# A PHYSICALLY-BASED APPROACH TO OBSERVE SHIPS IN DUAL-POLARIZED SAR DATA

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## 1. INTRODUCTION

Ship detection using marine Synthetic Aperture Radar (SAR) images has been widely persued in recent years since it is a topic of considerable interest in several application concerning environmental monitoring, marine surveillance, fisheries, ....
However, ship detection is a very complex problem which can hardly be optimized with conventional single-polarization SARs. Radiometric information provided by one classical polarization channel (HH, VV, or HV) is not generally sufficient to effectively detect ships, and detection methods, which are generally based on a thresholding decision over the K-distributed sea clutter, are also limited [1].
As a matter of fact, many studies have been undertaken on the use of polarimetric information for radar-based ship detection. Statistically-based approaches, e.g. Constant False Alarm Rate (CFAR) filters or convolution between different polarimetric channels, are employed to detect ships in both dual- and full-polarimetric SAR data [2]. Physically based approaches, based on the Cloude-Pottier decomposition parameters or on the Cameron's coherent target decomposition (CTD), improved to better exploit polarimetric information for ship detection purposes (SSCM), have been also developed and tested on polarimetric SAR data [3]. However, neither statistically- nor physically-based approaches are able to provide logical true-false outputs. Moreover, the above mentioned ship detection algorithms often require a high computational load.

In this study target symmetry properties are employed to detect ships in dual-polarimetric SAR data. The rationale of the study lies on the fact that most natural targets, as well as sea surface, are characterized by symmetry properties which make the correlation between the like- and cross-polarized channels very low. This is not the case for man-made targets, such as ships, which are characterized by no particular symmetry property.
Preliminary results, obtained by processing full-polarimetric C-band RADARSAT-2 data confirm the effectiveness of the proposed approach which, provides a logical true-false output without using any threshold, and is very suitable for segmentation purposes. Moreover, the proposed approach, being based on an algebraic operation, is also computer time effective.

## 2. METHODOLOGY

The most general way to describe polarimetric scattering employs the Stokes parameters, accordingly [5]:

$$\mathbf{s}^s = \frac{1}{(kr)^{-2}} \mathbf{M} \mathbf{s}^i \quad , \tag{1}$$

where $\mathbf{s}^{s(i)}$ is the scattered (incident) Stokes vector and $\mathbf{M}$ is the $4 \times 4$ Mueller matrix. The latter is a real matrix whose elements are ensemble averages of combinations of the scattering amplitudes. Eq.(1) represents a second-order incoherent scattering model which, due to the capability of the Stokes parameters to account for both fully and partially polarized waves, is the most general way to deal with polarimetric scattering [6].
The shape of $\mathbf{M}$ and the relationship between its elements depend closely on the scattering mechanism and on the symmetry properties of the observed scenario. In particular, the symmetry properties of the observed scenario further reduce the number of independent parameters in $\mathbf{M}$ [7]. The way target symmetry properties manifest themselves in the polarimetric scattering coefficients has been addressed in [4, 8]. For the purposes of this study, the reflection symmetry is accounted for.
Reflection symmetry is observed in media which present a mirror reflection with respect to a symmetry plane. When reflection

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symmetry applies, the correlation between like- and cross-polarized scattering amplitudes vanish. It can be demonstrated that the this result holds without any reference to the scattering mechanisms (surface scattering, volume scattering or volume-surface scattering) and with no matter on how dense the medium or how rough the surface is, as long as the scattering configuration has the corresponding symmetry [4]. As a matter of fact, when reflection symmetry applies, **M** consists of $8$ independent parameters only, since the terms involving the correlation between like- and cross polarized scattering amplitudes vanish:

$$\langle S_{hh} S_{hv}^* \rangle = \langle S_{vv} S_{hv}^* \rangle = 0 \quad , \tag{2}$$

It is now important to read reflection symmetry in marine physical terms.
Wind-induced waves on the sea surface show a reflection symmetry with respect to a vertical plane parallel to the wind direction. As a matter of fact, the like- and cross-polarized scattering amplitudes are expect to be uncorrelated:

$$\langle S_{hh} S_{hv}^* \rangle = \langle S_{vv} S_{hv}^* \rangle \approx 0 \quad , \tag{3}$$

Dealing with ships, neither the reflection nor the azimuth symmetry property can be assumed. As a matter of fact, the correlation between the like- and cross-polarized scattering amplitudes is expected to be larger than the sea surface one.

## 3. PRELIMINARY RESULTS

Following the above mentioned rationale, a filtering technique which basically estimates the correlation between the complex HH and VH channels by using a $3 \times 3$ moving window has been developed and applied to Single Look Complex RADARSAT-2 fine quad-pol data (see Fig.1). The nominal spatial resolution is $5.4 \times 8.0$ m (range $\times$ azimuth).
First results are shown in Fig.2. It can be easily noted that the ships are perfectly detected and emphasized with respect to the surrounding sea, if compared to the reference HV image.

## 4. CONCLUSIONS

A physically-based approach to observe ships in dual-polarized SAR data is proposed which is based on the different symmetry properties which characterize natural targets (sea surface) and man-made objects (i.e. ships). Preliminary results, obtained processing RADARSAT-2 SLC fine quad-polarized SAR data, demonstrates that the approach is able to emphasize the presence of ships in dual-polarized SAR data without any external threshold.

## 5. REFERENCES


[1] A. Gambardella, F. Nunziata and M. Migliaccio, “A Physical Full-Resolution SAR Ship Detection Filter,” *IEEE Geoscience and Remote Sensing Letters*, vol. 5, n. 4, pp. 760-763, 2008.

