A NEW TARGET DECOMPOSITION TECHNIQUE FOR COMPACT POLARIMETRIC SAR DATA.

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Introduction: The $m-\delta$ and the $m-\chi$ decomposition methods for compact polarimetric SAR data have been proposed in [1] and [2] respectively. The degree of polarization (m) and the relative phase (δ) were used to define the $m-\delta$ decomposition. The δ parameter works well if the transmitted field is purely circular. In [2] the $m-\chi$ decomposition for hybrid dual-polarimetric radar data were proposed to analyze the lunar surface. By replacing the relative phase parameter δ with the ellipticity χ this decomposition was able to resolve certain odd-even bounce scattering ambiguities observed over a lunar crater wall. Unlike δ parameter, χ is more robust to poor transmission circularity. It is mentioned in [2] that a three-component (m,χ,ψ) decomposition could be more appropriate to infer various scattering mechanisms with *a priori* knowledge of the ellipticity (χ) of the transmitting polarized EM wave.

In this paper, a new compact polarimetric SAR decomposition ($S-\Omega$) is proposed. The odd-bounce (and Bragg) and the even-bounce powers (P_s and P_d) are obtained by multiplying the received power in the opposite sense transmitted and the same sense transmitted with the polarized power fraction (Ω) respectively. The diffused power (P_v) is obtained by multiplying the total power with the unpolarized power fraction $(1-\Omega)$. The decomposition results are obtained for the CP data simulated from full-polarimetric (FP) data by varying the axial ratio (AR) of the transmitting EM wave. The results obtained from the new decomposition are both qualitatively and quantitatively compared with the $m-\chi$ decomposition.

Methodology: In the analysis of CP data, the four element real Stokes vector $\boldsymbol{S}=[S_0,S_1,S_2,S_3]^T$ of the scattered wave is of primary interest. The received Stokes vector S_r is related to the incident Stokes vector S_t by (1), where *R* is the distance between the target and the receiving antenna, *n* is the number of looks and M_k is the k^{th} single-look Mueller matrix.

$$S_r=\frac{1}{R^2}\frac{1}{n}\sum_{k=1}^{n}(M_k)S_t \tag{1}$$

The total received power (P_R) for a partially polarized wave ($0\leq m\leq 1$) can be expressed in terms of the incident and the received Stokes vectors (2).

$$P_R=\alpha(S_t)^T S_r \tag{2}$$

An average Stokes vector can be decomposed into a sum of a completely polarized wave and a completely unpolarized wave [3]. In equation (3), the first term correspond to the polarized power component (P_{UP}) and the second term correspond to the polarized power component (P_P).

$$\begin{aligned}P_R &= \{(1-m)\alpha S_{t0}S_{r0}\} \\ &+\left\{m\alpha S_{t0}S_{r0}\begin{bmatrix}1\\ cos2\chi_t cos2\psi_t\\ cos2\chi_t sin2\psi_t\\ sin2\chi_t\end{bmatrix}^T\begin{bmatrix}1\\ cos2\chi_r cos2\psi_r\\ cos2\chi_r sin2\psi_r\\ -sin2\chi_r\end{bmatrix}\right\} \\ &= P_{UP}+P_P\end{aligned} \tag{3}$$

The polarized power fraction (Ω) is expressed as the ratio of the polarized received power (P_P) to the total received power (P_R) (4),

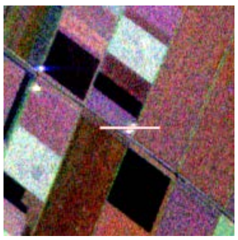
$$0\leq\Omega=\frac{P_P}{P_R}\leq 1 \tag{4}$$

The Ω parameter is a function of both the transmitting and the receiving ellipticities (χ_t,χ_r) and orientations (ψ_t,ψ_r). The odd-bounce (and Bragg) power (P_s: $Blue$) and the even-bounce powers (P_d: Red) are obtained by multiplying the received power in the opposite sense transmitted ($OC=(S_0+S_3)/2$) and the same sense transmitted ($SC=(S_0-S_3)/2$) with Ω respectively. The diffused scattering power (P_v: $Green$) is obtained by multiplying $S_0=SC+OC$ with the unpolarized power fraction $(1-\Omega)$ (5).

