OIL SLICKS DETECTION USING A POLARIMETRIC REGION CLASSIFIER

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ABSTRACT

A new region based classifier for polarimetric synthetic aperture radar data (PolSAR) was tested to evaluate its potential to discriminate different types of oil slicks at sea surface. This classifier uses a supervised approach to compare stochastic distances between complex Wishart distributions and hypothesis tests to associate confidence levels to the classification results. The preliminary results using the Battacharyya distance were promising, returning an overall accuracy of 90.61% at a significance level of 5%. Future works may compare the performance of different stochastic distances, together with the insertion of polarimetric features to improve the oil slicks classification.

Index Terms— *Synthetic Aperture Radar (SAR), Polarimetry, Region Based Classification, Stochastic Distances, Oil Slicks.*

1. INTRODUCTION

Oil spills are unpredictable events that may occur almost anywhere in the oceans, and sometimes in remote oceanic areas of difficult access. Depending on the meteo-oceanographic conditions, as well as the location, type and volume of the spilled oil, the slicks can spread over large areas and be broken into fragments of different geometries and thicknesses. In addition, the physical and chemical properties of the slicks can change significantly depending on the exposition time and weathering, which can make them look very different to visual observers as well as in remote sensing images.

The experience accumulated over decades using Synthetic Aperture Radar (SAR) to detect and monitor oil spills around the world, consolidated this microwave technology as the most operationally effective provider of data for this purpose, even under unfavorable meteorological conditions [1][2]. These coherent imaging systems are able to acquire data in different frequencies, incidence angles and resolutions with multiple polarizations, providing amplitude and phase information.

Recent studies [1][2][3], using several polarimetric attributes, have been investigating the potential of the polarimetric SAR (PolSAR) data to detect different backscatter mechanisms in oil slicks at sea surface, probably related to variations of the chemical properties, thickness and weathering. A range of classification methods has been tested, returning satisfactory results to separate mineral and plant oils, but with difficulties to discriminate between different types of mineral oils.

The objective of this paper is to present a new full polarimetric SAR data region classifier algorithm and the results of its application for oil spill detection. An important feature of the classifier is that, in addition to the classified image, a precision map of the classification is also provided.

2. POLSAR REGION CLASSIFICATION BASED ON STATISTICAL TESTS

The region classifier, named here PolClass, performs a supervised classification of PolSAR data, using stochastic distances and statistical tests involving these distances [4]. The entries of the classifier are the covariance matrix image (Z), a segmented image, and a set of training samples of the defined classes. The segmented image is an image with S disjoint segments, $R_1,\ldots R_S$. Let the covariance data (pixels) in the segment k be denoted by Z_{ik}, with $k = 1,\ldots,S$ and $i = 1,\ldots,N_k$, where N_k is the number of pixels in segment k. Assuming that Z_{ik} are Wishart distributed with parameters Σ_k and L, de maximum likelihood (ML) estimator of Σ_k is $\hat{\Sigma}_k = N_k^{-1}\sum_{i=1}^{N_k} Z_{ik}$ (in this work it is assumed that L is known).

Suppose also that the user wants to classify the image into C classes, assuming that the training samples of these classes are also Wishart distributed with parameter Σ_{C_j} and L, with $j = 1,\ldots,C$, and that the ML estimator of Σ_{C_j} based on samples of size M_j is denoted by $\hat{\Sigma}_{C_j}$.

The purpose of the classifier is to classify each of the S segments in one of the C classes. This classification is performed using stochastic distances between the distributions associated with each region and with each of the training samples. Frery et al. [5] developed five different distances between complex Wishart distributions: Kullback-Leibler, Battacharyya, Hellinger, Rényi and Chi-Square. In this work only the Battacharyya stochastic distance (d_{BW})

was used to evaluate the potential of PolSAR data to discriminate different types of oils and ocean. The Battacharyya distance between the two Wishart distributions, one associated to segment k and the other associated to the class j, is given by Frery at al. [5]:

$$d_{WB}\left(\hat{\Sigma}_k, \hat{\Sigma}_j\right) = L\left[\frac{\log\left|\hat{\Sigma}_k\right| + \log\left|\hat{\Sigma}_{C_j}\right|}{2} - \log\left|\left(\frac{\hat{\Sigma}_k^{-1} + \hat{\Sigma}_{C_j}^{-1}}{2}\right)^{-1}\right|\right]$$

Under the conditions stated by [5] [6], the hypothesis test $H_0 : \Sigma_k = \Sigma_{C_j}$ can be performed using the test statistic [4] [7], as indicated:

$$s_{WB}\left(\hat{\Sigma}_k, \hat{\Sigma}_{C_j}\right) = \frac{8N_k M_j}{N_k + M_j} d_{WB}\left(\hat{\Sigma}_k, \hat{\Sigma}_{C_j}\right)$$

