Polarimetric SAR Calibration and Processing Tool V1.0: A Tool for Polarimetric Calibration and Processing of SAR Data

Shashi Kumar
Photogrammetry and Remote Sensing
Indian Institute of Remote Sensing, ISRO
Dehradun, India
sksiirs@gmail.com

Varsha Kumari
Computer Science
Banasthali Vidyapith
Vanasthali, India
kvarsha668@gmail.com

Alice
Computer Science
Banasthali Vidyapith
Vanasthali, India
alicesingh31@gmail.com

Bhanu Prakash M E
Photogrammetry and Remote Sensing
Indian Institute of Remote Sensing, ISRO
Dehradun, India
bhanuprakashme28@gmail.com

Arun Babu
Microwave and Radar Institute German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt; DLR)
Wessling, Germany
arun.babu@dlr.de

Abhisek Maiti
Faculty of Geoinformation Science and Earth Observation (ITC),
University of Twente
City, Netherlands
mail2abhisek.maiti@gmail.com

Shefali Agrawal
Geospatial Technology and Outreach Programme Group
Indian Institute of Remote Sensing, ISRO
Dehradun, India
shefali_a@iirs.gov.in

***Abstract*— Polarimetric SAR (PolSAR) has been widely used as an active imaging remote sensing technique to characterize manmade and natural features. The PolSAR data needs to be corrected from the polarimetric distortions to minimize the ambiguities for the accurate information retrieval of scatterers. The present work is focused on the minimization of system-induced and atmosphere-induced errors from PolSAR data. A new software Polarimetric SAR Calibration & Processing Tool v1.0 (PSCP v1.0) has been introduced for processing of fully polarimetric and hybrid polarimetric SAR data. The PSCP v1.0, a software tool will be available for the scientific community to calibrate and process the fully polarimetric and the hybrid polarimetric space borne and airborne SAR data of current and future missions of ISRO, India and also for other space agencies.**

Keywords—PolSAR, PSCP v1.0, Calibration, Polarimetric Distortions, Hybrid Polarimetry

I. Introduction

The Polarimetric Synthetic Aperture Radar (PolSAR) is an advanced imaging radar system to analyze the scattering information from different ground targets on the Earth's surface. It is achieved by using the different polarization states of an Electromagnetic (EM) wave for the same center frequency. The PolSAR processing techniques are used for characterizing the ground targets by utilizing the multiple polarimetric channels available in the SAR product. A PolSAR system can be dual-polarized, quad-polarized or compact polarized. In a dual-polarized SAR system an EM waveform will be transmitted in either horizontal or vertical polarization and measures the received signals in both horizontal and vertical polarizations. A dual-pol SAR system, consists of horizontal transmit-horizontal receive (HH) and horizontal transmit-vertical receive (HV) channels or vertical transmit-horizontal receive (VH) and vertical transmit-vertical receive (VV) channels. The quad-pol SAR system contains all the four channels HH, HV, VH and VV and it provides an accurate and clear perspective of the target [1].

The compact polarized system comprises of one polarization in transmit and two polarizations on receive. The Compact Polarimetric (CP) SAR has been evolved as an alternative for the fully polarized SAR system, as it exhibits similar science quality polarimetric SAR data of the ground targets with the reduced hardware complexity, reduced data transmission rate, reduced Pulse Repetition Frequency (PRF), and with no compromise in the spatial resolution. The most commonly developed CP SAR architecture for both space borne and airborne platforms is the Circular Transmit-Linear Receive (CTLR) system, which transmits waves either in left or right circular polarization ($H \pm iV$) [2].

The SAR polarimetry has a wide range of applications ranging from classification, geophysical and biophysical parameter estimation, disaster management and other Earth observation studies [3]. This article is introducing the Polarimetric SAR Calibration & Processing Tool v1.0 (PSCP v1.0) which can perform polarimetric calibration and processing of polarimetric SAR data.

