AUTOMATIC DETECTION OF MARINE OIL SLICKS USING RADAR IMAGES: PETROLEUM AND ENVIRONNEMENTAL APPLICATIONS

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Introduction and objectives

Oil slicks in radar images

Oil slicks floating on the sea surface becomes visible on radar images because it damps the short gravity-capillary waves that are responsible for the radar backscattering (Fig.1).

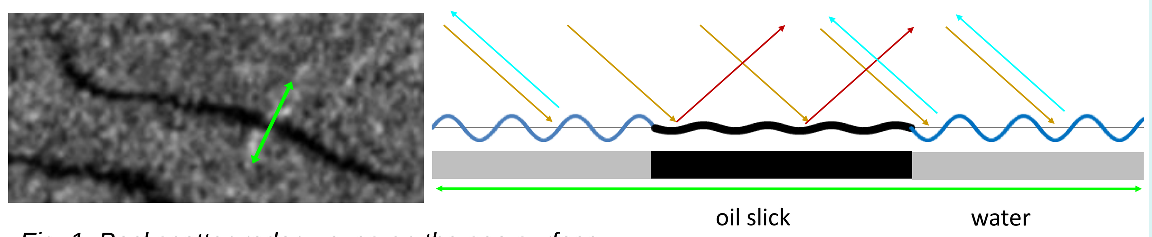


Fig. 1: Backscatter radar waves on the sea surface.

A huge amount of radar data to detect oil slicks

VisioTerra has gathered more than 45 TB of ERS SAR (Synthetic Aperture Radar) and Envisat ASAR data across the world, whose 10383 segment for Africa (Fig.2).

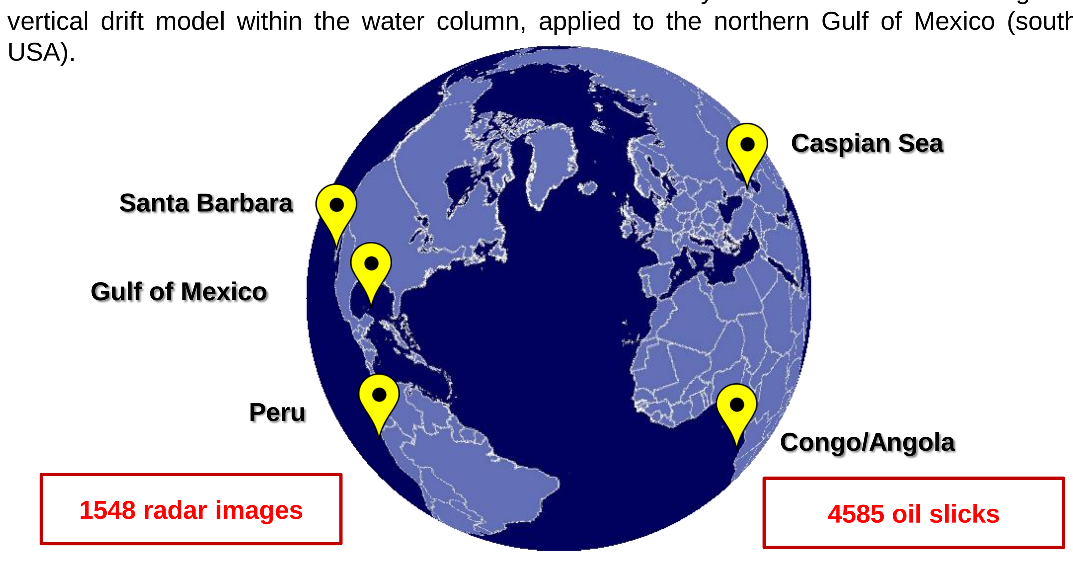
Objectives

This thesis deals with the preprocessing of radar images and their optimization for the analyzes in order to detect natural marine oil slicks (Sea surface Outbreak/SSO) as well as better determine their source location at the Sea Floor Source (SFS). We explained herein means, methods and difficulties encountered. This thesis consists of the following three distinct research axes represented by three submitted papers :

1- A stochastic approach for pre-processing and improvement of C-band radar images to automatically detect oil slicks;

2- A stochastic approach using a large quantity of radar images to evaluate the influence of wind speed and the different modes of the instrument (SAR) on the delectability of marine oil slicks ;

3- Accurate location of the Sea Floor Source of marine hydrocarbon emissions using a new vertical drift model within the water column, applied to the northern Gulf of Mexico (southern USA).



Methodology

Pre-processing

Original methods based on CMOD model have been developed to numerically process the images (Fig.3).

