

## DEVELOPMENT OF AN AIRBORNE MULTISENSOR SYSTEM FOR OIL SPILL DETECTION AND CONTROL

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### ABSTRACT:

This paper describes the results of RAPSODI (Remote-sensing Anti-Pollution System for geOgraphic Data Integration), an ongoing research project which is focused on the development of a new anti-pollution remote sensing system. The system tasks are the detection and monitoring of the accidental and voluntary maritime pollution and the support of the associated clean-up operations. The RAPSODI project belongs to the Fifth European Community Framework Programme. This paper discusses the main stages of the project, and presents the most significant results that were achieved to date: the realization of a real-size experimental campaign, which included oil slick realises and the acquisition of *in situ* and remotely sensed data; the SAR data processing; and the automatic extraction of oil slick contours on the SAR images.

### 1. INTRODUCTION

The transport-related maritime pollution is a question of major concern in maritime transport. Particular attention is focused on preventing oil spills from vessels, as well as pollution from other kinds of dangerous cargos. The oil spill pollution can originate from both maritime incidents such as hindrances, sinkings and collisions of oil tankers, and deliberate discharges (tank washings from oil tankers, discharges of machinery wastes, etc.).

The remote sensing systems play a key role in the monitoring of the accidental and voluntary maritime pollutions. In this field the major contribution is given by the airborne systems. A complementary contribution could be provided by the spaceborne systems, like those based on SAR sensors, e.g. see Girin et al. (1999), although different technical aspects (spatial and temporal resolution, near real time data availability, etc.) limit their operational use. The main European coastal countries are equipped with airborne systems based on different types of sensors, like infrared (IR) and ultraviolet (UV) scanners, visible cameras and SLAR's (Side Looking Airborne Radars). The use of a single sensor usually does not guarantee an operational pollution monitoring. For instance, the use of the IR and UV scanners and visible cameras is dependent on the environmental conditions, while the SLAR systems, which may work under any atmospheric conditions, provide a limited along-track resolution. This may cause false alarms, e.g. confusing a local wind variation or a slick with natural biological origins with oil spills.

The paper describes the results of an ongoing research project, named RAPSODI (Remote-sensing Anti-Pollution System for geOgraphic Data Integration), which is focused on the development of a new anti-pollution remote sensing system, whose tasks are the detection and monitoring of the accidental

and voluntary maritime pollution and the support of the associated clean-up operations. To achieve these tasks, a new multi-sensor airborne surveillance system is proposed. A major effort has been devoted to the development of a SAR (Synthetic Aperture Radar) system.

An existing airborne coherent X-band radar of Thales Airborne Systems has been used. Since originally it was not tailored to the specific needs of oil spill detection and control, a part of the project has been devoted to its specification and reconfiguration. In particular, the radar has been configured for optimal operation in strip-map mode. The SAR images have a remarkable higher resolution than the SLAR images: they provide an improved oil spill monitoring capability to the system. The SAR sensor will be used in association with other existing sensors such as IR/UV.

A scheme of the RAPSODI system is illustrated in Figure 1. The RAPSODI project belongs to the Information Society Technologies Programme of the Fifth European Community Framework Programme. It is carried out by multidisciplinary consortium, which includes experts in airborne maritime radars and systems (Thales Airborne Systems), in satellite remote sensing and image processing (Joint Research Centre), in radar signal processing (Institute of Geomatics) and in maritime pollution (CEDRE).

In this paper three major components of the RAPSODI project are described. Firstly, the realization of a real-size experimental campaign, designed to assess of the performances of the proposed system. The campaign involved two voluntary and controlled oil releases in the Atlantic Ocean. Then, the processing of the SAR raw-data collected during the campaign, which was based on a new processor tailored to the specific operational needs of the RAPSODI system. Finally, the

procedures employed for the detection of the oil spill contours based on SAR images.

