POLINSAR BASED MODELLING FOR SCATTERING CHARACTERIZATION AND FOREST PARAMETER RETRIEVAL

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ABSTRACT

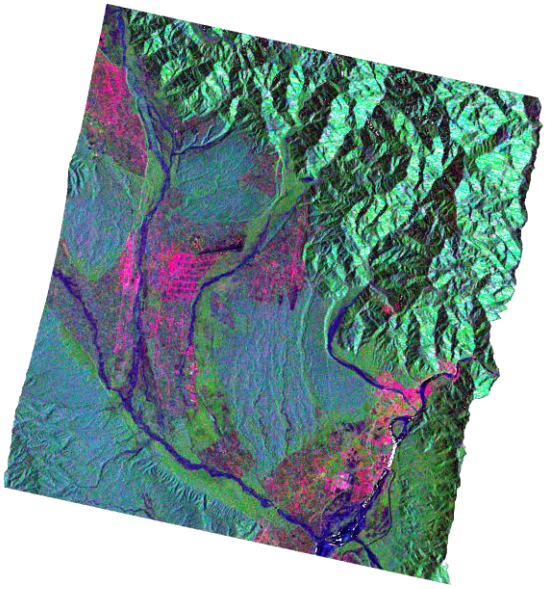
SAR remote sensing has already proven its capability to retrieve forest structural and biophysical parameters. Prime focus of the present study was to evaluate the potential of PolSAR, PolInSAR and PolInSAR tomography (PolTomSAR) for forest structural and biophysical parameter retrieval. This work includes the utilization of ALOS PALSAR, RADARSAT-2, RISAT-1 and TerraSAR-X data for scattering characterization and coherence estimation of different locations of forest. Tree height retrieval was performed with the model inversion using PolInSAR data and signal compression techniques of SAR tomography. Potential of PolTomSAR was evaluated to retrieve forest height and variation in backscatter power at different height levels. Fourier transform, beamformer and capon algorithms were compared for vertical profile of forest patch. Fully polarimetric capon showed best forest height result with RMSE of 2.58 m and an average accuracy of 88.64%. PolInSAR RVoG modelling based three stage inversion (TSI) and coherence amplitude inversion (CAI) techniques were implemented on PolInSAR data to generate forest height map. PolInSAR data was also used for AGB retrieval of forest with the help of coherence based Interferometric Water Cloud Model (IWCM). PolSAR based EWCM model was developed for L-band ALOS PALSAR data for Dudhwa National Park, India and the modelled output for AGB estimation showed 0.43 R^2 and 119 (t/ha) RMSE. IWCM based modelling for forest AGB retrieval showed R^2 value of 0.4, RMSE of 62.73 (t/ha) and a percent accuracy of 51%. TSI based PolInSAR inversion modelling showed the most accurate result for forest height estimation. The correlation between the field measured forest height and the estimated tree height using TSI technique is 62% with an average accuracy of 91.56% and RMSE of 2.28m. The obtained results showed that PolSAR and PolInSAR remote sensing based modelling approach have capabilities to provide structural and biophysical parameters of forest with reliable accuracy.

