Extraction optimum de l’information polarimétrique à partir du radar à ouverture synthétique

Ridha Touzi, Ing., Ph. D., habil.
Senior Research Scientist

Canada Centre for Remote Sensing
We are a Team

Recipient of the 1999 IEEE Geoscience and Remote Sensing Transactions Prize Paper Award for “a very significant contribution to the field of endeavor of the IEEE GRS Society”

Recipient of the 2003 NRCan Departmental Award for “a significant contribution to the field of polarimetric SARs and RADARSAT2”

More than 25 years experience on many aspects of Synthetic Aperture Radar (SAR): signal and image processing, polarimetry (since 1988), and airborne and spaceborne calibration.

Author of more than 200 papers and invited presentations in national and international conferences.
Coherence Estimation for SAR Imagery

Dr. Ridha Touzi

Collaboration and Partnership

Dr. Ridha Touzi has made significant contributions in the field of Synthetic Aperture Radar (SAR) polarimetry in Canada and at the international level. He has shown international leadership through organizing sessions at international conferences and workshops such as the International Geoscience and Remote Sensing Symposium held in Toronto in 2002 and in Toulouse in 2003, as well as the Advanced Aperture Radar Workshop, which was held at the Canadian Space Agency in 2003. Dr. Touzi has developed advanced methods of polarimetric data analysis. He has also developed and implemented a user-friendly Polarimetric Workstation that has been successfully licensed to nearly 20 other government departments, universities, and industry performers. Dr. Touzi is making key contributions to Canada's preparation for the RADARSAT-2 Synthetic Aperture Radar by developing appropriate data calibration methods, and by influencing the RADARSAT-2 antenna design to ensure that advanced data will be accessible to the user community.
OUTLINE

✦ Polarimetry at CCRS
✦ CCRS contribution to RADARSAT2
✦ Calibration of polarimetric SARs
✦ Theory of polarimetry and image synthesis
✦ Polarization information extraction for ship detection and identification
  ➢ Touzi anisotropy
  ➢ Touzi SSCM
✦ Polarization information extraction for wetland classification
  ➢ Incoherent target scattering decomposition (Touzi decomposition)
Polarimetry at CCRS since 1988
Convair-580 Polarimetric SAR

• Fully Polarimetric SAR X and C bands
• Viewed as a primary research tool to support CCRS work for RADARSAT-2 and ENVISAT

☞ C.E. Livingstone et al., CCRS SAR Polarimetry - Status Report, Proc. IGARSS’90
RADARSAT-2:
A Government-Industry Satellite SAR for Earth Observation
1998: RADARSAT2 Polarimetric Mission Approved
RADARSAT2: The Canadian Satellite SAR for Earth Observation

- 600 $M Canadian mission for EO
- Government-Industry polarimetric SAR mission approved in 1998
- Launched in December 2007
- Data continuity from RADARSAT-1
- Mission duration: 7 years
- The next step towards full commercialization of the RADARSAT program
- Emphasis on “information content”
  - maximizing the economic value
  - expanding the potential for further “Value-Added” processing
1998: RADARSAT2 Polarimetric Mission
CCRS well prepared to provide the right S&T at the right time

✧ C.E. Livingstone et al., CCRS SAR Polarimetry - Status Report, *Proc. IGARSS’90, College Park*, MD, USA, May 20-24
✧ R. Touzi, C.E. Livingstone, et al., Antenna Gain and Phase Patterns for *Calibration* of Polarimetric SAR Data; *IEEE TGRS*, 31, 6, 1993
✧ R. Touzi et al., Polarimetric *Discriminators* for SAR Images; *IEEE TGRS*, 30, 5, 1992
✧ R. Touzi and A. Lopes, Statistics of the Stokes Parameters of the Complex Coherence Parameters in One-look and Multi-look Speckle Field; *IEEE TGRS*, 34, 2, 1996
RADARSAT2 Mission Preparation

- Preparation of RADARSAT 2 mission **in collaboration** with CSA
  - influence RADARSAT2 system design & polarimetric calibration
  - investigate **applications** that promote the **unique** RADARSAT2 polarimetric capability
  - familiarize the Canadian public institutions, universities, and industry with Polarimetry:
    - PWS: software for polarimetric data analysis
    - PWS & Convair-580 SAR data (CSA prog: GRIP, EOADP)
    - Seminars

- Promotion of RADARSAT2 as an **essential** source of information for more efficient decision making on Government critical issues
- R&D in polarimetric SAR: Calibration, Methodology for optimum polarization information extraction, and Applications
- Provide federal and provincial governments, universities, and Canadian industry with **knowledge** and **expertise** in polarimetry
Outreach: The PWS a Friendly and Effective Tool for Optimum Extraction of Polarimetric Information

R. Touzi and F.J. Charbonneau

Abstract. The polarimetric workstation (PWS) is a user-friendly and efficient PC platform software package that has been developed at the Canada Centre for Remote Sensing (CCRS) for the optimum extraction of polarimetric information from RADARSAT-2 data. The PWS is currently being used by a majority of CCRS scientists in their investigation of polarimetric applications in geophysical, water-related and biological parameters, environmental monitoring, and industry for integration of this new source of information into their existing and operational activities. The PWS has been licensed for free to Canadian governmental institutions, universities, and colleges and for a nominal price to Canadian industry. In this paper, the PWS in presented and its main function and products are described. Future upgrades of the PWS are also presented.

Introduction

To promote the unique polarimetric capabilities of RADARSAT-2, scientists at the Canada Centre for Remote Sensing (CCRS), Natural Resources Canada, have investigated various applications using fully polarimetric data. The results obtained depend significantly on the tools used for polarimetric information extraction. For the optimum extraction of polarimetric information from RADARSAT-2 data, CCRS has developed a software system, the polarimetric workstation (PWS), which is currently being used by most CCRS scientists in their investigation of polarimetric applications (Van der Sande et al., 2003; McNamee et al., 2002; 2003; Guertler et al., 2001; Sokol et al., 2002; Sokol and Pohl, 2001). The PWS is based on an intuitive user interface that will provide Canadian industry, through technology transfer, a competitive advantage to explore the information potential of RADARSAT-2.

This paper presents the PWS and describes its main functions. Future upgrades of the PWS and examples of products generated by the PWS are also presented.

PWS presentation and functions description

PWS presentation

The PWS is a user-friendly and efficient PC-platform software package (Microsoft® Windows 2000®/Windows NT® or later environment) and includes a set of polarimetric tools that were selected from the wide set of tools published in the literature. Many polarimetric parameters have been developed for target characterization since 1950 (see the review paper of polarimetry by Touzi et al., 2004a). The appearance of the first imaging radar polarimetry, the National Aeronautics and Space Administration Jet Propulsion Laboratory (NASA-JPL) airborne synthetic aperture radar (AIRSAR) (Vogel et al., 1995),

Received 12 November 2003. Accepted 3 February 2004.

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The PWS a Friendly and Effective Tool for Optimum Extraction of Polarimetric Information

- To initiate federal and provincial governments, universities, and industry in the new and complex technology of polarimetry

- A friendly and effective polarimetric image analysis tool

- Based on 20 years experience in SAR polarimetry

- Licensed for free to Canadian Governments, universities, and for a nominal fee to industry.

- Used by industry for commercial and educational purposes

- RFP for commercial software (Atlantis and PCI)
Graphical Results Examples

Cloude H / α Decomposition

Channel Coherence

Polarization Signatures

Poincaré Sphere
### Canadian Governmental and Provincial Institutions
- Agriculture Canada
- Canadian Ice Service
- Canadian Space Agency
- DRDC of National Defence
- Emergencies Science and Technology Division
- Environment Canada
- Geological Survey of Canada and Canadian Forest Service
- Natural Resources of Canada
- Statistics Canada
- Natural Resources of Ontario
- Nova Scotia Department of Natural Resources

### Universities and Colleges
- CRIM
- INRS-ETE
- Nova Scotia Community College
- Royal Military College
- University of Calgary
- University of Montreal
- University of British Columbia
- York University
- University of Manitoba
- University of Waterloo
- Laval University

### Canadian Industry
- AUG signal Inc.
- C-CORE (Memorial University of Newfoundland)
- Geomat International Inc.
- Noetix Research Inc.
- RADARSAT International Ltd. (MDA)
- Vantage Point International Inc.
- VIASAT
- PCI
R&D for Optimum Extraction of RADARSAT-2 Polarimetric Information

✦ Unique tools developed:
  ➢ New polarimetric feature discriminators
  ➢ New Target Scattering Coherent and Incoherent Decompositions
  ➢ New polarimetric speckle filter & Segmentation with texture
  ➢ A friendly software, the PWS, for polarimetric data analysis

✦ The new tools are tested and refined through applications-specific research which promote the unique polarimetric capability of RADARSAT 2.


