M-delta Decomposition of Hybrid Dual-Polarimetric RISAT-1 SAR Data

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Abstract:
Scattering decomposition of polarimetric SAR data is essential to understand the predominant scattering type from a single or averaged resolution cell. For a given transmission polarization, the four element Stokes vector captures all of the information inherent to dual-polarized backscattered signals. The m-delta decomposition of hybrid dual polarimetric SAR data of RISAT-1 by deriving the Stokes parameters is presented in this paper.

Key Words: Stokes parameters, polarization, decomposition

I INTRODUCTION

In most of applications, the main objective is to enhance the measurement potential of a Space-borne Synthetic Aperture Radar (SAR) in response to backscattered energy from a randomly distributed targets having unknown orientation relative to the transmitted radar signal. Polarimetric SAR systems have opened the doors to many innovative and new applications. The concept of quadrature-polarization (or full polarization) was introduced to remote sensing community in the 1980s. Several recent papers [1,2,3] have demonstrated that dual polarization SAR systems can, in certain situations, reproduce fully polarimetric information based on a few simple assumptions. Souyris et al. [1] introduced the $\pi/4$ compact polarimetric mode and in another study, Stacy [3] demonstrated that a compact polarimetric mode based on a circular polarization transmit and (L, R) circular polarization receive could be implemented using slightly modified form of the original compact polarimetry algorithm. It should be stressed at the outset that the hybrid-polarization architecture [4] , or any other partial polarimetry scheme for that matter, is no substitute for quadrature polarization. Partial polarimetry is a major and efficient step up from a single channel system toward full polarimetric measurement capabilities. Partial polarimetry is a reasonable strategy when the system resources (power, mass, data volume or cost) preclude full polarimetry.

With recent advances in polarimetry, SAR with Hybrid–polarity (CL-pol) architecture transmitting circular polarization and receiving two orthogonal mutually coherent polarizations, which is one demonstration of compact polarimetry enable larger swath coverage, reduced PRF and SAR system complexity as compared to fully polarimetric systems. The first CL Space-borne SAR in Earth Observation orbit is India's Radar Imaging Satellite (RISAT-1) launched on 26th April, 2012 is a new-fangled gateway to remote sensing user community for crop and other land use classifications. The major advantage of hybrid polarimetry is that it offers double the swath width. Another advantage of Hybrid polarimetry radar can easily adopt to scan-SAR imaging mode which will offer more swath coverage than quad-pol system which has key issue for ocean surveillance. The majority of applications of compact polarimetry SAR data have been planetary and terrestrial including crop classification, soil moisture estimation, vegetation characterization, land cover mapping, maritime surveillance, ship detection and iceberg detection.

II STOKES PARAMETERS

The backscatter signal is usually partially polarized, that is, it contains a polarized component that has systematic polarization and an unpolarized component that has random polarization. The polarized component can be represented by a polarization ellipse, showing the path of the tip of the electric vector of the backscatter signal at a fixed point in space. The parameters of the polarization ellipse will be estimated from receive polarizations using the Stokes vector. Measurement potential is maximized if and only if the data are the four stokes parameters of the backscattered field (or their logical equivalent). Stokes vector analysis of the image data will be used to estimate the polarized circular and linear components of the backscatter signal. Coherently dual-polarized received signals in the linear basis are sufficient to calculate the four Stokes parameters, which are rotationally invariant with respect to geometric trends in the scene since the transmit polarization is circular.

Detected images conventionally delivered by traditional dual-polarized radars are sufficient to calculate two of the stokes parameters (S_0, S1) in terms of linearly polarized data or (S_0,S3) if circularly polarized. As a consequence, the parameters which depend on cross product between channels cannot be evaluated. This omission discards potentially valuable information. In response to circularly polarized illumination, multiple scattering within a subsurface volume in combination with surface scattering imposes linear polarization components into the backscatter. This effect can be observed through the four stokes parameters, but not through the detected images alone. The degree of linear polarization which is closely related to the observed field's entropy is one means of quantifying the effect. Access to the Stokes parameters allows characterization of linearly polarized reflection properties from circularly polarized data. The circular polarization ratio is anomalously large in response to volume scattering which is calculated from either linearly or circularly polarization transmissions [5]. Stokes parameters and their norms can be derived equally well for either linearly or circularly polarized backscatter generated in response to circularly polarized transmissions.