1. INTRODUCTION

The scientific community of Earth observation to retrieve structural and biophysical parameters of the forest has successfully used SAR Polarimetry (PolSAR) and PolSAR Interferometry (PolInSAR) data (Gupta, Kumar and Pandey, 2016; Mangla, Kumar and Nandy, 2016; Prajapati, Kumar and Agrawal, 2016; Tomar *et al.*, 2016). Dual- and single-polarised SAR data have been used in semiempirical modelling approaches for vegetation parameter retrieval (Richards, Sun and Simonett, 1987; McDonald and Ulaby, 1991; Santoro *et al.*, 2002). The limitation of these modelling approaches was their dependency on field-collected data for model calibration and its parameter retrieval (Kumar *et al.*, 2012). Retrieval of forest parameters from PolSAR based modelling approaches have shown less dependency on the field data, which makes it suitable and reliable for forestry applications (Sai Bharadwaj *et al.*, 2015; Agrawal, Kumar and Tolpekin, 2016; Kumar, Garg and Kushwaha, 2016). Polarimetric SAR based Extended Water Cloud Model (EWCM) was used with fully and hybrid polarimetric approaches to retrieve AGB and Stem Volume of the forest (Sai Bharadwaj *et al.*, 2015; Tomar *et al.*, 2016). The polarimetric SAR data provided by the spaceborne sensors have the capability to provide the scattering information contributed by top canopy, ground-stem interaction and the scattering from ground (Joshi, Kumar and Agrawal, 2016; Kumar, Garg and Kushwaha, 2016). The interferometric acquisition of PolSAR data has shown the potential of PolInSAR coherence for forest height and aboveground biomass estimation with very high reliability (Singh, Kumar and Kushwaha, 2014; Joshi, Kumar and Agrawal, 2016). PolInSAR based inversion modelling has been successfully implemented by several researchers to retrieve forest height using Airborne and spaceborne SAR data (Garestier, Dubois-Fernandez and Papathanassiou, 2008; Neumann, Ferro-Famil and Reigber, 2010; Tan, Yang and Yang, 2010; Li *et al.*, 2014). Random Volume Over Ground (RVOG), (Neumann, Ferro-Famil and Reigber, 2010; Ballester-Berman, Vicente-Guijalba and Lopez-Sanchez, 2015; Wenxue *et al.*, 2016) based three stage inversion (TSI) (Cloude and Papathanassiou, 2003; Wenxue *et al.*, 2016; Lopez-Sanchez *et al.*, 2017) and coherence amplitude inversion (CAI) (Cloude, 2005; Joshi and Kumar, 2017a) models have been widely used for forest height estimation. Interferometric Water Cloud (IWCM) is the interferometric coherence based approach to retrieve forest structural and biophysical parameters (Kumar, 2009; Kumar *et al.*, 2012; Askne, Soja and Ulander, 2017). A polarimetric extension of the IWCM was developed and incorporated by Kumar et al. (2017) to retrieve forest AGB with less dependency of field-collected data to calibrate the model parameters (Kumar *et al.*, 2017). After getting the forest height from spaceborne and airborne SAR sensors, researchers have extended the work for vertical profile retrieval of forest vegetation and the total power of scattering contributed by different layers of the vegetation structure with the help of tomographic processing of multibaseline SAR and PolSAR data (Joshi *et al.*, 2016; Joshi and Kumar, 2017b; Kumar and Joshi, 2017; Kumar, Joshi and Govil, 2017). The prime focus of the present study is to show the potential of SAR remote sensing based processing and modelling approaches for forest parameter retrieval. This study will also show the results of super-resolution techniques for tomographic processing of multibaseline SAR data for forest vertical profile generation.

2. STUDY AREA AND DATA

Three study sites were chosen to show the potential of SAR Remote Sensing for forest parameter retrieval. First study site was Barkot forest range of Doon Valley (Fig. 1a). PolInSAR inversion for forest height retrieval, RADRSAT-2 PolInSAR data based IWCM, RADARSAT-2 PolSAR and RISAT-1 Hybrid polarimetry based EWCM for AGB retrieval was carried for the Barkot forest range of Doon Valley (Fig. 1b), Uttarakhand, India. Second study site of Dudhwa National Park (Fig. 1c), Uttar Pradesh, India was chosen to show the potential of EWCM for AGB retrieval using L-band ALOS PALSAR data. Third study site was plantations of Hadwani forest (Fig. 1d), Uttarakhand, India. Tomographic processing was performed with TerraSAR-X data to show the potential of supper-resolution techniques for vertical profile retrieval of forest vegetation.



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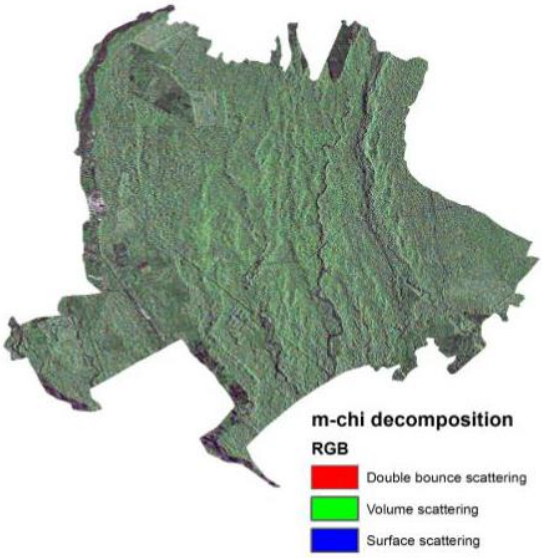