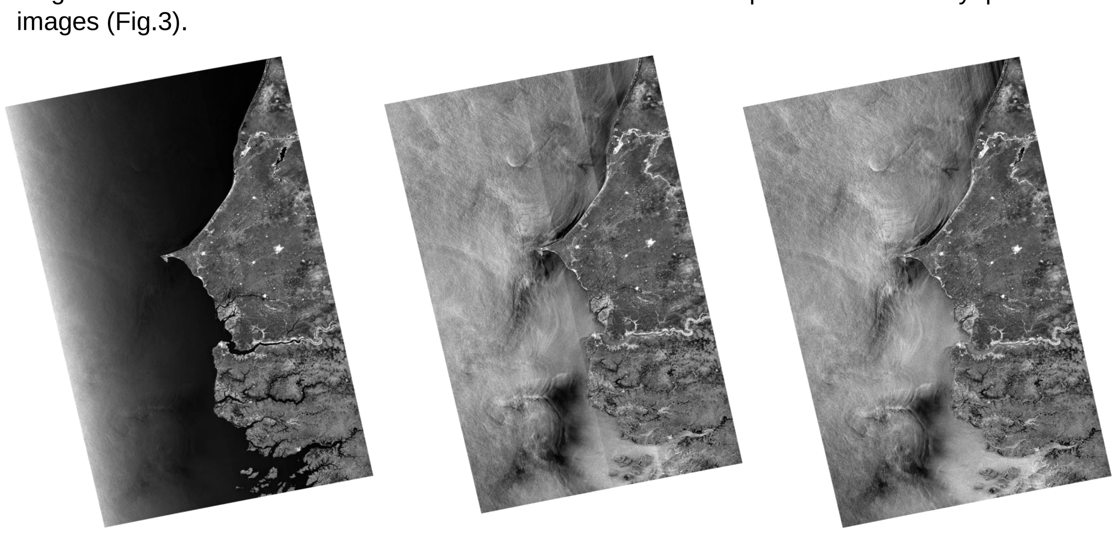


Fig. 3: Example of application of a model-based equalization and inter-swath correction

Segmentation

The used segmentation consist on a simple thresholding. The principle of this method is to use a threshold value *T* from which the pixels whose gray level is below *T* become black, and those above become white. The output of the thresholding segmentation is a binary image.

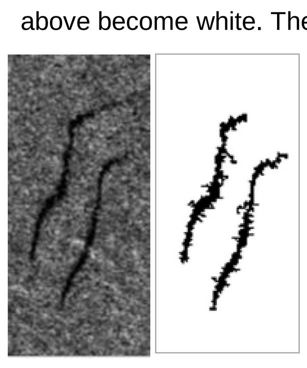


Fig. 4: Oil seep and threshold image

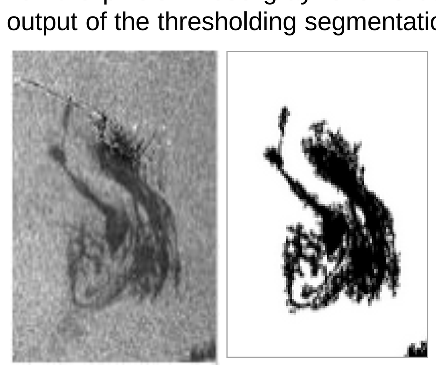


Fig. 5: Oil spill from platform and threshold image

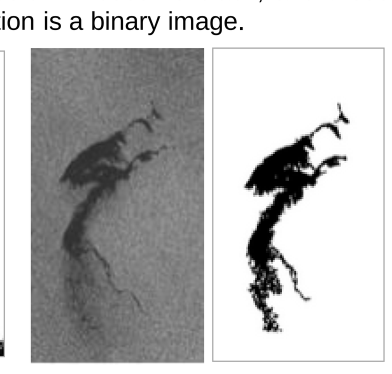


Fig. 6: Oil spill from ship and threshold image

Classification

Oil slicks are divided into two major categories: biogenic or mineral. Biogenic oil slicks are produced by plankton and fish substances normally released into the environment. The mineral oils are subdivided into those of natural seeps from the sea bottom or anthropogenic oil spills that originate from ships, refineries, oil terminals, industrial plants, oil platforms, and pipelines (Fig.7).

The mean non-oil features (oil slicks lookalikes) present on the sea surface are mostly due to meteorological conditions. They include upwelling, internal wave, rain cell, wind shadow, and sea currents.

The discrimination between oil slicks and lookalikes is usually based on different characteristics such as geometry, shape, texture, and other contextual information related to the surroundings. The treatment and characterization of lookalikes is important for oil slicks automatic detection since it helps to reduce false alarms.

