THE TOUZI DECOMPOSITION FOR WETLAND CLASSIFICATION USING POLARIMETRIC C-BAND SAR

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I. INTRODUCTION

Target scattering decomposition has become the standard method for the extraction of natural target geophysical parameters from polarimetric SAR data \cite{2, 3, 4, 5}. Cloude-Pottier’s decomposition \cite{2, 3} has been currently the most used method for incoherent decomposition of natural extended target scattering. Recently, concerns have been raised regarding Cloude’s \(\alpha\) scattering type ambiguities that occur for certain scatterers \cite{6, 1}, and a new method, the Touzi decomposition \cite{1}, has been introduced for a roll and unique incoherent decomposition of target scattering. In contrast to the Cloude-Pottier decomposition that characterizes target scattering type with a real entity, the so-called Cloude \(\alpha\), the Touzi decomposition uses the magnitude \(\alpha\) and the phase \(\Phi\) of the symmetric scattering type introduced in \cite{1} for an unambiguous characterization of target scattering. Target helicity \cite{7, 8} is used to assess the symmetric nature of target scattering.

In this study, the Touzi decomposition is investigated for wetland classification. We will show that the information provided in particular by the phase of the dominant scattering type is very promising for wetland classification \cite{9}. The incoherent decomposition is briefly presented in the following Section, and the degree of coherence is introduced for the assessment of scattering type coherence. The Mer Blue wetland study site, which was surveyed by the Convair-580 polarimetric C-band SAR \cite{10}, is described in a later section. In the last Section, the Convair-580 polarimetric C-band SAR data are used to derive the decomposition parameters of the dominant scattering, and the results obtained are analyzed with reference to ground measurements to assess the potential of the incoherent scattering decomposition for wetland classification.

II. THE TOUZI INCOHERENT TARGET DECOMPOSITION

Like Cloude-Pottier’s incoherent target decomposition (ICTD) \cite{2}, the Touzi decomposition \cite{1} is based on the incoherent characteristic decomposition of the coherency matrix \([T]\). For a reciprocal target, the characteristic decomposition of the Hermitian positive semi-definite target coherency matrix \([T]\) permits the representation of \([T]\) as the incoherent sum of up to three coherency matrices \([T]_i\) representing three different single scatterers, each weighted by its appropriate positive real eigenvalue \(\lambda_i\) \cite{11}:

\[
[T] = \sum_{i=1}^{3} \lambda_i [T]_i
\]  

Each single scattering \(i\) \((i=1,3)\) is represented by the coherency eigenvector matrice \([T]_i\) of rank 1, and the corresponding normalized positive real eigenvalue \(\lambda_i/(\lambda_1 + \lambda_2 + \lambda_3)\), which is a measure of the relative energy carried by the eigenvector \(i\). In contrast to the Cloude-Pottier decomposition \cite{2, 3}, the Touzi decomposition \cite{1} uses a roll invariant coherent scattering model for the parameterization of the coherency eigenvectors in terms of unique target characteristics. Each coherent scatterer can be represented by the roll invariant coherent scattering model given by \cite{1}:

\[
\vec{e}_i^{SV} = m|\vec{e}_T|_m \cdot \exp(j\Phi) \cdot \vec{V}
\]

with

\[
\vec{V} = \begin{bmatrix}
\cos \alpha_s \cos 2\tau_m \\
-j \cos \alpha_s \sin 2\psi \sin 2\tau_m + \cos 2\psi \sin \alpha_s e^{j\Phi}\alpha_s \\
-j \cos \alpha_s \cos 2\psi \sin 2\tau_m + \sin 2\psi \sin \alpha_s e^{j\Phi}\alpha_s
\end{bmatrix}
\]

For non-interferometric applications, the absolute target phase \(\Phi\) is ignored, and the coherent scatterer is uniquely characterized with 5 independents parameters; \(\alpha_s, \Phi_{\alpha_s}, \psi, \tau_m, \) and \(m\). \(\alpha_s\) and \(\Phi_{\alpha_s}\) are the polar coordinates of the symmetric scattering type introduced in \cite{1}, \(\psi, \tau_m, \) and \(m\) are the maximum polarization parameters \cite{7, 8}; the orientation angle, the helicity, and the maximum return parameters.
Each coherency eigenvector $i$, which corresponds to a single scattering, is presented in terms of roll-invariant target scattering parameters, as follows:

$$ICTD_i = (\lambda_i, m_i, \psi_i, \tau_{m_i}, \alpha_{s_i}, \phi_{\alpha_{s_i}})$$

(3)

Target scattering can be fully characterized by a deep analysis of each of the three eigenvector parameters of (3). Since one objective of this study is to promote the use of the new Touzi scattering type phase for an enhanced understanding of wetland target geophysical parameters, only the dominant target scattering component is considered. The scattering type phase $\Phi_\alpha$ can only be exploited under coherence conditions, and the dominant scattering, which is characterized with the coherency eigenvector of the highest eigenvalue $\lambda_1$ ($\lambda_1 > \lambda_2 > \lambda_3$), should correspond to the most coherent phase, as discussed later. The coherence of the dominant scattering type phase will be assessed using the degree of coherence introduced in [12]. The information provided by $\lambda_1$, the entropy $H$ (equation (49) of [2]), the symmetric scattering type magnitude $\alpha_{s_1}$, the symmetric scattering type phase $\phi_{\alpha_{s_1}}$, and its degree of coherence $p_{\phi_{\alpha_{s_1}}}$, will be analyzed with reference to ground measurements.