II. The PSCP v1.0 Tool

Currently, there are only a few number of software that is freely available and those are maintained by European Space Agency (ESA) and The National Aeronautics and Space Administration's Jet Propulsion Laboratory (NASA's JPL). In India, there is a number of indigenous satellites that are proposed such as The NASA-ISRO Synthetic Aperture Radar (NISAR), Radar Imaging Satellite 1 (RISAT-1), and RISAT-2. Hence, there is a requirement of software and tools for polarimetric calibration and processing of the SAR data.

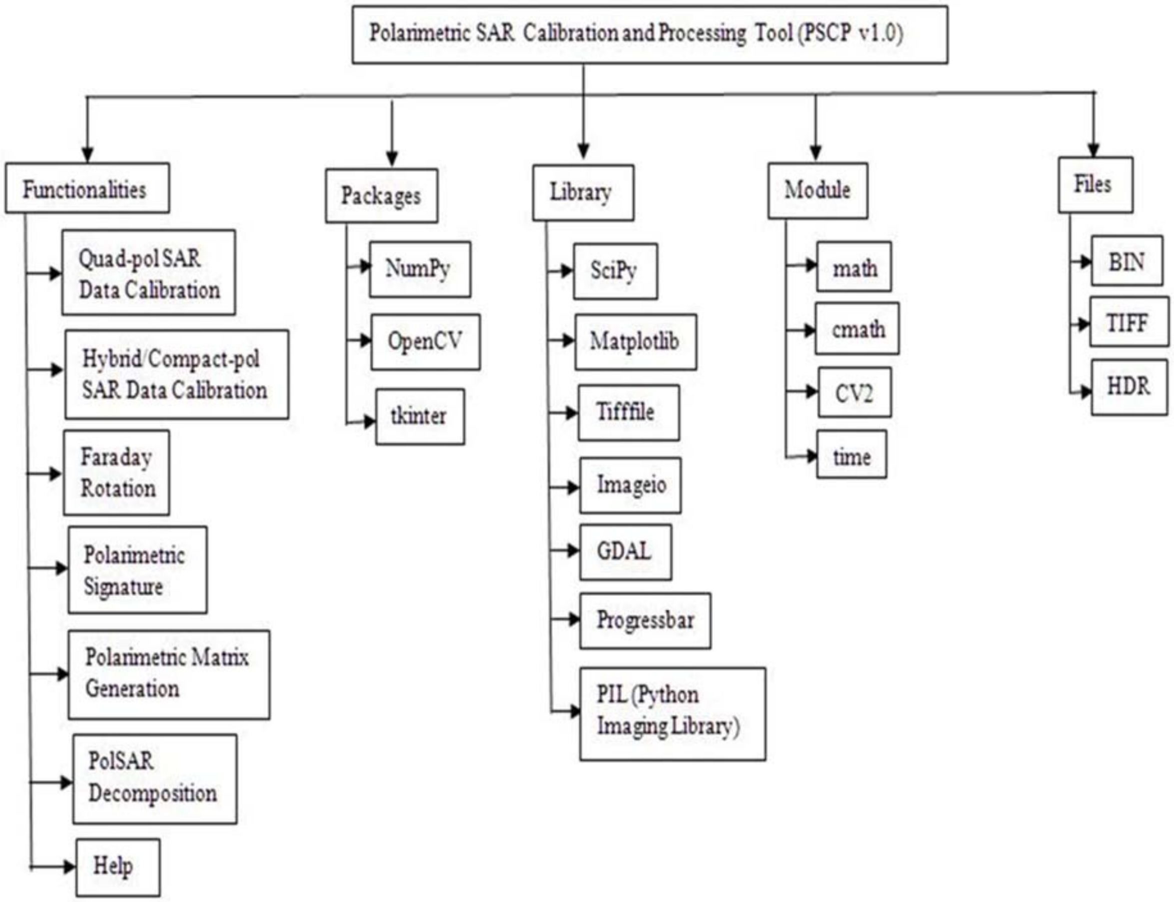


Fig. 1. Architecture View of PSCP v1.0

The PolSAR data is useful in understanding the different scattering mechanisms of the objects. It also helps to get phase and amplitude information from different polarimetric channels with the help of polarimetric decomposition and classification techniques. But the polarimetric distortion in the PolSAR datasets may cause overestimation or underestimation of scattering mechanism which may create an error in the polarimetric decomposition modeling for characterization of manmade and natural features.

