RADAR POLAR DECOMPOSITION FOR NATURAL SURFACES CARTOGRAPHY

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ABSTRACT

Illustrations of parameters obtained from polar decomposition derived from fully polarimetric data acquired by ALOS-PALSAR over the Mai-Ndombo lake, in the Democratic Republic of Congo are presented. Results show their complementarity to usual polarimetric indices, such as the entropy or the alpha parameters

Index Terms— One, two, three, four, five

1. INTRODUCTION

The frame of this work is the evaluation of fully radar polarimetric data for the cartography of natural vegetation in tropical environment. This topic is particularly of interet when national parks management and/or biodiversity monitoring are involved. we present the parameters derived from a decomposition, called the polar decomposition, presented in a recent paper [1]. Their comparison with other polarimetric parameters is made over a study site located in the Democratic Republic of Congo.

2. THE POLAR DECOMPOSITION

Expressed in the $(\hat{p},\hat{q})$ polarization basis, the scattered field $\vec{E}^s$ is linked to the incident field $\vec{E}^i$ through the scattering matrix $\overline{\overline{S}}$ as follow:

$$\begin{bmatrix} E_p^s \\ E_q^s \end{bmatrix} = \begin{bmatrix} S_{pp} & S_{qp} \\ S_{pq} & S_{qq} \end{bmatrix} \cdot \begin{bmatrix} E_p^i \\ E_q^i \end{bmatrix} = \overline{\overline{S}} \cdot \begin{bmatrix} E_p^i \\ E_q^i \end{bmatrix}$$

At the difference of standard decompositions that use a additive decomposition of the scattering matrix $\overline{\overline{S}}$, the polar decomposition is based on a multiplicative of approach. The $\overline{\overline{S}}$ matrix being non singular (its determinant $\xi \neq 0$), it can be represented as

$$\overline{\overline{S}} = \xi^{1/2}\ \overline{\overline{Y}} \cdot \overline{\overline{H}} \quad (1)$$

where $\overline{\overline{Y}}$, called the rotation matrix, is unitary ($\overline{\overline{Y}}^{t*} = \overline{\overline{Y}}^{-1}$, where ^{t} and * stands for transpose and conjugate operators), and $\overline{\overline{H}}$, called the boost matrix is positive hermitian ($\overline{\overline{H}}^{t*} = \overline{\overline{H}}$).

The representation of these matrices with the help of quaternion formalism is given in the following section. More details can be found in [4]. A quaternion A is a quantity of the form a0 + l . a1 + m . a2 + n. a3, where a0, a1, a2, and a3 are complex numbers. By analogy with the complex numbers, l, m, and n are considered as 3 imaginary units, verifying:

$$\begin{cases} l^2 = m^2 = n^2 = l \cdot m \cdot n = -1 \\ l \cdot m = -m \cdot l = n \\ l \cdot n = -n \cdot l = -m \\ m \cdot n = -n \cdot m = l \end{cases} \quad (2)$$

The quaternion A is generally denoted

$$A = a0 + [a1, a2, a3] = a0 + \vec{A}$$

a0 is also called the real part of the quaternion, and is denoted $a0 = \Re_q(A)$. The vector $\vec{A}$ is called the complex pol-vector. With the multiplication given by (1), complex quaternions form a group known as the quaternion groups.

The $\overline{\overline{S}}$ matrix is decomposed onto the Pauli basis (I, Q, U, V) following:

$$\overline{\overline{S}} = s0 \cdot \overline{\overline{I}} + s1 \cdot \overline{\overline{Q}} + s2 \cdot \overline{\overline{U}} + s3 \cdot \overline{\overline{V}} = \begin{bmatrix} s0+s1 & s2-i\cdot s3 \\ s2-i\cdot s3 & s0-s1 \end{bmatrix}$$

where

$$s0 = (S_{pp} + S_{qq})/2 \qquad s1 = (S_{pp} - S_{qq})/2$$
$$s2 = (S_{pq} + S_{qp})/2 \qquad s0 = (S_{pq} - S_{qp})/2i$$

where *i* is the usual pure imaginary complex number (*i*² = -*1*). The $\overline{\overline{S}}$ matrix is subsequently associated to the quaternion:

$$\overline{\overline{S}} \rightarrow S = s0 + [s1, s2, s3] = s0 + \vec{S} = \Re_q(S) + \vec{S}$$

