RADAR AND OPTICAL REMOTE SENSING IN OFFSHORE DOMAIN TO DETECT, CHARACTERIZE AND QUANTIFY OCEAN SURFACE OIL SLICKS

Véronique Miegebielle(1), Sébastien Angelliaume(2), Françoise Viallefont-Robinet (2), Elise Koeniguer (2), Fabrice Janez (2), Xavier Ceamanos(2), Cédric Taillandier(1), Dominique Dubucq(1), Alexandre Boulch(2), Philippe Déliot (2)

1. Total, Recherche, CSTJF, 6 Avenue Larribau, 64018 Pau, France
2. ONERA, Office National d'Etude et de Recherches Aérospatiales, France

ABSTRACT

One of the objectives of NAOMI (New Advanced Observation Method Integration) research project, partnership between Total and ONERA, is to work on the detection, the characterization and the quantification of off shore hydrocarbon at the sea surface. Search of natural (Seeps) or anthropogenic (Spill) gas or liquid hydrocarbon exhaust, will contribute to:

- The selection of large scale basins and mining domain selection for exploration application
- The detection of oil spill extension and location for environmental application.

This application concerns the detection of oil leakage for regular monitoring of offshore production facilities or in case of incidents occurring on sea surface (spill, boat sewages…). It is important to determine rapidly spill location and extension, but also to predict its drift, in order to inform where interventions teams should take action, and to evaluate the timing of impact areas. For the detection, metocean information as wind and wave improve the quality of the interpretation.

Distinction between natural oil seeps, oil spill and look-alikes such as natural algae may be tricky and requires variety data comparison. To that aim, this paper presents an airborne acquisition campaign carried out in 2015 named NOFO (Norwegian Clean Seas Association for Operating Companies) over controlled released of oil, off the Norwegian coast, dedicated to the testing of anti pollution equipment. First R&D works and perspectives are presented, related to the emergence of new techniques.

Index Terms— Radar, SAR, Optical, Fusion, Multifrequency, Polarization, Hydrocarbon, NOFO, NAOMI (New Advanced Observation Method Integration)

1. INTRODUCTION

The objective of this paper is to present research work developed in Total-Onera partnership (NAOMI) in terms of detection of natural (seeps) and anthropogenic (spill) hydrocarbons in the offshore domain for Environment and Exploration applications:

- In response to incidents potentially occurring at or nearby offshore oil facilities
- Regular monitoring of the mining area.
- Research related to the emergence of new technologies to distinguish hydrocarbons from look-alikes (algae atmospheric phenomena, low wind area, island, rain cell, …)

It should be noted that in the offshore domain, the majority of the satellite data used for the detection of hydrocarbons in operational context is SAR sensors. However, the use of optical data is important because the physicochemical properties linked to the optical data make possible the discriminate between hydrocarbon indices and look-alikes. Moreover, the complementarities of multi-frequency radar data, multi-band optical data and radar / optical data is an important way of improvement in the context of slicks monitoring. In order to work in these fields, an acquisition campaign in Norway during the 2015 NOFO (Norwegian Clean Seas Association for Operating Companies) was led. Images (SAR/Optical) of these exercises, first R&D works and perspectives, related to the emergence of new techniques are presented in the following.

2. NOFO EXPERIMENTATION: AERIAL CAMPAIGN

The aim of this work is to develop methods and optimal sensor configurations for the detection, characterization and quantification of hydrocarbons at sea. An acquisition campaign in Norway was carried out by SETHI (ONERA airborne system onboard a Falcon 20) during controlled releases of oil realized by NOFO in June 2015.

SETHI is an airborne remote sensing imaging system developed by ONERA. It integrates a new generation of radar and optronic payloads and can operate over a wide range of frequency bands. SETHI is a pod-based system operating onboard a Falcon 20 Dassault aircraft, which is owned by AvDEF. For these experiments, imaging sensors are as follows:

- 2 synthetic aperture radar (SAR) at X and L bands, in a full polarimetric mode (HH, HV, VH, VV)
- 2 HYSPEX hyperspectral cameras in the VNIR and SWIR bands

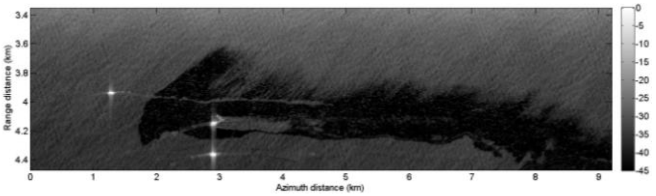
Radar and optical acquisitions are made successively on each sheet according to flights: an optical sighting vertical to the zone of interest and a radar sight when passing on the opposite axis.