PSCP v1.0 is a software tool developed with the goal of making the polarimetric processing easy and intuitive. It provides a complete package to calibrate and process the fully polarimetric and the hybrid/compact/partial polarimetric SAR data. PSCP v1.0 is able to do the PolSAR calibration and the decomposition and will be freely available for researchers, scientists, professors and Ph.D. students for their research and education purposes. The one more unique feature of this software is that it will be able to do PolInSAR decomposition. In existing software, each of the polarimetric distortion was estimated separately while this software proposes incorporation of well-established algorithms as a unified algorithm that estimates the channel imbalances, phase bias, crosstalk and Faraday rotation from the scattering matrix. PSCP v1.0 software is developed using Python programming language and it uses the powerful modules of scientific packages. The used modules, packages, library and file format for developing of PSCP v1.0 is shown in fig. 1. And it is also showing the functionalities of PSCP v1.0. Help menu function is providing the user documentation, a part of the Library Reference explaining the precise working and the functionalities of the tool.

III. USER INTERFACE AND CODE SNIPPET

Figure 2 shows the main view of the developed tool with full functionality.

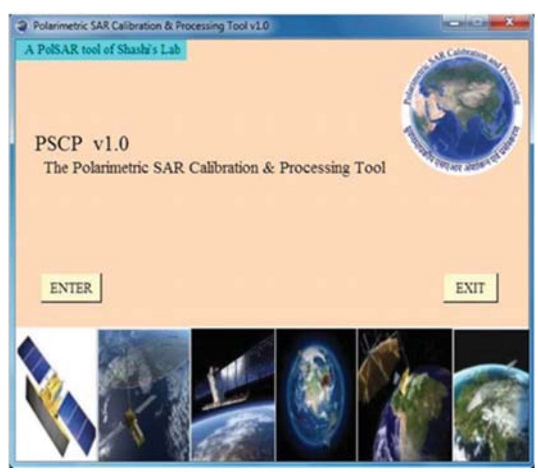


Fig. 2. PSCP v1.0 Main Entry Screen

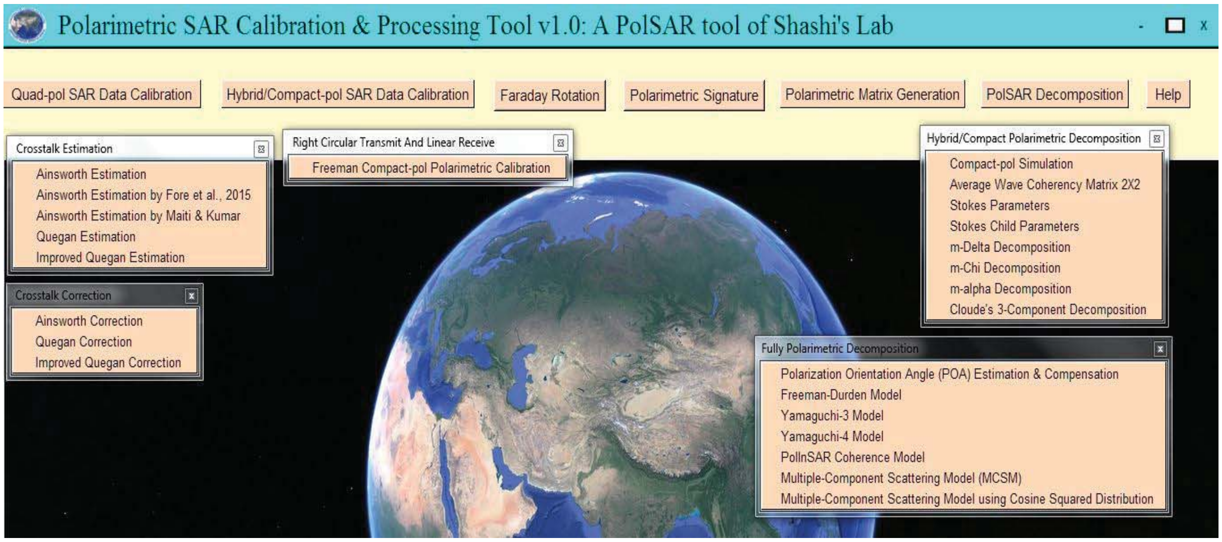


Fig. 3. Full view of the Polarimetric SAR Calibration and Processing Tool v1.0

```python
def ainsworth_correction():
    from ainsworth_correction import run_ainsworth_correction
    run_ainsworth_correction()

def quegan_correction():
    from quegan_correction import run_quegan_correction
    run_quegan_correction()

def improved_quegan_correction():
    from improved_quegan_correction import run_improved_quegan_correction
    run_improved_quegan_correction()

def faraday_rotation():
    from faraday_rotation import run_faraday_rotation
    run_faraday_rotation()

def polarimetric_signature():
    from polarimetric_signature import run_polarimetric_signature
    run_polarimetric_signature()

def pauli():
    from pauli_matrix import run_pauli_matrix
    run_pauli_matrix()

def lex():
    from lexicographic_matrix import run_lexicographic_matrix
    run_lexicographic_matrix()

def coh():
    from coherency_matrix import run_coherency_matrix
    run_coherency_matrix()
```

Fig. 4. Code snippet to add functionalities of PSCP v1.0 in the tool