III. DESCRIPTION OF THE MER BLEUE RAMSAR WETLAND SITE

The Mer Bleue (45.30N, 75.61W) is a raised boreal peat dome located 10km east of Ottawa, Canada. The site designated as a conservation area within the Greenbelt is protected by the National Capital Commission (NCC). Mer bleue was surveyed by the Convair-580 polarimetric C-band SAR [10] in June 1995, at an illumination angle of about 50 degree. During the flight, corner and active reflectors have been deployed for calibration, aerial and ground photos and in-situ data have been collected to facilitate the identification of wetland classes and other surface types.

The four main wetland classes present at Mer Bleue are: marsh, treed bog, shrub bog, and fens. Theses classes are specified using the Canadian Wetland Classification System (National Wetlands Working Group 1997). Although most of the peatland is composed of bog vegetation, areas of poor fen also occur. Poor fen vegetation is composed primarily of sedges and an understory of Sphagnum mosses. Marshes have persistent surface water underneath hygrophilous herbs (cattails). Treed bog is mainly dominated by conifers (black spruce, tamarack, aspen, and pine). Upland areas mainly consist of deciduous dominated forest and agriculture lands. The aerial and ground photos and in-situ data collected during the flight have been combined with the Greenbelt forest cover inventory obtained from the NCC to identify the main wetland classes, as presented in Figure 1. The Greenbelt forest cover inventory layer is based on standard forest resources inventory methodologies current in Quebec and Ontario. The classification of Figure 1 will be used in the following Section as the reference for the assessment and validation of the Touzi decomposition.

IV. TOUZI DECOMPOSITION: RESULTS AND DISCUSSIONS

The Convair-580 polarimetric SAR data are processed, calibrated as described in [13], and then geocoded. Figure 2 presents the HH-polarization image. For unbiased estimation of the incoherent target decomposition parameters, we have shown [14] that the coherency matrix has to be estimated within a moving window that includes a minimum of 60 independent samples. The incoherent decomposition is applied on the Mer Blue image with a moving window of approximately 60 independent looks.

The dominant scattering parameters $\alpha_{s_1}$ and $\phi_{\alpha_{s_1}}$ are presented in Figures 3, and 4. In order to exploit $\phi_{\alpha_{s_1}}$ information, $\phi_{\alpha_{s_1}}$ should be coherent. The phase coherence is measured using the degree of coherence $p_{\phi_{\alpha_{s_1}}}$, which corresponds to the distance that separates the scattering point inside the symmetric scattering Poincaré sphere from the sphere center [12]. The main advantage of the use of the degree of coherence $p_{\phi_{\alpha_{s_1}}}$, in comparison with the conventional coherence [15], is that the coherence remains high even when the symmetric signal energy is carried by only one channel (trihedral or dihedral scattering) in the trihedral-dihedral symmetric scattering decomposition [12]. The analysis of $p_{\phi_{\alpha_{s_1}}}$ image of Figure 5 leads to the following conclusions:

- $p_{\phi_{\alpha_{s_1}}}$ enhances the discrimination of the wetland site from uplands, as can be assessed using Figure 4 in which the wetland site is delineated manually. This may be explained by the presence of the water underneath the wetland vegetation that minimizes the volume scattering component, and this leads to a more coherent wetland target backscattering in comparison with upland backscattering.
- $\phi_{\alpha_{s_1}}$ is highly coherent within the wetland site with a degree of coherence $p_{\phi_{\alpha_{s_1}}}$ higher than 0.85. The coherence is significantly lower for the second component (about 0.6) to become close to zero for the 3rd component with a scattering type phase meaningless.

The analysis of target helicity leads to the conclusion that, at the exception of Treed bog and uplands forests that have a significant helicity value, wetland classes identified in Figure 1 are dominated by symmetric scattering (with $|\tau_1|$ values lower than $10^2$). For thiss symmetric targets, the symmetric scattering type magnitude and the Cloude scattering type are similar; $\alpha_{s_1} \simeq \alpha_1$. The analysis of the symmetric scattering type magnitude $\alpha_{s_1}$ of Figure 3, which is identical to Cloude $\alpha_1$ for most the wetland classes, reveal that both $\alpha_{s_1}$ and $\alpha_1$ are not efficient for wetland classes discrimination. The poor potential of $\alpha_1$ and $\alpha_{s_1}$ in vegetations species discrimination, confirms the limitation of the scattering type radiometric information for wetland classification. We will show in the following that the new symmetric scattering type phase, $\phi_{\alpha_{s_1}}$ introduced in [1] provides the missing key information for vegetation type discrimination, and this leads to a signifi-
cant improvement of wetland classification.