## 2. THE RAPSODI EXPERIMENTAL CAMPAIGN

One of the main goals of the RAPSODI project was the realisation of a real-sized experiment, suitable to test a prototype of the proposed anti-pollution remote sensing system. In May 2001, two voluntary releases of oil were performed in controlled situations in the Atlantic Ocean. The experiment, which was organised by CEDRE, was carried out under the responsibility of the French Navy. The measurements campaign involved three ships, two aircrafts and one helicopter. The main ship had the tasks of coordinating the experiment, creating the crude oil spills and spraying dispersant for the slick treatment. This ship was equipped with the DACAMA pumping system. A second ship had the main duty of spraying dispersant, while an assistance ship was in charge of the water surface and water column sampling.

During the campaign, the atmospheric data (wind, temperature and humidity) were measured by a MARISONDE buoy of Météo France, while the sea state was measured by a WAVERIDER buoy from the French CETMEF (*Centre d'Etude Technique Maritime et Fluvial*). The main ship created two oil slicks: each oil slick was 300-400 m wide, with a distance between the slicks of less than 1 km. Each slick was marked with different buoys: two NORDA and one IESM belonging to the French SHOM (*Service Hydrographique de la Marine*). The drift of the spills was tracked by the helicopter and an aircraft; a slick drift prediction model of Météo France was also employed. Each slick was sampled and dispersed at different stages. Several physical-chemical parameters were extracted from the on site samplings: viscosity, density, emulsion stability, water content, evaporation, flash point and oil dispersibility.

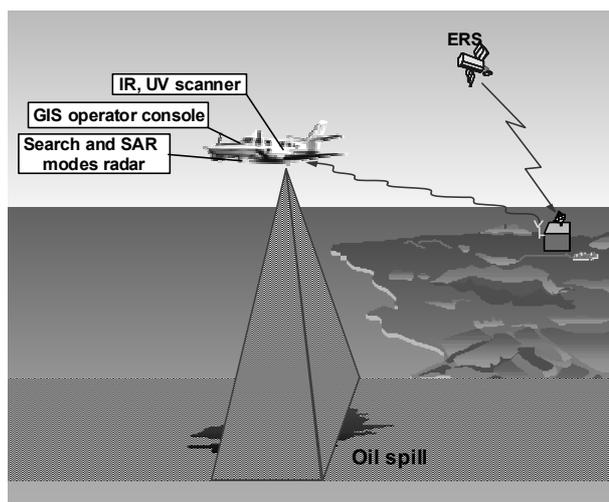


Figure 1. Scheme of the RAPSODI anti-pollution system.

During the experiment a Mystere-20 plane of the French Test Flight Centre, which was equipped with the Thales Ocean Master coherent X-band radar, flew over the test area. In addition, an aircraft dedicated to oil pollution monitoring, the POLMAR-2, collected SLAR and IR/UV images. Moreover, Radarsat satellite images of the test area have been acquired. The trajectory of the SAR aircraft, in its third flight during the campaign, is shown in Figure 2. The SAR data acquisition strategy was based on four perpendicular passes over each oil slick, as it is illustrated in Figure 3: in order to maximize the information to be derived from the data, each oil slick was observed from two perpendicular directions. At the operating geometries the sea reflectivity is maximum when the wind is blowing towards the radar line of sight (Long, 1983; Daley et al., 1970).