The tools for calibration of fully polarimetric SAR data involves algorithm for cross talk estimation, channel imbalance estimation and Faraday rotation estimation. Hybrid polarimetric calibration is having the capacity to calibrate the dataset of right circular transmit and linear receive (CTLR) mode. The complete list of functionalities available in this tool is displayed in the Fig. 3. Fig. 4 shows a sample python code used for the defining the individual functions corresponds to the different algorithms supported by the tool. The option for adding a new algorithms or editing the current algorithm is given to satisfy the requirement of improvement or enhancement in the tool. For any new functionality being added to the tool, a function is created in the main class of the code (Fig. 4).

IV. CALIBRATION MODULE OF PSCP v1.0

There are mainly two types of polarimetric distortions occurring in the SAR data; system-induced and atmosphere induced distortions. System induced polarimetric distortions occurs due to the hardware non-idealities of the SAR system so exists in both space borne and airborne SAR platforms. System induced polarimetric distortions are channel imbalance and crosstalk [4]. Atmospheric induced polarimetric distortions occurs mainly due to the effects caused by the Earth's ionosphere, so exists only in the space borne SAR platforms. Faraday rotation error is the primary atmosphere induced polarimetric distortion. To get actual scattering information of the object appearing on the earth's surface polarimetric distortions need to be removed from the SAR data. The minimization of all these polarimetric distortions using polarimetric calibration techniques is very important. The Polarimetric Calibration (PolCAL) aims to correct the system distortion effects in SAR observation by obtaining distortion parameters including crosstalk and channel imbalances [5]. Generally, PolSAR technology discriminates ground objects by the coherence and difference of these channel images. Therefore, before PolSAR images can be used for further researches and applications, PolCAL is needed to ensure the relative amplitude and phase of the different image channels. In essence, the PolCAL converts uncalibrated PolSAR data into calibrated PolSAR data by minimizing polarimetric distortions. But so far existing software is not supporting PolSAR calibration. PSCP v1.0 provides the polarimetric calibration of Quad-pol and Hybrid/Compact-pol SAR datasets acquired using airborne and space borne platforms for the estimation and correction of polarimetric distortions caused due to the channel imbalance, phase bias, crosstalk and Faraday rotation using the corner reflectors and distributed targets.