In Figure 4, a color wheel with equally spaced bins between $-\pi/2$ and $\pi/2$ is used to represent the symmetric scattering type phase $\phi_{s1}$. The wetland site is identified on Figure 4 with the black contour that separates the wetland site from upland areas. Even though $\phi_{s1}$ based classification process has been applied, the four wetland classes identified in Figure 1 are well discriminated with $\phi_{s1}$ in Figure 4: marsh (turquoise), treed bog (yellow), shrub bog (dark blue), and fen (magenta). $\phi_{s1}$ can separate well (about 25 degree offset) the treed bog dominated by conifers (mainly black spruce and tamarack) from the upland forest dominated mainly with deciduous trees (poplar, maple, and willow). $\phi_{s1}$ can also discriminate sedge or shrub dominated fens from shrub dominated bogs, with about 20° phase offset between the two classes.

The results obtained with $\phi_{s1}$ within the wetland site looks very promising. However, discrimination of wetland classes from upland areas looks less efficient, as seen in Figure 4. $\phi_{s1}$, which permits a good separation of sedge fen from shrub bog, cannot discriminate sedges fen from agriculture fields, as seen in Figure 4. These two targets may be better discriminated using the degree of coherence $p_{\phi_{s1}}$ of Figure 5, in which the agriculture fields demonstrate lower phase coherence than fens. Enhanced discrimination can also be obtained using the dominant scattering eigenvalue $\lambda_1$. Like the entropy $H$, $\lambda_1$ permits the assessment of the dominant scattering homogeneity, with the highest value (1) for a pure single scattering (of entropy zero). The analysis of $\lambda_1$ leads to the conclusion that fen scattering is more homogeneous (i.e. pure) than agriculture field scattering: $\lambda_1 \approx 0.66$ for sedge fen whereas $\lambda_1 \approx 0.55$ for agriculture fields. This may be explained by the presence of the water underneath the vegetation that minimizes the volume scattering component. As a result, the coherence $p_{\phi_{s1}}$ of sedge fen is much higher than the one of agriculture fields, as seen in Figure 5. The combination of $\phi_{s1}$ with $p_{\phi_{s1}}$ (or $\lambda_1$) permits a better discrimination of the sedge fen from agriculture fields, and should lead to a more effective wetland classification. Notice also for the marsh class, that the high surface water level underneath cattails leads to a more pure scattering (Low entropy $H$ about 0.1) with very high value of $\lambda_1 \approx 0.90$ and $p_{\phi_{s1}} \approx 0.95$, as seen in Figure 5.

V. CONCLUSION

The information provided by the Touzi phase of the dominant scattering type looks to be very promising for wetland classification using C-band polarimetric SAR. It is confirmed that the scattering type radiometric information, which is provided by $\alpha_s$ or the Cloude $\alpha$ combined with the entropy $H$, does not permit taking full advantage of polarimetric SAR for an effective wetland classification. As with HH-Radarsat-1, the poor potential of $\alpha_s$ and $\alpha$ for discrimination of wetland vegetation species limits the efficiency of polarimetric SAR for wetland classification. The new phase $\phi_{s1}$ of the symmetric scattering type introduced in [1] provides the key information missed by $\alpha_s$ and $\alpha$ for an enhanced vegetation type discrimination and this leads to more effective wetland classification. The use of the dominant scattering type phase, $\phi_{s1}$, makes possible the discrimination of shrub dominated bog from sedge dominated fen, and permits even the discrimination of conifer dominated treed bog from upland deciduous forest under leafy conditions. $\phi_{s1}$ permits a clear identification of the four Mer Bleu classes: sedge fen, marsh, shrub bog and conifer dominated treed bog. The phase degree of coherence $p_{\phi_{s1}}$ is required for the exploitation of the scattering type phase under coherence conditions. In addition, $p_{\phi_{s1}}$ permits an enhanced discrimination of the wetland site from uplands, and the combination of $\phi_{s1}$ with the degree of coherence $p_{\phi_{s1}}$ should be used for an enhanced wetland-uplands classification. The use of the scattering type magnitude $\alpha_s$ in addition to the phase information $\Phi_s$ and $p_{\phi_{s1}}$ remains essential for an unambiguous description of wetland target scattering, as discussed in [9]. Target helicity, which assesses the symmetric nature of target scattering, is further investigated in [16]. It is shown that the helicity, which is generated for the first time from incoherent target scattering decomposition [1], is very promising for forest structure characterization and detection of forest changes between leafy and no leave conditions [16].

REFERENCES


Fig. 1. *Wetland classification based on the forest inventory provided by NCC*

Fig. 2. *Convair-580 HH SAR Image (Mer Bleu)*

Fig. 3. *Dominant scattering type magnitude $\alpha_{s1}$*

Fig. 4. *Dominant scattering type phase $\phi_{\alpha_{s1}}$. The black contour indicates the wetland site extent*

Fig. 5. *Degree of coherence of the scattering type phase $\phi_{\alpha_{s1}}$*