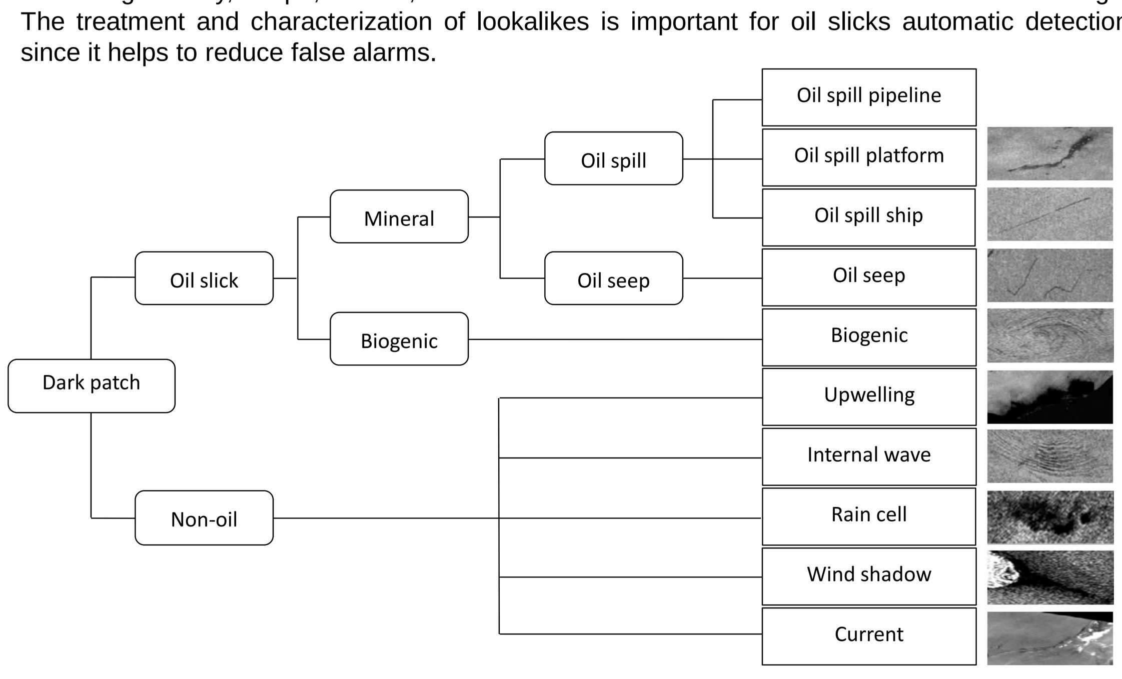


Fig. 7: Main offshore dark patches seen in SAR images.

The used classification method is based on decision trees (Fig.8).

The inputs of the decision tree are the geometric, textural and contextual parameters of the dark bodies.

The classification method has been applied to three large study areas (Congo Basin, Caspian Sea and Santa Barbara).

To estimate the performance of the classifier, control data was used. The confusion matrix indicates that **76%** of dark objects were well classified (Fif.9)

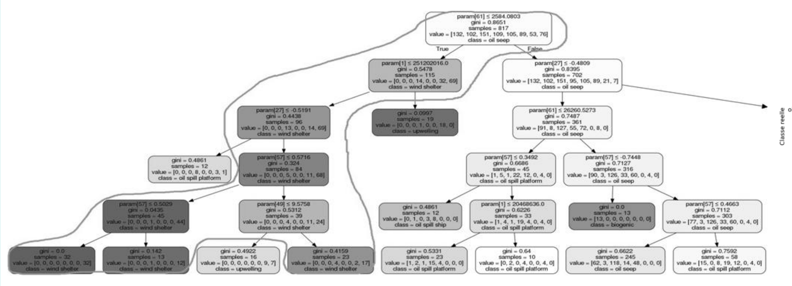


Fig. 9: A decision tree for the wind shelter class.

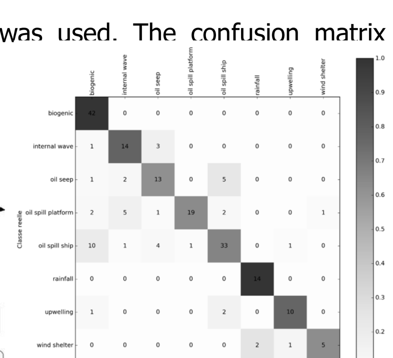


Fig. 8: Oil spill from ship and threshold image

Results

Oil slicks detectability

The assessment of the influence of the wind speed on the detectability of oil slicks consists of calculating the probability to detect an oil slick for a given wind speed.