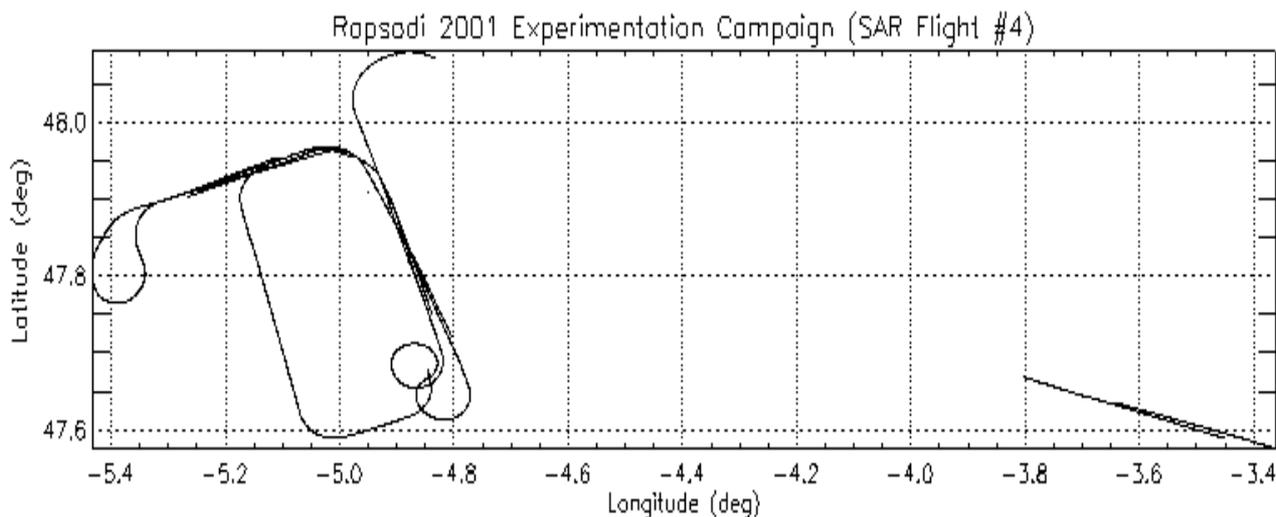


Figure 2. Trajectory of one SAR flight of the RAPSODI experimental campaign.

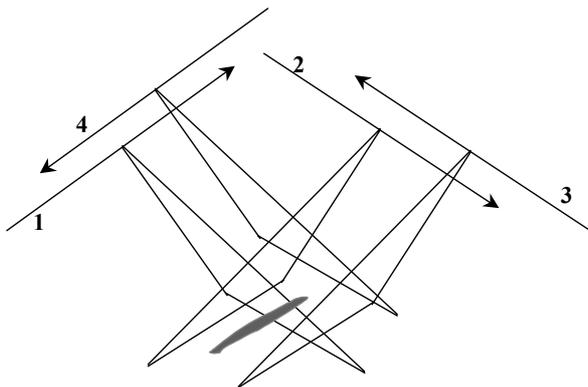


Figure 3. Four passes over an oil slick, which is seen under different viewing angles.

### 3. SAR DATA PROCESSING

The SAR raw-data collected during the experiment were processed at the Institute of Geomatics with a processor developed in the frame of the RAPSODI project. This processor includes procedures for the “motion compensation”, based on the navigation data provided by an integrated GPS/INS system (Stevens et al., 1995), and for the estimation of several processing parameters based on the radar data themselves. In particular, the processor implements algorithms for the estimation of the Doppler Centroid (Madsen, 1989; Bamler and Runge, 1991), the Doppler Rate (Li et al., 1985) and the

displacements on the line of sight (Mayer and Moreira, 1996; Moreira, 1990). During the experimental campaign thirty SAR images were acquired. Four of these images cover an area where a radar reflector for image calibration was installed. The sea images were then analysed at JRC to develop appropriate oil slick detection algorithms (see section 4).

Two SAR images of the campaign are shown in Figure 4. In Figure 4b it is shown an image of an oil slick, which covers approximately 1.8 by 3.3 km. The slick dimensions are about 0.4 by 3 km. In Figure 4a it is shown a calibration image, which includes the airport used during the campaign. The incidence angle (with respect to the vertical axis) of both images was about 80° (i.e. there was almost a horizontal incidence). Despite the very high incidence angle, one may notice that the oil slick is visible in Figure 4b. In principle, a lower incidence angle would be recommended to increase the oil spill backscattering contrast in a wide range of sea states (Pavlakis et al., 1996). However, a large incidence angle allows increasing the covered swath, while keeping a low flight height. During the acquisition of the SAR images all the ships involved in the campaign were operating in the test area. A SAR image of one of the ships is shown in Figure 5 (the image covers 8.6 by 1.8 km). The image proves the effectiveness of the employed SAR focusing algorithm. All images acquired during the campaign were geocoded using the navigation data (GPS/INS). It is important to emphasise that the geocoding represents a key step for a successful integration of multi-sensor data. An example of geocoded and radiometrically calibrated SAR image of an oil slick is shown in Figure 6.

