SEA OIL SLICK OBSERVATION BY MEANS OF FULLY-POLARIMETRIC ALOS PALSAR DATA

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ABSTRACT

A study on sea oil slick observation by means of L-band polarimetric synthetic aperture radar (SAR) data is accomplished. It is based on the different sea surface scattering mechanism expected with and without surface slicks. Polarimetric measurements are processed by means of a simple and very effective filtering technique which is electromagnetically based on the Mueller scattering matrix. Moreover, some polarimetric features, evaluated on both the slick-free and slick-covered sea surface, are analyzed for confirming the filter output. Experiments are accomplished on polarimetric SAR data acquired by the PALSAR sensor, mounted on board of the ALOS satellite, and are relevant to an oil slick, due to a tank accident, and a look-alike. Results demonstrate, for the first time, that L-band polarimetric SAR measurements are useful for oil slick observation purposes and witness the capability of ALOS PALSAR data for such application.

Key words: Polarimetry; ALOS-PalSAR; oil slick.

1. INTRODUCTION

In this study an electromagnetic approach has been firstly proposed for exploiting polarimetric information for sea oil slick observation in PALSAR data. The presence of a surface slick, reducing the signal backscattered to the radar antenna, generates a low-backscattering area which, in SAR images, appears as a dark area. Following this rationale image processing techniques are commonly employed on single-polarimetric SAR data to detect dark areas. Since other natural phenomena generate dark areas in SAR images semi-automatic approaches, based on the extraction of some radiometric, texture or geometric related features, allow classifying the detected dark areas as oil slick or look-alikes. The approach proposed in this study is based on the different sea surface scattering expected with and without surface slicks. In particular, it has been demonstrated in [1, 2] that though the sea surface scattering follow a Bragg or tilted Bragg scattering mechanism, the presence of a surface slick, depending on its damping properties, may lead to a completely different non-Bragg scattering mechanism. In this study, following this theoretical rationale, a filtering technique, based on the Mueller matrix (**M**)[2], is firstly applied for oil slick observation over L-band SAR data. Successively, the true-false logical output is verified by analyzing the slick-free and slick-covered co-polarized signature and the polarimetric entropy, performed by using the Kennaugh and the coherence matrix, respectively [4, 5].

Experiments accomplished on full-polarimetric ALOS PalSAR SAR data show the effectiveness of the proposed approach for sea oil slick observation. Experimental results allow underlining the importance of fully polarimetric L-band SAR data for oil slick observation.

2. POLARIMETRIC ANALYSIS

Polarimetric surface scattering can be described by using $\mathbf{M}$, a 4×4 real matrix, never symmetric [3], which relates the scattered Stokes vector $\mathbf{s}^s$, to the incident one $\mathbf{s}^i$:

$$\mathbf{s}^s = \langle \mathbf{M} \rangle \mathbf{s}^i \quad , \tag{1}$$

where $\langle \cdot \rangle$ means ensemble averaging.
Since it is well-known that the Stokes vector can be used to represent also partially polarized waves with a degree of polarization less than one, the Mueller matrix is the most general representation of a scattered field.

In the case of sea surface scattering, as detailed in [2], it is possible to distinguish the scattering mechanism occurring with and without surface oil slicks looking at the terms of $\mathbf{M}$ related to the co-polarized and cross-polarized scattering amplitudes. Following this theoretical rationale a filter (a.k.a. Mueller filter), capable to both observe oil slicks and to distinguish them from biogenic look-alikes, has been developed [2].
It is important to remark that, from an operational viewpoint, the filter is very important since it provides a true-false logical output which is very much advisable for segmentation purposes.

Proc. of '4th Int. Workshop on Science and Applications of SAR Polarimetry and Polarimetric Interferometry – PolInSAR 2009', 26–30 January 2009, Frascati, Italy (ESA SP-668, April 2009)

Two polarimetric analysis, accomplished on the slick-free and the slick-covered sea surface, are then applied to verify the filter output.
The first one is based on the use of the co-polarized polarimetric signature, which has been recently demonstrated to be useful in the context of sea oil slick observation [4]. It was shown that the amount of unpolarized backscattered energy, which is responsible for the pedestal in co-polarized signature, can be related to the presence of a surface slick, under low to moderate wind conditions.
The second polarimetric analysis was firstly proposed for oil slick observation in [5] and it is based on the use of the polarimetric entropy (H) derived by the Cloude-Pottier decomposition theorem [6]. As a matter of fact, H can be related to the different sea surface scattering mechanism with and without surface slicks [1, 5, 7].