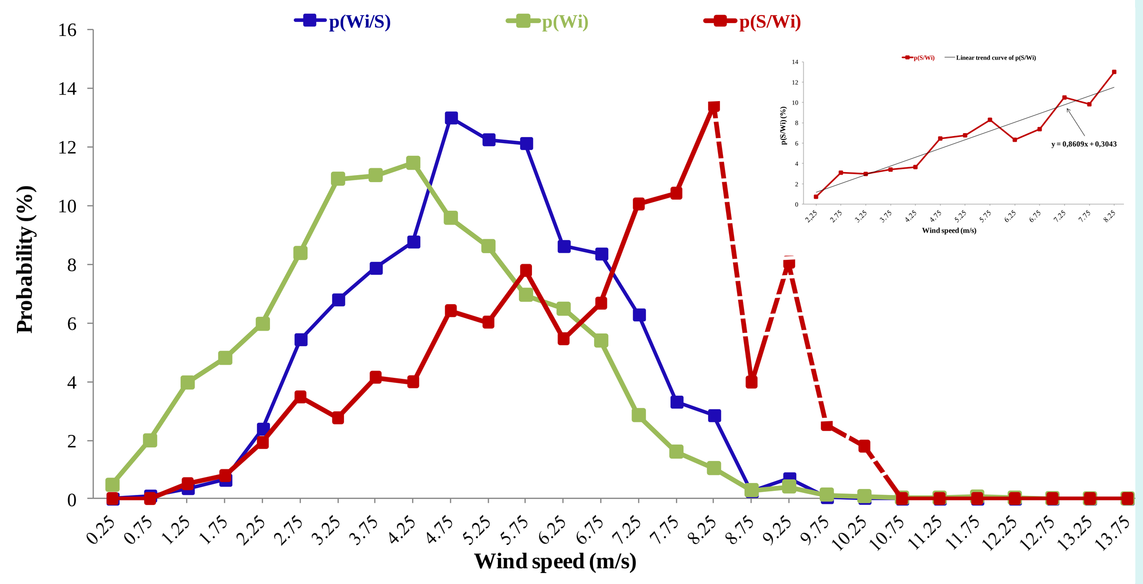


Fig. 10: Probability to detect an oil slick on the sea surface. (red curve). The blue curve - p(Wi/S)- (left panel) corresponds to the wind speed distribution obtained from ECMWF model on all observed oil slicks (total 3903 studied); The green curve is the wind speed distribution in all location where a minimum of one oil slick is observed on all the SAR image dataset (total 609.220 studied samples same); Consequently, the red curve corresponds to the probability-p(S/Wi)- to detect an oil slick for a given wind intensity. It is the decorrelation in between the blue and the green curves as it is calculated from the ratio of p(Wi/S): p(S/Wi). For the first time, contrasting to previous studies, the red curve prove that the probability to detect an oil slick arises almost linearly with the increase of the wind speed as we observe that the maximum probability is reached at 8.25m/s

Petroleum application

Oil seeps migration from deep sediments to sea surface

Offshore natural oil seeps are streams of naturally occurring oils that migrate from the sediments below the seafloor and flow through the water column as oil drops, resulting in telltale slicks on the sea surface (Fig.11).

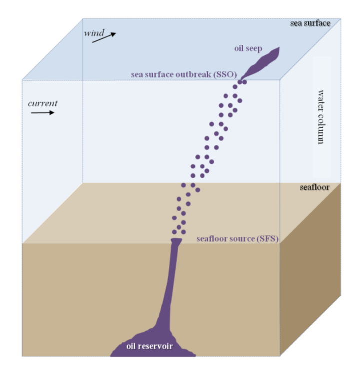


Fig. 11: Oil seeps migration from deep sediments to sea surface.

The Vertical Drift Model

Our goal is to locate the SeaFloor Source (SFS) from the oil seeps Sea Surface Outbreaks (SSO) observed on the radar images.