A. Quad-pol SAR Data Calibration To Remove System distortion

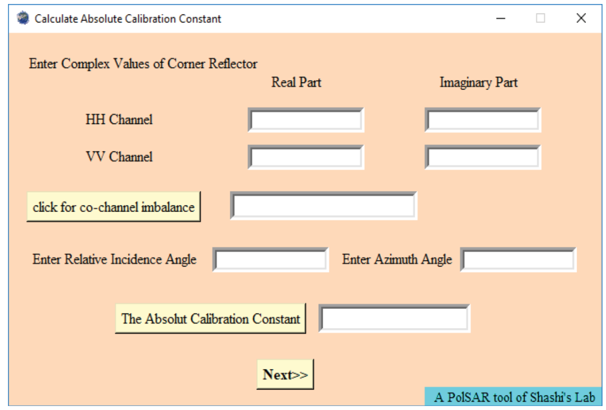
For Quad-pol datasets first step is to do channel imbalance by calculating the absolute calibration constant (A). For A using corner reflector, the theoretical Radar Cross Section (RCS) of the corner reflector is required. The theoretical RCS of a Trihedral corner reflector is estimated as follows [6]:

$$\sigma_{cr} = \frac{4\pi a^2}{\lambda^2}\left(\cos\theta + \sin\theta\ (\sin\varphi + \cos\varphi) - \frac{2}{\cos\theta + \sin\theta\ (\sin\varphi + \cos\varphi)}\right)^2 \quad (1)$$

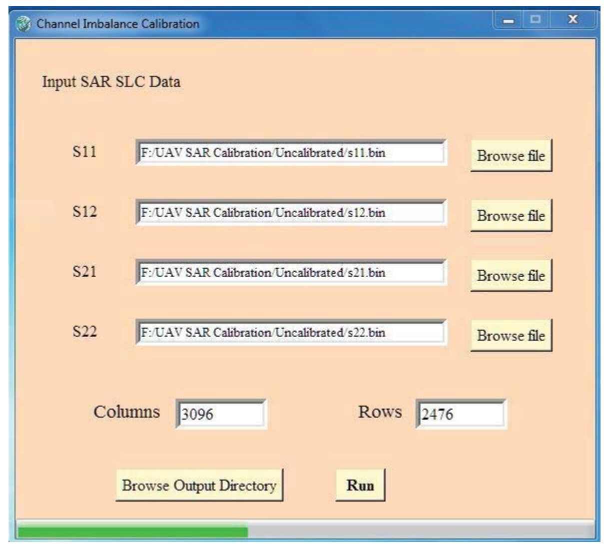
Where a represents the inner leg length of the corner reflector, λ is the wavelength of the radar, φ is the azimuth angle and θ is the relative incidence angle, which is the sum of the incidence angle and the elevation angle of the corner reflector. Equation 2 is showing the calculation of the absolute calibration constant A and is estimated using the relationship [6]:

$$10\log_{10}\frac{\sigma_{cr}}{O_{hh}O_{hh}^{*}} = -10\log_{10}A^2 \quad (2)$$

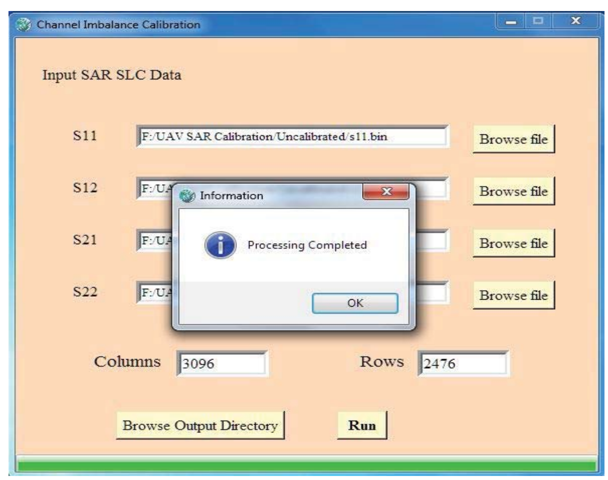
Where, A is the absolute calibration constant, σ_{cr} is the theoretical RCS of the corner reflector, O_{hh} is the peak complex backscatter value of the corner reflector pixels in the HH channel of the uncalibrated scattering matrix and O^{*}_{hh} is the complex conjugate of $O_{hh.}$ Then the user has to click on next to browse the scattering matrix in the form of BIN files to do channel imbalance.



(a)



(b)



(c)

Fig. 5. (a) Calculation of absolute calibration constant for corner reflector values of UAVSAR data, (b) Taking scattering matrix of UAVSAR data as input in the BIN format to do channel imbalance, (c) Message to a user for process completion.