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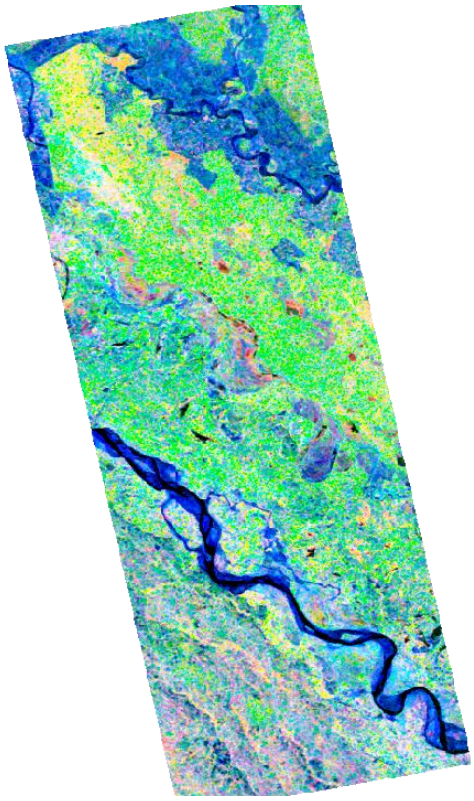

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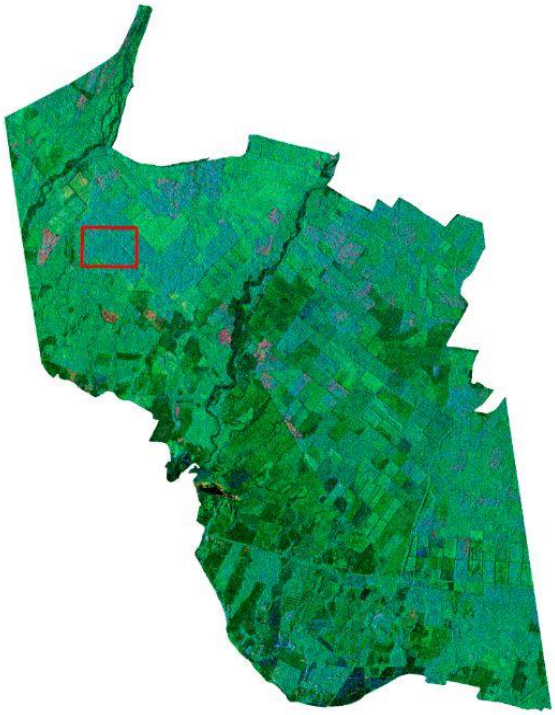


(d)

Fig.1 (a) Terrain Corrected PolSAR Decomposition of C-band RADASAT-2 Data for Barkot Forest Range. (b) m-chi decomposition of RISAT-1 Hybrid Polarimetric SAR data for Barkot Forest Range. (c) Terrain Corrected PolSAR Decomposition of L-band ALOS PALSAR Data for Dudhwa National Park, Uttar Pradesh, India. (d) Terrain Corrected PolSAR Decomposition of TerraSAR-X data for Hadwani forest, Uttarakhand, India. Red box shows area of teak plantation for which Tomographic profile was generated.

3. METHODOLOGY

The complete methodology is divided in four part. The first part deals with Fully and Hybrid polarimetric SAR data based EWCM for forest AGB retrieval. The second part is focussed on PolInSAR based modelling for forest height retrieval and AGB estimation. The third part describes the tomographic processing for vertical profile retrieval of forest vegetation. The fourth part is field data collection for validation of the modelled output of SAR data. The complete methodology is shown in Fig. 2.