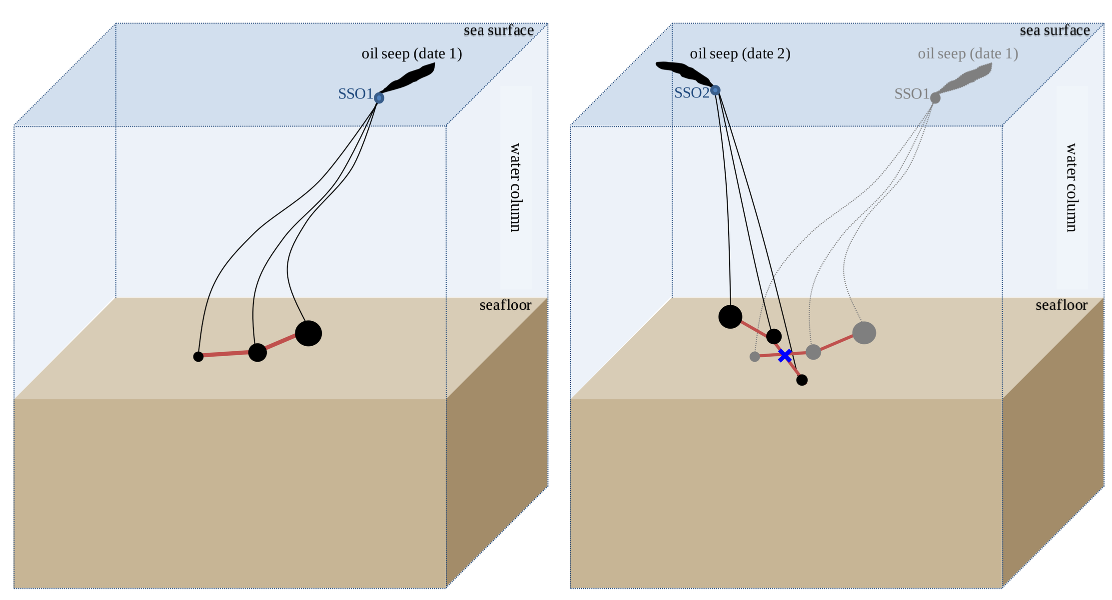


Fig. 12: Illustration of the sources paths principle. Left: sources path (red line) of a sea surface outbreak (SSO1) corresponding to an oil seep 1(observed on date 1). The black disks are the seafloor sources corresponding to droplets sizes'. Right: sources paths corresponding to the oil seep 1(observed on date 1) and the oil seep 2(observed on date 2). The red point corresponding to the intersection between the two sources paths is likely the seafloor source of the two multidate oil seeps.

