FULLY POLARIMETRIC SLICK-FREE AND SLICK-COVERED SEA SURFACE SCATTERING

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ABSTRACT

In this study, the use of the extended Bragg scattering model for fully polarimetric SAR data is proposed for describing sea surface scattering. Experiments are conducted on fully polarimetric C- and L-band SAR data. Analysis conducted so far, indicates that the proposed model is suitable for the description of the sea surface scattering and can be useful to assist oil spill observation.

1. INTRODUCTION

Synthetic Aperture Radar (SAR) is an important tool for obtaining target information in remote sensing. A single-polarized SAR has only one data channel, whereas the fully polarimetric SAR has four, which afford us much more information. In other words, polarimetric SAR is able to provide additional information for environmental remote sensing applications. A topic of interest, which is still an open issue, is represented by the oil spill observation in SAR marine measurements [1]. New studies have been conducted in recent years [2]-[4] showing the usefulness of polarimetric SAR data for oil spill observation. All this motivated the study here presented.

Dealing with polarimetry this means considering the whole scattering matrix \( S \) (i.e. full polarimetric measurements). To exploit fully the polarimetric information contained in \( S \), a promising approach consists of analyzing the polarimetric coherency matrix \( T \) which contains the second-order moments of the scattering process. This approach has lead to the definition of an extended Bragg scattering model in terms of \( T \) which has been successfully used for the extraction of surface parameters such as soil moisture or roughness [5]-[6] and firstly considered for the sea surface case to model the polarimetric radar backscatter from breaking ocean waves at grazing incidence angles in the surf zone measured by a X-band polarimetric radar [7]. In this study, the use of the extended Bragg scattering model is proposed for the case of the sea surface. The objective is to assess the potential usefulness of the proposed model firstly for describing the sea surface scattering with and without surface slicks, and secondly for distinguishing oil look-alikes (where the extended Bragg scattering model still holds) and oil slicks (where the scattering mechanism is non-Bragg).

Experiments, conducted on fully polarimetric L-band single-look complex ALOS PALSAR data and C-band multi-look complex SIR-C/x-SAR ones, are aimed at examining the scattering contributions from sea surface and detecting dark areas due to the presence of anthropogenic and biogenic slicks. Results show the usefulness of the proposed approach.

2. THE MODEL

A fully polarimetric SAR measures the scattering matrix \( S \), which relates the wave scattered by the observed scene \( E' \) to the incident one \( E \) for each resolution cell. Considering, without loss of generality, the horizontal and vertical linearly polarized electric fields, \( S \) is given by:

\[
S = \begin{bmatrix}
S_{HH} & S_{HV} \\
S_{VH} & S_{VV}
\end{bmatrix}
\]

(1)

where each complex element of the scattering matrix is termed as scattering amplitude. The basic model for sea surface studies is the classical vector small perturbation or Bragg scattering model [8]. Here the interaction of microwave and surface is manifest through a coupling of the field to a component of the surface roughness spectrum which is in resonance with the radar wavelength and local geometry. This model predicts different scattering amplitudes for VV and HH with \( S_{VV} > S_{HH} \). Note that to first order there is zero cross polarization HV in the simple Bragg model. Also, the model predicts zero depolarization. Hence the predicted \( T \) matrix is of rank 1 and the entropy zero. This model is too simplistic for microwave polarimetric studies of sea surface scattering, where depolarization is observed in measured data.

One way to do this is to assume the addition of a reflection symmetric depolarizing component to the Bragg model (called the extended or X-Bragg model [5]). In this way we can model depolarization in the presence of large scale tilt and hence extend the model to a 2-scale roughness profile. According to this model, the coherency matrix can be generated from the scattered field as:
The coefficient $m_c$ is the backscatter amplitude containing the information about the roughness condition of the surface; the Bragg component are function of the complex permittivity $\varepsilon_r$ and the local incidence angle $\theta$, respectively. Bragg coefficients are averaged over a single parameter statistical distribution $p(\phi)$ to obtain a surface which depolarises the incident radiation and generate cross polarization. The form of the averaging is dictated by the requirement to keep the local surface normal an axis of reflection symmetry in the problem.

Dealing with sea surface scattering two cases must be distinguished. When the long-wave structure is negligible ($\phi \to 0$), the $(B_{HH}+B_{VV})(B_{HH}-B_{VV})$ coherence is one and the HV backscattered power is zero. In this case the coherence matrix has the form of a “pure” Bragg coherence matrix. When the long-wave structure is not-negligible ($\phi \neq 0$), a two scale scattering mechanism is in place. The main effect of the long-wave scattering is increasing the cross-polarized depolarisation of the co-polarized channels witnessed by the low value of the $T_{33}$ element of $T$ for the sea case. In the case of oil-covered sea surface, due to the strongly damping properties of oil slicks, a non-Bragg scattering mechanism, a low backscattered signal and a high polarimetric entropy are expected and demonstrated [2], [3]. Hence the expression of $T$ shown in (2) do not stands.

3. EXPERIMENTS

In this section we show the results obtained using the extended Bragg model, described in section 2. The processed data set consists of two L-band ALOS-PalSAR data in which an oil slick and a look-alike are present, respectively, and the C-band SIR-C/X-SAR data in which an oil slick and an Oleyl Alcohol (OLA) slick are present, respectively. OLA forms a monomolecular surface film which well simulates a biogenic surface slick [9].