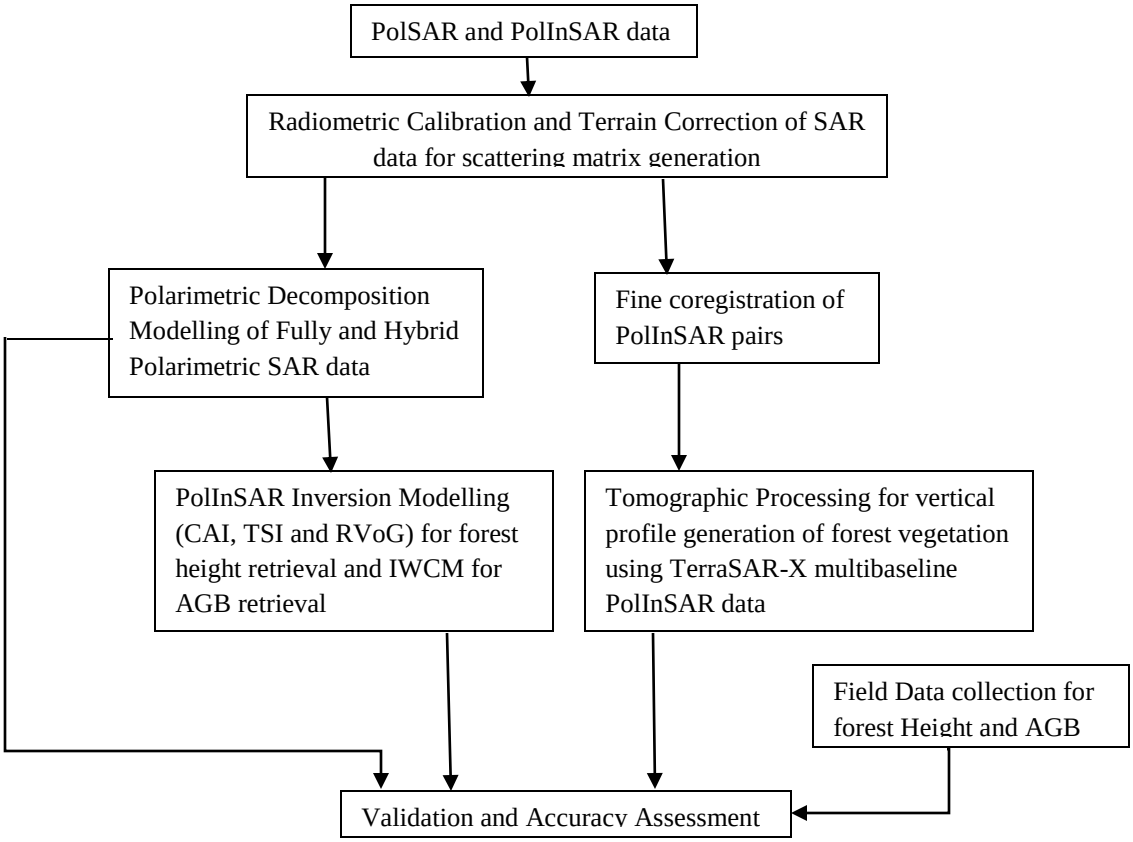


Fig. 2 Methodological Flow Diagram

Radiometric calibration was performed to calibrate the SAR data to get radar cross section of each and every resolution cess. Terrain correction was performed on radiometrically corrected SAR data to get actual ground information by minimising the effect of geometric distortions due to slant range ambiguity of SAR data. PolSAR decomposition modelling was performed on the radiometrically calibrated and terrain corrected scattering matrix of SAR data. Yamaguchi four component decomposition was performed on Quad-pol based scattering matrix of PolSAR data for scattering element retrieval and Hybrid polarimetric decomposition was performed on RISAT-1 Hybrid polarimetric SAR data. EWCM was performed with scattering elements for forest AGB retrieval. IWCM parameters were retrieved from PolInSAR data and the coherence based modelling was performed for AGB retrieval. CAI and TSI modelling was performed with PolInSAR based output for forest height retrieval. Supper-resolution based Fourier transform, beamformer and capon algorithms were implemented for tomographic processing of multibaseline PolInSAR pairs to get forest vertical structure. Modelled output for forest height and AGB were validated with field-collected data.

4. RESULT AND DISCUSSION

Fig. 3 shows the results of PolSAR based EWCM for forest AGB estimation of Dudhwa National Park, Uttar Pradesh, India using L-band ALOS PALSAR data.