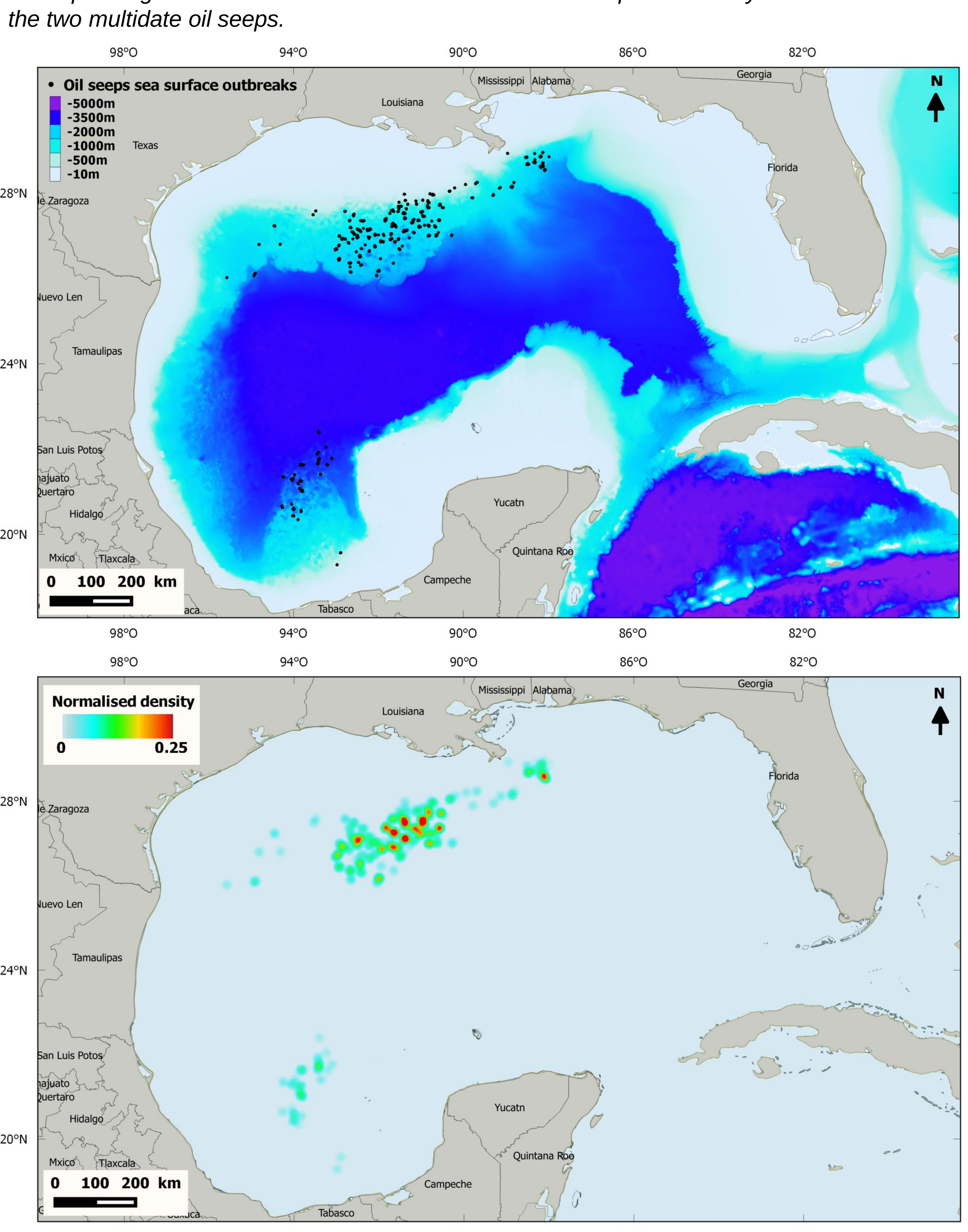


Fig. 13: Oil seeps in the Gulf of Mexico. Left: the 682 Sea Surface Outbreaks (SSO = Black dots), calculated from the 682 oil seeps sea surface outbreaks visually detected from 215 SAR images (2002-2012). Color chart: GOM bathymetry. Right: the normalized density map of the 682 Sea Surface Outbreaks

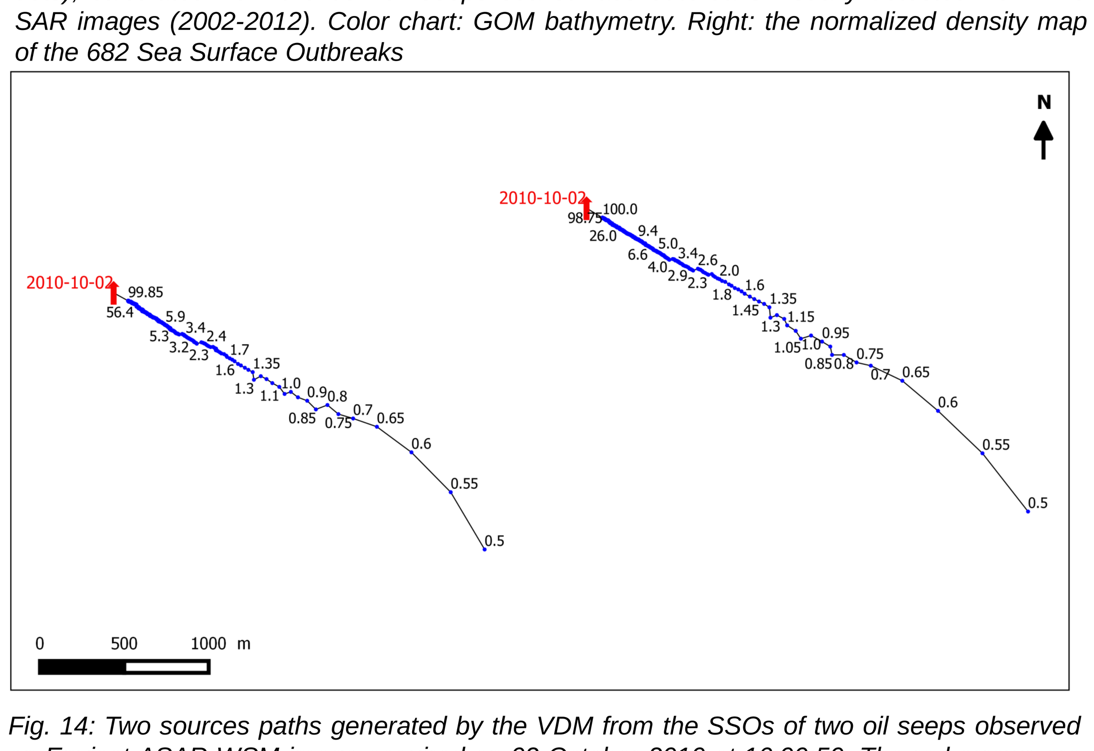


Fig. 14: Two sources paths generated by the VDM from the SSOs of two oil seeps observed on Envisat ASAR WSM image acquired on 02 October 2010 at 16:00:50. The red arrows are the SSOs while the blue points are the seafloor sources. The black polyline that joins the seafloor sources of an oil seep forms the sources path. Numbers correspond to the relative oil droplet diameters.