☛ Influence and help the Canadian industry, through R&D technology transfer.

☛ Transfer of knowledge and technology to Canadian universities through graduate thesis supervision, and professor sabbatical year
CCRS investigates applications that promote the unique RADARSAT2 polarimetric capability

http://geopub.nrcan.gc.ca/moreinfo_e.php?id=220108
http://geopub.nrcan.gc.ca/moreinfo_e.php?id=219802
Continuous Communication and Outreach

A review of polarimetry in the context of synthetic aperture radar: concepts and information extraction

R. Touzi, W.M. Boerner, J.S. Lee, and E. Luusenburg

Abstract. This study provides an update of the polarimetric tools currently being used for synoptic information extraction from polarimetric synthetic aperture radar (SAR) images. The basics of polarimetric theory are summarized and discussed in the context of SAR. Concepts of polarimetric SAR, which is an important tool for the retrieval of meaningful polarimetric information, is reviewed. Information extraction using the scattered and received wave parameters and target decomposition theory is considered. In particular, the use of coherency vectors and target decomposition is discussed and the practical limitations of these target decompositions are verified. Specific filtering and classification of polarimetric SAR images are also thoroughly analyzed, and the important directions for future research are outlined.


Introduction

The time-varying direction of the electric field vector, generally described as an ellipse in a plane transverse to propagation, plays an essential role in the interpretation of electromagnetic “vector waves” with metallic bodies and the propagation medium. Whereas this polarization manifestation behavior, expressed in terms of the “polarization ellipse”, is named “ellipismetry” in optical sensing and imaging (Azuma, 1977; Born and Wolf, 1959; Jones, 1941; Mueller, 1948; Wolf, 1954), it is termed “polarimetry” in radar and lidar-ladar sensing and imaging (Boerner et al., 1998; Krummholz, 1951; Oeschger, 1956; Poynting, 1905; van Zijl et al., 1977; Zöllner and van Zijl, 1991), using the ancient Greek meaning of “measuring inclination and object shape”. Thus, ellipismetry and polarimetry, which use the banks of the polarizability of electromagnetic waves introduced in the 19th century and at the beginning of the 20th century (Stokes, 1852; Wiener, 1900; Mueller, 1948; Born and Wolf, 1959), are concerned with the characterization of the polarization properties of optical and radio waves, respectively. Ellipismetry started anew in the 1960s with the significant advent of optical polarization phase control devices and the associated development of mathematical ellipismetry, such as the introduction of the 2 × 2 Coherent Jones forward scattering (propagation) matrix (Jones, 1941; 1947) and the associated 4 × 4 average power density Mueller (Stokes) propagation matrix (Mueller, 1949). Polarimetry research became active during the late 1990s with the introduction of dual-polarized antennas (Ginsburg, 1951; Sinclair, 1959; Rems, 1959; Németh, 1957; McCormick and Haney, 1972; 1982) and the subsequent formulation of the 2 × 2 coherency Sinchard radar backscattering matrix (Sinclair, 1959) and the associated 4 × 4 Rems, radar backscattering power density matrix (Kennough, 1951), as summarized in detail in Boerner et al., (1998) and in the review paper of Amling et al. (1998). Based on the original pioneering work of Kennough (1951), Poynting (1905), and Sugaya (1979) developed a phenomenological approach to radar polarimetry that has had a stable status in the steady advancement of polarimetry (1980) and gave a boost to further development, which continues today. Since the work of Sugaya, important contributions have been made to the...
CJRS RADARSAT2 Special Issue, Volume 30, Number 3, June 2004
CCRS Contribution


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Theory and Concepts of Polarimetric SARs
Canada Centre for Remote Sensing • Earth Sciences Sector

A review of polarimetry in the context of synthetic aperture radar: concepts and information extraction

R. Touzi, W.M. Boerner, J.S. Lee, and E. Lueneburg

Abstract. This study provides an update of the polarimetric tools currently being used for optimum information extraction from polarimetric synthetic aperture radar (SAR) images. The basics of polarimetric theory are summarized and discussed in the context of SAR. Calibration of polarimetric SAR, which is an important issue for the extraction of meaningful polarization information, is reviewed. Information extraction using the scattered and received wave parameters and target decomposition theory is considered. In particular, the use of coherent versus incoherent target decomposition is discussed and the practical limitations of these target decompositions are outlined. Speckle filtering and classification of polarimetric SAR images are also thoroughly analyzed, and the important directions for future research are outlined.


Introduction

The time-varying direction of the electric field vector, generally describing an ellipse in a plane transverse to propagation, plays a central role in the interaction of electromagnetic “vector waves” with material bodies and the propagation medium. Whereas this polarization transformation behavior, expressed in terms of the “polarization ellipse”, is termed “ellipsometry” in optical sensing and imaging (Azarian, 1977; Born and Wolf, 1959; Jones, 1941; Mueller, 1948; Wolf, 1954), it is denoted “polarimetry” in radar and lidar-ladar sensing and imaging (Boerner et al., 1998; Kennaugh, 1951; Dechamps, 1951; Runyan, 1951; Graves, 1950; Huygen, 1970; Van Zyli et al., 1987a; Zebker and van Zyl, 1991), using the ancient Greek meaning of “measuring orientation and object shape”. Thus, ellipsometry and polarimetry, which use the basics of the polarization of electromagnetic waves introduced in the 19th century (Stokes, 1852; Wiener, 1930; Mueller, 1948; Born and Wolf, 1959), are concerned with the characterization of the polarization properties of optical and radio waves, respectively.

Ellipsometry started a new era in the 1940s with the significant advent of optical polarization phase control devices and the associated development of mathematical ellipsometry, such as the introduction of the 2 × 2 coherent Jones forward scattering (propagation) matrix (Jones, 1941, 1947) and the associated 4 × 4 average power density Mueller (Stokes) propagation matrix (Mueller, 1948). Polarimetry research became active during the late 1940s with the introduction of dual-polarized antenna technology (Kennaugh, 1951; Sinclair, 1950; Runyan, 1951; Hutchinson, 1973; McCormick and Hendy, 1973; 1985) and the subsequent formulation of the 2 × 2 coherent Sinclair radar backscattering matrix (Sinclair, 1950) and the associated 4 × 4 Kennaugh radar backscattering power density matrix (Kennaugh, 1951), as summarized in detail in Boerner et al. (1998) and Ulaby and Elachi (1990). Based on the original pioneering work of Kennaugh (1951), Huygen (1965; 1970) developed a phenomenological approach to radar polarimetry that had a notable impact on the steady advancement of polarimetry (Giuli, 1985) and gave an impetus to further development, which continues today. Since the work of Huygen, important contributions have been made to the

Received 5 November 2003. Accepted 30 January 2004.