The null hypothesis is rejected at a α significance level if $\Pr\left(\chi_\nu^2 > s_{WB}\left(\hat{\Sigma}_k, \hat{\Sigma}_{C_j}\right)\right) \leq \alpha$, where χ_ν^2 represents a chi-square distribution with ν degrees of freedom, being ν the number of parameters of the Wishart distribution. Therefore, assuming L known, ν = 9 for a 3x3 covariance matrix. The classification based on a minimum test statistic consists in assign the segment (R_k) to the class (l), if $s_{WB}\left(\hat{\Sigma}_k, \hat{\Sigma}_{C_l}\right) < s_{WB}\left(\hat{\Sigma}_k, \hat{\Sigma}_{C_j}\right)$, $\forall j \neq l$. When a segment R_k is assigned to the class l, the p-value ($p_{k,l}$) is calculated as $p_{kl} = \Pr\left(\chi_\nu^2 > s_{WB}\left(\hat{\Sigma}_k, \hat{\Sigma}_{C_l}\right)\right)$. At the end of the classification process, two images are provided, the classified and the *p*-values images. The *p*-values give the uncertainties of the classification.

3. RESULTS OF THE POLSAR REGION BASED CLASSIFIER

Complex polarimetric SAR data, containing different types of oil in the same scene, confirmed with field truth are rare. To test the potential of the proposed classifier to detect different types of oil, a Fine Quad-Pol Radarsat-2 image in a Single Look Complex (SLC) format (see details in Table 1), acquired during an open-water-exercise promoted by Norwegian Clean Seas Association for Operating Companies (NOFO) in North Sea, was used.

Table 1 – Radarsat-2 acquisition details.

DATA DESCRIPTION			
Data	8-Jun-2011	**Polarizations**	HH-VV-HV-VH
Time (UTC)	17:27:53	**Number of Looks**	1
Orbit	Ascending	**Swath (km)**	25x25
Mode	Fine Quad-Pol	**Pixel Spacing (m)**	4.7 x 5.1 (R x A)
Product Type	SLC / FQ15	**Lines x Columns**	6307 x 3369

During this occasion three different types of oil were released being [2]: (*i*) 0.4 m^3 of plant oil, used to simulate false alarms caused by natural biogenic oils; (*ii*) 20m^3 of emulsion containing 69% of water; (*iii*) 30m^3 of crude oil. Figure 1 shows the Pauli RGB composition of Radarsat-2 image, indicating the position of the three types of oil.

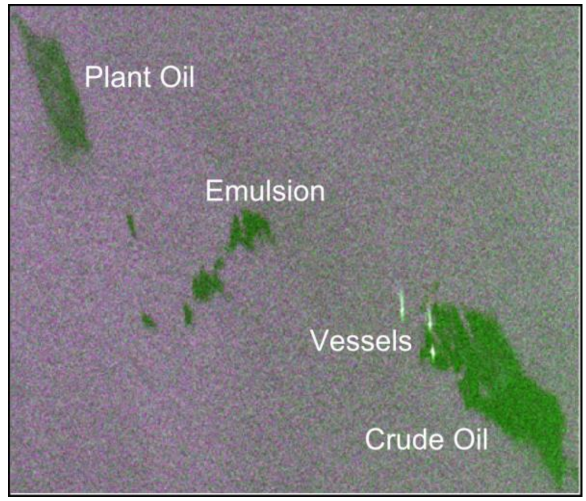

Figure 1. Pauli RGB composition using Radarsat-2 data acquired in a Fine Quad-Pol beam mode.

To provide the segmented image (Figure 2) to the PolClass classifier, an in-house hierarchical multi-level region growing segmentor was used, considering the minimum area as 100 pixels.

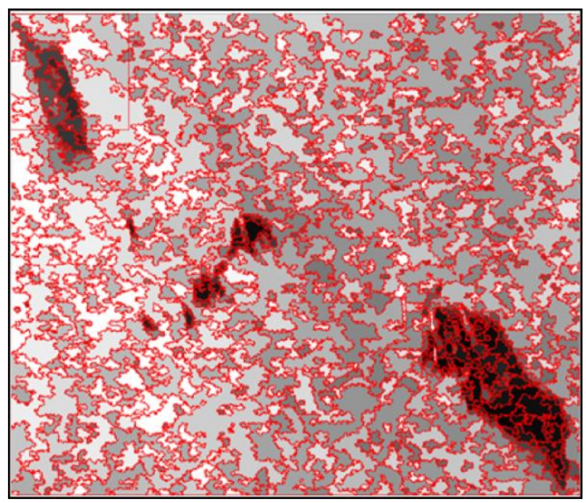

Figure 2. Segmentation results presenting the VV intensity averages in gray levels and the contours of the segments in red.