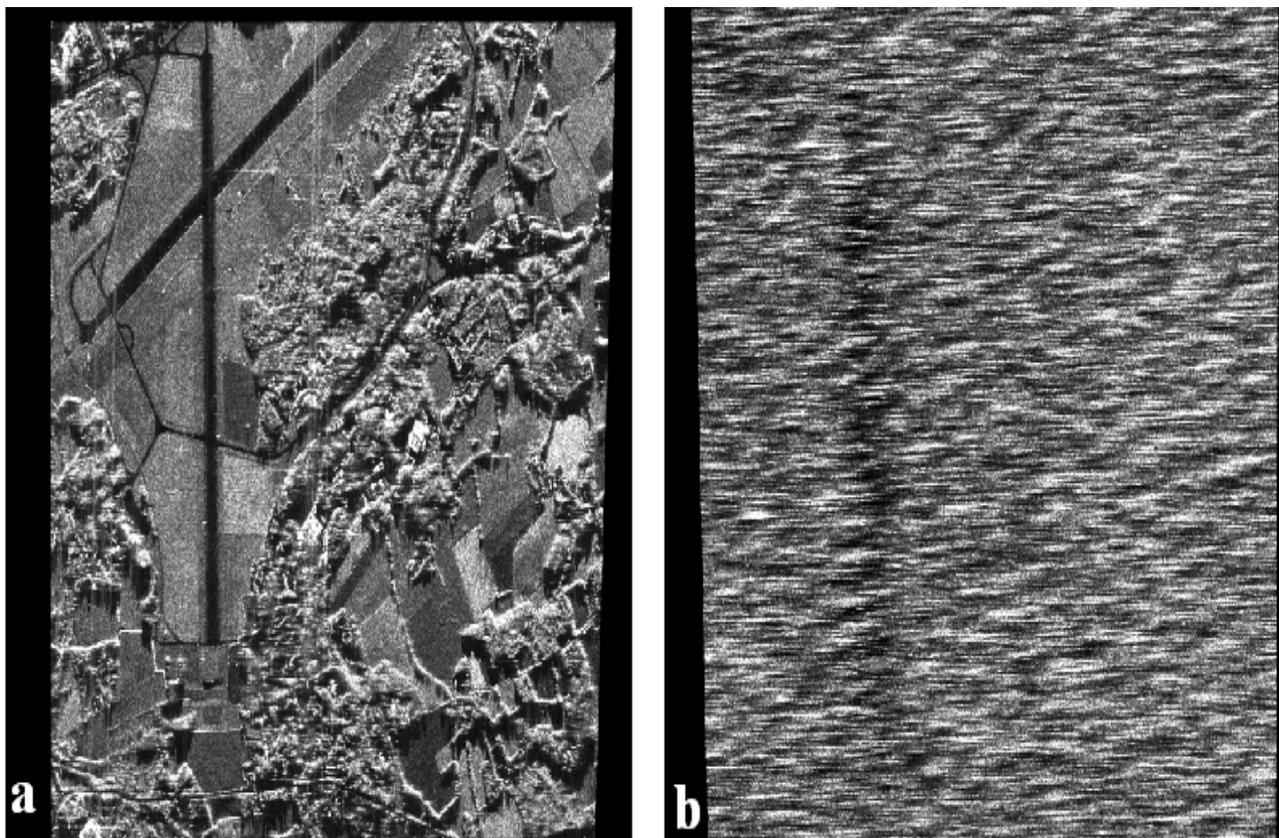


Figure 4. SAR images of the RAPSODI campaign covering the airport area (above) and an oil slick (below).