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Polarization of an e.m. Monochromatic Plane Wave

- Locus of the end point of the electric field in a plane orthogonal to the direction of wave propagation as a function of time.

\[
\left(\frac{E_x}{a_x}\right)^2 + \left(\frac{E_y}{a_y}\right)^2 - 2\left(\frac{E_x}{a_x}\right)\left(\frac{E_y}{a_y}\right)\cos(\delta) = \sin^2(\delta)
\]

\[E_x(z,t) = a_x \cos(\omega t - kz + \delta_x)\]

\[E_y(z,t) = a_y \cos(\omega t - kz + \delta_y)\]

\[E_z(z,t) = 0\]

\[\delta = \delta_y - \delta_x\]
Polarization of an e.m. Monochromatic Plane Wave
Characterization of the State of Polarization: Jones Vector

- \((a_x, a_y, \text{ and } \delta)\) or \(s_0, \alpha, \text{ and } \delta\)
- \(\psi\) (orientation angle), \(\chi\) (ellipticity), and \(s_0\)

\[s_0 = a_x^2 + a_y^2 = a_\eta^2 + a_\xi^2\]

Jones (unitary) vector:

\[
\hat{E} = (a_x e^{j\delta_x} \hat{x} + a_y e^{j\delta_y} \hat{y}) \cdot e^{-jkz}
\]

\[
\hat{E} = \hat{h} \cdot \|\hat{E}\| e^{-jkz} e^{j\delta_x}
\]

\[
\hat{h}(\alpha, \delta) = \cos \alpha \cdot \hat{x} + \sin \alpha \cdot e^{j\delta} \cdot \hat{y}
\]

\[
\hat{h}(\psi, \chi) = [\text{Rot}(\psi)] \cdot (\cos \chi \cdot \hat{x} + j \sin \chi \cdot \hat{y})
\]

\[0 \leq \psi \leq \pi\]

\[\tan \alpha = a_y / a_x\]

\[0 \leq \alpha \leq \pi / 2\]

\[-\pi / 4 \leq \chi \leq \pi / 4\]

\[\tan \chi = a_\eta / a_\xi\]
Polarization of target scattered waves:
Partially polarized waves

- SAR of Narrowband transmission \(\Rightarrow\) **Quasi-** monochromatic waves

\[
\begin{align*}
\tau &\ll \tau_c \\
\Rightarrow &\quad \text{Completely polarized waves} \\
\text{No} \quad \rightarrow &\quad \text{Partially polarized waves}
\end{align*}
\]

\[
\begin{align*}
E_x(z,t) &= a_x(t)\cos(\bar{\omega} t - \bar{k} z + \delta_x(t)) \\
E_y(z,t) &= a_y(t)\cos(\bar{\omega} t - \bar{k} z + \delta_y(t)) \\
E_z(z,t) &= 0
\end{align*}
\]

\(\tau\) : measurement time duration, \(\tau_c\) : target coherence time
Poincaré Sphere and Stokes vector for 
Representation of completely polarized and partially polarized waves

\[
\begin{align*}
  s_0 &= <a_x^2 + a_y^2> \\
  s_1 &= <a_x^2 - a_y^2> \\
  s_2 &= <2a_x a_y \cos \delta> \\
  s_3 &= <2a_x a_y \sin \delta> \\
\end{align*}
\]

\[
\h S = \hat{i}
\]

\[
p = \frac{\sqrt{s_1^2 + s_2^2 + s_3^2}}{s_0}
\]

- Degree of polarization: ratio of the intensity of Completely Polarized (CP) intensity to the total intensity:

  \[p=1 \Rightarrow \text{CP}, \ p=0 \Rightarrow \text{Completely Unpolarized CUP}\]
Mathematical characterization of target scattering: Scattering and Mueller matrix

• Electric field of the linearly polarized incident and scattered wave:

\[
\vec{E}^i = E_h^i \hat{h}_i + E_v^i \hat{v}_i \\
\vec{E}^s = E_h^s \hat{h}_s + E_v^s \hat{v}_s
\]

• Scattering matrix \([S]\) at the distance \(r\) from the scatterer:

\[
\vec{E}^s = \frac{e^{jkr}}{r} \begin{bmatrix}
S_{hh} & S_{hv} \\
S_{vh} & S_{vv}
\end{bmatrix} \cdot \vec{E}^i \\
S_{hv} = \sqrt{\sigma_{hv}} e^{j\phi_{hv}}
\]

• Stokes vector and Mueller matrix

\[
\vec{S}^s = \frac{1}{r^2} [M] \vec{S}^i
\]

\( [S] \) or \([M]\) \(\Rightarrow\) \(\sigma^\circ\) at any combination of transmitting-receiving polarizations
Polarization Synthesis using the Convair-580 SAR
Polarimetric SARs: POLARIMETERS

- Measure almost **simultaneously** the amplitude and phase of the reflected wave in (HH, HV, VH, VV).

E. Pottier, W. Boerner, et al. (IGARSS seminars)
Calibration of Polarimetric SAR for the extraction of meaningful polarization information:
Uncalibrated SAR provides misleading information on spatial wetland extent

Simulated RADARSAT-2 SAR image of the Montmagny area used to map the spatial extent of tidal marsh wetlands. The arrows in the calibrated image indicate a clear presentation of tidal marsh wetlands that have shallow water and levels that usually fluctuate daily, seasonally and annually due to tides, flooding, groundwater recharge and/or seepage losses. Significant errors in the spatial wetland extent are introduced when uncalibrated data are used.
Calibration of the Convair-580 Polarimetric SAR

R. Touzi, C.E. Livingstone, and F. Charbonneau

Abstract. The polarimetric model, which was developed for the calibration of the early X-band polarimetric Convair-580 SAR of the Canada Centre for Remote Sensing (CCRS), is adapted for the calibration of the Convair-580 SAR system. Measurements of the complex reflectivity of a 45°-45° polarimetric active radar reflector (ARR) and a corner reflector are combined with the V and V isotropic gain parameters estimated to calibrate the polarimetric SAR within ±20% from the bistatic configuration angle with an accuracy of 1 dB in reflectivity and 5° in phase. Tests run on various targets lead to the conclusion that the Convair-580 SAR system is quite stable in the short term but not over the long term. The Corner reflector deployment at 45°-45° for each flight. An angular stability of the hardware is suggested as a convenient solution to avoid deployment of a reference point target at each flight. On the other hand, several datasets demonstrate the existence from time to time of a significant crossed term. It is shown that the general calibration method can still be applied to retrieve pure polarizations from the distorted measurements.

Introduction

An imaging polarimeter is usually implemented by configuring the hardware to measure almost simultaneously the four scattering matrix elements for every resolution element in the scene (van Zyl et al., 1987; Livingstone et al., 1995; Christensen et al., 1998). All existing imaging polarimeters provide the four measurements in the linear horizontal (H) and vertical (V) polarizations HH, HV, VH, andVV. These measurements might be affected by cross-talk between the transmitting-receiving antennae or the switches used to select the H or V polarization at transmission and reception (Touzi et al., 1993). To synthesize the backscattering coefficient, €g, for any combination of transmitting-receiving antenna polarizations, pure H and V polarizations should be extracted from the distorted voltage measurements (Touzi et al., 2004). Since 1990, interest attention has been given to the importance of calibration for the meaningful use of polarimetric data. Van Zyl (1990) was the first to introduce a method for the calibration of the airborne synthetic aperture radar (AirSAR) data using image parameters and a reference point target. Since then, many papers have been published on the calibration of polarimetric AirSAR data, which were widely diffused and extensively used all over the world (Feozen, 1992; Klein, 1992; Touzi et al., 1993). The appearance of other polarimetric SARs has led to the development of various specific system calibration methods (Christensen et al., 1998; Horo, 1996; Skriver et al., 1994; Touzi et al., 1993).