The PolClass was employed considering five classes: Plant Oil (PO), Emulsion (EM), Crude Oil (CO), Vessels (VE) and Ocean (OC). To minimize the effect of the spatial correlation on the Battacharrya distance and on its corresponding statistical test, the image, the training and test samples were subsampled using a factor of 2 in range and azimuth directions.

The classified image and its associated uncertainty map are shown in Figure 3(a) and 3(b), respectively. The blue regions in the uncertainty map represent the segments classified with low uncertainties (*p*-values greater than 0.01), and the red regions show the segments classified with high uncertainties (p-values lower than 0.01). The white lines in this image represent the contours around the five classes.

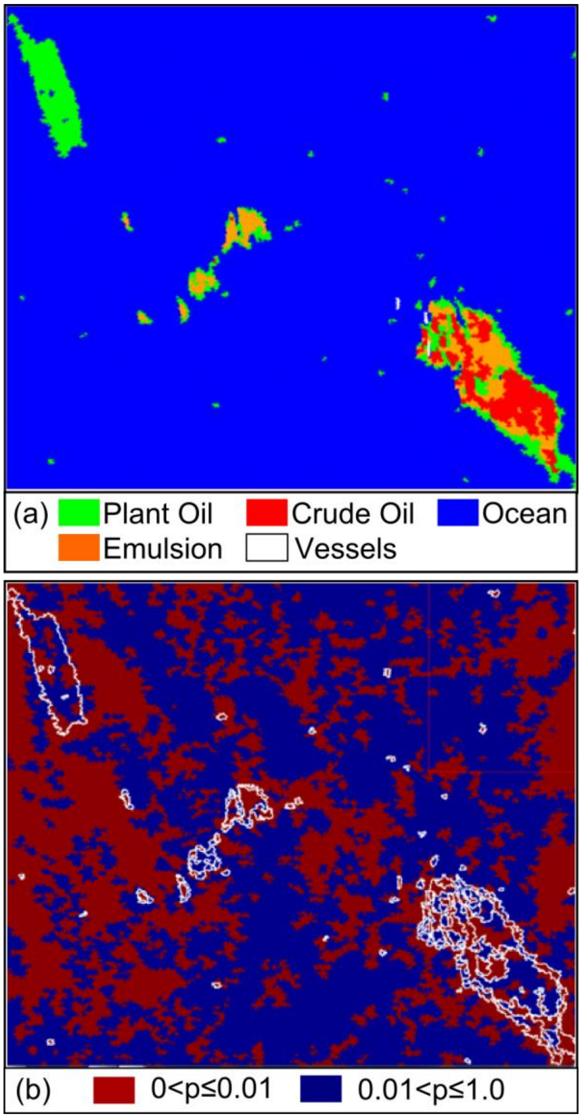

Figure 3. (a) Classified image; and (b) Uncertainty map.

To evaluate the quality of the classification, test samples selected from each class were used to compute the confusion matrix (Table 2), being: 252 pixels of EM, 375 of CO, 415 of OC, 288 of PO and 23 of VE.

Table 2. Confusion matrix calculated for the PolClass classification results.

		Actual Class				
		EM	**CO**	**OC**	**PO**	**VE**
Classification	**EM**	86.90	24.50	0	0	0
	CO	6.74	75.20	0	0	0
	OC	0	0.26	100	0.34	0
	PO	6.35	0	0	99.65	0
	VE	0	0	0	0	100

Figure 4 highlights the classification and the uncertainty levels for PO [4(a) and 4(b)], EM [4(c) and 4(d)], CO [4(e) and 4(f)], and VE [4(g) and 4(h)].