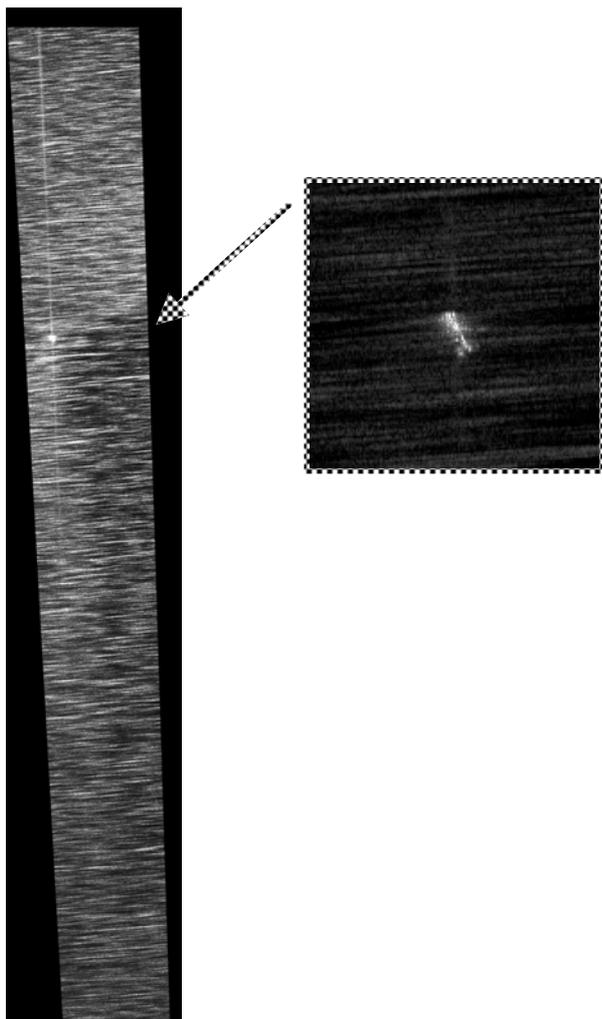


Figure 5. SAR image of one ship of the RAPSODI campaign.

#### 4. OIL SLICK DETECTION

An important task of the RAPSODI system is the automatic detection of the oil slicks and the extraction of the oil slick contours. A patch of oil is usually visible in a SAR image because the oil dampens out the surface waves, thus reducing the radar backscattering and making this area darker than the surrounding water (van Kuilenburg, 1975).

In the frame of the RAPSODI project the spill contour extraction represents a quite difficult task due to the peculiar characteristics of the SAR images, which were acquired with very high incidence angles. The results discussed in this paper represent the preliminary outcomes of an ongoing research. The oil spill radar signature at near grazing incidence angles is strongly degraded by different dynamic and periodic structures of the sea surface, like the long gravity waves, the boundary layer rolls (wind helical motion, which is aligned approximately in the wind direction), Langmuir circulation (sea strikes that are aligned approximately in the wind direction) and sea spikes (strong radar returns due to wave movement and breaking, which are aligned in the azimuth direction).

In the first part of the project various oil spill detection algorithms have been tested. An example of oil slick contour extraction is shown in Figure 7. One may notice that the image smoothing achieved with the classical median filtering (7b) is not suitable for the contour detection, while better results are obtained through an adaptive filtering, which is tailored to the specific features of the airborne SAR images (7c).

In general, owing the peculiar characteristics of these images, the classical algorithms developed for slick detection on spaceborne SAR images proved to be not adequate to the detection on the airborne images of the RAPSODI project. In the second part of the research, particular attention will be paid to the development of contour extraction algorithms optimised for airborne SAR images. Some preliminary encouraging results have been obtained using directional and spectral filters, which take into account the above-mentioned periodic structures of the sea surface.