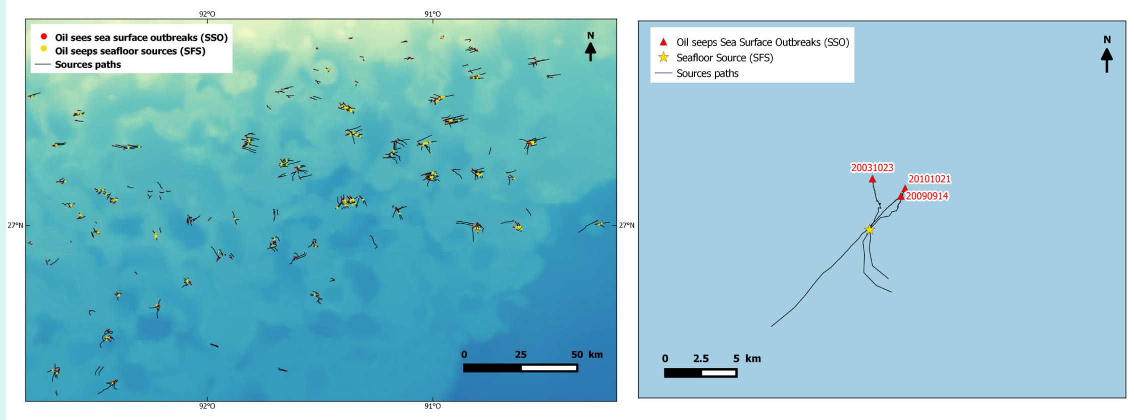


Fig. 15: The sources paths and their intersections in the Texas-Louisiana Slope. Left: the intersections points (yellow points) correspond to the estimated seafloor sources (SFS). Right: an example of three sources paths crossing. The yellow star is the estimated SFS of the three oil seeps observed on 23/10/2003, 14/09/2009, and 21/10/2010.

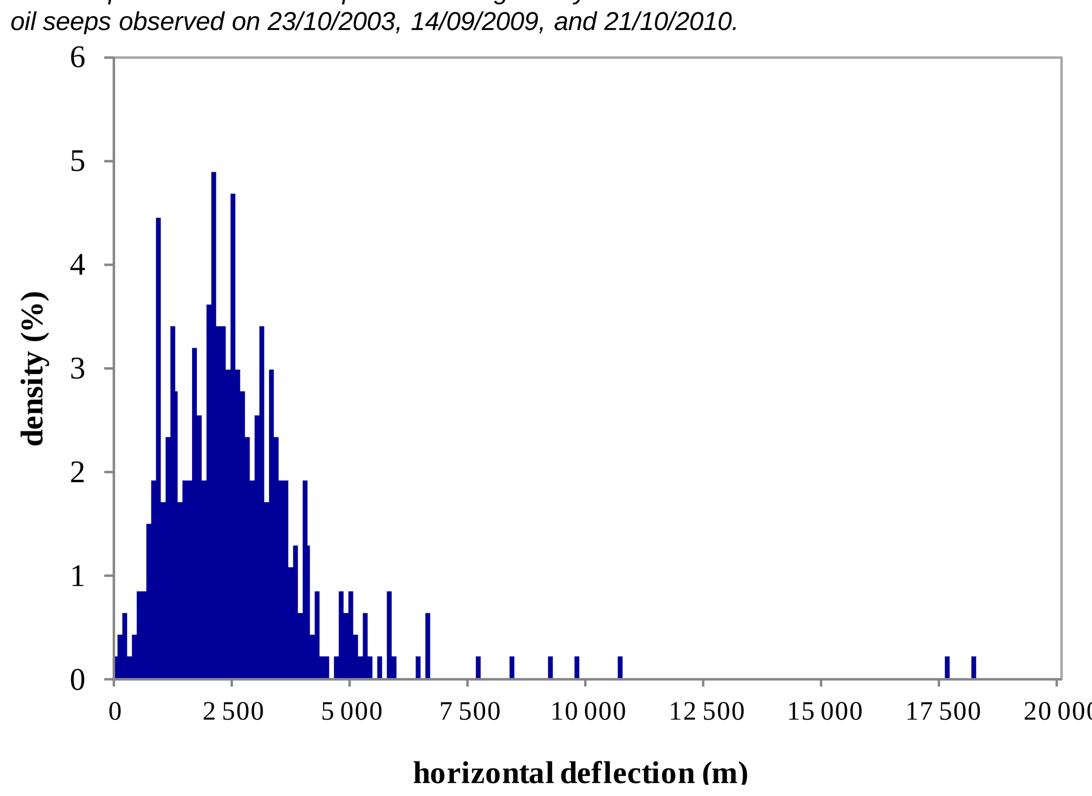


Fig. 16: The histogram of the distance of the observed oil seeps from their seafloor sources.