To calibrate a polarimetric SAR system, accurate system modeling should be completed. In contrast to most existing polarimetric SARs, the Convair-580 SAR utilizes two receiving configurations as a function of the transmitting polarization H or V (Livingstone et al., 1995). A general polarimetric model, which includes systems whose receiving configuration is independent of the transmitted polarization, was introduced by Touzi and Charbonneau (1999). This model was used to develop a calibration method for the early X-band polarimetric SAR developed at the Canada Centre for Remote Sensing (CCRS) (Touzi et al., 1999). A simplified method was adopted for the C-band SAR system that is equipped with polarized switched characteristics by high isolation (better than 30 dB) (Livingstone et al., 1995; Hawkins et al., 1999, Touzi, 1999). The high isolation (better than 30 dB) of the H and V antennas permits the retrieval of the system
Calibration of the Convair-580 Polarimetric SAR

- **Fully polarimetric X-band SAR (from 1988 to 1993)**

- **Fully Polarimetric C-band SAR (since 1991)**

- **C-band SAR: Viewed as a primary research tool to support CCRS work for RADARSAT-2**
Convair-580 Receiving Configurations

- Receiving configuration depends on the transmitted polarization
- VanZyl calibration model cannot be used ⇒ New Model
Measured versus pure voltage: Polarimetric Calibration

\[
[ V ] = K \cdot \frac{n_{az} \rho_{az}}{R^2} \cdot [D_r]^T \cdot [g_r(\theta)]^T \cdot [S] \cdot [g_t(\theta)] \cdot [D_t]
\]

- [D]: Distortion matrix
- [g(\theta)]: Antenna distortion matrix

CALIBRATION

Pure (HH, VV, HV, VH) from distorted measurements

Reference point or natural targets
Calibration of the Convair-580 X&C -band system

• Antenna characteristics:
  – Highly isolated H and V antennas (35 dB)
  ➢ Calibration parameters estimated at a given incidence angle can be used for the whole range of incidence angles

urve System calibration completed using 1 ARC + 1 CR + 1 azimuthally symmetric target

♦ Antenna gain pattern measurement accurate at ± 20° from the boresight angle

❖ Accuracy: within 1-2 dB in radiometry and 5° in phase

❖ C-band: Switches highly isolated (better than -50 dB)
  ➢ Only ARC + CR required
Calibration of the Convair-580 X-band SAR

- Development of a more complex suitable model
  - Use of CR, ARC, + natural target

Fig. 8. Co-polarized signatures of shrubs. (a) Before calibration. (b) After calibration.
Calibration of ALOS Faraday rotation

✦ Member of the international calibration/validation committee of the Japanese satellite ALOS

✦ Collaboration with JAXA (Japan)

☛ PALSAR antenna highly isolated (better than -35 dB)

☛ An operational method based on the Touzi Decomposition for the calibration of ALOS using Target of symmetric scattering

Calibration of Faraday sensitive systems using targets of symmetric scattering

✦ Amazonian forest stable with polarization
  ➡ Radiometric correction (Antenna gain patterns, range variation, transmit power ..etc)
  ➡ Antenna cross-talk removal

☞ After removal of antenna cross-talks (stable)

\[
\begin{bmatrix}
M_{hh} & M_{vh} \\
M_{hv} & M_{vv}
\end{bmatrix} =
\begin{bmatrix}
1 & 0 \\
0 & f_1
\end{bmatrix}
\begin{bmatrix}
\cos\Omega & \sin\Omega \\
-\sin\Omega & \cos\Omega
\end{bmatrix}
\begin{bmatrix}
S_{hh} & S_{vh} \\
S_{hv} & S_{vv}
\end{bmatrix}
\begin{bmatrix}
\cos\Omega & \sin\Omega \\
-\sin\Omega & \cos\Omega
\end{bmatrix}
\begin{bmatrix}
1 & 0 \\
0 & f_2
\end{bmatrix}
\]

✦ Azimuthally symmetrical target ➡ f_2/f_1

➡ Deployment of CR for f_1 estimation

☞ Use of targets of symmetric scattering for calibration
Extrema of the degree of polarization for San-Francisco Segmentation (Touzi et al., CESR, France, 1988-90)
Polarimetric Discriminators for SAR Images

Ridha Touzi, Stéphane Gour, Thry Le Tou, Member, IEEE, Armand Lopes, and Eric Mougin

Abstract—A new method is developed to optimize the degree of polarization of a partially polarized wave reflected by a monostatic scattering target. The method permits, for a scattered wave and a given target characterized by its Mueller matrix, analytic computation of the maximum and minimum values of the degree of polarization, and the corresponding transversal polarizations. A procedure for the optimization of the scattered wave intensity is also proposed. The degree of polarization and the total scattered intensity extreme are then analyzed experimentally on JERS data. It is shown that several criteria such as the received intensity extremes, the condition of vanishing, the transversal polarization, and the spot, which are currently used for target discrimination, can be derived from combinations of the maximum and minimum values of the degree of polarization and the scattered wave intensity. Finally, a classification of the San Francisco image based on these indices is conducted for a better understanding of the specific physical mechanism of such targets.

Index Terms—Polarimetry, degree of polarization, partially polarized wave, SAR image.

I. INTRODUCTION

OVER the past few years, images acquired by polarimetric SAR systems have raised much interest in the remote sensing community. Compared to conventional SAR images, more detailed information regarding the medium are exposed thanks to the use of this new tool. In addition, researches on such a system, its polarization discrimination and characterization of targets and surface cover types, are numerous.

Several techniques have been developed recently to analyze polarimetric radar data for such scientific applications. To describe the polarization of the surface target, several quantities have been derived from the received wave intensity to be used as indicators of the target scattering properties. The resulting information can be used to generate images that optimize the target return from different surfaces, to map land cover and also to give better insight into the nature of the radar wave and scattering medium interaction.

Evans et al. [1] used the maximum and minimum of the received wave intensity at different polarizations to separate cover types. Van Zyl et al. [2] defined the coefficient of variation, which is the ratio of the maximum to the minimum received power to indicate target heterogeneity, resulting from the variation of scattering properties of adjacent pixels, or to indicate the presence of multiple scattering. Zege et al. [3] defined the fractional polarization $F = F_{0} - F_{00} / F_{00}$, where $F_{00}$ and $F_{0}$ are the maximum and minimum values of the received intensity as the polarized state is varied. They used the fractional polarization as a measure of the polarization purity of the scene. It indicates, for a given target, the degree to which one may infer the return from that target relative to the rest of the image. Another quantity is used, called the span of the scattering matrix defined as the sum of the squares of all the original scattering matrix elements $[4]$, as an indicator of the target scattering properties in the classification process.

In this paper, we will examine two basic quantities: (i) the degree of polarization, and (ii) the total scattered intensity of a partially polarized wave scattered from a fluctuating (or non stationary spatially stationary) target. The idea is to use the maximum and the minimum of these two quantities to separate different targets in polarimetric images.

The paper is structured as follows. First, a procedure we developed to optimize the degree of polarization and the total intensity of the scattered wave is presented in Section II. The procedure enables us to compute analytically the maximum and the minimum values of both of the degree of polarization and the total scattered intensity for a given target described by its Mueller matrix. The four basic vectors that result—i.e., the four basic indicatrices—are examined in Section III in terms of their relationships with the above mentioned discriminators currently used in the literature. For comparison purposes, we apply our method to the polarimetric data set used in the previous studies, i.e., the San Francisco JERS image acquired by the NASA/JPL radar polarimeter.

II. OPTIMIZATION OF THE SCATTERED WAVE PARAMETERS

A. Introduction

Before presenting the optimization procedures, let us briefly summarize the fundamental definitions concerning partially polarized waves and describe the indices which will be used in the following. The Stokes vector $\mathbf{S}$ of a fluctuating target scattered wave, described by its 4x4 Mueller matrix $\mathbf{M}$, is related to the Stokes vector $\mathbf{R}$ of the transmitted wave by the
The Touzi Anisotropy

- The total intensity of the scattered wave $R_o = \text{tr}([J])$ varies with the polarization of the transmitting antenna.
- The degree of polarization $p$ varies with the polarization of the transmitting antenna.

$\Rightarrow$ Entropy $H$ varies with the polarization of the transmitting antenna.

Dynamic range of the entropy: $\Delta H$

$\Rightarrow$ Touzi Anisotropy: $\Delta H \Rightarrow$ measure of target scattering complexity.

$\Rightarrow$ The more the target is structured the higher is $\Delta H$. 

Touzi Polarimetric SAR, Journée Grd-Isis, Paris 28 Mars
Application to Ship Detection
Convair-580 SAR data DRDC/CCRS

  - Incidence angle range: 45°-70°
  - Calm wind & sea conditions
  - Ship not ground-truthed

- Crusade’00 off Cape Race, Newfoundland, Mar. 2000 (DRDC)
  - Incidence angle range: 20°-55°
  - 22 March: wind (16 knots), swell 3-4m, 1 ship imaged at 22°
  - 28 March: Wind (7 knots), swell amplitude of about 4m
    - 2 ships imaged, one at 35° and the second at 45°
  - 30 March: Wind (20 knots), swell 4m, 1 ships imaged at 45°
HH and VV polarization
(incidence angle: 46°-70°)
HV and Circular RR polarization
*(incidence angle: 46°-70°)*
The Touzi Anisotropy
(incidence angle: 46°-70°)
Ships-Sea Contrast (in dB)
Characterization of Target Symmetric Scattering 
Using Polarimetric SARs

Ridha Touzi, Member, IEEE, and F. Charbonneau

Abstract—The symmetric scattering characterization method (SCM) has been recently proposed for high-resolution characterization of targets under coherent conditions. It is based on the use of symmetric SAR and synthetic aperture radar (SAR) data. The symmetric scattering characterization method is a generalization of the target decomposition (TDC) method, and it is based on the symmetric scattering matrix representation, which is more efficient than the traditional TDC method. The symmetric scattering characterization method is more accurate and robust than the traditional TDC method, and it can be used for a wider range of applications, including remote sensing and target recognition.