Images were acquired on 3 leaks during 4 Flights which constitutes a unique database for research work. However due to poor weather conditions, the quality of some optical acquisitions is not optimal

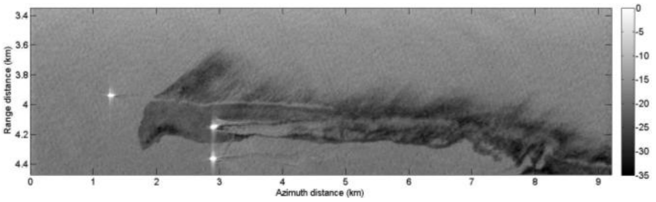
3. MICROWAVES DOMAIN

For this experiment at sea, quad-pol SAR data were acquired by ONERA at X- and L-band, with a range resolution of 0.5 m and 1.0 m respectively. Images are processed with an azimuth resolution equal to the range resolution at both X- and L-band, which implies an integration time equal to 1.1 s at X-band and 4.1 s at L-band. Imaged area is 9.5 km in azimuth and 1.5 km in range, with incidence angles from 34° to 52°. The Noise Equivalent Sigma^0 (NESZ) has been estimated using the method proposed in [1]. It is ranging from around -37 to -50 dB at X-band and from around -51 to -53 dB at L-band. These very low values must allow a sufficient signal to noise ratio (SNR) over oil slick for efficient analysis.

The added value of multifrequency POLSAR imagery for monitoring oil slicks at sea is illustrated in Figure 1.



(a): X-band



(b): L-band

Figure 1: SAR imagery over oil slicks at X-band (a) and L-band (b), VV polarization, 9 June 2015 10:02 UTC

As previously observed in [2], we measure here that the contrast between the oil slick and the clean sea surface is more significant at high frequency (X-band in this study) than at low frequency (L-band). However, while at X-band the slick seems homogeneous (Figure 1a) at L-band (Figure 1b) we observe strong variations of the EM signal into the slicks with dark patches. Short gravity-capillarity waves, corresponding to the X-band Bragg wavelength, are damped anywhere within the spill which implies a uniformly low response over the polluted area. At L-band, the slicks looks heterogeneous and a high SNR allows us to identify areas where the released product as a stronger impact than elsewhere, probably due to a higher concentration of the oil. These observations support previous results [2], [3] and the NRCS model [4] which all show that the characteristics of EM backscatter over contaminated seawater are wavelength-dependent. Thus, by using different frequency bands, we should be able to better characterize the released product. From these first observations, we recommend to use multifrequency SAR imagery in the following way: high frequency is used to detect the slick and low frequency is then used to quantify the relative concentration of the detected product. This particular aspect will be analyzed in more details later in our studies.

4. OPTIC DOMAIN

Main optical data are delivered by the two hyperspectral cameras. The VNIR camera provides hypercubes between 0.4 and 1.0µm with a spectral resolution of 3.7 nm and a spatial resolution of 0.8m. For the SWIR camera, the spectral range is 1.0 to 2.5µm with a spectral resolution of 6 nm and a spatial resolution of 1.6m. Data are first corrected for atmospheric effects to retrieve surface reflectance. The following step consists in processing the VNIR and SWIR images separately. The detection is performed thanks to spectral indexes borrowed from the literature: Fluorescence Index (FI) and Rotation Absorption Index (RAI) [5] for the VNIR and Hydrocarbon Index (HI) [6] for the SWIR. The FI and RAI indexes calculate a contrast between two spectral bands, blue and red for FI, blue and 0.85 µm for RAI. For the RAI, the contrast is multiplied by the norm of the reflectance, which manages to eliminate the clouds. The drawback of taking into account the norm of the reflectance is to be sensitive to the change of the background reflectance of the sea. The combination of the FI and the RAI enables to eliminate clouds, as shown in the green circle of Figure , and changes of the background level except when they occur simultaneously, as shown in the red circle of Figure . The HI provides the magnitude of the absorption peak of hydrocarbons around 1.7 µm. This enables to detect the thicker parts of the oil slick, as shown in the upper right side of Figure 3.

