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Forest Stand Height Estimation using Inversion of RVoG Model over Forest of North-Eastern India

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Abstract. Multiple studies have been carried in recent years to estimate forest height using remote sensing techniques. The forest height is an essential forest resource parameter that is usually used in biomass estimation contributing to carbon sequestration studies. Polarimetric Interferometric SAR (PolInSAR) is a remote sensing technique that combines SAR Polarimetry (PolSAR) with SAR Interferometry (InSAR) and has demonstrated tremendous ability for forest height extraction as it is sensitive to the vertical arrangement of the scattering media. In this paper, we examine the Random Volume over Ground (RVoG), the polarimetric canopy scattering model, for the forward modeling, and the three-stage inversion (TSI) for retrieving vegetation stand height. We investigate the performance of the inversion algorithm for forest height estimation using single baseline L-band ALOS-2 PALSAR data collected on December 17, 2018, and December 31, 2018, over the Saipung Reserve Forest, Meghalaya, over North-Eastern India. Correlation between the field measured forest height, and the estimated tree height using the TSI technique is 0.81 with RMSE of 5.05 m. The study suggests that the PolInSAR approach has significant potential for retrieval of forest biophysical parameters such as stand height.

Keywords: Synthetic Aperture Radar (SAR), Forest Height Estimation, Polarimetric Interferometric SAR (PolInSAR)

1 Introduction

Vegetation parameter estimation (using remote sensing techniques), at large scale, is very critical to perform ecosystem modeling effectively and to address essential science questions related to climate change, global warming, etc. [1]. In this short paper, we showcase an algorithm based on single-baseline Polarimetric SAR Interferometry (PolInSAR) to retrieve one of the vital vegetation parameters, viz., the canopy height.

PolInSAR combines the utilities of two SAR technologies: Polarimetry and Interferometry. PolSAR (Fully Polarimetric Synthetic Aperture Radar) provides the three complex scattering matrices at each image pixel, which provides insight into the structural information of the scatterer (geometry, shape, and dielectric constant). InSAR (Interferometric SAR) leads to interferogram generated out of SAR images acquired with an appropriate baseline (spatial or temporal). A common problem for all estimation techniques emerges from the nature of the scattering process. In terms of the interferometric observables, it does not provide an effective separability of the physical forest parameters. This limits a straightforward parameter estimation and requires the inversion of a scattering model, which relates the interferometric observables to the physical parameters of the scattering process [2, 3]. This is where combining PolSAR with InSAR becomes advantageous. In this paper, we examine the Random Volume over Ground (RVoG), the polarimetric canopy scattering model, for the forward modeling, and the three-stage inversion (TSI) for retrieving vegetation stand height. This inversion also estimates other forest parameters such as canopy extinction, ground-to-volume amplitude, and ground topographic phase [4].

The study was conducted in Saipung Reserve Forest, East Jantia Hills district ($25°11' E$ to $25°18' E$ Latitude to $92°34' N$ to $92°52' N$ Longitude) covers 144 km^2, located in Meghalaya, a state situated in the north-eastern corner of India.

2 Methodology

A realistic scattering model has to consider both the vegetation layer and ground interactions in the case of forest scattering at L-band. A standard model to describe such a scenario is the Random Volume over Ground (RVoG) scattering model [3]. This model containing six unknown parameters is optimally inverted using the three complex coherences from the monostatic PolInSAR system, viz., $\tilde{\gamma}_1$, $\tilde{\gamma}_2$, and $\tilde{\gamma}_3$. In this model, the vegetation layer is modeled as a layer of thickness h_V containing a volume with randomly oriented particles and scattering amplitude per unit volume m_V. This cloud of particles is located above a ground scatterer with scattering amplitude m_g. The complex interferometric coherence $\tilde{\gamma}$, after range spectral filtering, written as [5, 6],

$$\tilde{\gamma}(\omega) = e^{j\phi} \frac{\tilde{\gamma}_v + m\left(\vec{\omega}\right)}{1 + m\left(\vec{\omega}\right)} \tag{1}$$

Where $\vec{\omega}$ is a unit vector that describes the polarization, $\tilde{\gamma}_v$ is the volume coherence, ϕ is the phase related to the ground topography, and m is the effective ground-to-volume scattering ratio. $\tilde{\gamma}_v$ is defined as [5, 6],

$$\tilde{\gamma}_v = \frac{I}{I_0} \quad \begin{cases} I = \int_0^{h_V} \exp\left(\frac{2\sigma x}{\cos\theta_0}\right) \exp(i\kappa_z x)\, dx \\ I = \int_0^{h_V} \exp\left(\frac{2\sigma x}{\cos\theta_0}\right) dx \end{cases} \tag{2}$$

Where σ is the wave mean extinction, κ_z is the vertical wavenumber, and θ_0 is the mean incidence angle.

Inversion on Equation (1) involves taking observations of the complex coherence at several different polarizations and minimizing the difference between the model predictions and observations in the least square manner. Three-stage Inversion (TSI) follows three stages, according to [4] is (1) Least square line fitting, (2) Vegetation bias removal, and (3) Height Estimation. The end-to-end workflow of the forest height estimation technique is given in Fig. 1.