I. INTRODUCTION

The objective of the symmetric scattering characterization method is to improve the accuracy of target decomposition methods, which are used to characterize polarimetric SAR data. The symmetric scattering characterization method is based on the symmetric scattering matrix representation, which is more efficient than the traditional TDC method. The symmetric scattering characterization method is more accurate and robust than the traditional TDC method, and it can be used for a wider range of applications, including remote sensing and target recognition.

II. CARRIER'S METHOD FOR CT AND SYMMETRIC SCATTERING REPRESENTATION

A. Carrier's CTD

Carriers CTD

B. Carrier's SCM

Carrier's SCM

Manuscript received November 15, 2018, revised July 22, 2019. This work was supported by the Natural Sciences and Engineering Research Council of Canada, Ottawa, Ontario, Canada (S. A. Y. A.)

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2012 IEEE

On the Use of Permanent Symmetric Scatterers for Ship Characterization

Kirtika Touzi, Member, IEEE, R. Keith Ramey, Life Fellow, IEEE, and François Charbonneau

Abstract—The symmetric scattering characterization method (SCM) has been recently proposed for high-resolution characterization of targets under coherent conditions. It is based on the use of symmetric SAR and synthetic aperture radar (SAR) data. The symmetric scattering characterization method is a generalization of the target decomposition (TDC) method, and it is based on the symmetric scattering matrix representation, which is more efficient than the traditional TDC method. The symmetric scattering characterization method is more accurate and robust than the traditional TDC method, and it can be used for a wider range of applications, including remote sensing and target recognition.

I. INTRODUCTION

SAR target recognition and ship detection are important in commercial and military applications. In this paper, we propose a new method for the characterization of symmetric targets using polarimetric SAR data. The method is based on the symmetric scattering characterization method (SCM), which is more efficient than the traditional TDC method. The method is more accurate and robust than the traditional TDC method, and it can be used for a wider range of applications, including remote sensing and target recognition.

II. CTD OF TARGETS USING SYMMETRIC SCATTERING CHARACTERIZATION METHOD

A. Carrier's CTD

Carrier's CTD

B. Carrier's SCM

Carrier's SCM

Manuscript received September 30, 2010; revised April 22, 2011. This work was supported by the Natural Sciences and Engineering Research Council of Canada, Ottawa, Ontario, Canada.

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2011 IEEE

This work was supported by the Natural Sciences and Engineering Research Council of Canada, Ottawa, Ontario, Canada.
Coherent Target Decomposition

Coherent ([S] matrix) Target Decomposition (CTD):
✧ Target scattering characterization in terms of roll invariant parameters (Kennaugh & Huynen)
✧ Phase is preserved and used as an additional source of information
☞ Finer resolution

✦ Limited to coherent scattering areas

✦ Kennaugh & Huynen CTD (1965): abandoned

✦ Krogager CTD (1990): Not unique

✦ Cameron CTD (1996): Target with a significant symmetric scattering component

✦ The Touzi SSCM method
☞ Optimum exploitation of Cameron’s maximized symmetric scattering component under coherent scattering conditions.

☞ High resolution scattering classification in comparison with Cameron’s coarse resolution

☞ Kennaugh-Huynen used for target coherence assessment
∀ \( \psi_a \): Target axis orientation angle (line of sight direction LOS)

\( \psi_a \): geometrical motion parameter does not affect scattering matrix

⇒ Subtract \( \psi_a \) effect \( \Rightarrow \) orientation invariant target parameters
Kennaugh-Huynen Coherent Target Decomposition

\[
[S] = \begin{bmatrix}
\text{Rot}(\psi_m) & T(\chi_m) & S_d & T(\chi_m) & \text{Rot}(-\psi_m)
\end{bmatrix}
\]

\[
[S_d] = \begin{bmatrix}
me^{2j(\nu+\rho)} & 0 \\
0 & m\tan^2\gamma e^{2j(\nu+\rho)}
\end{bmatrix}
\]

\[
[T(\chi_m)] = \begin{bmatrix}
\cos\chi_m & -j\sin\chi_m \\
j\sin\chi_m & \cos\chi_m
\end{bmatrix}
\]

- \([S]\) Pseudo-eigenvalues
- \(\Rightarrow\) Orthogonal eigenvectors
- \(\Rightarrow\) \textbf{Complex} pseudo-eigenvalues
- \(\bowtie\) Kennaugh-Huynen parameters
  \(\begin{pmatrix}\psi_m, \chi_m, m, \gamma, \nu, \rho\end{pmatrix}\)

\(\psi_m\): orientation angle, \(m\): maximum polarization, \(\tau_m\): helicity angle, \(\gamma\): polarizability angle, \(\nu\): skip angle, \(\rho\): the absolute phase

\[
[S] \cdot \hat{V} = \lambda \hat{V}_i
\]
Symmetric and Nonsymmetric radar targets
(Kennaugh 1950, Huynen 1965)

Symmetric Target: \( \tau_m = 0 \)

- Target having an axis of symmetry in the plane orthogonal to the radar LOS.

- [S] can be diagonalized by a rigid rotation about the LOS

- Linear eigenpolarizations with the maximum return aligned or orthogonal to the target axis.

Nonsymmetric Target: \( \chi_m \neq 0 \)
Maximum Symmetric Scattering Component (Cameron 1996)

* Decomposition of target scattering matrix using the Pauli orthonormal basis:

\[ \tilde{S} = \alpha \tilde{S}_a + \beta \tilde{S}_b + \gamma \tilde{S}_c + \delta \tilde{S}_d \]

\[ \tilde{S}_a = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \quad \tilde{S}_b = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \quad \tilde{S}_c = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \quad \tilde{S}_d = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix} \]

* \( S_{\text{sym}} \) maximum at the rotation orientation angle \( \psi_a = -\theta/2 \)

\[ \tilde{S} = A \cdot \left[ \cos \tau \cdot \tilde{S}_{\text{sym}}^{\text{max}} + \sin \tau \cdot \tilde{S}_{\text{Nsym}} \right] \quad \tan(2\theta) = \frac{\beta \gamma^i + \beta^i \gamma}{|\beta|^2 - |\gamma|^2} \]

\[ \tilde{S}_{\text{sym}}^{\text{max}} = \alpha \cdot \tilde{S}_a + \varepsilon \cdot \tilde{S}_b \quad \varepsilon = \beta \cos \theta + \gamma \sin \theta \]
Cameron’s Classification

Normalized diagonal matrix in the linear polarization basis:

\[ \Lambda^T(z) = \frac{1}{\sqrt{1 + |z|^2}} (1, 0, 0, z) \]

Symmetric scattering metric d:

\[ d(z, z_s) = \cos^{-1} \left[ \frac{\max(|1 + z z_s^i|, |z + z_s^i|)}{\sqrt{(1 + |z|^2)(1 + |z_s|^2)}} \right] \]

- Trihedral: \( z_s = 1 \)
- Diplane: \( z_s = -1 \)
- Dipole: \( z_s = 0 \)
- Cylinder: \( z_s = 1/2 \)
- Narrow diplane: \( z_s = -1/2 \)
- Quarter wave: \( z_s = j \)
Problems with Cameron’s Classification

✧ Each pixel is assigned to an elemental scatterer class

 عالية Class dispersion ⇒ radiometric dispersion up to ± 8 dB

Applied without test of coherent scattering

Miss-leading Classification
Scattering Class Dispersion (in dB)
Problems with Cameron’s Classification