It is shown that the quaternion associated to a unitary $\overline{\overline{Y}}$ and a hermitian $\overline{\overline{H}}$ matrix takes the form:

$$Y = \cos\eta + i \cdot \sin\eta \cdot \vec{1}_y$$
$$H = \cosh\gamma + \sinh\gamma \cdot \vec{1}_h$$

where $\vec{1}_y$ and $\vec{1}_h$ are 2 real components unimodular vectors $\left(\vec{1}_y \cdot \vec{1}_y = \vec{1}_y \cdot \vec{1}_h = 1\right)$.

From the quaternion S associated to the $\overline{\overline{S}}$ matrix, the 2 quaternions Y and H are derived following:

$$\cosh 2\gamma = \frac{|s0|^2 + |S|^2}{\left|s0^2 - \vec{S}^2\right|}$$

$$\vec{1}_h = \frac{\Re\left(s0^* \cdot \vec{S}\right) + \Im\left(\vec{S}\right) \wedge \Re\left(\vec{S}\right)}{\left|\Re\left(s0^* \cdot \vec{S}\right) + \Im\left(\vec{S}\right) \wedge \Re\left(\vec{S}\right)\right|}$$

$$\cos\eta = \frac{\sqrt{2} \cdot \Re\{s0 \cdot \exp(-i \cdot \phi_d/2)\}}{\sqrt{|s0|^2 + |S|^2 + \left|s0^2 - \vec{S}^2\right|}}$$

$$\vec{1}_y = \frac{\Im\left\{\vec{S} \cdot \exp(-i \cdot \phi_d/2)\right\}}{\left|\Im\left\{\vec{S} \cdot \exp(-i \cdot \phi_d/2)\right\}\right|}$$

γ, $\vec{1}_h$, (η, $\vec{1}_y$), are called the boost (rotation) parameter and the boost (rotation) axis.

From these polar decomposition parameters, a classification scheme can be performed that is summarzed fig. 1. This classification is useful over deterministic targets. In the case of natural surfaces, this single look decomposition is meaningless, and incoherent process has to be performed, leading to the determination of the average polarimetric coherency matrix:

$\overline{\overline{T}} = \left\langle \vec{k}_P \cdot \vec{k}_P^{t*} \right\rangle$, where $\vec{k}_P = [s0, s1, s2, s3]^t$ is the target vector, and $\langle \cdot \rangle$ denotes a spatial averaging process.

In this case, it can be shown that the averaged boost parameter γ^{av} is closely related to the degree of polarization dispersion ΔP. The degree of polarization is defined as the ratio between the maximum and minimum power densities carried by the backscattering wave when the transmitted polarization takes any value on the Poincaré sphere. It is estimated as follow:

$$\Delta P = \frac{\lambda_1 - \lambda_2}{\lambda_1 + \lambda_2} = 2\frac{\left|\left\langle \Re\left(s0^* \cdot \vec{S}\right) + \Im\left(\vec{S}\right) \wedge \Re\left(\vec{S}\right)\right\rangle\right|}{\left\langle \left|s0^2\right| + \left|\vec{S}\right|^2 \right\rangle} = \tanh 2\gamma^{av}$$

Consequently, $\gamma^{av} \geq 0$ and the values observed has the same interpretation than γ given in Fig. 1. It is an indicator of polarization susceptibility.