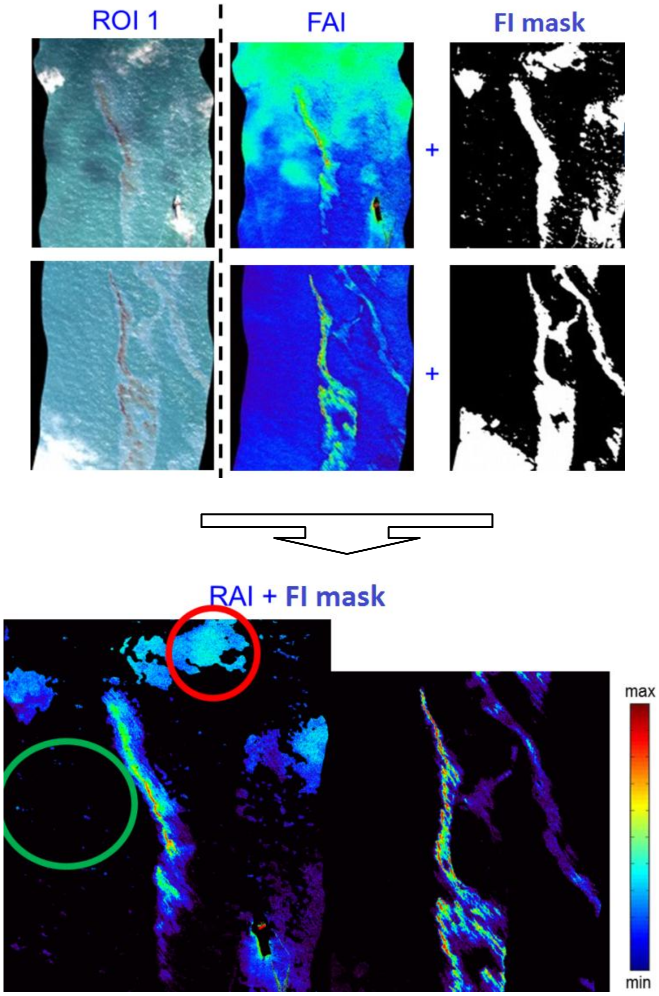


Figure 2: Detection with FI and RAI

The characterization and the quantification of the oil slick are performed thanks to spectral matching technique. This relies on a spectral library. Our spectral library has been built thanks to in laboratory spectral reflectance measurements of samples of the emulsion poured into the sea. The different emulsion samples are constituted with a varying thickness. Unfortunately, the delay between the laboratory measurements and the emulsion production was quite long and the emulsion state is likely different between the airborne acquisitions and the sample measurements.

The Spectral Information Divergence (SID) [6] is the chosen algorithm for the spectral matching, as it is a classical measure that is sensitive to the shape of the reflectance spectra. The application of the SID provides a map of the slick thickness, as shown in Figure 3. The spectrum of the library corresponding to the majority of the detected pixels is selected to build a new spectral library. New spectra are computed by linearly mixing emulsion and clean water spectra in order to characterize pixels which are only partially covered by the emulsion. The ratio between the spectra corresponds to the area fraction that is to say the proportion of pixel area covered by the emulsion. The SID is computed once again and provides a map of area fraction as shown in Figure 4.

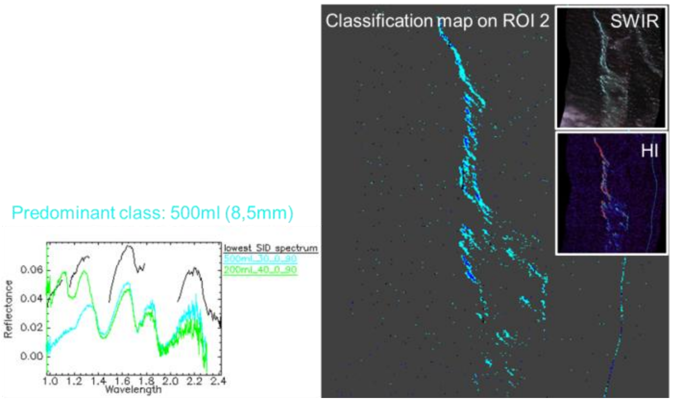


Figure 3: Spectral matching for width estimation

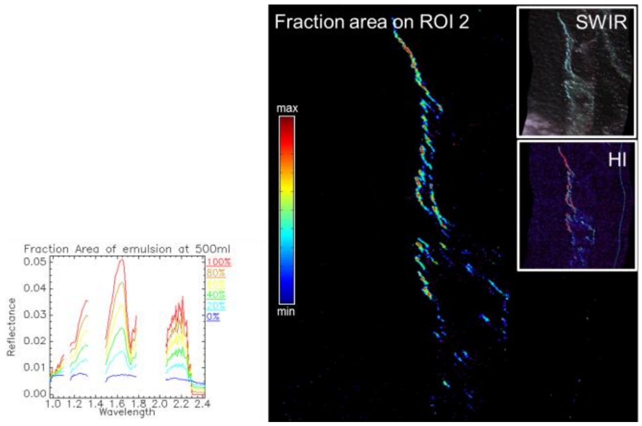


Figure 4: Spectral matching for fraction area estimation

These first results are very encouraging. Further work will aim to mix the oil emulsion again in order to have a better spectral library. Also, registered VNIR and SWIR images will be processed.