The fig 5. (a) shows the dialog box appears as the user selects the required functionality with an example of absolute calibration constant calculation. The view of taking input is showing in Fig. 5(b) and after completion of processing user will get the message as shown in Fig. 5(c). After completion of the process, the new scattering matrix free from channel imbalance and phase bias error will be saved in the browsed output directory. For the crosstalk estimation and correction, PSCP v1.0 provides a collection of the algorithm. Users can select any algorithm according to their preference and convenience. The input files for crosstalk estimation will be the files generated by channel imbalance whereas for the crosstalk correction input files will be the files generated by channel imbalance and the files generated by crosstalk estimation. The output files will be the scattering matrix free from system distortion in the .bin file format.

B. Faraday Rotation

Due to the ionospheric propagation of microwaves of the SAR system Faraday rotation occurs in the data which rotates the orientation angle of the polarization ellipse. Input will be scattering matrix having Faraday rotation error but free from all other polarimetric distortions [7]. The output will be the scattering matrix (free from all polarimetric distortions including Faraday error) and ohm (the Faraday rotation angle by which the polarization plane of the EM wave is rotated in the Ionosphere).

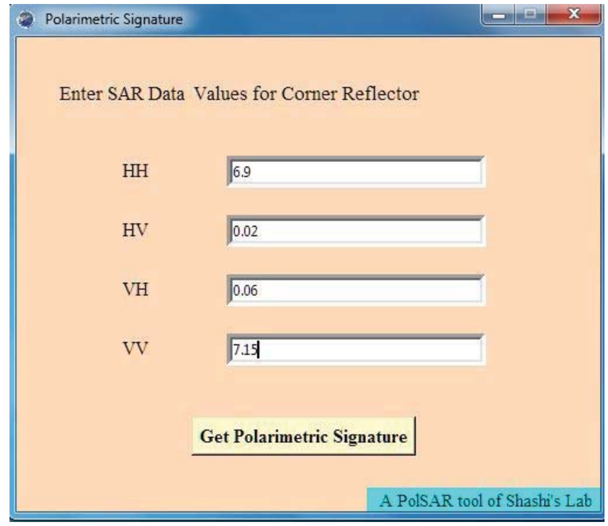
C. Hybrid/Compact-pol SAR Data Calibration

Hybrid/Compact Polarimetry transmits circularly polarized wave and receives two orthogonal mutually coherent linear polarizations [8], [9]. Therefore, the wave is circularly transmit-linearly receive (CTLR). The combination of transmitted and received wave signals is as: right circular transmitted-horizontal received (RH) and right circular transmitted-vertical received (RV) [10].

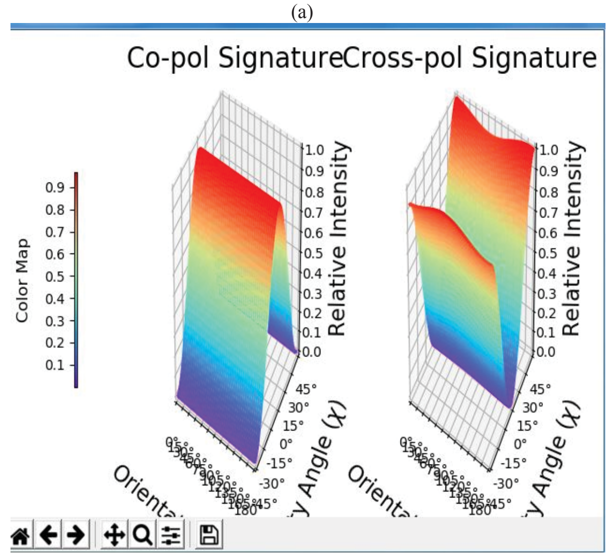
According to the survey over numerous quantitative studies demonstrates the effectiveness of Hybrid/Compact Polarimetry. The hybrid/compact polarimetry is giving more performance accuracy when compared with the accuracy delivered by a quadrature-polarized SAR. The most common compact-pol architecture is the circular transmit-linear receive (CTLR) system, which transmits the EM wave in either left or right circular polarization (H ± V) and receives linear H and V polarizations. Currently, only one satellite has circular polarization and right circular polarization has been evaluated by several researchers. In PSCP v1.0 the polarimetric calibration algorithm developed by Anthony Freeman for compact-pol data is implemented [7]. So, calibration for right circular transmits and linear receive is added. For left circular transmit & linear receive will be added in the future. In the Freeman algorithm, it is assumed that the system is perfect during signal transmission and the polarimetric distortions induced during the signal reception are estimated and corrected [1]. The output will be the scattering matrix free from all polarimetric distortions.