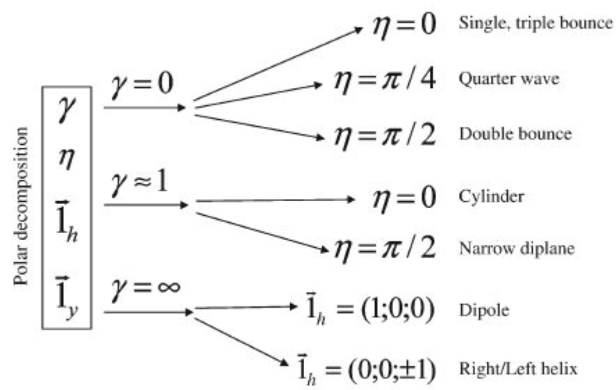

Fig. 1: Classification scheme based on single look polar decomposition parameters

The interpretation of the other averaged parameters are less obvious than for γ^{av}.
However, for each rotation and boost matrix, a target vector $\vec{k}_P^{rot}$ and $\vec{k}_P^{boost}$ can be derived, leading to the derivation of a rotation $\overline{\overline{T}}^{rot} = \left\langle \vec{k}_P^{rot} \cdot \vec{k}_P^{rot\,t*} \right\rangle$ and a boost $\overline{\overline{T}}^{rot} = \left\langle \vec{k}_P^{boost} \cdot \vec{k}_P^{boost\,t*} \right\rangle$ coherency matrices. A standard eigenvalue and eigenvector analysis to both matrices and allows to derive entropy ε^{rot}, ε^{boost} and angle parameters α^{rot} and α^{boost}.

3. RESULTS

The polar decomposition is applied to the region of the Mai-Ndombo Lake In the Republic Democratic of Congo. It is located 2° South latitude and 18°15' East longitude. An ALOS-PALSAR acquisition has been acquired the 9th of May 2007 in fully polarimetric mode. The Pauli decomposition image is shown Figure 2. Dense Forest appears in green, flooded forests in red tones, and clear cuts and mud banks in blue. Other parameters are presented fig. 3 to fig. 10, and compared to the usual entropy (fig. and alpha parameters derived from the Cloude and Pottier decomposition.

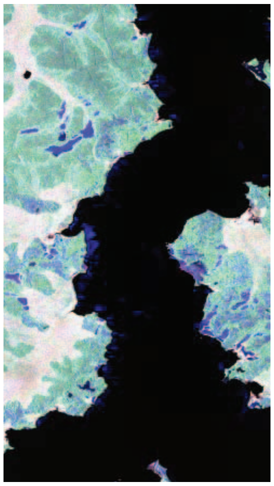

Fig 2: ALOS-PALSAR polarimetric image of the Mai-Ndombo Lake Pauli decomposition (B: single bounce, G: volume, R: double bounce).

