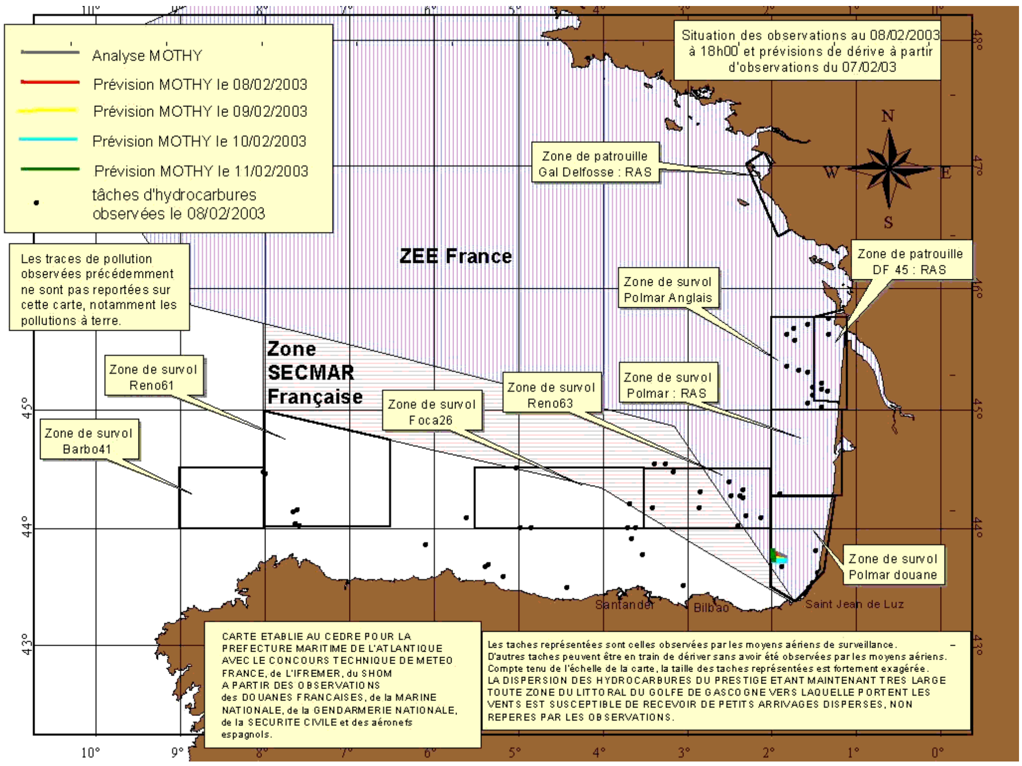

Figure 8: Situation at sea on 8/2/2003 as reported by the responsible authorities (Courtesy of Le Cedre)

IV. Conclusions

The Prestige Tanker accident has been characterized by a number of peculiar aspects, most of them previously not encountered or even unknown. They basically concern the type of discharged oil, the amount of discharged oil, the extent of the affected area, the time period of persistence of oil at sea, as well as the mutual interactions between them.
Such a complex context 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 we want to distinguish the technical/scientific aspects 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;
- no information has been provided in some cases due to the well known limitations of the sensor (i.e. unfavourable sea conditions);
- positive and/or negative identification of pollution not confirmed by other observations.

The last point has many different explanations such as the misinterpretation due to complex situations, the lack of knowledge of the characteristics and of the behaviour of the discharged oil, the lack of experience in dealing with accidental spills and the lack of contextual information at the time of image interpretation. The Prestige case highlights a number of technical/scientific needs where additional investigations and technical improvements are necessary. Many of them are not specific for the oil pollution identification in case of accidental spilling but are a part of the general problem of detecting and identifying marine oil pollution from vessels. 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 oceanographic data).
- Refinement of sensors and methodologies to improve the retrieval of oil slick thickness and the detection of submersed oil. Both aspects are important when heavy oil is discharged, as in the case of the Erika accident. Similar problems arose also in the case of the Prestige since oil remained at sea for a long time and its physical-chemical characteristics were strongly modified. This process led 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.
- Refinement of methodologies for the prediction of oil slicks movement, including oil dispersion model and ocean circulation models. This is a crucial aspect in case of accidents, as in the Prestige case, but also in case of deliberate spilling close to the coastline.

Concerning the operational aspect it should be noted that in most cases the information extracted from satellite images has been delivered to the end-user in a time largely unsatisfactory. Consequently, even images providing useful information loose their operational value. The aspect of minimizing the time delay from image acquisition and delivery of information to the final user is fundamental and substantial improvements to meet the operational requirements are possible. From a technical point of view today is possible to deliver the interpreted image to the user within one hour from the satellite pass. Such a time delay may be acceptable in case of accidental pollution. Then the problem is essentially of organizational nature. The actual mechanism based on the Charter is an optimal starting point, since it is assuring the provision of the space data of interest. Nevertheless further developments are necessary in order to reinforce and tune the activities on the specific operational needs in case of emergency such as the Prestige. In particular it should be considered the creation of a technical body in charge not only of the image interpretation but also of the coordination with all the other actors on the scene as well as of the integration of any other relevant information and expertise to extract the maximum of information from satellite imagery. We hope that the need for such a structure will be always decreasing in the future but at same time we think that it is necessary to build on the lessons learnt from the Prestige accident in order to optimize the operational use of space data as a valid complement to aerial and naval means.

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