First data set is related to the acquisition of 27 August 2006, 14:22 UTC (PALSAR, ALPSRP031440190, ascending pass) relevant to a well-known oil spill accident widely documented in literature [10]. Fig.1(a) shows an excerpt of the L-band VV power SAR image in which an oil slick is clearly visible. In Fig.1(b) is shown the estimated polarimetric entropy, in Figs.1(c)-(d) the estimated $T$ matrices and their normalized forms, for the surrounding slick-free sea surface and the oil spill, are shown, respectively. The same format is considered in the following of the section to show the experimental results. Results’ analysis confirms that (2) holds for the slick-free sea surface and, likewise, it does not hold for oil-covered one. As expected and confirmed by the polarimetric entropy image, in case of oil-covered sea surface the scattering mechanisms is non-Bragg.

Second data set is related to the acquisition of 10 March 2007, 15:19 UTC (PALSAR, ALPSRP059890330, ascending pass) off the coasts of Đ’a Nang (Vietnam) in which a look-alike is present, see Fig.2(a). In this case the ground truth was not available and the first guess was provided by expert SAR image analysts. As expected, the proposed model for $T$ holds both for the sea surface and the look-alike. This results is confirmed by the analysis of the polarimetric entropy image.

The third data set were acquired on April 11, 1994 (processing number, (p.n.) 17041). Fig.3(a) shows an excerpt of the VV power SAR image in which an oil slick is clearly visible. Experimental results confirm what experienced for the L-band case except for a lower depolarization of the co-polarized channels witnessed by the low value of the $T(33)$ element of $T$ for the sea case. The fourth and last data set is related to the acquisition of 15 April 1994, 2:14 UTC (p.n. 11588). Fig.4(a) shows an excerpt of the VV power SAR image in which an OLA slick is clearly visible. In this case too, experimental results confirm the proposed theoretical model.
Figure 1: a) excerpt of the L-band VV power SAR image related to the acquisition of 27 August 2006, 14:22 UTC (PALSAR, ALPSRP031440190, ascending pass); b) entropy image relevant to Fig1(a); c) estimated $T$ matrices; d) normalized $T$ matrices.

Figure 2: a) excerpt of the L-band VV power SAR image related to the acquisition of 10 March 2007, 15:19 UTC (PALSAR, ALPSRP059890330, ascending pass); b) entropy image relevant to Fig2(a); c) estimated $T$ matrices; d) normalized $T$ matrices.
\[ T_{\text{SEA}} = \begin{bmatrix} 0.0220 & 0.0066 & 1.8183 \times 10^{-5} \\ 0.0066 & 0.0093 & 7.8332 \times 10^{-5} \\ 1.8183 \times 10^{-5} & 7.8332 \times 10^{-5} & 8.7838 \times 10^{-4} \end{bmatrix} \]
\[ T_{\text{SLICK}} = \begin{bmatrix} 0.0017 & 6.1386 \times 10^{-5} & 2.9436 \times 10^{-5} \\ 6.1386 \times 10^{-5} & 0.0013 & 6.8909 \times 10^{-5} \\ 2.9436 \times 10^{-5} & 6.8909 \times 10^{-5} & 5.4107 \times 10^{-4} \end{bmatrix} \]

\[ T_{\text{SEA,n}} = \begin{bmatrix} 0.3018 & 0.4252 & 0.0036 \\ 0.0083 & 0.0036 & 0.0400 \end{bmatrix} \]
\[ T_{\text{SLICK,n}} = \begin{bmatrix} 0.0789 & 0.0279 & 0.0013 \\ 0.0013 & 0.0031 & 0.0246 \end{bmatrix} \]

Figure 3: a) excerpt of the L-band VV power SAR image related to the acquisition of April 11, 1994 (SIR-C, p.n. 17041); b) entropy image relevant to Fig3(a); c) estimated \( T \) matrices; d) normalized \( T \) matrices.

\[ T_{\text{SEA}} = \begin{bmatrix} 0.7094 & 0.0904 & 0.0058 \\ 0.0904 & 0.2669 & 3.9279 \times 10^{-4} \\ 0.0058 & 3.9279 \times 10^{-4} & 0.0028 \end{bmatrix} \]
\[ T_{\text{SLICK}} = \begin{bmatrix} 0.2999 & 0.0363 & 0.0028 \\ 0.0363 & 0.1161 & 2.8370 \times 10^{-4} \\ 0.0028 & 6.8909 \times 10^{-5} & 0.0016 \end{bmatrix} \]
\[ T_{\text{SEA,n}} = \begin{bmatrix} 1 & 0.1275 & 0.0081 \\ 0.1275 & 0.3762 & 5.5370 \times 10^{-4} \\ 0.0081 & 5.5370 \times 10^{-4} & 0.0040 \end{bmatrix} \]
\[ T_{\text{SLICK,n}} = \begin{bmatrix} 0.4227 & 0.0511 & 0.0039 \\ 0.0511 & 0.1636 & 3.9992 \times 10^{-4} \\ 0.0039 & 3.9992 \times 10^{-4} & 0.0023 \end{bmatrix} \]

Figure 3: a) excerpt of the L-band VV power SAR image related to the acquisition of April 11, 1994 (SIR-C, p.n. 17041); b) entropy image relevant to Fig3(a); c) estimated \( T \) matrices; d) normalized \( T \) matrices.
4. CONCLUSIONS
In this study, the use of the extended Bragg scattering model for fully polarimetric SAR data is proposed for describing sea surface scattering with and without surface slicks. The aim is to experimentally validate the proposed model for describing the sea surface scattering and to evaluate its capability in distinguishing among biogenic look-alikes and oil slicks. The working hypothesis is that in the first case the slick-free sea surface scattering model holds whereas it is does not hold for the second one. The proposed model is suitable for the description of the sea surface scattering and can be useful to assist oil spill observation.

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6. REFERENCES