3. EXPERIMENTS

In this section results obtained applying the Mueller filter and performing the polarimetric analysis on a meaningful set of Level 1.1 L-Band PALSAR polarimetric data are shown and discussed. The nominal slant (ground) resolution is 9.4 (26.0) meters in range and 4.5 meters in azimuth. The scattering matrix is converted into the Mueller one by using a 7×7 moving window.
The first case considered is related to the acquisition of 27 August 2006, 14:22 UTC (PALSAR, ALP-SRP031440190, ascending pass) relevant to a well-known oil spill accident widely documented [8]. An estimated 200,000 liters of heavy oil leaked in this accident, drifting to the sand beach and mangrove forests along the coastline of Guimaras Island. Fig.1 shows the module of the SLC ground projected VV SAR image relevant to a sub-image of the PALSAR data in which the oil slick is clearly visible. The filtering output is a black and white image, which clearly shows features related to the oil slick, Fig.2. This result confirms the completely different scattering mechanism which is expected in case of oil-free and oil-covered sea surface. Moreover, it must be explicitly noted that, despite in literature the C-band data are preferred to the L-band ones for oil slick observation [1, 9], in this study, for the first time, the usefulness of L-band polarimetric SAR data is demonstrated. Though in this case a documented oil spill case has been analyzed and, thus, a deeper polarimetric analysis is not necessary, the latter is still performed to investigate the sensitivity of both the co-polarized signature and the polarimetric entropy to the presence of oil slicks in L-band SAR data.
The normalized co-polarized signature has been evaluated for both the slick-free (see Fig.3) and the slick-covered (see Fig.4) sea surface, by considering two region of interest (ROI) of equal size. The results of this polarimetric analysis technique confirm the Mueller filtering ones. In fact, by comparing the two co-polarized signatures it can be noticed that the oil slick, increasing the amount of unpolarized backscattered energy, makes the pedestal higher.
A second confirm of the capability of fully polarimet-

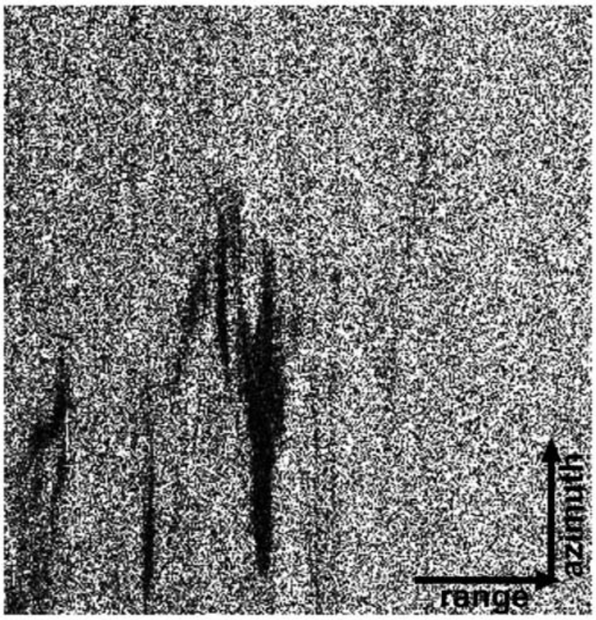

Figure 1. Module of the SLC ground projected VV SAR image to the acquisition of August 27, 2006, ALP-SRP031440190, in which an oil slick is present.

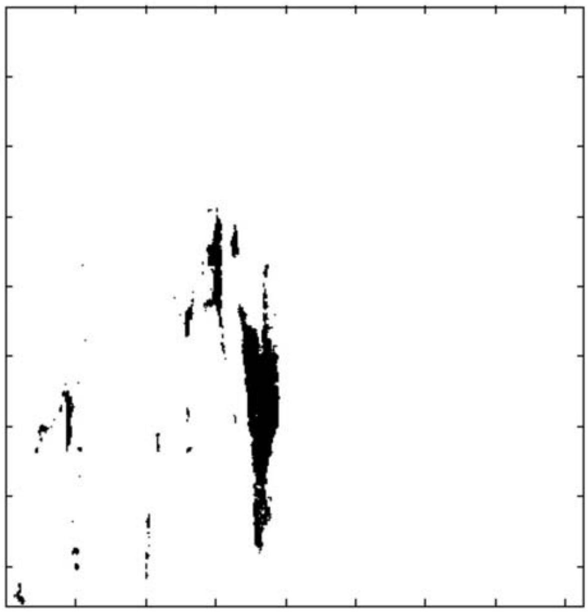

Figure 2. Mueller filter output relevant to the PalSAR data shown in Fig.1.