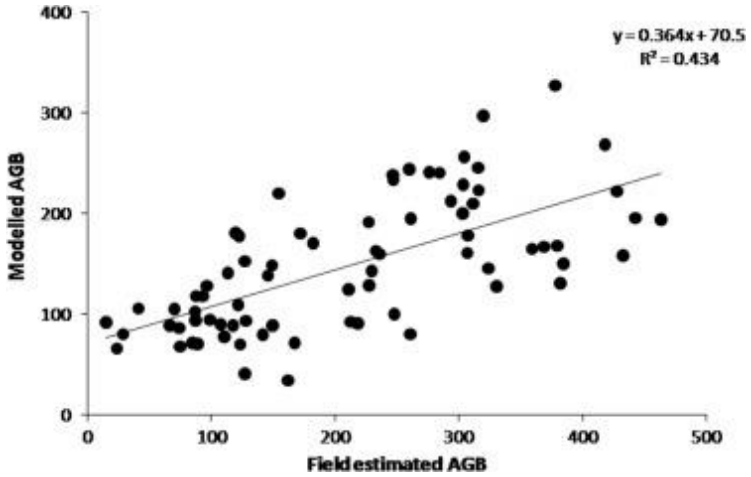


Fig. 3 Linear regression between Field-estimated AGB and Modelled AGB. Source: (Sai Bharadwaj *et al.*, 2015)

Linear regression between field-measured AGB and modelled AGB gave a coefficient of determination (R^2) of 0.43 and the recorded RMSE was 119 (t/ha).

Table 1 shows the RMSE of EWCM modelled out put with Hybrid polarimetric RISAT-1 and fully polarimetric RADARSAT-2 data for Barkot forest range, Doon Valley, Uttarakhand. Minimum RMSE in AGB retrieval was obtained from RISAT-1 based m-chi decomposition for forest AGB retrieval using EWCM.

Table 1. RMSE obtained from modelled AGB and field biomass for Barkot forest range

Modelled AGB	*RMSE* (t ha^{-1})			
	m-delta Decomposition	m-chi Decomposition	m-alpha Decomposition	Yamaguchi Decomposition
	64.422	45.995	63.156	73.424

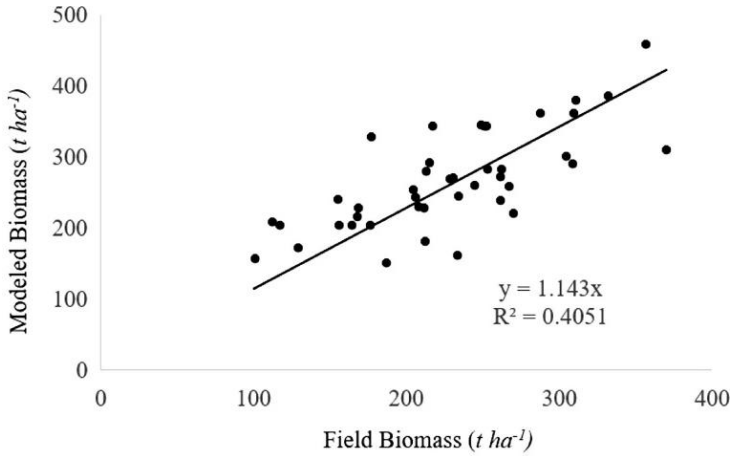
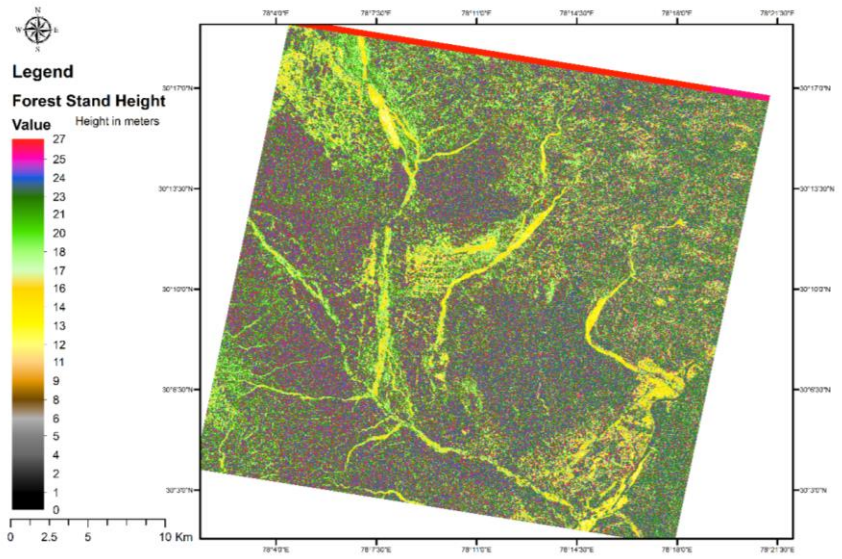