D. Polarimetric Signature

Polarimetric signature is another functionality of PSCP v1.0 as shown in Fig. 4. It is a 3D representation of polarimetric information in various polarization bases. It provides a graphical representation of various features in polarimetric SAR data and can be generated using electromagnetic wave synthesis [11].



(a)



(b)

Fig. 6. (a) Taking corner reflector values of HH, HV, VH and VV channels as an input. (b) The scattering patterns of the given target.

The user has to enter the values of the corner reflector of HH, HV, VH & VV channels and select the "Get Polarimetric Signature" option as shown in Fig. 6 (a). Fig. 6(b) is showing the scattering pattern output corresponds to the target.

V. DECOMPOSITION MODULE OF PSCP V1.0

Polarimetric decomposition approaches provide a measure of the relative contributions of backscatter from different scattering mechanisms and hence, the selection of the proper decomposition method plays a vital role in the classification of natural distributed targets [12], [13]. Backscattered images generated using these decomposition models were used to extract the required information in the form of surface, volume and double bounce scattering [11], [14]. In PSCP, polarimetric decomposition is implemented for both compact-pol datasets as well as for fully polarimetric SAR datasets.

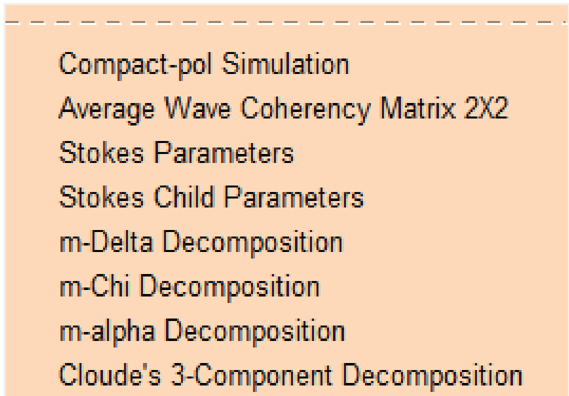


Fig. 7. Functionalities helpful in Hybrid/ Compact decomposition models.

In PSCP, there are four models implemented for hybrid polarimetric decomposition:

- M-delta decomposition
- M-chi decomposition
- M-alpha decomposition
- Cloude's 3-component decomposition

PSCP v1.0 provides functionalities that are helpful in performing hybrid decomposition models as shown in Fig. 7. The inputs required for the Cloude's 3-component decomposition are the Stokes first parameter (S1), Stokes child parameters, polarization angle (alpha) and the degree of polarization (m) (Fig. 7). The option "Stokes Parameters" generate S1 parameter, whereas alpha and m will be generated by the "Stokes Child Parameters" option. The output will be saved in .tiff format. The options available for the decomposition of fully polarimetric SAR data are shown in Fig. 8.

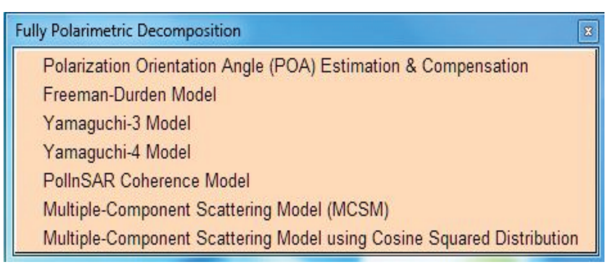


Fig. 8. Decomposition models implemented in PSCP v1.0 for fully polarimetric SAR data.