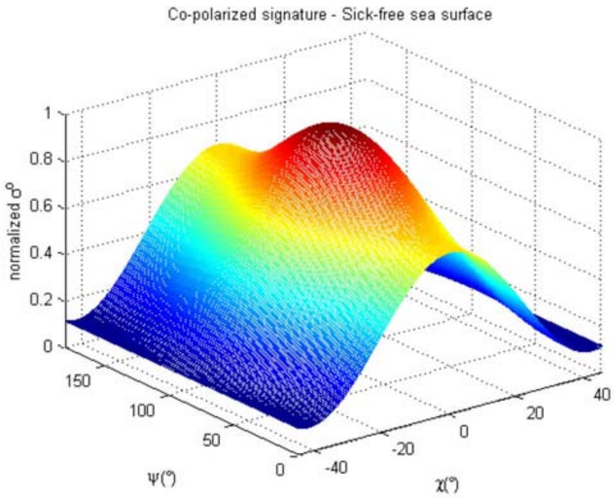

Figure 3. Co-polarized signature relevant to the oil-free sea surface.

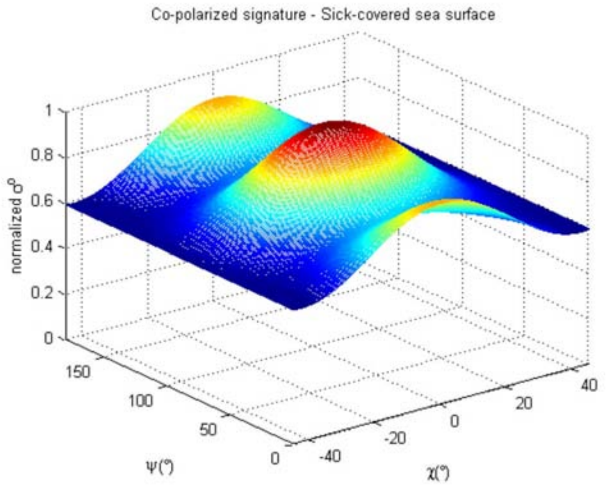

Figure 4. Co-polarized signature relevant to the oil-covered sea surface.

ric L-band SAR data for oil slick observation is provided by the analysis of the estimated H (see Fig.5). It can be noted that the H values, within the oil-covered area are higher than the surrounding sea.

The second case considered belongs to the acquisition of 10 March 2007, 15:19 UTC (PALSAR, ALPSRP059890330, ascending pass) off the coasts of Dà Nang (Vietnam) in which a look-alike is present. The module of the SLC ground projected VV PALSAR sub-image in which the look-alike is clearly visible, is shown in Fig.6. The filtering output (Fig.7) does not show any remarkable feature related to the dark area of Fig.6. This result allows classifying the dark area as a look-alike. The same conclusion can be drawn looking at the normalized co-polarized signature, evaluated for both the slick-free sea surface (see Fig.8) and the dark area (see Fig.9), and analyzing the estimated H (see Figs.10).

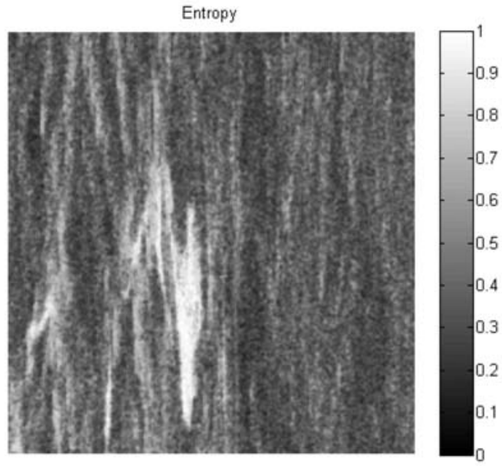

Figure 5. Estimated entropy relevant to the PalSAR data shown in Fig.1.