1/4 Wave

Dihedral

Narrow Dihedral

Dipole

Cylinder

Trihedral

Perfect Trihedral

Linear Pol (dB): $\theta_0 = 0.00; \chi_0 = -40.00; \phi_0 = 0.00$
Circular Pol (dB): $\theta_0 = 40.00; \chi_0 = 0.00; \phi_0 = 40.00$

CO-POL RESPONSE

Normalized

Cross-POL RESPONSE

Normalized

Max Co-Pol ( $\psi = 60^\circ; \chi = 360^\circ$ )
Min Co-Pol ( $\psi = 90^\circ; \chi = 360^\circ$ )
Pedestal Height Co-Pol: 0.00

Max Cross-Pol ( $\psi = 60^\circ; \chi = -45^\circ$ )
Min Cross-Pol ( $\psi = 90^\circ; \chi = -45^\circ$ )
Pedestal Height Cross-Pol: 0.00

WW/HH = -2.5 dB

Linear Pol (dB): $\theta_0 = 0.00; \chi_0 = -40.00; \phi_0 = -2.00$
Circular Pol (dB): $\theta_0 = -18.03; \chi_0 = 1.16; \phi_0 = 18.03$

CO-POL RESPONSE

Normalized

Cross-POL RESPONSE

Normalized

Max Co-Pol ( $\psi = 30^\circ; \chi = 90^\circ$ )
Min Co-Pol ( $\psi = 90^\circ; \chi = 30^\circ$ )
Pedestal Height Co-Pol: 0.00

Max Cross-Pol ( $\psi = 30^\circ; \chi = -45^\circ$ )
Min Cross-Pol ( $\psi = 90^\circ; \chi = -45^\circ$ )
Pedestal Height Cross-Pol: 0.00

Area Location: 595.4440 | Number of samples: 4900
Symmetric Scattering Characterization Method: The SSCM

Cameroon’s disk not suitable representation

New representation tools

Information measured in \[ S \]

Coherent scattering test tools for Distributed & Point targets
Poincaré Sphere Representation

\[
\hat{\Lambda}^T = \frac{1}{|\alpha|^2 + |\epsilon|^2} (|\alpha|^2 + |\epsilon|^2, |\alpha|^2 - |\epsilon|^2, 2 \Re(\alpha \epsilon^i), 2 \Im(\alpha \epsilon^i))
\]

- \( S_{\text{sym}}^{\max} \): point on the sphere surface at latitude-longitude \((2 \psi_c, 2 \chi_c)\)
- Rotation angle ambiguity \(\Rightarrow 1/2 \) of the sphere for \( \psi_c \in [0, \frac{\pi}{2}] \)

\[
\psi_c \in \left[ \frac{\pi}{2}, \pi \right] \quad \Rightarrow \quad \psi'_a = \psi_a \pm \frac{\pi}{2} \quad \left( \psi'_c = \pi - \psi_c, \chi'_c = -\chi_c \right)
\]

- Partially coherent scattering mapped as a point inside the sphere at the distance \( p_{\text{sym}} \):

\[
\begin{align*}
\sqrt{\frac{|\alpha|^2 + |\epsilon|^2}{|\alpha|^2 - |\epsilon|^2} + 4} & = 2 \\
\sqrt{\frac{|\alpha|^2 - |\epsilon|^2}{|\alpha|^2 + |\epsilon|^2}} & = 2 \\
\therefore \quad p_{\text{sym}} & = 2
\end{align*}
\]

- \( p_{\text{sym}} \): scattering coherence \(\Rightarrow\) Distributed target coherence test
Target Poincaré Sphere

\[ S_{\text{sym max}} \]

- 1/4 Wave
  \( \psi_c = 0^\circ \)
  \( \chi_c = 45^\circ \)

- Trihedral
  \[ \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \]

- Cylindrical
  \( \psi_c = 18^\circ \)
  \( \chi_c = 0^\circ \)

- Dipole
  \( \psi_c = 45^\circ \)
  \( \chi_c = 0^\circ \)

- Narrow Dihedral
  \( \psi_c = 82^\circ \)
  \( \chi_c = 0^\circ \)

- Dihedral
  \[ \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix} \]
• Riccan distribution $\Rightarrow$ S/C of 15 dB ($\pm \pi/8$ or 0.85 coherence)

☞ Test applied on the Huynen diagonalized image
Symmetric Scattering Characterization Method
The SSCM Flowchart

\[ [S] = \begin{pmatrix} s_t & i_s \\ i_s & s_b \end{pmatrix} \]

\[ S_{\text{Fmax}} = \alpha S_s + \beta S_b \]

DT Coherence Test

No

Huygens Diagonalization

Yes

PT Coherence Test

No

Yes

Angle & Phase Images
Application of the SSCM to Ship Characterization using the Crusade Trail

<table>
<thead>
<tr>
<th>Ship</th>
<th>Size (ft)</th>
<th>Estimated RCS (dBm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Incidence Angles</td>
</tr>
<tr>
<td></td>
<td></td>
<td>25°</td>
</tr>
<tr>
<td>M/V Anne S Pierce</td>
<td>116</td>
<td>31</td>
</tr>
<tr>
<td>M/V Arctic Pride</td>
<td>60</td>
<td>24</td>
</tr>
<tr>
<td>HMCS Ville de Québec</td>
<td>436</td>
<td>44</td>
</tr>
</tbody>
</table>
Crusade Trail 2000

- Crusade’00 off Cape Race, Newfoundland, Mar. 2000
- Led by DRDC (Defence R&D Canada)

✦ Incidence angle range: 20°-55°

✦ 22 March: wind (16 knots), swell 3-4m, 1 ship imaged at 22°

✦ 28 March: Wind (7 knots), swell amplitude of about 4m
  2 ships imaged, one at 35° and the second at 45°

✦ 30 March: Wind (20 knots), swell 4m, 1 ships imaged at 45°
Ship Characterization using Crusade’00 data

- ASP well ground truthed

<table>
<thead>
<tr>
<th>ASP</th>
<th>Date</th>
<th>Wind</th>
<th>Waves</th>
<th>Inc. Ang</th>
<th>Orient</th>
<th>Pitch</th>
<th>Roll</th>
</tr>
</thead>
<tbody>
<tr>
<td>35m</td>
<td></td>
<td></td>
<td></td>
<td>[o]</td>
<td>[o]</td>
<td>[o]</td>
<td>[o]</td>
</tr>
<tr>
<td>L1P3</td>
<td>28-Mar</td>
<td>7 kt</td>
<td>4m</td>
<td>39</td>
<td>8</td>
<td>-1.05</td>
<td>4.74</td>
</tr>
<tr>
<td>L6P8</td>
<td>28-Mar</td>
<td>7 kt</td>
<td>4 m</td>
<td>35</td>
<td>15</td>
<td>0.23</td>
<td>2.85</td>
</tr>
</tbody>
</table>
Anne St-Pierre (ASP)

21.2 m

14.2 m

6.9 m

14.3 m

27 m

12.7 m

1.5 m

35.4 m
L6P8
$\Delta \phi = -8 ^\circ$
$\theta = 34.8 ^\circ$

28-March-00
Wind: 7 kt

L1P3
$\Delta \phi = 15 ^\circ$
$\theta = 38.9 ^\circ$
Rotation angle for Roll-Pitch Measurement
Adaptation of Lee equation

\[ tg(\psi_a) = \frac{tg(\theta_p)\cos(\phi)}{-tg(\theta_r)\cos(\theta_i) + \sin(\theta_i)} \]

- \((90^\circ - \phi)\): orientation angle \((\phi = 90^\circ \text{ ship azimuth direction})\)
- \(\forall \theta_p: \text{pitch}\)
- \(\forall \theta_r: \text{roll}\)
Tables of ASP SSCM parameters: Pitch angle estimate