Environmental application

In addition to the petroleum concern, marine oil slicks represent environmental stake. Opportune and accurate detection of oil slicks can help identification and management of polluted areas and assessment of oil slicks drift in order to protect the coasts.

In the framework of this thesis, an automatic detection system of marine pollution has been performed. One the pollution detected, an alert is generated.

According to the extent of the pollution an drift model is triggered or not.

A model of the horizontal drift of oil slicks has been also developed. Knowing the position of the pollution, the model predict de drift according to the wind and current conditions (Fig.19).

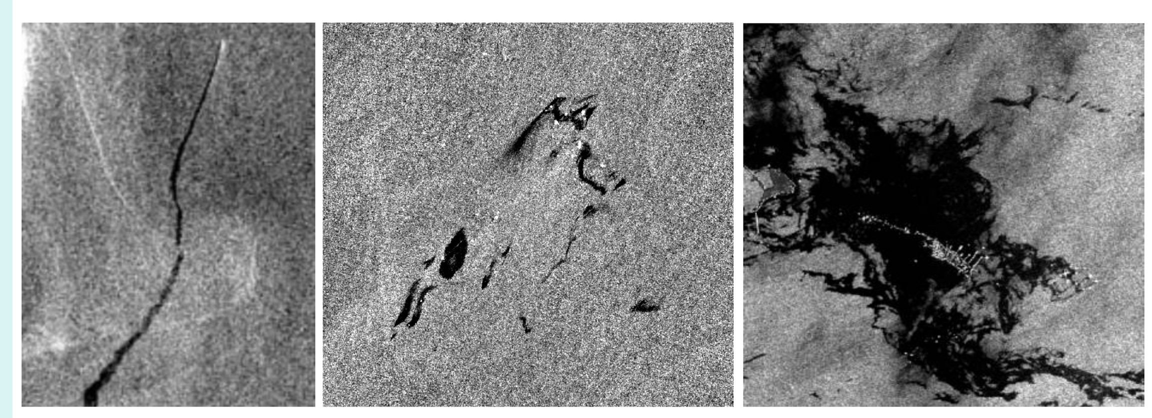


Fig. 17: Examples of oil spills.

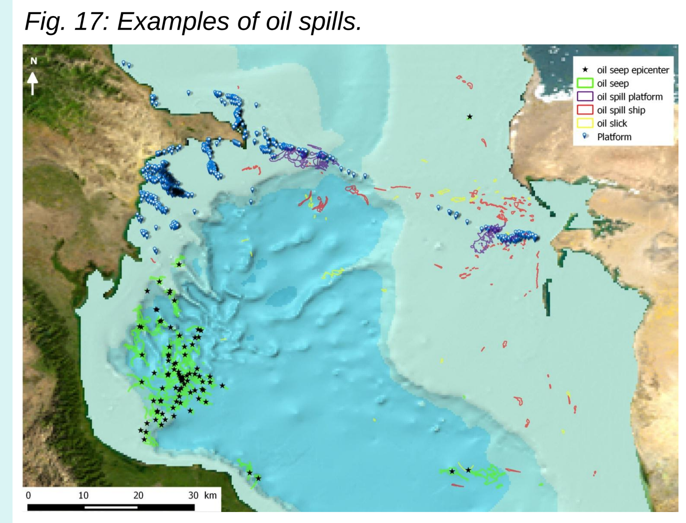


Fig. 18: Oil slicks in the Caspian sea.

Fig. 19: Horizontal drift model.

Conclusion

This work led us to a certain number of results whose aim is to improve the detection of oil slicks on the surface of the sea, whether they are of natural or anthropogenic origin. It has also allowed us to develop a new method allowing a better localization of the sources of the tablecloths, when these are of natural origin. It was also an opportunity to look at data preprocessing that allows the analysis and interpretation of radar images either manually or automatically.

An industrial process
- To optimize the detection of oil slicks on the surface of the sea,
- Detect the sources on the ocean floor of natural oil slicks observed on the sea surface.

Stochastic approach
- Large number of radar images
- Multivariate **problem**
- Wind patterns and currents

Outputs
- Optimal pretreatment regardless of distance to nadir, location on Earth, weather conditions...
- The influence of wind on detectability: global approach, all types and ages of oil slicks, seasonality, geographical contexts ...
- Models of vertical drift of oil slicks: geological validity.

limitations
- Using templates
- Time interpolation problem

Acknowledgement

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