#### 5. CONCLUSIONS

In this paper, the main results of the RAPSODI project have been discussed. This project is devoted to the development of a new anti-pollution remote sensing system for the detection and monitoring of maritime pollution and the support of the associated clean-up operations. The project belongs to the Fifth European Community Framework Programme and is carried out by multidisciplinary consortium, which includes experts in airborne radar systems, in satellite remote sensing, in radar signal processing and in maritime pollution.

One of the main operational goals of the project has been the realization of a real-size experimental campaign, which has been performed in completely controlled conditions. For its important characteristics (e.g. the oil slick realises, the wide range of *in situ* measurements, the acquisition of remotely sensed data) the RAPSODI campaign represents a valuable source of experimental data. In this paper the main characteristics of the campaign have been described.

The SAR raw-data collected during the RAPSODI campaign have been processed with a new SAR processor tailored to the specific needs of the RAPSODI system. This processor implements motion compensation procedures and estimates several processing parameters (Doppler Centroid, the Doppler Rate and the displacements on the line of sight) from the radar data themselves. All the images collected during the campaign (thirty SAR images) have been processed and geo-referenced using the navigation data (GPS/INS). The geocoding represents a fundamental step to guarantee a successful integration of multi-sensor data. Despite the unfavourable geometric conditions of the SAR acquisitions (all images were acquired with very high incidence angle) the images proved to be suitable to support the oil slick detection.

An important task of the RAPSODI system is the automatic detection of the oil slicks and the extraction of their contours. This represents a quite difficult task: the classical algorithms developed for slick detection on spaceborne SAR images proved to be not adequate to the detection on the airborne images of the RAPSODI project. Further research is required to develop automatic and reliable contour extraction algorithms.