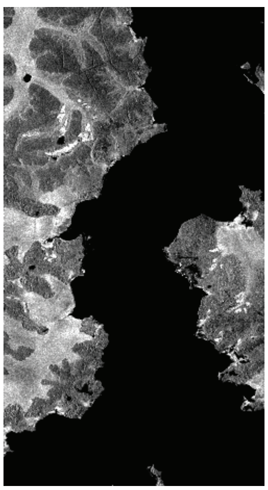

Fig. 3: SPAN image

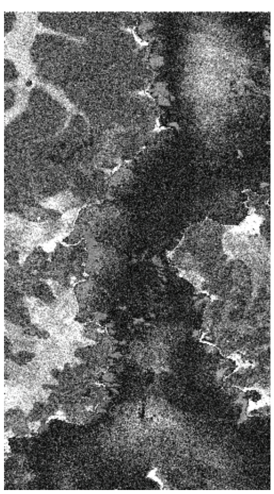

Fig 4: Polarization degree dispersion ΔP, (or γ^{av}) image

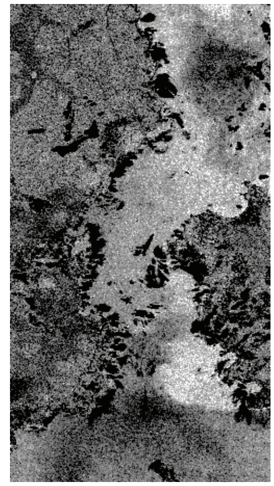

Fig. 5: Entropy image derived from Cloude and Pottier decomposition

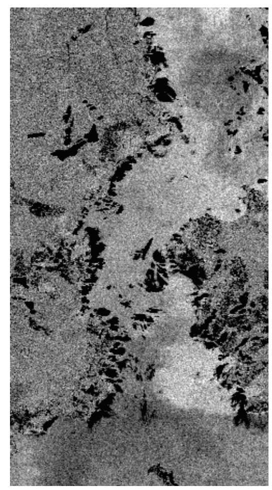

Fig. 6: ε^{rot} image

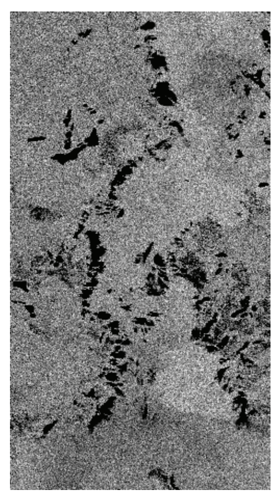

Fig. 7: ε^{boost} image

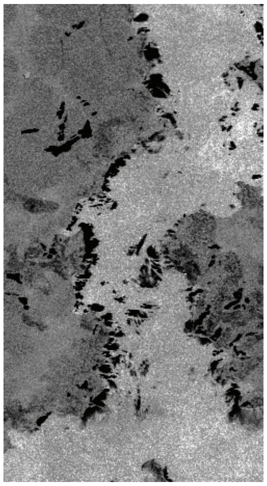

Fig. 8: α parameter image from Cloude and Pottier decomposition

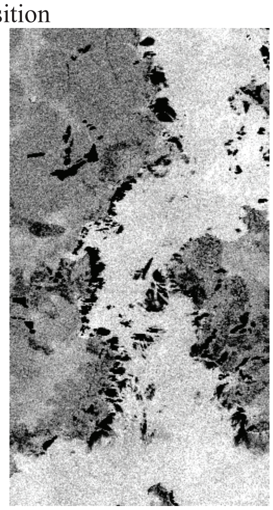

Fig. 9: α^{rot} image

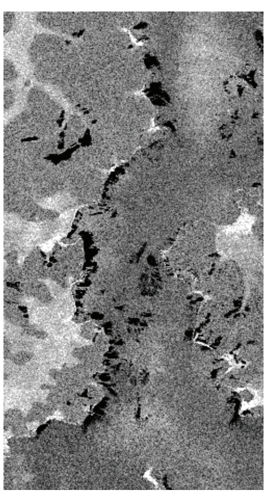

Fig. 10: α^{boost} image

Care must be taken before interpreting the high values of entropy observed within the water. It is rather due to the low signal to noise ratio over this low backscattered zone.

The different entropy parameters (fig. 5-7) show different features, underlying their complementarities.

The α^{rot} parameter (fig. 9) behaves in a similar way that α (fig. 8) and observe a better preservation of edges, contrast and texture. The α^{boost} parameter presents a similar behaviour with the degree of polarization dispersion, this latter presenting a significant contrast enhancement.

4. CONCLUSION

The parameters derived from the polar decomposition are presented over a region located in the Democratic Republic of the Congo. It confirms their complementarity with usual polarimetric indices. Additional studies have to investigate the additional value of these parameters for natural vegetation classification. In particular, their integration in supervised classification method, such the SVM (Support Vector Machine) which has shown promising results for polarimetric radar day [3] will allow to assess their contribution in a quantitative way.

5. REFERENCES

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