For radar like RISAT-1, the fundamental requirement for generating the Stokes parameters is that the complex amplitudes of the focused images are available from both orthogonally polarized received channels. The radar backscatter from the terrain includes fully and randomly polarized constituents primarily from volumetric materials that give rise to multiple internal reflections which obliterate the transmitted polarization characteristics. The polarized portion of the backscattering can be bifurcated into two classes namely single (odd) bounce(Bragg Scattering as well as specular reflection from a quasi planar surface perpendicular to transmitted signal) and double (even) bounce (dihedrals or di-planes)[6]. In response to a right-circularly polarized transmitted signal, circular polarimetry provides stokes parameters (S_0, S_1, S_2, S_3) given in eq. 1 by using data received in two mutually orthogonal channels. The four stokes parameters of the backscattered field are represented in matrix form as

$$\begin{bmatrix} S_0 \\ S_1 \\ S_2 \\ S_3 \end{bmatrix} = \begin{bmatrix} \langle |E_{RH}|^2 + |E_{RV}|^2 \rangle \\ \langle |E_{RH}|^2 - |E_{RV}|^2 \rangle \\ 2Re\langle E_{RH} E_{RV}^* \rangle \\ -2Im\langle E_{RH} E_{RV}^* \rangle \end{bmatrix} \quad \text{---- (1)}$$

In each case, E_{RH} represents complex voltage received by the channel with right-circular transmit and horizontal receive, E_{LH} represents complex voltage received by the channel of right-circular transmit and vertical polarization receive, * indicates complex conjugate, < . . .> denotes ensemble average, and *Re* and *Im* represent the real or the imaginary value (respectively) of the complex image. Data from CL-pol SAR are fully characterized through a 2x2 matrix, which is well-suited to streamline decomposition.

III DECOMPOSITION METHODOLOGY

Polarimetric analysis in related fields has developed a mature alternative technique known as decomposition, in which two or more suitably selected parameters are used jointly to classify fundamental characteristics of the observed field. A decomposition method based on elements of Stokes 'child' parameters which best suits for hybrid circular polarimetric data is 'm-δ' decomposition method suggested by Dr. K. Raney et al 2008[8]. Based on the derived stokes parameters, several useful quantitative measures follow like circular polarization ratio (CPR, representative of scattering associated with dihedral reflection), Degree of linear polarisation (m_L, an indicator of volume Vs subsurface scattering), Degree of Polarisation (DoP) (m, representative of polarized and diffused scattering) and relative phase (δ) between the two linear E-vectors of the backscattered field (an indicator of double bounce scattering). The state of polarization of an electromagnetic wave can be characterized by the DoP and relative phase expressed in terms of Stokes parameters as

$$m = \frac{\sqrt{S_1^2 + S_2^2 + S_3^2}}{S_0} \qquad 0 \le m \le 1 \qquad \text{------ (2)}$$

$$\delta = \tan^{-1}\left(\frac{S_3}{S_2}\right) \qquad -180^0 \le \delta \le 180^0 \qquad \text{------ (3)}$$

Mathematically, on the Poincar`e sphere, the DoP represents the distance of a normalised Stokes vector's last three components from the origin. The surface of the unit Poincar`e sphere corresponds to m=1, and represents all totally polarized states. Once polarized wave interacts with a random medium, the polarization state of the backscattered wave may change. Hence, depolarization is associated with a reduction in the polarization of incident states. A decomposition method along with suitable weighting functions has to be made available which maps Stoke's parameters to RGB image space. If the degree of polarization, relative phase between two orthogonal channels and total received power is estimated, then odd bounce, even bounce and volume scattering targets are separated using the weighting functions.