Input for all these models is the scattering matrix in .bin file format for the ease of processing and less memory utilization. The decomposition output is in .tiff format.

VI. CONCLUSION AND FUTURE SCOPE

The proposed PSCP v1.0 is a powerful tool for the calibration and decomposition of quad-pol and compact-pol SAR data. The tool is designed with an efficient user interface. Several basic and advanced calibration and decomposition algorithms are implemented in this tool. The future concern of the proposed tool will be on the incorporation of new algorithms and functionalities.

ACKNOWLEDGMENT

The authors are thankful to the Python Software Foundation for the flexibility of Python and the powerful ecosystem of packages and also for providing easy access to all Scientific Packages. Extending sincere thanks to PolSARPro (Polarimetric SAR Data Processing and Educational Toolbox) and PyRAT (Python Radar Analysis Tools) development team for providing source codes of the modeling approaches, which helped in giving a clear understanding of PolSAR decomposition.

REFERENCES

[1] D. Velotto, C. Bentes, B. Tings, and S. Lehner, "First Comparison of Sentinel-1 and TerraSAR-X Data in the Framework of Maritime Targets Detection: South Italy Case," *IEEE J. Ocean. Eng.*, vol. 41, no. 4, pp. 993–1006, 2016.

[2] C. Livingstone, I. Sikaneta, and C. Gierull, "RADARSAT-2 system and mode description," *Def. Res. Dev. Canada Ottawa*, no. 2005, pp. 1–22, 2006.

[3] T. Ullmann, S. N. Banks, A. Schmitt, and T. Jagdhuber, "Scattering characteristics of X-, C- and L-band polsar data examined for the tundra environment of the Tuktoyaktuk Peninsula, Canada," *Appl. Sci.*, vol. 7, no. 6, p. 28, 2017.

[4] A. Maiti, "Polarimetric Calibration of Sar Data Using Manmade Point Targets and Uniformly Distributed Natural Targets," University of Twente, 2019.

[5] A. Babu, "Polarimetric calibration of SAR data to minimize cross talk and channel imbalance from scattering matrix," Andhra University, 2019.

[6] A. G. Fore *et al.*, "UAVSAR polarimetric calibration," *IEEE Trans. Geosci. Remote Sens.*, vol. 53, no. 6, pp. 3481–3491, 2015.

[7] A. Babu, S. Kumar, and S. Agrawal, "Polarimetric Calibration of RISAT-1 Compact-Pol Data," *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.*, vol. 12, no. 10, pp. 3731–3736, 2019.

[8] K. S. Tomar, S. Kumar, and V. A. Tolpekin, "Evaluation of Hybrid Polarimetric Decomposition Techniques for Forest Biomass Estimation," *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.*, vol. 12, no. 10, pp. 3712–3718, 2019.

[9] K. S. Tomar, "Hybrid Polarimetric Decomposition for Aboveground Biomass Estimation Using Semi- Empirical Modelling," University of Twente, 2015.

[10] A. Babu, S. Kumar, and S. Agrawal, "RISAT-1 Compact Polarimetric Calibration and Decomposition," *Proceedings*, vol. 18, no. 1, p. 3, 2019.

[11] S. R. Cloude, D. G. Goodenough, and H. Chen, "Compact decomposition theory," *IEEE Geosci. Remote Sens. Lett.*, vol. 9, no. 1, pp. 28–32, 2012.

[12] A. Freeman and S. L. Durden, "Three-component scattering model for polarimetric SAR data," *IEEE Trans. Geosci. Remote Sens.*, vol. 36, no. 3, pp. 963–973, 1998.

[13] H. Y. Yamaguchi Yoshio, Toshifumi Moriyama, Motoi Ishido, "Four-Component Scattering Model for Polarimetric SAR Image Decomposition based on Asymmetric Covariance Matrix," *Ieee Trans. Geosci. Remote Sens.*, vol. 104, no. 8, pp. 1699–1706, 2005.

[14] R. K. Raney, "Hybrid-polarity SAR architecture," *IEEE Trans. Geosci. Remote Sens.*, vol. 45, no. 11, pp. 3397–3404, 2007.