<table>
<thead>
<tr>
<th>ASP</th>
<th>Wind</th>
<th>Inc. Ang</th>
<th>Orient.</th>
<th>$\psi$ MID</th>
<th>$\psi$ DF</th>
<th>$\chi$ MID</th>
<th>$\chi$ DF</th>
</tr>
</thead>
<tbody>
<tr>
<td>28-Mar</td>
<td>[knots]</td>
<td>[°]</td>
<td>[°]</td>
<td>DB</td>
<td>MID</td>
<td>DF</td>
<td>DB</td>
</tr>
<tr>
<td>L1P3</td>
<td>7</td>
<td>38.9</td>
<td>15</td>
<td>14.6</td>
<td>53.6</td>
<td>49.7</td>
<td>31.1</td>
</tr>
<tr>
<td>L6P8</td>
<td>7</td>
<td>34.8</td>
<td>8</td>
<td>13.1</td>
<td>50.7</td>
<td>48.8</td>
<td>12.7</td>
</tr>
</tbody>
</table>

✧ MID: $\psi$ stable but $\chi$ different
✧ L6P8 not well focussed (trace 50% longer)
✧ L1P3 well focussed + small orientation
⇒ Pitch estimate from L1P3
Extraction optimum de l’information polarimétrique à partir du radar à ouverture synthétique

Incoherent Target Decomposition for Wetland Classification
Coherent and Incoherent Target Scattering Decomposition

**Coherent Target Decomposition (CTD):**
- Applied on 1-look scattering matrix
- Limited to target of coherent scattering

**Incoherent Target Decomposition (ICTD):**
- **Objective:** express the average scattering mechanism as the sum of independent single scatterers *(Cloude-Pottier 97)*
- Natural targets that exhibit significant natural variability in their scattering properties

**Cloude-Pottier ICTD** $\alpha|H$ scattering classification
Roll Invariant Target Scattering Decomposition

✧ **Cloude-Pottier incoherent Decomposition** (1996, 1997)
  - Scattering type ambiguity related to $\alpha$ (Corr EUSAR02, Touzi 04)
  - Target phase parameters $\phi_i$ and $\beta$ vary with the polarization basis

✧ **1952-Kennaugh-Huynen CTD Abandoned**
  - E. Luneberg 2002: “*It should be pointed put that Huynen's parameters are not unique and need to be reevaluated, in particular the skip angle, due to no uniqueness of the coneigenvalues phases*”

✧ **Boerner**: “Polarization dependence in e.m. inverse problems”, IEEE Ant. and. Prop. 1981

✧ **Touzi-Cloude-Pottier-Kennaugh-Huynen-Boerner’s Decomposition**: coherent and partially coherent scattering
The Touzi Scattering Model
for Coherent Target Decomposition (CTD)

The model in the Pauli Basis:

\[ \tilde{e}^{SVM} = m|\tilde{e}^{SVM}|_m e^{j\Phi_s} \cdot \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos 2\psi & -\sin 2\psi \\ 0 & \sin 2\psi & \cos 2\psi \end{bmatrix} \begin{bmatrix} \cos \alpha_s \cos 2\tau_m \\ \sin \alpha_s e^{j\varphi}\alpha \\ -j \cos \alpha_s \sin 2\tau_m \end{bmatrix} \]

Target scattering parameters: \((\alpha_s, \Phi_{\alpha_s}, \tau_m, \psi, m)\)

- **New parameter**: Complex entity to describe symmetric scattering type

\[ \alpha_s^c = (\alpha_s, \Phi_{\alpha_s}) \]

\[ \alpha_s = \text{Cloude } \alpha \text{ for symmetric targets } (\tau_m = 0) \]

\((\alpha_s, \Phi_{\alpha_s}) \) **not affected** by coneigenvalue ambiguity

- \(\psi\): target orientation, \(\tau_m\): helicity, \(m\): maximum polarization

**Roll (basis-) invariant CTD \(\Rightarrow\) unique target characteristics**
Two Poincaré sphere for representation of the Roll Invariant Scattering Vector

- Target symmetric scattering sphere ($\alpha_s, \Phi_{\alpha s}, \tau_m=0$) $\Rightarrow$ ($S_a, S_b, S_c$)
- (in phase-$S_a-S_b$)-Target scattering ($\alpha_s, \tau_m, \Phi_{\alpha s}=0$) $\Rightarrow$ ($S_a, S_b, \text{Im}(S_c)$)

$\bullet$ ($\alpha_s, \Phi_{\alpha s}, \tau_m$) $\Rightarrow$ an unambiguous description of target scattering type

$\frac{-\pi}{4} \leq \tau_m \leq \frac{\pi}{4}$

$0 \leq \alpha_s \leq \frac{\pi}{2}$
Touzi-ICTD for a **Roll invariant**

Decomposition of Natural Target Scattering

\[
[T] = \lambda_1 [T_1] + \lambda_2 [T_2] + \lambda_3 [T_3]
\]

\[
[T] = \langle \tilde{k}_p \cdot \tilde{k}_T \rangle i.
\]

- **Touzi-ICTD**: scattering vector model for parameterization of eigenvectors

- **Single Scattering Parameters**: \( (p_i, \psi_i, \tau_{mi}, \alpha_{si}, \Phi_{\alpha_{si}}) \)

- **Average Scattering Parameters** (loss of information):

\[
(H, \psi, \tau_m, \bar{\alpha}_s, \bar{\Phi}_s)
\]

\[
H = \sum_{i=1}^{3} -p_i \log_3 p_i \quad \bar{\alpha}_s = \sum_{i=1}^{3} p_i \alpha_{si}
\]

- **Asymmetric** scattering: solves for Cloude-Pottier’s phase parameter ambiguities

- **Symmetric** scattering, \( \alpha_s = \alpha \) but \( \Phi_{\alpha_s} \) should be used for an unambiguous scattering
Target Scattering Decomposition in Terms of Roll-Invariant Target Parameters

Ridha Touzi, Member, IEEE

Abstract—The Kenmochi-Herrmann scattering matrix concomitatively is a fundamental basis to derive a new scattering vector model for the representation of coherent target scattering. This model is a polarimetric basis invariant representation of coherent target scattering in terms of the independent target parameters: the magnitudes and phase of the symmetric scattering matrix introduced in this paper, and the maximum polarimeter parameters orientation, helicity, and maximum return. The new scattering vector model solves for the assessment of the Cloud-Pott's coherent target decomposition. Wherein the Cloud-Pott's scattering type α and entropy H are roll-invariant β and the so-called target-phase parameters do depend on the target orientation angle for asymmetric scattering. The scattering vector model is then used as the tool for the development of new coherent and incoherent target decompositions in terms of unique and roll-invariant target parameters. It is shown that both the phase and magnitude of the symmetric scattering type should be used for an unambiguous description of symmetric target scattering. Target helicity is required for the assessment of the symmetric scattering matrix of target scattering. The symmetric scattering type phase is shown to be very promising for wetland characterization in particular, using polarimetric Coarse-ISIS synthetic aperture radar data collected over the Ranamak Reservoir wetland site in the east of Ottawa, ON, Canada.

Index Terms—Characteristic decomposition, coherence, coherent, directional polarimetry, eigenvalues, eigenphases, entropy, incoherent, polarimetry, spectrally, synthetic aperture radar (SAR), wetlands

I. INTRODUCTION

The OBJECTIVE of the incoherent target decomposition (ICTD) theory is to express the average scattering mechanism in the sum of independent elements in order to associate a physical mechanism with each component [1–4]. Target scattering decomposition permits the extraction of target characteristic information provided that the decomposition satisfies the general requirement of being robust against a change of wave polarization basis (i.e., roll invariant) [4–9]. Cloud-Pott's ICTD [1, 1, 7] is presently the most used method for decomposition of natural extended target scattering. The characteristic decomposition of the matrix is based on the maximization of the target symmetric scattering.

II. NOMENCLATURE AND ABBREVIATIONS

α [model] Model introduced by Cloud-Pott for parameterization of the coherence eigendirections.
ICTD Incoherent target decomposition.
SSCM Symmetric scattering characterization method introduced by Touzi and Charbonneau for optimization of the maximized target symmetric scattering.
ρ and ρ0 Scattering matrix.
κ Target scattering vector introduced by Cloud-Pott.
α Scattering type parameter introduced by Cloud-Pott.
β Orientation angle introduced by Cloud-Pott.
α0 Symmetric scattering type introduced in this paper as a complex entity.
κ Symmetric scattering type magnitude.
κ Symmetric scattering type phase.
ρ, ρ0, and ρ0 Magnitude of the symmetric scattering type.
λ, λ2, and λ3 Coherence eigenvalues.
λ Dominant eigenvalue of the scattering.
λ2 Eigenvalue of the second scattering.
λ3 Eigenvalue of the third scattering.
H Coherence entropy.
α and β Symmetric scattering type magnitude and helicity of the global scattering, respectively.