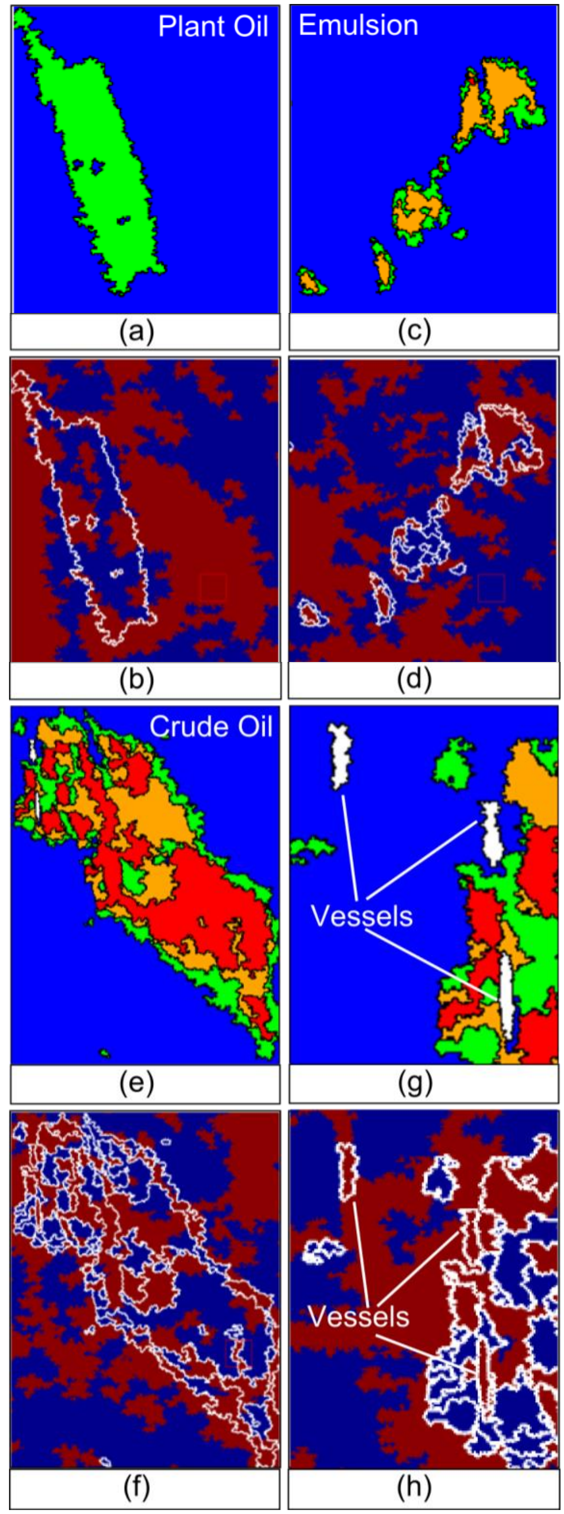

Figure 4. Classification and the uncertainty levels for: (a; b) Plant Oil (PO); (c; d) Emulsion (EM); (e; f) Crude Oil (CO); and (g; h) Vessels (VE).

The PolSAR region based classifier results achieved 90.61% of global accuracy with Kappa Coefficient of Agreement equals to 0.87. Considering the covariance matrix as input, the classifier was visually able to discriminate oil slicks from the ocean surrounding. Additionally, the results reflected the potential of the classifier to discriminate different types of oil, reaching a global accuracy of 99.7% for PO, 86.9% for EM and 75.2% for CO.

As indicated, the best classification performance among the oil slicks was observed for PO. The EM was better classified in the central portion of the slick, whereas the confusion with the PO occurred along the borders. The major confusion was observed for the CO classification, where 24.5% of its segments were assigned as EM in the center of the slick and the confusion with the PO was concentrated along the borders. The error of the classification visually observed along the borders of the CO and the EM was not adequately represented in the confusion matrix, probably because the test samples were concentrated at the center of the slicks.

An important observation to be done is that most of the areas of CO classified as EM or as PO is associated with high uncertainty classification levels. It is interesting to note that, for the mineral oils (EM and CO) the higher uncertainty levels were recurrently observed along the borders of the slicks, where the spreading and weathering mechanisms are more influent. The classifier also demonstrated efficiency to detect Vessels with 100% of global accuracy.

4. CONCLUSIONS AND FUTURE PERSPECTIVES

A region based classifier for full polarimetric data using a proper statistical modeling, was tested and evaluated, demonstrating the potential of PolSAR data to discriminate plant oils from mineral oils at sea surface. These results improve the perspectives to minimize the ambiguities caused by the presence of biogenic oils, reducing the occurrence of false alarms.

The emulsion was well classified, except along the borders. The classification results showed that the crude oil, characterized by its covariance matrix, presented high heterogeneity, being similar to the emulsion in the center of the slick and similar to the plant oil in its borders. Probably, these results were influenced by the physical and chemical processes that may cause variations in the thicknesses and densities along the slicks.

Future works must be done to investigate properly the relationship between the backscatter signal and the thickness variations along the mineral oils. The uncertainty map represented a contribution for the analyses, indicating the confidence level of the classified segments.

Finally, to consolidate the conclusions about the PolSAR data contribution to discriminate different types of oils new controlled experiments, increasing the diversity of oils released, should be done. As a final remark, we acknowledge the necessity of a larger data set of PolSAR images associated with different ocean conditions of surface winds and wave action to evaluate the performance of the presented classifier under different oceanic environmental conditions.

5. ACKNOWLEDGEMENTS

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