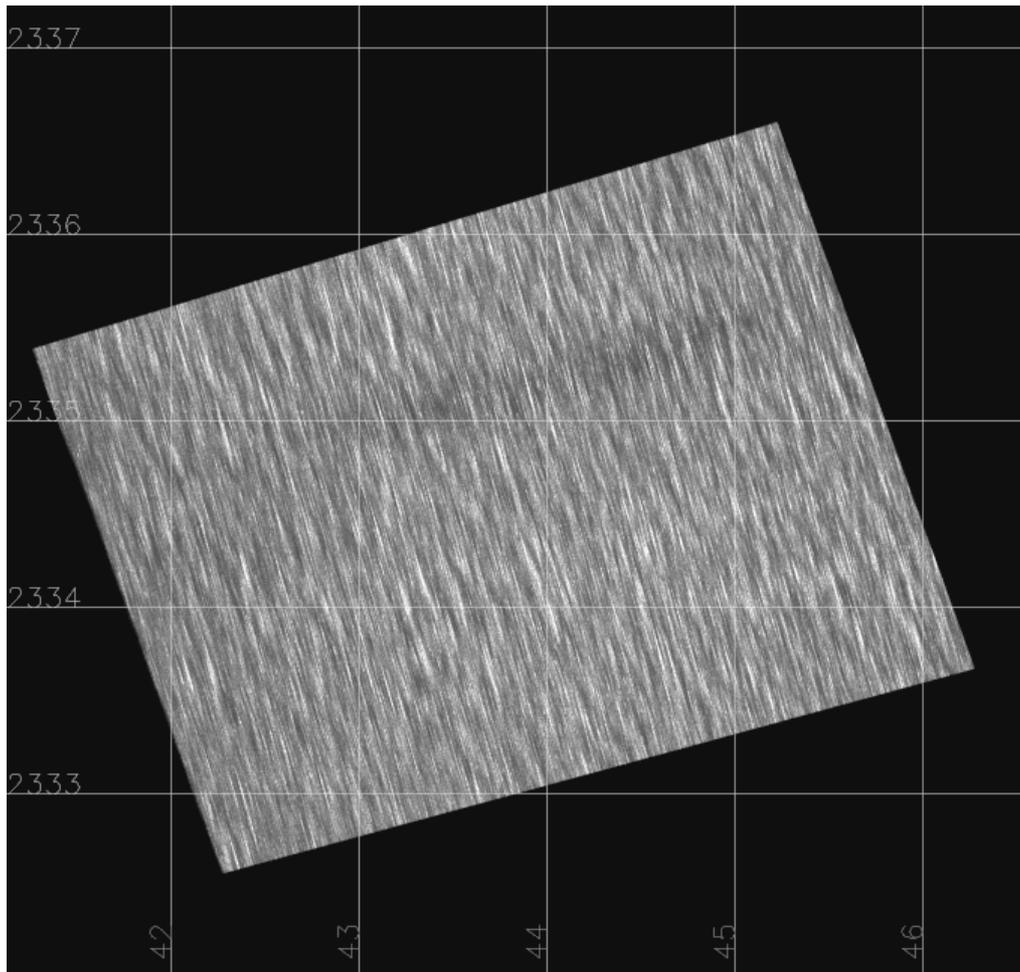


Figure 6. Geocoded and radiometrically calibrated SAR image of the RAPSODI campaign covering an oil slick.

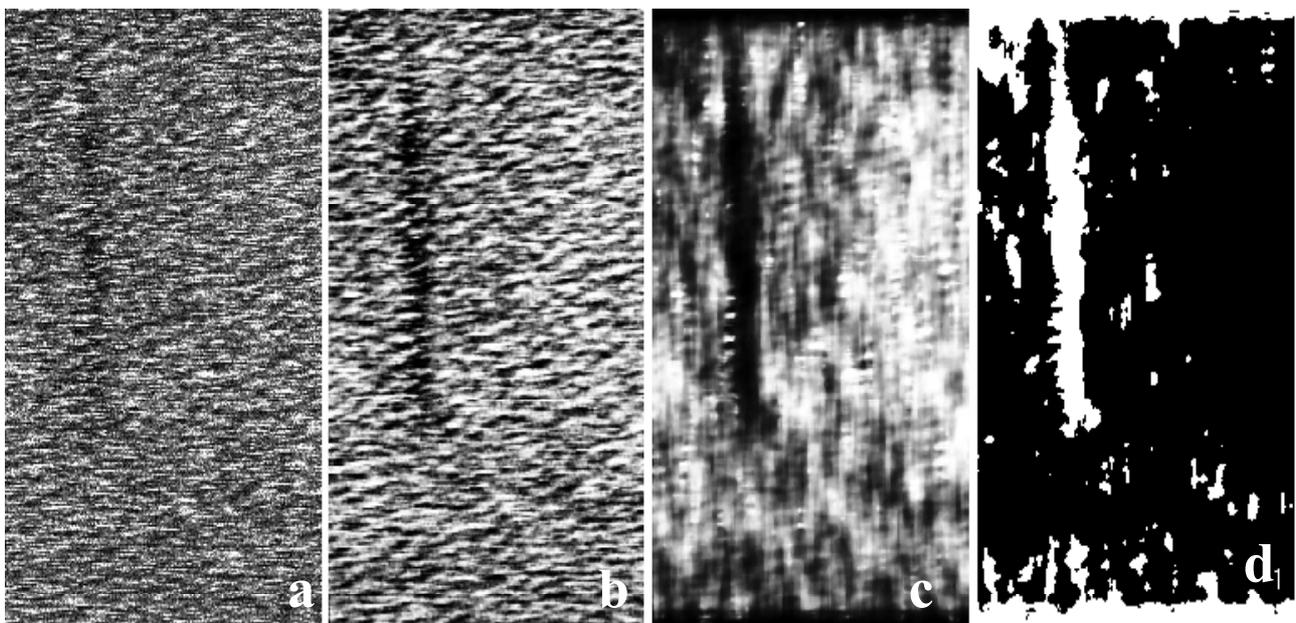


Figure 7. Oil slick detection and extraction of the oil slick contours on an airborne SAR image of the RAPSODI campaign. Original SAR image (a); image smoothed with the classical median filtering (b); image smoothed with an adaptive filtering (c); final binary image obtained by a thresholding applied on the previous image (d).

### ACKNOWLEDGMENTS

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