5. DATA FUSION

As can be seen in the preceding paragraphs, the different portions of the electromagnetic spectrum provide complementary information. To quantify this synergy, whether for detection or characterization, a first step is to study images in a common reference frame, using a co-registration method. This step is essential for the fusion because the images acquired by the various sensors do not perfectly match, even after geo-referencing:

- On the one hand the VNIR and SWIR sensors are different and it is necessary to correct the geometrical distortions existing between them
- On the other hand, optics and radar images are not perfectly simultaneous. Temporal baselines are about 10

minutes and we want to compensate the likely movements of oil spilled

To this aim, we use a co-registration method based on image information without auxiliary data, called GeFolki. To coregistrate VNIR and SWIR images, we choose to compute the deformation in the common frequency band. In this case, our method is particularly robust, even if a low contrast exists in this wavelength between the spill and the sea surface. Therefore, the algorithm has been applied successfully and makes it possible to correct the biases of a few pixels existing on the position of the oil spilled between two sensors, as illustrated on the superposition of VNIR and SWIR on Figure 5.

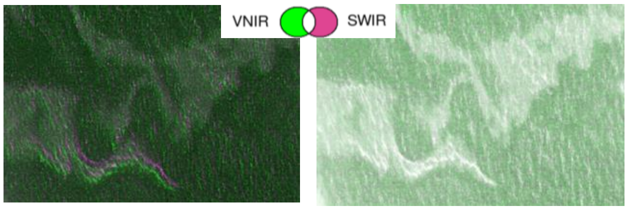


Figure 5: Superimposition of the common VNIR and SWIR bandsbefore (left) and after (right) coregistration

Concerning the registration of the optical data and radar, the problem is different and we apply our algorithm in its version dedicated to heterogeneous images. The aim is to see if it is possible to recover the deformation of the spill that occurred in a few minutes. An in-depth analysis of this task is underway.

6. FUTURE ADVANCED PROCESSING

Furthermore, for future automatic processing, machine learning algorithm including deep learning methods can be considered, particularly interesting for multivariate images. For example, by using user annotation on the image, neural networks can handle color regression on the coded signal to propose an automatic visualization that highlights the desired contrasts, as on the example in Figure 6.

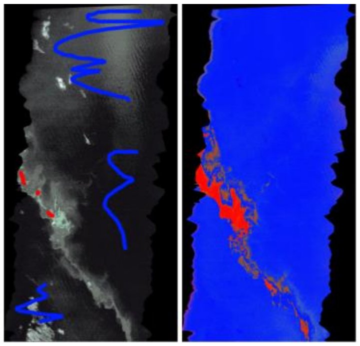


Figure 6: External annotations used as color guidance to highlight deepwater oil spill.

7. CONCLUSION AND PERSPECTIVES

This publication describes an offshore radar / optical acquisition campaign.

This data set is unique in the world, because its provides access to a realistic and comprehensive data set for the detection of hydrocarbons within the offshore segment. The validation of conventional methods has been achieved based on the results of this campaign. In addition, the study indicated good perspectives for the validation of alternative innovative methods based on signal physics and on "machine learning" methods.

8. REFERENCES

[1] I. Hajnsek, E. Pottier and S. R. Cloude, "Inversion of surface parameters from polarimetric SAR," in *IEEE Transactions on Geoscience and Remote Sensing*, vol. 41, no. 4, pp. 727-744, April 2003

[2] V. Wismann, M. Gade, W. Alpers and H. Huhnerfuss, "Radar signatures of marine mineral oil spills measured by an airborne multi-frequency radar," *Int. J. Remote. Sens.* 19, 3607-3623(1998).

[3] M. Gade, W. Alpers, H. Hühnerfuss, H. Masuko, and T. Kobayashi, “Imaging of biogenic and anthropogenic ocean surface films by the multifrequency/multipolarization SIR-C/X-SAR,” *J. Geophys. Res.*, vol. 103, no. C9, pp. 18 851–18 866, 1998.

[4] M. Lennon, V. Mariette, A. Coat, V. Verbeque, P. Mouge, G. A. Borstad, P. Willis, R. Kerr and M. Alvarez “Detection and mapping of the November 2002 Prestige tanker oil spill in Galicia, Spain, with the airborne multispectral CASI sensor”, *3rd EARSEL workshop on Imaging Spectroscopy*, Herrsching, 13-16 May 2003.

[5] F. Khûn, K. Oppermann and B. Hôrig, "Hydrocarbon index – an algorithm for hyperspectral detection of hydrocarbons", *INT. J. Remote Sensing*, vol. 25, N° 12, pp 2467-2473, 2004.

[6] C.-I. Chang, « An Information-Theoretic Approach to Spectral Variability, Similarity, and Discrimination for Hyperspectral Image Analysis », *IEEE Transactions on Information Theory*, 46, 5, August 2000.