IV IMPLEMENTATION AND RESULTS

Initiating from focused, Single-Look Complex (SLC) SAR image data of RISAT-1 operating in right circular polarimetry in Fine Resolution Stripmap (FRS-1) mode having 75 MHz chirp bandwidth has been considered for applying the decomposition method which essentially utilize the degree of polarization and relative phase of the targets and imposes sinusoidal weighting on them in order to segregate the odd/even and volume scattering targets in the scene. The power scattered by odd and even bounce targets are obtained by applying sinusoidal weighting function (1-sin(δ))/2 for even bounce targets and (1+sin(δ))/2 for odd bounce targets respectively [7]. The voltage level contribution from odd, even and volumetric targets to generate scattering type RGB image can be expressed as

$$f_{odd} = \sqrt{S_0 * m * \frac{1+\sin(\delta)}{2}} \qquad \text{--- (4)}$$

$$f_{even} = \sqrt{S_0 * m * \frac{1-\sin(\delta)}{2}} \quad \text{---} \quad (5)$$

$$f_{volume} = \sqrt{S_0 * (1-m)} \quad \text{---} \quad (6)$$

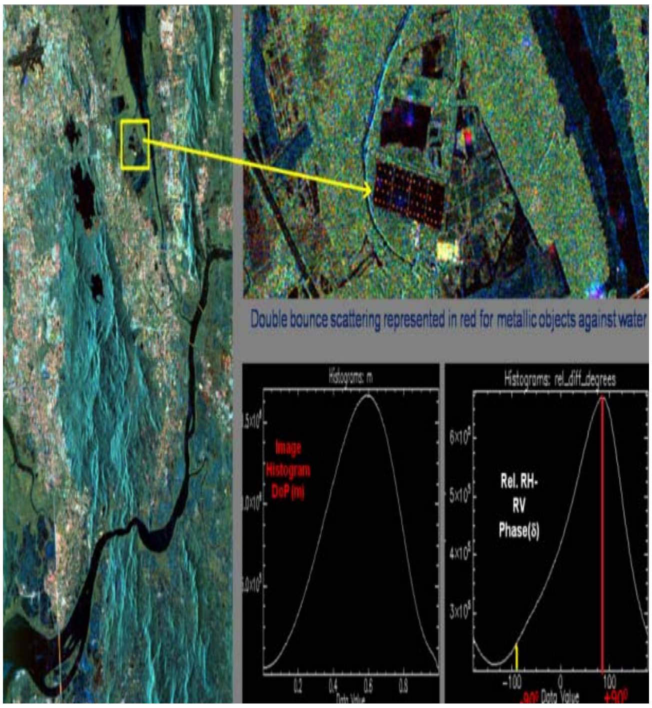

Figure: 1 RGB image (Mumbai area) generated with m- δ decomposition depicting Surface, volume and double bounce scatterings along with distribution of ‘m’ and relative phase between RH and RV.

The ‘m- δ’ decomposition method is applied on cFRS-1 SLC data (orbit: 3071, DOP: 15-11-12, scene no:2, Mumbai area) to generate scattering type RGB image where blue indicates single bounce (and Bragg) backscattering, Red corresponds to double-bounce and Green represents the randomly polarized constituent or volume scattering as shown in figure 1. It is observed through the distribution of DoP and relative phase between RH and RV approximately around $+/6^0$ w.r.t 90^0 signifying right circular polarisation transmission with partial linear component. The application of m- δ decomposition methodology and its validation has been evaluated by considering an image where trihedral corner reflectors were deployed having three perpendicular plates resulting in odd bounce effect is represented in blue colour as shown in figure 2. The city area in Ahmedabad is represented in red colour signifying the corner reflector effect from man-made structures. The green colour representing volumetric scattering from vegetated areas is due to the depolarization of transmitted signal when interacted with such surfaces. The objects which have odd bounce scattering are represented in blue colour as shown in the image.