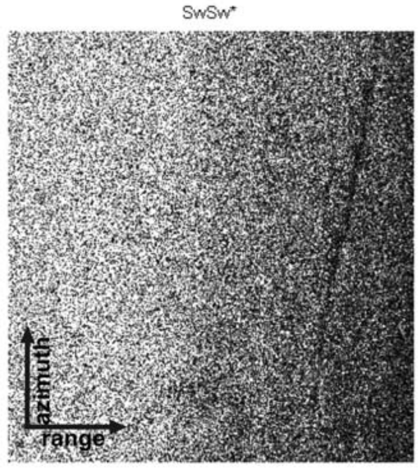

Figure 6. Module of the SLC ground projected VV SAR image to the acquisition of March 10, 2007, ALP-SRP059890330, in which a look-alike is present.

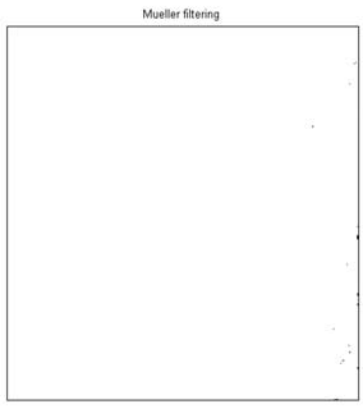

Figure 7. Mueller filter output relevant to the PalSAR data shown in Fig.6.

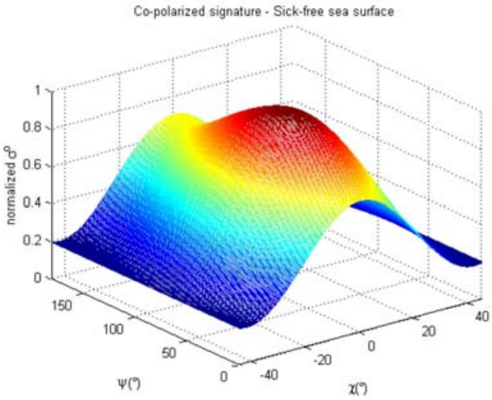

Figure 8. Co-polarized signature relevant to the slick-free sea surface.

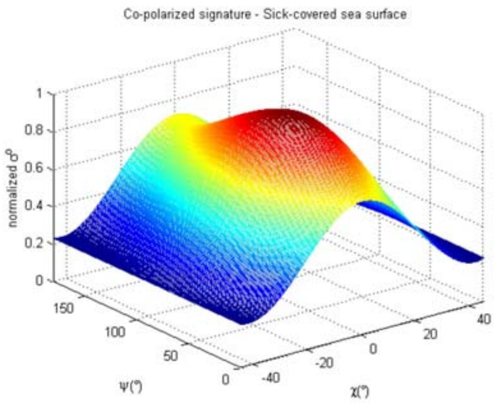

Figure 9. Co-polarized signature relevant to the slick-covered sea surface.

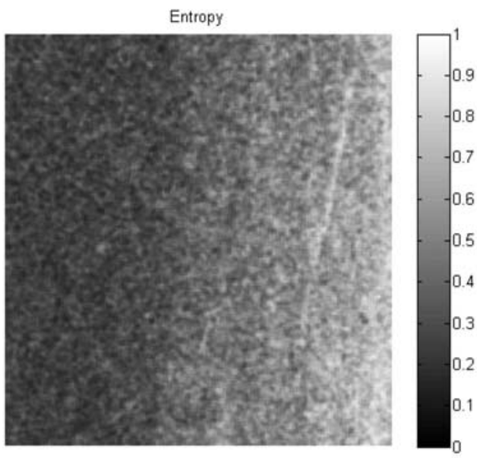

Figure 10. Estimated entropy relevant to the PalSAR data shown in Fig.6.

4. CONCLUSIONS

In this study ALOS-PALSAR polarimetric SAR data has been firstly exploited to observe sea oil slicks. The working hypothesis was that the extra-information provided by the polarimetric measurements can be exploited to distinguish sea surface scattering mechanism with and without surface slicks. The data set, which concerns both oil slicks - due to a tank accident - and oil look-alikes, has been processed and analyzed. Experimental results show the effectiveness and the usefulness of polarimetric L-band SAR data for sea oil slick observation.

ACKNOWLEDGMENTS

Authors acknowledge the Earth Observation Research and Application Center (EORC) of the Japan Aerospace Exploration Agency (JAXA) for providing the data used in this study.

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