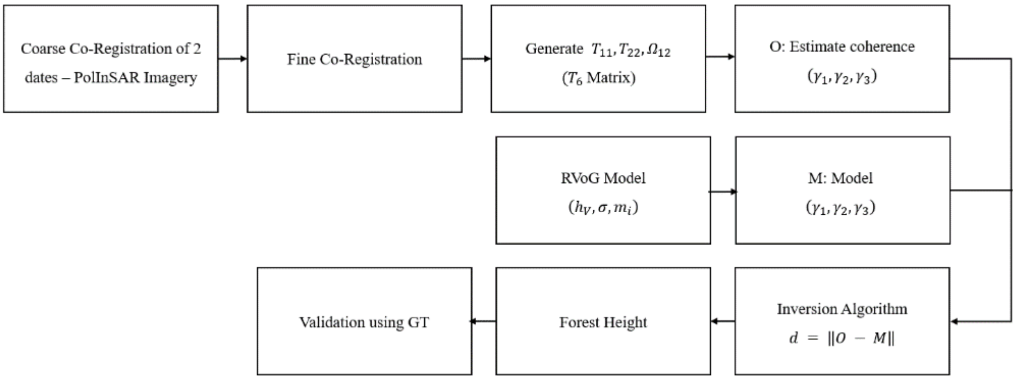

Fig. 1. PolInSAR processing flow for the forest height retrieval using RVoG model

For this analysis, a pair of fully polarimetric ALOS-2 PALSAR data is procured over the Saipung forest region of Meghalaya state in North-East India. We follow the methodology outlined in Fig. 1. The pre-processing involves co-registration of the two PolSAR imagery, up to sub-pixel level accuracy. The complex coherences are estimated for the PolInsAR data and plotted on the complex plane. To invert the model, the three-stage strategy introduced earlier is employed.

3 Results and Discussion

The results of TSI are shown in Table 1 for a subset of ground truth points. It shows the estimated height for different field locations in meters collected during the December 2018 expedition to the national reserve forest (carried out through the Principal Chief Conservator of Forests, Meghalaya). It is clear from the table that TSI performs well for our study area with enough sensitivity to the low and high end of the vegetation stand height.

Table 1. Estimated height in meters for the study area

Lat	Long	Field Height (m)	Retrieved Height (m)
92.74064	25.352757	24	24.76
92.74287	25.34275	27	28.88
92.74774	25.39293	4.3	6.4
92.7491	25.38815	6.1	6.36
92.70664	25.34185	14.6	13.94
92.72391	25.32471	21.2	21.01
92.71197	25.32915	24.4	19.45
92.64638	25.41916	20	21.08
92.63165	25.31202	11.8	4.75
92.64669	25.2713	8.7	5.72

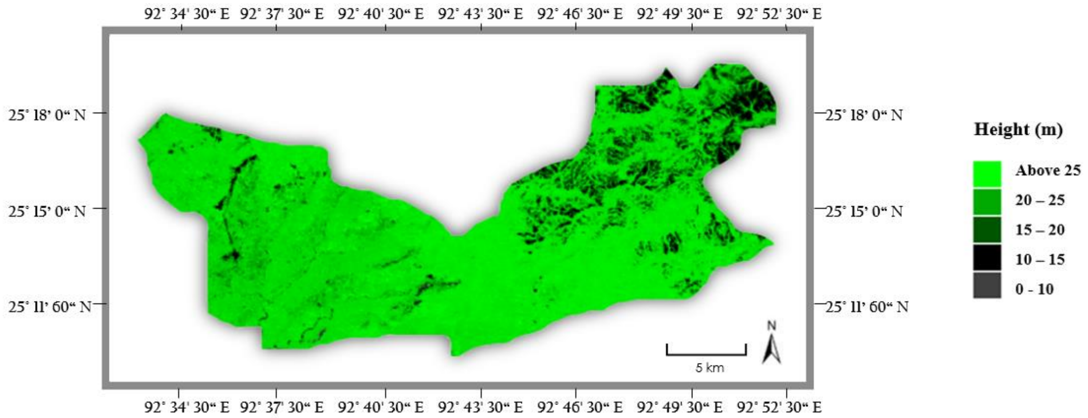

Fig. 2. Saipung Reserve Forest height map derived using the PolInSAR based technique outlined in the paper. It shows the sensitivity of retrieval to the varying height zones of the reserve forest.

The algorithm has been run for the whole study area to prepare the height map. Fig. 2 shows the forest stand height map for Saipung Reserve Forest over the North-Eastern part of India. As can be seen, most of the reserve forest is quite dense with average height shooting above 25 m.

This research's primary purpose is to estimate forest height from the PolInSAR inversion. A regression analysis was carried out to appraise the accuracy of the TSI method. For this, we use the ground truth data of field-measured height, some of which were already shown in Table 1. The correlation coefficient between estimated and field-measured tree height is 0.81 for three-stage inversion. It indicates that the modeled height provides a statistically significant relationship with the field measured height.

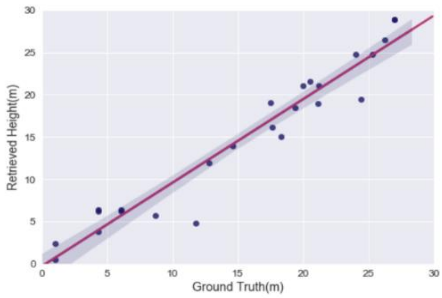

Fig. 3. Retrieved height using Three-stage Inversion (TSI)

The RMSE of the retrieval is found to be approximately 5 meters. This is in agreement with other studies reported in the literature using single-baseline PolInSAR. This figure can be improved by using multi-baseline techniques or using more sophisticated canopy scattering models.

4 Conclusions

In this work, PolInSAR forest height estimation is established from the L-band dataset acquired from ALOS-2 PALSAR system. The RVoG canopy scattering model and the three-stage inversion have been implemented (Python 3) to estimate vegetation stand height. This study suggests that the PolInSAR technique has significant potential for retrieving forest biophysical parameters such as stand height, and can substantially augment the biomass estimation over areas like reserve forests where accessibility for field data collection remains difficult.

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