[2] M. Sciotti, D. Pastina and P. Lombardo, “Exploiting the polarimetric information for the detection of ships in non-homogeneous SAR image,” *Geoscience and Remote Sensing Symposium, 2002. IGARSS ’02. 2002 IEEE International*, vol.3, pp. 1911-1913, 2002.

[3] R. Touzi, F.J. Charbonneau, R.K. Hawkins and P.W. Vachon, “Ship detection and characterization using polarimetric SAR,”*Canadian Journal of Remote Sensing*, vol. 3, no. 3, pp. 552-559, 2004.

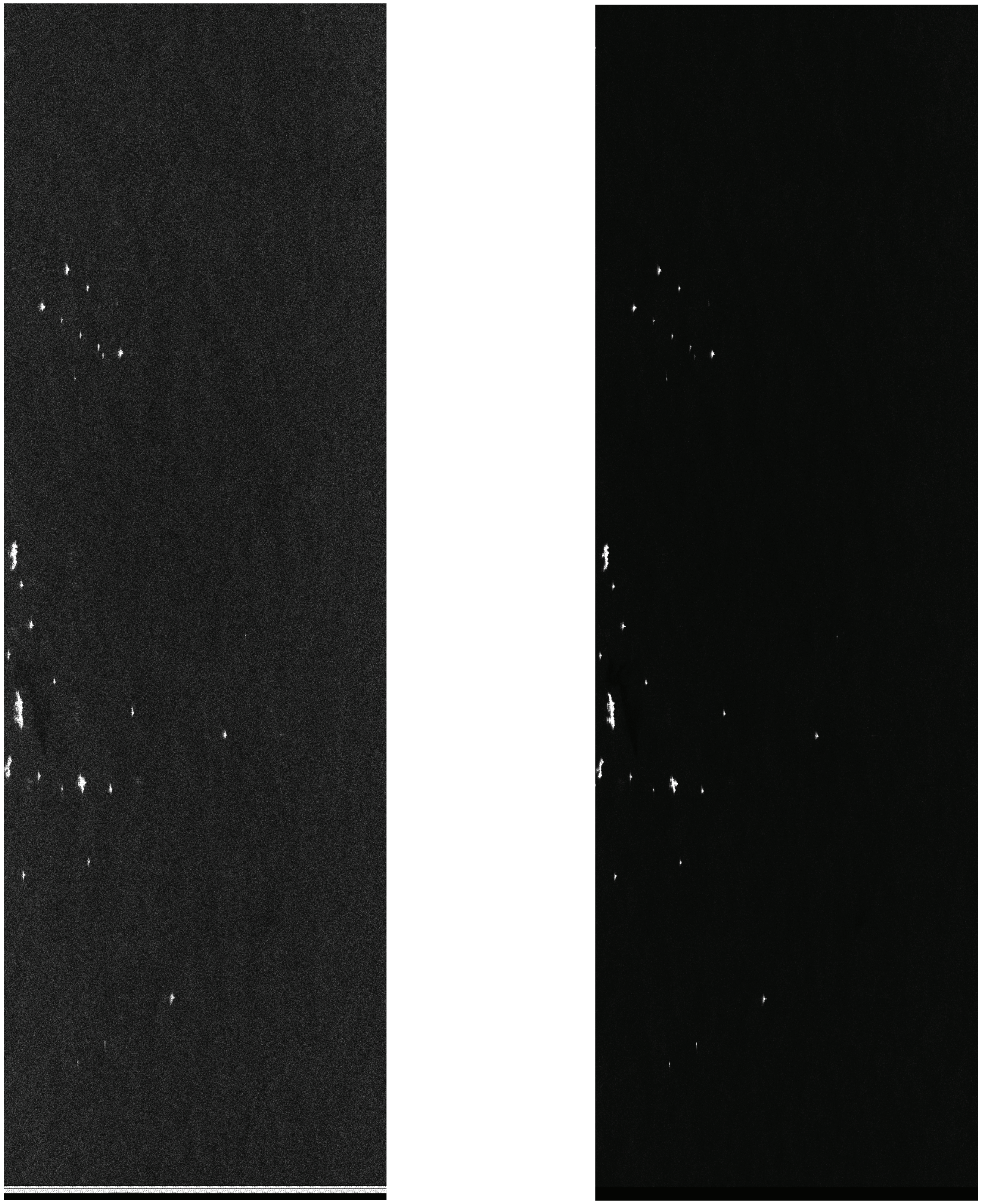
[4] S.V. Nghiem, S.H. Yueh, R. Kwok, and F.K. Li, “Symmetry properties in polarimetric remote sensing,” *Radio Science*, vol. 27 no. 5, pp. 693-711, 1992.

[5] A. Guissard, “Mueller and Kennaugh matrices in radar polarimetry,” *IEEE Transaction on Geoscience and Remote Sensing*, vol. 32, no. 3, pp. 590-597, 1994.

[6] J.J. van Zyl, C.H Papas, and C. Elachi, “On the optimum polarization of incoherently reflected waves,” *IEEE Transaction on Antennas and Propagation*, vol. AP-35, pp. 818-826, 1987.

[7] H.C. van de Hulst, *Light scattering by small particles*. Dover Publications, Inc., New York, 1981.

[8] S.H. Yueh, R. Kwok and S.V. Nghiem, “Polarimetric scattering and emission properties of targets with reflection symmetry,”*Radio Science*, vol. 29, no. 6, pp. 1409-1020, 1994.



(a)HV power

(c)Filter's result

**Fig. 1**. RADARSAT-2 SLC SAR fine quad-pol SAR data.