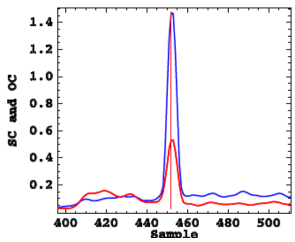
$$\begin{bmatrix}P_s\\P_d\\P_v\end{bmatrix}=\begin{bmatrix}\Omega(S_0+S_3)/2\\ \Omega(S_0-S_3)/2\\ S_0(1-\Omega)\end{bmatrix} \tag{5}$$

Backscatter echo from a circularly polarized wave on the transmission has both the opposite (OC) and the same (SC) sense components. The OC echo has both quasi-specular and diffused mechanisms while the SC echo has both even reflections from the target and diffused mechanisms.

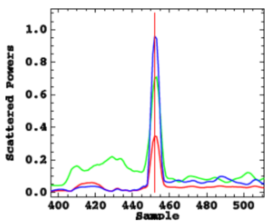
The scattering powers estimated for the two areas for the L-band AIRSAR flevoland data are shown in Fig. 1(a) and Fig. 2(a) to illustrate the proposed methodology. It can be seen that in Fig 1(b) the OC (odd-bounce) component is roughly three times larger than the SC (even-bounce) component over a target. It can be also seen in Fig. 1(c) and (d) that the odd-bounce power (P_s) obtained by the two methods are almost equal for this target. However, the even-bounce power (P_d) is estimated to be almost zero by the $m-\chi$ decomposition even though the SC component is not equal to zero (Fig. 1(b)). The contribution of this SC component to the even-bounce power (P_d) is evident in the $S-\Omega$ decomposition (Fig. 1(c)) with $\Omega \approx 0.65$. In another example a target for which the ratio, SC/OC ≈ 1 is considered. In this case the powers estimated by the proposed methodology are approximately equal to that of the $m-\chi$ decomposition powers as shown in Fig. 2(c) and (d) with $\Omega \approx 0.3$. This suggests, that the powers estimated by the proposed decomposition are in complete agreement with the $m-\chi$ decomposition powers only when SC/OC = 1 or either SC/OC << 1 (pure odd-bounce) or SC/OC >> 1 (pure even-bounce).



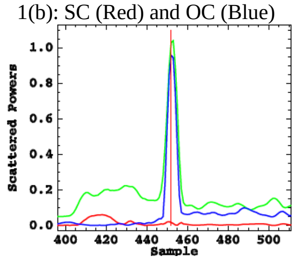
1(a): (Pauli RGB)



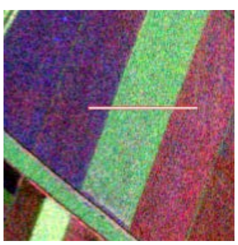
1(b): SC (Red) and OC (Blue)



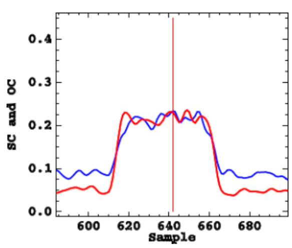
1(c): $S-\Omega$



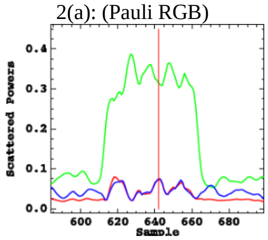
1(d): $m-\chi$



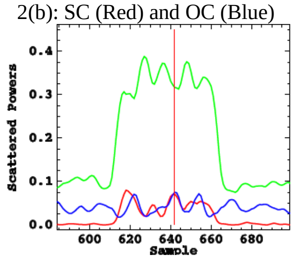
2(a): (Pauli RGB)