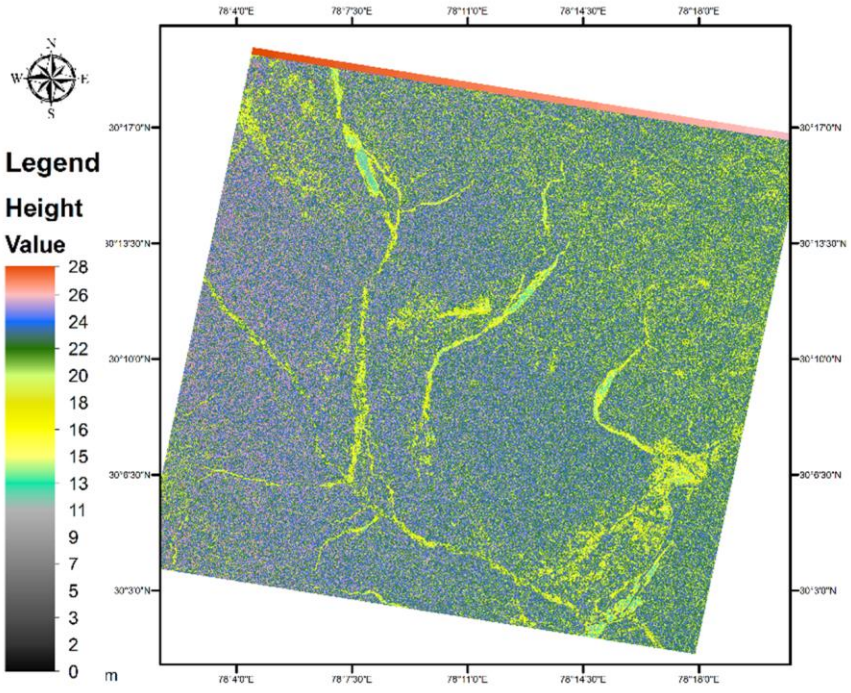
Fig. 4 Linear regression between Field-estimated AGB and Coherence based IWCM based Modelled AGB. Source: (Chandola, 2014; Kumar *et al.*, 2017)

As shown in Fig. 4 PolInSAR coherence based IWCM modelling provided an output of AGB with coefficient of determination of 0.40 and the RMSE between field-estimated biomass and modelled biomass was 62.73 (t/ha) with a percent accuracy of 51%.

Fig. 5 shows the output of PolInSAR inversion modelling and the potential of modelling approach was evaluated with RMSE and percentage accuracy as shown in Table 2.



(a)



(b)

Fig. 5 PolInSAR inversion based height map using (a) TSI model (b) CAI model. Source: (Khati, 2014; Kumar *et al.*, 2017)

Table 2. PolInSAR based forest Height Retrieval (Khati, 2014)

Forest Height Derived using	Mean height	Variance	RMSE	Correlation	Average Accuracy
Three Stage Inversion technique	23 m	4.505	2.28 m	0.62	91.56 %
Coherence Amplitude Inversion Technique	23.61 m	2.922	2.76 m	0.34	90.10%

Forest height map was generated for Barkot forest range using RADARSAT-2 PolInSAR data and it was found that the TSI based modelled output provided an RMSE of 2.28m with 0.62 correlation with field data and 91.56% of average accuracy. CAI based modelled out showed the correlation of 0.34 with field data and RMSE was 2,76m with 90.10% of average accuracy.

Tomographic processing was performed with multibaseline TerraSAR-X data of Haldwani forest. Fig. 6 shows the vertical profile of forest vegetation generated from tomographic processing.