Received 7 May 2006; revised 14 August 2006. This work was supported in part by the National Science and Engineering Research Council, Ottawa, ON, Canada. Digital Object Identifier 10.1109/TGRS.2006.880676

Canada Centre for Remote Sensing • Earth Sciences Sector

Touzi Decomposition for Wetland Characterization


Wetland characterization using polarimetric RADARSAT-2 capability

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Abstract—The use of single-polarization (HH) RADARSAT-2 synthetic aperture radar (SAR) data has been shown to be important for wetlands water extent characterization. However, the limited capability of the RADARSAT-2 single-polarization C-band SAR in vegetation type discrimination makes the use of coherently dependent, multi-invariant (VSN) data necessary for wetland mapping. In this paper, the potential of polarimetric RADARSAT-2 data for wetland characterization is investigated. The Touzi incoherent decomposition is applied for the coherently invariant decomposition of wetland scattering. In contrast with the Cloud-Pott decomposition that-characterizes target scattering type with a real entropy and the Touzi decomposition uses a coherent entity, the symmetric scattering type, for unambiguous characterization of wetland target scattering. It is shown that, like the Cloud-Pott scattering type, the magnitude of the symmetric scattering is not affected by orientation, but the direction of the symmetric scattering type is characterized by helicity. The phase of the symmetric scattering type is used for better characterization of wetland vegetation species. The unique information provided by α is necessary for improved wetland classification and discrimination using Coarse-ISIS polarimetric C-band SAR data collected over the Mer Bleue wetland in the east of Ottawa, Canada.

Résumé—L'utilisation des données radar à un seul système d'orientation (RSC) de RADARSAT-2 en polarisation unique (H) a été mise à l'essai pour la caractérisation de la surface d'eau et végétation. Cependant, la capacité limitée de l’RSC en bande C de RADARSAT-2 en polarisation unique pour l'identification des types de végétation veint la nécessité de données multi-invariantes, comme les formes d'onde cohérentes (VSN) qui sont dépendantes de conditions de clarté pour la cartographie des milieux humides. Dans cet article, nous analysons le potentiel des données polarimétriques de RADARSAT-2 pour la caractérisation des milieux humides. La décomposition incohérente d’interaction de la durabilité des milieux humides est utilisée pour le décomposion incohérente des radars de l’espace et de la végétation. La phase de la direction du spectre de la durabilité n'est pas affectée par l'orientation, mais la caractéristique de la direction du spectre de la durabilité est caractérisée par la direction de la durabilité. L'orientation de la phase est utilisée pour une caractérisation plus fine des espèces de végétation. L'information unique fournie par α est nécessaire pour une meilleure classification et discrimination des zones humides au moyen de données polarimétriques de RADARSAT-2 en bande C de COSTAL-ISIS acquis au-dessus du fleuve Mer, à l'est de Ottawa, Canada. L’utilisation de α est possible de distinguer des zones humides, lesquelles sont difficiles à distinguer entre eux et permet de mieux déterminer entre les différentes zones humides limitées par les confins et les fronts de glaciers dans les zones humides.
HH-HV-VV ⇒ Better wetland classification than $\alpha_s \cong \alpha$

 HH-HV-VV

$\alpha_s \cong \alpha \ (\tau \cong 0)$

Radiometric information of the scattering type not efficient for vegetation species discrimination
Dominant Scattering Type Phase for Wetland Target Scattering Characterization

- Dominant scattering (of largest eigenvalue $\lambda_1$) should have the most coherent scattering type phase $\phi_{a_s}$

- Investigation of dominant scattering parameters

$$(\lambda_1 = p_1, \alpha_{s1}, \Phi_{a_{s1}}, \tau_{m1}, m)$$

- Need for a tool to assess the phase coherence

- The degree of coherence $p_{\text{sym}}$ introduced for the SSCM test of distributed targets

Degree of coherence for the assessment of $\phi_{as}$ coherence

- Partially coherent scattering mapped as a point inside the sphere at the distance $p_{\text{sym}}$

- $p_{\text{sym}} \Rightarrow$ scattering type phase coherence

- Degree of coherence is close to 1 even if the scattering is dominated by one component (trihedral or dihedral)
Scattering Type Phase Coherence

- Dominant scattering of highest $p_{sym} (>0.8)$
- $3^{rd}$ component of very low $p_{sym} (<0.5)$
- $\phi_{sym3}$ not meaningful
Scattering Type Phase $\Phi_{s1}$ for Wetland Classification

Color aerial photographs (2002) overlaid with a wetland classification based on the NCC the forest cover inventory.

$\Phi_{s1}$ (June 95)
3 Major Classes

- **Class 1**: Marsh
- **Class 2**: farm, sedge-(Fen&Bog), shrub-bog
- **Class 3**: conifer treed bog + upland deciduous forests

| Class                  | HH (dB) | $\alpha_{s_1}$ | $\phi_{s_1}$ | $|\tau_1|$ | $\lambda_1$ | Entropy |
|------------------------|---------|-----------------|--------------|------------|-------------|---------|
| Marsh                  | -5.2    | 45.3°           | 1.4°         | 0.5°       | 0.92        | 0.31    |
| seges-Fen              | -16.6   | 24.5°           | -38.1°       | 4.5°       | 0.66        | 0.79    |
| Shrub Bog              | -16.3   | 25.8°           | -56.4°       | 5.2°       | 0.64        | 0.81    |
| Conifer-Treed Bog      | -11.5   | 20.9°           | 49.27°       | 19.3°      | 0.57        | 0.89    |
| Upland deciduous Forest| -12.8   | 18.4°           | 22.8°        | 16.6°      | 0.58        | 0.88    |
| Agriculture Fields     | -16.1   | 15.3°           | -29.8°       | 9.6°       | 0.55        | 0.80    |
Scattering type magnitude

\( \alpha_{s1} \equiv \alpha_1 \)

- **Class 1**: Marsh \( \Leftrightarrow \) low entropy dipole
- **Class 2**: farm + sedge-(Fen&Bog) + shrub-bog \( \Leftrightarrow \) medium entropy surface scattering
- **Class 3**: conifer treed bog + upland deciduous forests \( \Leftrightarrow \) high entropy surface scattering

“Not exploitable” because of the **high entropy** scattering type ambiguity
Scattering Type Phase $\Phi$

$\alpha_s$ for Wetland Classification

- $\Phi_{\alpha_s}$ solves for the **high entropy** scattering type ambiguity
- **Conifer** treed bog **discriminated** from upland **deciduous** forests under **leafy conditions** (June)
- Sedge-dominated **fens** and shrub-**bog** well separated
- Sedge fen and farm field **not** separated ☝️ phase coherence psym
**Degree of coherence** $p_{\text{sym}}$

- Wetland is well separated from upland ($p_{\text{sym}} > 0.85$)
- Presence of water underneath the vegetation minimises the volume scattering component
- Sedge fen of higher $p_{\text{sym}}$ than farm field
\( \lambda_1 \) higher when water level higher (June) \( \Leftrightarrow \) Cattails water level?
- Treed bog: Conifers including Larch and Black Spruce
  - Change in Larch that loose its needles in the fall.
- Upland forests mainly deciduous (poplar, birch, maple, and willow)
CWI Approach: RADARSAT-1/Landsat

- RADARSAT-1 of Limited Capability for Wetland Type Classification
- RADARSAT-1 combined with clear-sky-dependent Landsat for wetland classification

(Canadian Wetland Inventory, led by Environment Canada)
 RADARSAT2 ➔ Better classification than RADARSAT1-Landsat
 Operational use of RADARSAT2 for wetland monitoring

Φας ➔ discrimination of Sedge&shrub Fen and Shrub- Bog

Landsat&Radarsat1 Classification
(J. Li and W. Chen, IJRS, Vol.26, 2005)
Clim. Change effect on Polar Bear Habitat
Wapusk Field measurement (Aug. 07)