2(b): SC (Red) and OC (Blue)



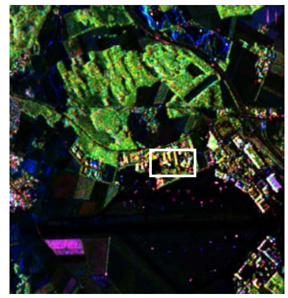
2(c): $S-\Omega$



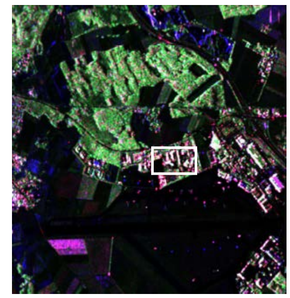
2(d): $m-\chi$

Results and Discussion:

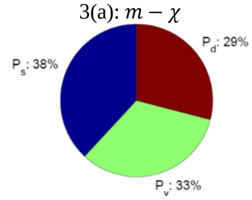
The L-band E-SAR data over the Oberpfaffenhofen test site, Germany is used in this study. A hybrid polarimetric data is simulated from the full-polarimetric data with AR = 0 dB. The even, odd and the diffused powers estimated from the two decompositions are shown in Fig. 3(a) and Fig. 3(b). It can be observed in Fig. 3(c) and Fig. 3(d) that the even and the odd-bounce powers for the $S-\Omega$ decomposition are 4% and 5% more than the $m-\chi$ decomposition in the area marked in the figures respectively. Consequently the diffused power estimated by the $S-\Omega$ is 9% less than the $m-\chi$ decomposition.



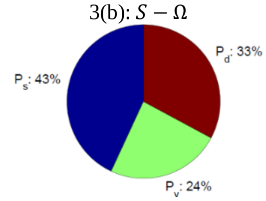
3(a): $m-\chi$



3(b): $S-\Omega$

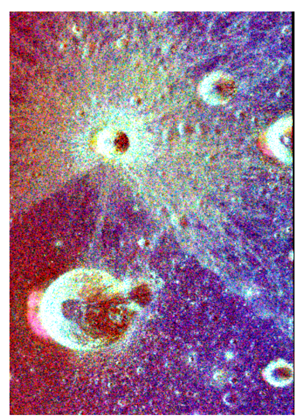


3(c): Power distributions

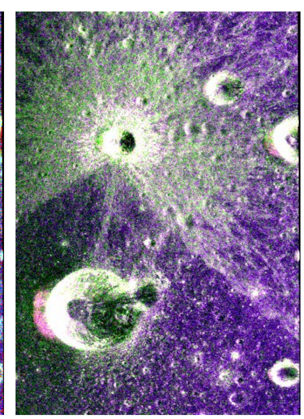


3(d): Power distributions

The $m-\chi$ and the proposed decompositions are also shown for the LRO's Mini-RF data over the Kies C crater (Fig. 4(a) and Fig. 4(b)). The even-bounce signature from the crater floor-wall is evident in both the images showing the red halo in the far range.



4(a): $m-\chi$



4(b): $S-\Omega$

The transmitted field of Mini-RF is nominally circular (AR = 2.5 dB [4]). The $S-\Omega$ decomposition takes into account this transmitting ellipticity to better discriminate the scattering mechanisms. The diffused scattering by the crater ejecta and the crater floor is also more prominent in the $S-\Omega$ decomposition (Fig. 4(b)).

References:

[1] Raney R. (2007) *TGRS, 45*(*11*),3397–3404. [2] Raney R. et al. (2012) *JGR, 117(E12)*. [3] Wolf E. (1954) *Il Nuovo Cimento,12(6)*, 884–888. [4] Raney, R. K. et al. (2011) *Proc. IEEE*, 99, 808-823.