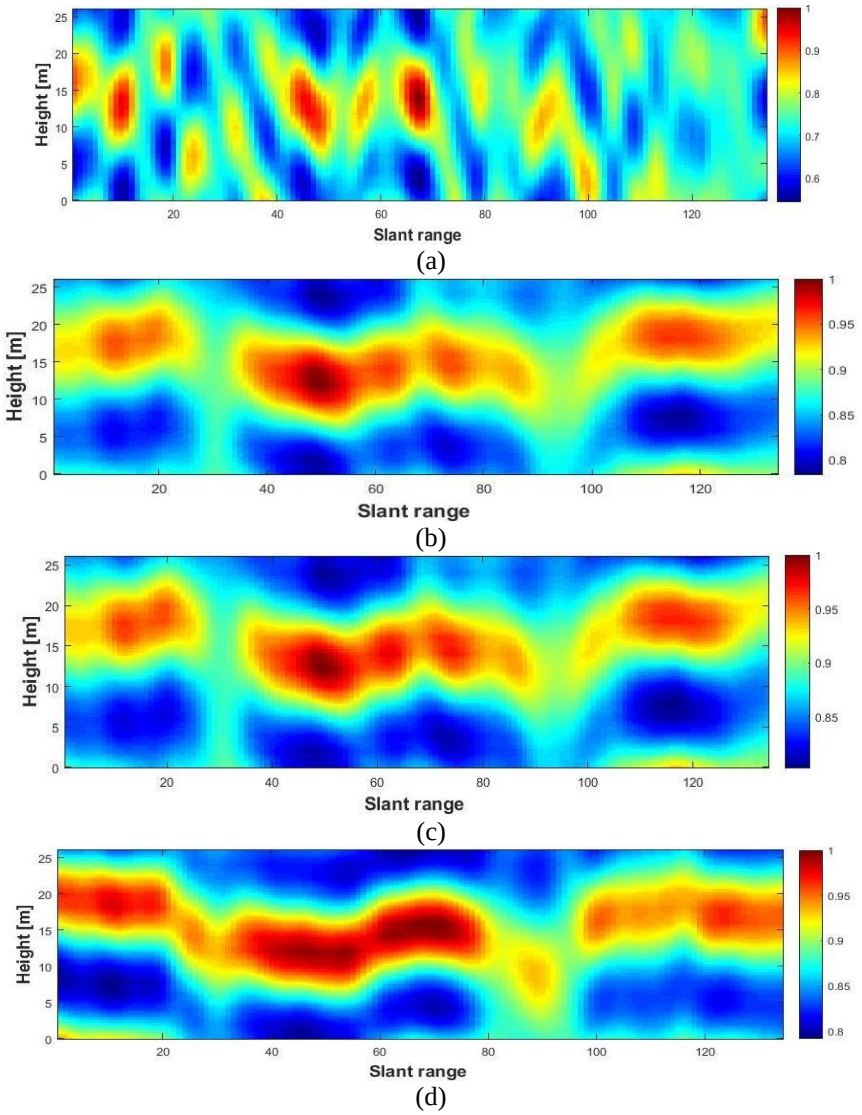


Fig. 6 Multibaseline TerraSAR-X HH polarisation based tomographic profile of forest vegetation using (a) Fourier (b) Beamforming (c) Capon and (d) Quad-pol based fully polarimetric Capon. Source: (Joshi, 2016)

From the Fig. 6, it can be understood that there are two openings through which the wave has penetrated. This may be due to the high resolution of the dataset where the radar wave could find some gap to penetrate in the dense forest canopy. The advantage Capon gives over the Fourier and beamformer is that it reduces the spatial leakage in the tomogram and thus improve the resolution and target identification. Fully polarimetric tomographic reconstruction based forest height showed RMSE of 2.58 m and an average accuracy of 88.64%.

5. CONCLUSION

The prime focus of the present study was to show the potential of SAR data for structural and biophysical parameter retrieval of forest vegetation. An EWCM was developed for aboveground biomass estimation of Dudhwa National Park and this modelling approach showed a reliable result with polarimetric parameters based input. The EWCM was also implemented with Hybrid Polarimetric parameters of RISAT-1 data for AGB retrieval and RMSE obtained from the modelling showed that the EWCM can be implemented on PolSAR and Hybrid-pol SAR data for biophysical characterisation of forest vegetation. A reliable estimation of forest above ground biomass was performed using, PolInSAR coherence based IWCM for AGB estimation. The obtained result showed very less dependency on field-based parameters to calibrate the model for AGB estimation. Extension of IWCM for PolInSAR coherence based modelling was sussefully implemented with 0.40 R^2 and 62.73 (t/ha) with percent accuracy of 51%. PolInSAR inversion for forest height estimation was performed with CAI and TSI based modelling approaches over Barkot forest range, Doon Valley, Uttarakhand. PolInSAR based modelling was performed on spaceborne C-band RADARSAT-2 data and it was found that TSI based approach is better in comparison to the CAI based modelling. Vertical profile of forest vegetation of Haldwani forest was performed with multibaseline TerraSAR-X data. Three super-resolution algorithms Fourier, Beamforming and Capon were implemented for the tomographic processing. Capon showed advantage over other super-resolution techniques. Fully polarimetric Capon showed reduced the spatial leakage in the tomographic profile.

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