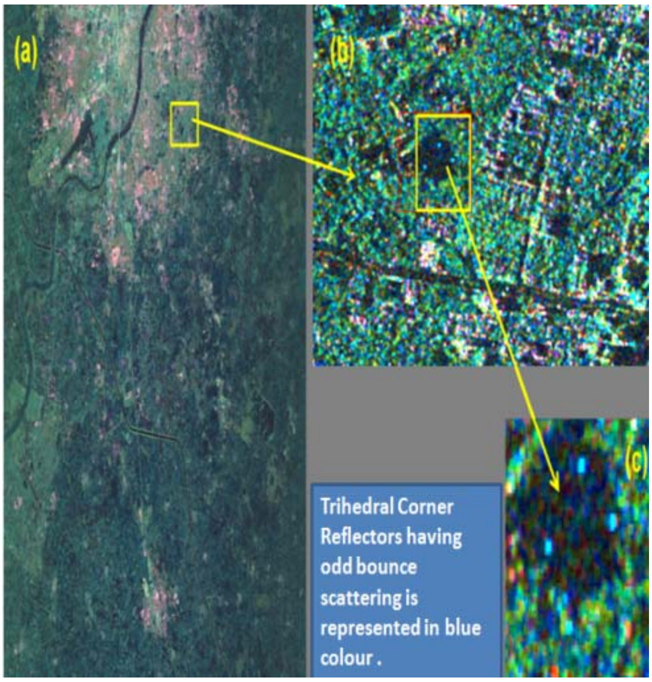

Figure: 2 (a) RGB image (Ahmedabad) generated with m- δ decomposition (b) Trihedral corner reflectors deployed at SAC campus (c) depicting odd bounce scattering shown in blue colour

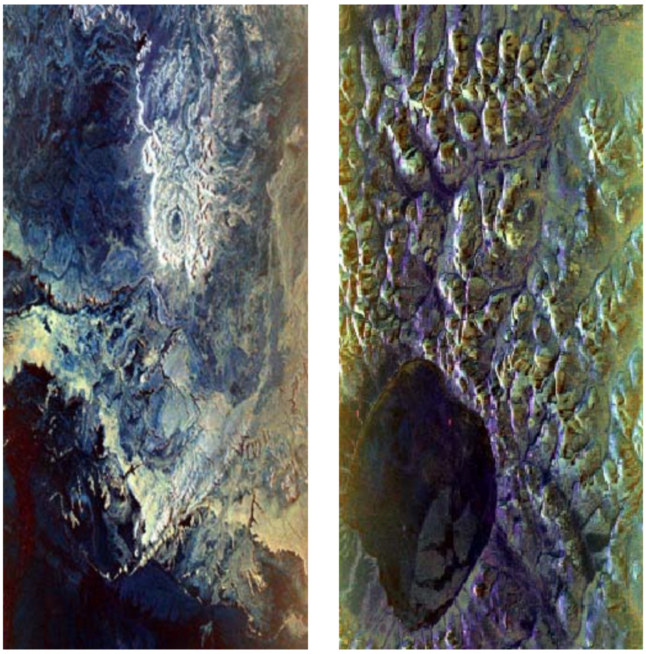

Figure 3: Algerian and Russian Crater images derived using m-delta decomposition technique.

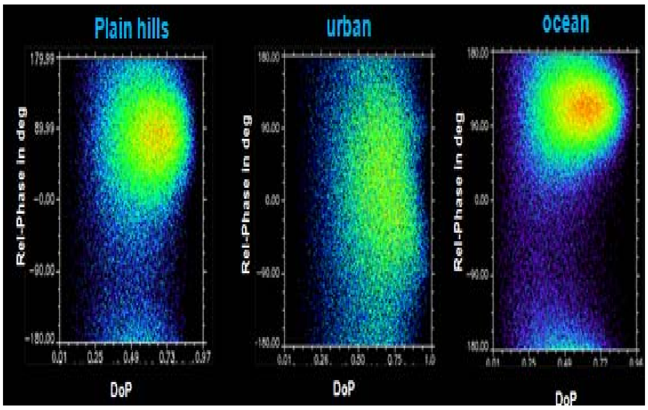

Figure 4: Scatter plots of DoP versus Relative phase in deg over different regions of Mumbai area of RISAT-1 Data.

It is noted that that in order to decipher the linearly polarization constituent in the transmitted field, Poincare' ellipticity parameter χ (chi) is the second decomposition variable which is one of the three principal components (m, χ, ψ) that are necessary and sufficient to describe the polarized portion of a partially-polarized quasi-monochromatic EM filed of average strength S1.

CONCLUSION

Scattering decomposition of polarimetric SAR data is essential to understand the predominant scattering type from a single or averaged resolution cell. Power scattered by even bounce and odd bounce targets are dependent on the state of polarization and relative phase values of the targets. If the degree of polarization, relative phase between two orthogonal channels and total received power is estimated, then odd bounce, even bounce and volume scattering targets are separated using the weighting functions. Depolarized targets indicate volume scatters. Very encouraging preliminary results were obtained by using m-delta decomposition technique on RISAT-1 hybrid polarimetric data.

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